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Greening Transport: Final Report

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Rialtas na hÉireann
Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY

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- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

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Greening Transport: Final Report

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EPA Research Report

Prepared for the Environmental Protection Agency

by

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Executive Summary

The Greening Transport project examined the behavioural response of commuters within the Greater Dublin Area (GDA), Ireland, to a range of policy incentives devised to encourage travellers to make greater usage of sustainable travel modes for trips to places of work or education. Several policy measures were evaluated using behavioural and transportation modelling techniques, to identify a means of stimulating a shift from single-occupancy vehicle use to alternative modes such as walking, cycling, public transport and the more sustainable use of private cars, namely carpooling and car-sharing. Such policy tools were examined for their potential to increase the levels of "car-shedding" behaviour in the GDA by increasing the likelihood of sustainable mode choice, through making alternative modes more time and cost efficient, safer and ultimately more convenient to use when commuting than private cars.

The Greening Transport project comprehensively evaluated the potential environmental, economic and health impacts associated with the Irish road transport fleet. In addition, it proposed a solution through the introduction of a set of hypothetical policies that could potentially mitigate the impacts of road transport and increase electric vehicle uptake, while also investigating the possible reduction in impacts that would result from the alternative traffic scenarios caused by these policy interventions. The examination of emissions from the Irish fleet was done at national level and not at GDA level, as it is not possible to disaggregate the fleet. Emission levels from road transport were estimated using an emission model for the current scenario and for several future scenarios comprising the continuation of the current situation (business-as-usual scenario) and alternative scenarios. Uncertainty modelling of emissions was carried out through sensitivity analyses of the input parameters. The findings of this research indicate that emission levels from the future fleet will increase under business-as-usual scenarios because of an increase in car ownership levels and a low uptake of alternative fuel and technology options. However, emission levels could potentially be reduced with alternative fleet options resulting from additional policy measures. The results also reveal that Ireland's air quality is good with respect to nitrogen oxides (NO_x) and fine particulate matter ($PM_{2.5}$) pollution when compared with limits recommended as safe by the World Health Organization and the European Union. The findings of this research not only provide policymakers with a timely and useful evaluation of the potential impacts of the road transport fleet in Ireland, but also set an example of how controlling air pollution could be prioritised, similar to other policy interventions aimed at improving air quality and public health.

Extensive transport modelling was subsequently conducted using the National Transport Authority Regional Modelling System to represent the policy changes explored in a comprehensive survey experiment aimed at producing real-life estimates of trip-making behaviour. Changes to model parameters in the mode choice and trip assignment stages of the Eastern Regional Model (covering the GDA) were made to account for improvements to the infrastructure, frequency, time and cost attributes of various modes included in the model. The changes were made based on "Do Nothing/base", "Do Something" and "Do Maximum" scenarios, which were designed based on the attribute level values identified from a stated preference survey. The outputs generated from these model scenarios demonstrated that, in the GDA, walking, as a transport mode, was more sensitive to changes to the parameters of the model than the other transport modes tested. This was highlighted in the active modes and optimal car-shedding model results, where walking experienced the largest or, in some cases, the only increase in mode share as a result of policy implementation. In addition to this, daily CO_2, NO_x and $PM_{2.5}$ emission reductions were estimated from changes recorded in the vehicle-kilometres travelled by private cars. The economic savings associated with these reductions were similarly estimated, which showed that up to €5705 as a result of CO_2 emission reductions, up to €5499.94 as a result of NO_x emission reductions and up to €9010 as a result of $PM_{2.5}$ emission reductions could be saved from daily commute trips.

Overall, the results produced in this research suggest that policy incentives alone, leading to tangible improvements in commuting time and cost

characteristics, could act as effective mechanisms for encouraging car-shedding behaviour or a sustainable mode shift in the GDA. The empirical results explored in this research support this hypothesis, which may constitute valuable guidance and recommendations for policymakers who are pursuing methods of reducing the environmental consequences of emissions from transport in Ireland as a matter of urgency.

1 Introduction and Project Outline

The vision of the Greening Transport project was to merge the technical evaluation of emissions from transport, and improvements in their calculation, with an assessment of the behavioural changes needed to realise reductions in emissions. Past attempts to evaluate land passenger transport policies in terms of emission reductions from transport have failed to fully merge these two disciplines. The project team believes that, in order for the Environmental Protection Agency (EPA) to have a holistic picture of the potential emission reductions that are possible in Ireland by 2030 (and beyond), it is vital not to ignore the behavioural constraints in which transport analysis is framed. While it is possible to predict targets for take-up using assumptions, to ignore human behaviour would be to fail to fully grasp the problem in question.

With this in mind, the work packages for this project were designed to tackle technical emissions and land transportation modelling, as well as the application of behavioural constraints to these models, to provide the EPA with details of what emission reductions are possible based upon current research.

The research was conducted through the following work packages:

- work package 1: project management;
- work package 2: review of environmental and transportation modelling methods and development of a transport emission model;
- work package 3: examining smarter travel options to reduce emissions;
- work package 4: examining the emission reductions from changes in the private car fleet and the public transport bus fleet;
- work package 5: measuring the impacts of fiscal changes on promoting sustainable car use.

Reports for all of the above Greening Transport work packages are available on the Greening Transport website (www.greeningtransport.ie). This report presents the main highlights of the project but further details of the research conducted are available on the website (www.greeningtransport.ie).

2 Review of Transport and Environmental Models

2.1 Objectives

The first section of this report provides an overview of a selection of relevant economic, environmental, land use and transportation models currently available in Ireland and internationally that were considered for use in the Greening Transport project. The models were deemed suitable by the project team based on the methods that they employ, the nature of the inputs that are included in the models and most importantly the utility of the outputs generated. A key goal of the Greening Transport project was to use a transport emission model capable of combining transportation modelling practices with the outputs generated from an emission model, to accurately analyse the effect of behavioural and policy changes on greenhouse gas (GHG) emissions from transport in Ireland.

2.2 Review of Transport Models

The following five transport-related models were reviewed:

1. the National Transport Authority (NTA) Greater Dublin Area (GDA) Model;
2. the Transport Infrastructure Ireland (TII) National Transport Model (NTpM);
3. the Irish Sustainable Development Model (ISus), linked to the Economic and Social Research Institute (ESRI) Harmonised Economic Research Models on Energy Systems (HERMES);
4. University College Dublin's (UCD's) Monitoring Urban Land Cover Dynamics (MOLAND) model.

In addition to this, transport parameters from the Department of Transport, Tourism and Sport (DTTaS) were reviewed and modelling frameworks from the UK, the Netherlands and Sweden were examined to enable a comparative analysis of international best practice in the area of transport and emission model unification.

2.2.1 National Transport Authority model

The NTA is the main government-funded entity responsible for a range of transportation functions in Ireland, including transport planning and investment; national public transport delivery; and bus and taxi regulation. Accordingly, the NTA has the most comprehensive bank of transportation data in Ireland. As a result, the NTA's foremost transportation model – the GDA model – is central to the draft transport strategy 2011–2030 in addition to the proposed GDA Transport Strategy 2016–2035 (NTA, 2016) and Dublin City Development Plan (DCC, 2016). Table 2.1 outlines the main inputs and outputs of the NTA model.

Table 2.1. Outline of the NTA model

Inputs	Outputs
Place of Work, School or College – Census of Anonymised Records (POWSCAR)	Trip generation – estimation and prediction of the number of trips generated by and attracted to a zone by purpose (commuting, education, business, etc.)
GDA Travel to Education Survey	Trip distribution – patterns of trips between sets of trip generators and trip attractions (trip ends)
GDA Household Survey	Car Ownership Model – car ownership trends over time, determination of the probability of car availability for a particular trip (i.e. car available/not available)
CSO Small Area Population Statistics datasets	Mode choice – trip matrices split into different modes of travel (car, public transport and active modes, i.e. walking and cycling); hour of travel choice (AM Peak only) – trips further split, down to the hour of travel
Macroeconomic forecasts and regional planning guidelines to predict travel demand in the future	Trip assignment to road or public transport networks

CSO, Central Statistics Office of Ireland.

Critical analysis of the NTA GDA model

Pros:

- A wide range of stakeholders, partners and other parties can make use of the model.
- The model includes trips by all the main modes of travel.
- Travel behaviour is based on comprehensive and detailed travel surveys and travel datasets not generally available in other strategic models. By studying behavioural changes and restraints in this respect, our research was capable of examining the steps needed to induce emission reductions as result of such behavioural shifts.
- The model covers the GDA, and takes full account of travel within, into and out of the modelled area.
- Peak spreading highlights the advantages of taking active modes of transport to avoid peak time congestion – for this reason, active modes are not included in the "hour of travel choice" stage of the model.

Cons:

- The model does not include car-sharing, carpooling, taxi/on-demand services, which are examples of sustainable and efficient resource use and contribute to reducing road congestion and encouraging the higher occupancy of cars.
- Although walking and cycling trips are included in the model, they are not assigned to equivalent walking and cycling networks. Hence, whereas the cost of travel by mechanised modes is based on travel demand and network characteristics, the cost of travel for non-mechanised modes is calculated as a simple combination of travel time and distance.
- Walkability maps or audits and walking and cycling networks must be created and integrated into the model to fully take account of the assignment of active travel modes in the GDA; such modes are growing thanks to schemes such as Dublinbikes.

2.2.2 Transport Infrastructure Ireland National Transport Model

TII commissioned the development of the NTpM, completed in 2008, which was subsequently enhanced in 2010 and 2011 to include the National Rail Model, the National Bus Model and a variable demand model. An overview of the inputs and outputs of the TII NTpM are outlined in Table 2.2.

Critical analysis of the TII NTpM

Pros:

- The TII NTpM provides a high level of functionality, allowing for the following responses to be assessed:
  - changes in traffic assignment due to network changes;
  - changes in mode share due to increases/ decreases in travel time by car, public transport fares, fuel prices, tolling/road prices;
  - demand responses to changes in the cost of travel, including fuel price, public transport fares, congestion, tolling/road pricing and other demand management policies;

Table 2.2. Outline of the TII NTpM

Inputs	Outputs
NAVTEQ GIS data for all existing roads in Ireland	Outputs from the Demographic and Economic Models and the Car Ownership Model converted into O–D trip end totals (vehicle or passenger trips) for each mode
TII Traffic Monitoring Units network data	TDM – O–D trip end totals distributed between the zones in the model
CSO census data – Small Area Population Statistics	Travel (trip matrices) allocated to the network; travel costs generated for each mode
Place of Work, School or College – Census of Anonymised Records (POWSCAR); public transport timetables and scheduling	Variable Demand Model – impact of a change in the transport network or a change in travel costs (fuel price fluctuations, fares) on travel demand is assessed; highway, public transport demand by trip purpose; AM & Inter Peak O–D vehicle demand

CSO, Central Statistics Office of Ireland; GIS, geographic information system; O–D, origin and destination.

  - calculation of costs and benefits based on the outputs of travel time, congestion, vehicle-kilometres travelled (VKTs) and accident predictions on individual links and across the network.
- It is the first Irish model to provide a perspective from across the island of Ireland.
- The Variable Demand Model is effective in forecasting behavioural decisions in various scenarios based on a "do minimum" scenario.

Cons:

- The TII NTpM does not model urban/city transport networks and services, as these are left to urban/city transportation models.
- As a result of this, these urban areas are centres of highly concentrated GHG emissions. For example, examining the benefits of walking and cycling, and exploring the growth of renewable and sustainable fuels and alternative tax scenarios will be studied separately, from the perspective of city-suburban areas. Therefore, the outputs from the TII NTpM, although very beneficial from a national perspective, will be utilised to only a minor extent in the research conducted as part of the Greening Transport project.

2.2.3 ESRI HERMES and ISus

ISus, as previously specified, is a specially developed model capable of modelling the impact of economic activity (including transport) on the environment that can be linked to HERMES through feedback from the environment to the macroeconomy. An overview of the inputs and outputs of ISus are presented in Table 2.3.

Critical analysis of ISus

Pros:

- Projections of GHG emissions from economic processes to 2025 are significant in the context of the GDA draft transport strategy for 2030.
- The Car Stock Model will be applied in our research to examine the effect of sustainable car usage and reduced car ownership rates.

Cons:

- A closer examination of other modes of transport and their carbon emission projections to 2025 is a stark limitation of ISus, as public transport, although sustainable in the long term, must be studied to identify ways of increasing fuel efficiency and reducing the number of high-emitting vehicles in the fleet.

2.2.4 UCD MOLAND model

The MOLAND model was developed as part of a project carried out by the European Commission's Joint Research Centre for assessing and analysing urban and regional development trends across Europe. It has been used, mainly in research projects, to test transportation and land use policies. Table 2.4 details the main inputs and outputs associated with the MOLAND model.

Critical analysis of the MOLAND model

Pros:

- The MOLAND model provides a tool to aid understanding of the outcomes of specific policies spatially and the effect that this has on transport accessibility.

Table 2.3. Outline of ISus

Inputs	Outputs
CSO data – Small Area Population Statistics	Projections of GHG emissions from economic processes to 2025
Car Stock Model: CSO Household Budget Survey – income elasticity of demand for each engine category; CSO data on the average distance travelled by type of car; SEAI fuel efficiency data	Levels of car ownership stock, distance travelled, emission levels based on population income and numbers of automotive drivers; fuel efficiency estimates for each car by engine size, age and fuel type
Estimates and forecasts fed from HERMES and returned to inform economic policymaking decisions concerning the environment	Assessments of implications of different growth paths for national objectives on sustainable transport

CSO, Central Statistics Office of Ireland; SEAI, Sustainable Energy Authority of Ireland.

Table 2.4. Outline of the MOLAND model

Inputs	Outputs
Land use maps produced by ERA-Maptec Ltd; county boundary and electoral division maps from OSI	Maps of predicted land uses and their locations (analyses quantitatively and spatially)
Transport network – road and rail datasets from NTA and TII	Illustration of land use change over time that identifies irresponsible planning and zoning of land
Zoning maps developed with protected, conservation and national heritage areas included	Provides a tool to aid understanding of outcomes of specific policies spatially and the effect that this has on transport accessibility
Socio-economic data – CSO and ESRI datasets and extrapolation technique used to generate forecasts	Illustration of socio-economic trends using GIS software; recognises that mixed-use higher density land use is the best strategy for urban planning to reduce or limit emissions from transport

CSO, Central Statistics Office of Ireland; GIS, geographic information system; OSI, Ordnance Survey Ireland.

- A variety of spatial planning scenarios and the effects on specific sectors of the economy can be analysed.
- It offers an extensive framework for the comparison of conflicting socio-economic trends up to 2026 (in line with NTA and ESRI forecasts) and visualises these patterns using GIS (geographic information system) software.
- The business-as-usual (BaU) scenario acts essentially as a "do minimum" scenario in relation to current trends, which, similarly, links well with the NTA and TII models.

Cons:

- The updated version of the MOLAND model, with its extended transport model, was not made available within the time frame of this project.
- Significant data gaps exist. These have been highlighted by the MOLAND project team, including a lack of harmonised data (scalar, temporal and contextual) relating to the zoning status of land in the GDA.

2.2.5 Comparison of the models

An overview of the key elements of the transportation models discussed is presented in Table 2.5. The NTA model was chosen for the majority of the research conducted in this project. This decision was based on the fact that the NTA model was deemed to cover mobility patterns and behavioural changes more extensively than any of the other models available to the research team.

2.3 Review of Emissions Models

Road traffic is one of the greatest contributors to the GHG and air pollutant emissions (e.g. nitrogen oxides – NO_x). Reducing these emissions has become one of the main goals of sustainable transport policies. An analysis of the main factors influencing GHG emissions is essential for designing environmentally efficient strategies for road transport.

2.3.1 Classification of emission models

Various models can be used to calculate emissions from road transport, which can be broadly classified into static models (also known as top-down or macro-scale emission models) and dynamic models (also known as bottom-up or micro-scale models) (Elkafoury *et al*., 2014). The static models can further be classified to average speed emission models and aggregated emission factor (EF) models, whereas dynamic models can be sub-classified into traffic situation models and instantaneous models. These static and dynamic models, which are appropriate for the scale on which this research was conducted (i.e. on the GDA scale), have been discussed in the following section.

Average speed emission models

These are the most commonly used models and they assume that the average emission rate throughout a trip depends on the average speed of the vehicle during that trip. One important drawback of average emission models is that they do not allow the spatial resolution of emission calculations, but this limitation is not that relevant for vehicular emission calculations

Table 2.5. Summary of the models

Elements	NTA GDA model	TII NTpM	ESRI ISus	UCD MOLAND model
AM and PM peaks	✓	✓	–	–
Carbon emissions and environmental concerns	✓	–	✓	–
Land use	✓	–		✓
Private car ownership	✓	✓	✓	✓
Demand forecasting	✓	✓	✓	✓
Stated preference modelling of scenarios	–	✓	–	–

for vehicle fleets or at national level (Elkafoury *et al*., 2014). Some examples of average speed models are the Computer Programme to Calculate Emissions from Road Transport (COPERT) and the Vehicle Emissions Prediction Model.

Aggregated emission factor models

Models of this type operate at the simplest level, with a single EF being used for a broad category of vehicles and a general driving condition, such as road type (Wang and McGlinchy, 2009). These models calculate vehicular emissions on the basis of the amount of fuel consumed and VKTs (Elkafoury *et al*., 2014). Examples of this type of model are the Mobile Source Emission Factor Model (MOBILE) and the National Atmospheric Emission Inventory.

Traffic situation models

In this type of modelling approach, driving dynamics are also taken into account along with average speed. Traffic situations are defined by traffic conditions (e.g. congested, free flow, stop and go) on a specific type of road, such as urban roads, along with the speed limit value on that particular road (Wang and McGlinchy, 2009). One issue with this type of model is that it requires detailed statistics about vehicle speed and traffic situations associated with the trips (Elkafoury *et al*., 2014). Examples of traffic situation models are the Handbook of Emission Factors for Road Transport (HBEFA), the Assessment of Road Transport Emission Model (ARTEMIS) and the Vehicle Fleet Emission Model.

Instantaneous models

These models operate at highest level of complexity. Models of this type assign some emission rates to each combination of instantaneous speed and acceleration rate (Wang and McGlinchy, 2009). The disadvantage of these models is that they demand detailed data about vehicle and engine characteristics, the geometry of the road and the ambient temperature (Elkafoury *et al*., 2014). An example of an instantaneous or modal model is the Passenger Car and Heavy-duty Vehicle Emission Model.

2.4 Existing Emission Modelling Tools

This section gives a brief summary of various models developed to calculate emissions from road transport. Apart from models that have been developed by European countries, models developed in the USA and New Zealand have also been included. Table 3.2 presents the advantages and disadvantages of all the important transportation emission models.

2.4.1 Assessment of Road Transport Emission Model

ARTEMIS is a traffic situation model (André *et al*., 2009). It is one of the most comprehensive transportation emission models and it can operate at both macro and micro levels (Wang and McGlinchy, 2009). It contains four sub-models: (1) a traffic situation model; (2) an average speed model; (3) an instantaneous model; and (4) a kinematic regression model. Instantaneous models and kinematic regression models are for calculating emissions from light vehicles, but they are very complex models. In terms of the input data required, ARTEMIS requires very elaborate and reliable data regarding vehicle activity, fleet composition, driving conditions, etc. In addition, a detailed classification of the vehicles (e.g. size, technology) is required for accurate emission calculations. The vehicles must be classified as cars, light-duty vehicles, motorcycles, heavy-duty vehicles (HDVs), buses or coaches. Vehicle sub-categories, such as rigid or articulated, can also be provided. The model can estimate the emissions of most of the regulated pollutants.

ARTEMIS can calculate emissions from road, rail, air and ship transport and provides consistent emission estimates at both national and regional levels. The ARTEMIS tools were designed for three main applications: emission inventories, scenario calculations for assessing the impacts of alternative measures and to provide inputs for air quality models for assessing spatial and temporal impacts on the environment (UNECE Transport Division, 2012). As per the UNECE Transport Division report (2012), ARTEMIS has been fully implemented for compiling national air emission inventories in only four countries, namely Germany, Austria, Switzerland and Sweden. The application of the model in other countries will not be possible without the involvement of the ARTEMIS modelling team.

2.4.2 Computer Programme to Calculate Emissions from Road Transport

COPERT is an average speed model. It was developed for official road transport emission inventory preparation for the European Environment Agency (EEA) member countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, North Macedonia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK) (EMISIA, 2014).

The latest version, COPERT 5, can calculate emissions from a wide range and variety of vehicles, e.g. hybrid private cars, compressed natural gas (CNG) buses, liquefied petroleum gas (LPG) private cars and conventional HDVs, in addition to conventional diesel vehicles. Three types of roadway situation can be considered in COPERT: urban, rural and motorways. COPERT 5 includes many important EFs such as the cold-to-hot ratio, the ambient temperature, and vehicle use, mileage, fuel characteristics, etc. For HDVs, loading and gradients are also taken into account.

Uncertainties in estimating non-exhaust particulate matter (PM) emissions are also associated with COPERT 5 as with the other emission models. However, this model is applicable to all relevant research, scientific and academic applications. The input data are consistent with the Eurostat classification. As a result, the model is well suited for European Union (EU) Member States' reporting of detailed statistical information (UNECE Transport Division, 2012).

2.4.3 Handbook of Emission Factors for Road Transport

HBEFA is a traffic situation model. The first version of HBEFA was published in 1995 and the most recent version (3.2) was produced in 2014. It was developed on behalf of several European countries (i.e. Germany, France, Sweden, Switzerland and Austria) (Schmied, 2014).

It takes into account all important vehicle classes, including private cars, light commercial vehicles (LCVs), HDVs, buses, motorcycles, mopeds, etc., differentiated by fuel, engine capacity and weight classes for a variety of traffic situations.

HBEFA calculates emissions of GHGs and most air pollutants from road transport. It provides EFs (hot exhaust emissions, cold start emissions, evaporative emissions) for all regulated and important non-regulated air pollutants.

HBEFA can be applicable to city/local levels or regional levels. However, HBEFA also contains a database of all the country-specific vehicle fleet data necessary for running the model. It is not possible for the user to apply the model to countries other than those already included in the database (Wang and McGlinchy, 2009; NZ Transport Agency, 2013; Schmied, 2014). Thus, HBEFA cannot be applied for calculating emissions from road transportation in Ireland.

2.5 Emission Modelling Tools – Conclusions

It can be seen from the above review that the vehicle emission models vary in their modelling approaches, and in the levels of detail required in their input data. They are suitable for different applications and situations regarding spatial and temporal scales and depending on whether the models are being used to test relative changes under different scenarios or to predict absolute levels of emissions at a given time or place.

From the available literature, it can be stated that COPERT and MOVES (or its previous version MOBILE) are the most extensively used modelling methods for calculating emissions from mobile sources.

2.6 Transport and Emission Models Used in the Greening Transport Project

The research team decided to use the NTA model for the transportation analysis and COPERT as the main emission model. The main reasons for this decision are as follows:

- The NTA model is the most sophisticated transport modelling tool in Ireland and the one that is best suited for the policy analysis conducted in the Greening Transport project.
- The EPA recommend the COPERT model/ calculator for emission estimations and it is the model most widely used in the EU.
- The results that are estimated from the Greening Transport project can be compared with other policy analyses that have been conducted using the NTA GDA model.

3 Smarter Travel Options to Reduce Emissions

3.1 Objectives

This chapter of the report explores a strategy to encourage a realistic mode shift from private car use to sustainable travel modes such as walking, cycling, bus and rail and other modes such as carpooling and car-sharing in the GDA. It examines the responsiveness of a sample to a range of policy measures aiming to incentivise sustainable practices for commuting to places of work and education in the GDA. By means of a stated preference (SP) experiment, a selection of policies was tested in various hypothetical scenarios to gauge responses in terms of travel behaviour change, ultimately quantified by analysing the potential mode shift. This chapter assesses relevant literature on this subject and delineates the experimental design and the survey creation process, and most importantly delves into the discrete-choice modelling results and analysis of this study.

This part of the project had the following objectives:

- to test the hypothesis that a range of transport policy incentives could encourage commuters, particularly those who commute by car, to shift to other more sustainable modes of transport;
- to determine the most suitable policy measures that could be adopted in Ireland to increase the use of sustainable modes of transport;
- to quantify behavioural responses and determine potential levels of car-shedding in the GDA given significant changes to transport policy using the NTA Eastern Regional Model (ERM; essentially the same as the NTA GDA model described in Chapter 2);
- ultimately to reduce the modal share of private car use, to sway attitudes in favour of sustainable transport modes and to destabilise long-standing car hegemony and driving habits in the GDA by providing the necessary testing of various policy approaches through choice modelling.

Each of the objectives outlined above were then incorporated into the research plan developed for this section of the study (see Figure 3.1).

3.2 Current State of the Transport Sector and Sustainable Mobility Provision within the Greater Dublin Area

The study area for this project is the GDA, which includes the counties of Dublin, Meath, Kildare and Wicklow. The GDA was selected as the most appropriate area for this research because there is a greater range of alternative transport options available in this region than in the rest of Ireland (i.e. more alternatives to the private car to offer as viable options in the choice scenarios). In recent years, the GDA has seen the introduction of several travel options as alternatives to the private car and various projects seeking to extend, improve and connect existing public transport routes such as the Luas Cross City project. Moreover, there are currently two car-sharing/car-club providers in operation: GoCar and Toyota’s Yuko car club.

GoCar, in partnership with the German car-sharing company Cambio, was launched in 2008 and has grown substantially in Dublin and continues to be the largest car-sharing provider in Ireland. Yuko (Japanese for “Let’s Go”) is Ireland’s newest car-sharing provider; it was launched in Dublin in June 2016. Yuko is a noteworthy addition to the car-sharing scene in Dublin, as the vehicles available are all plug-in hybrid electric vehicles (PHEVs). As further support of shared mobility, a range of bike-sharing providers are in operation in Cork, Galway and Limerick as well as the largest operation – Dublinbikes – in Dublin; that provider has grown substantially since launching in 2009. In the Dublin network, there were in 2015 1500 bicycles at 101 stations, with a further 15 stations and an additional 100 bikes planned to be made available in the summer of 2017. Since its launch, almost 30 million journeys have been made through the Dublinbikes scheme, with a long-term subscription base of over 66,000 people and an average journey duration of 16 minutes (Dublinbikes, 2020). A carpool networking website (www.carsharing.ie), not to be confused with the type of service that GoCar and Yuko provide, also exists. Mobility services such as car-sharing and bike-sharing, carpooling and

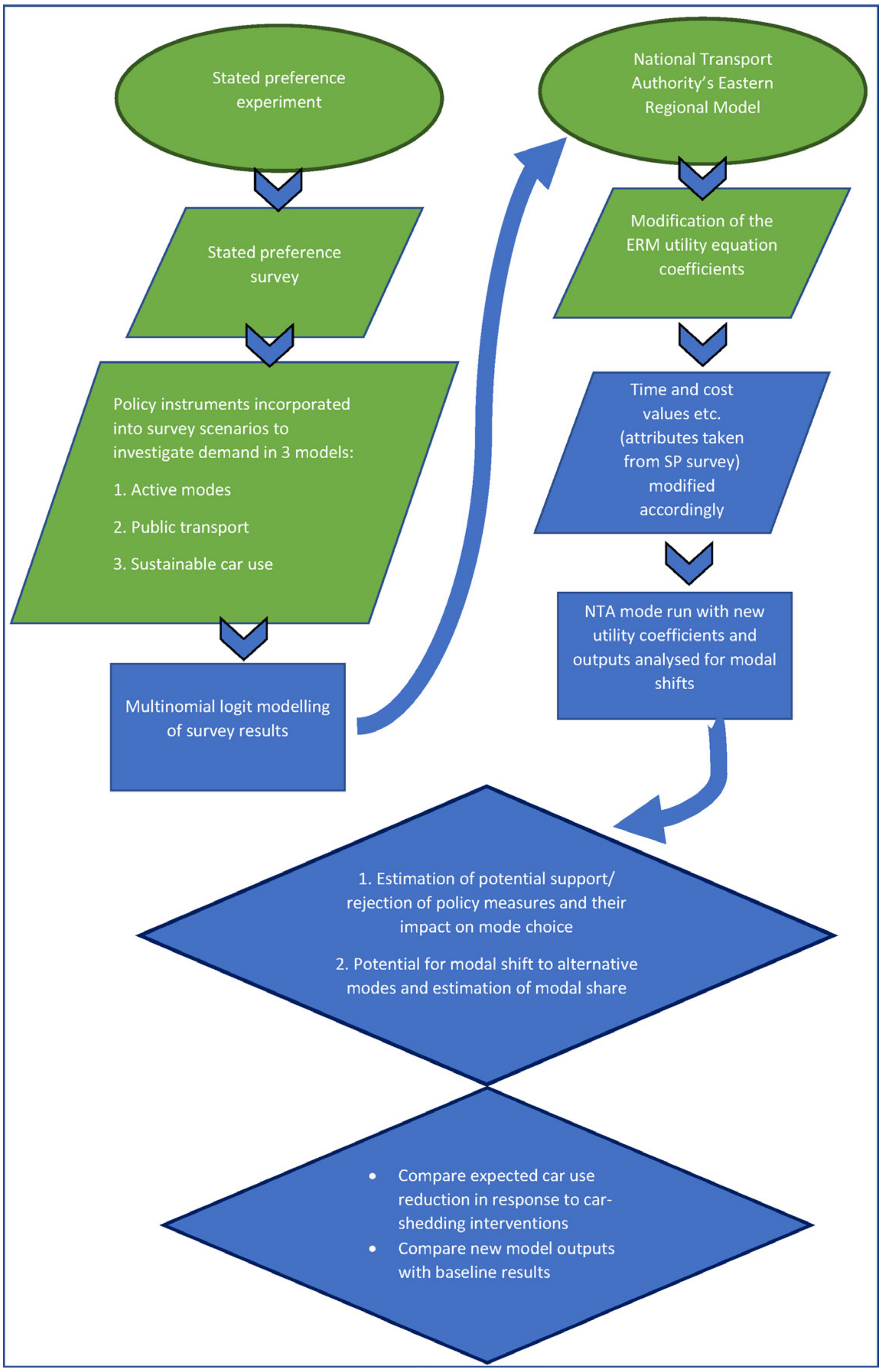

Figure 3.1. Research plan.

on-demand taxi services (i.e. Mytaxi, etc.) offer further sustainable alternatives to commuters that can help reduce the need to own a car, thus contriburing to the car-shedding process.

3.3 Stated Preference Survey Design and Structure

Revealed preference (RP) assesses actual or current market occurrences due to existing market forces. Census mode share data are an example of RP data, as they are collected based on the population's actual preferences and not on attributes in hypothetical scenarios. SP data on the other hand are hypothetical but built upon a solid experimental design. SP approaches are extensively utilised in travel behaviour research to identify behavioural responses to choice situations that are not revealed in the market (i.e. hypothetical or projected scenarios).

Accordingly, SP experimentation was deemed to be an appropriate and established method for evaluating the impacts of a range of policy measures on mode choice behaviour. In addition, a study such as this has (to date) not been conducted in Ireland; thus, it was estimated that this study would significantly add to the understanding of how sustainable travel behaviour may be encouraged through the application of particular, incentivising policy approaches.

In the SP experiment in this study, respondents were be asked to rank in order their preferences from a set of three alternative travel options or modes (i.e. walking, cycling, driving). Each of these choice tasks was framed as a choice scenario, with differing levels of attribute intensity associated with each alternative. The attributes are essentially the variants in the experiment and, therefore, they differ depending on the choice alternatives in each model. Figure 3.2 illustrates the three defined models used in this study, one examining active modes (walking and cycling), the second concerning public transport (bus and rail) and the third considering the sustainable usage of the private car (smarter car use), which consists of carpooling or car-sharing. Each of the three models will be analysed independently to examine the influence of a number of alternative-specific attributes or policy tools on modal choice behaviour. The models were represented in separate choice sub-sections of the SP survey to effectively isolate the choice scenarios. As shown in Figure 3.2, the private car (drive alone) option is present in each model; this is considered a constant or "no choice"/"status quo" option that has no attributes applied to it. The decision to do this was made for a number of reasons. First, there was reluctance to disincentivise car owners by, for example, raising the costs of owning a car, as these costs generally grow year on year and so this would perhaps bother or anger potential respondents. Second, it is held in the literature that including a base alternative or "current choice" option in fact brands decisions more realistic and leads to better predictions of market penetrations, and also better mimics consumer choices, increasing experimental efficiency.

For more information on the modelling approach used in this study, readers are encouraged to consult Deliverable 3.1 from the Greening Transport project (Carroll *et al*., 2017).

3.4 Applying the Discrete Choice Modelling Approach

To create an effective SP choice scenario, it is necessary to provide respondents with a scenario that prompts them to make a trade-off between a number of alternatives. The attributes applied to the alternatives define the appeal of each option, thus highlighting their importance in an SP survey. The alternative-specific attributes for active modes, public transport, and carpooling and car-sharing in the models were carefully considered, with reference

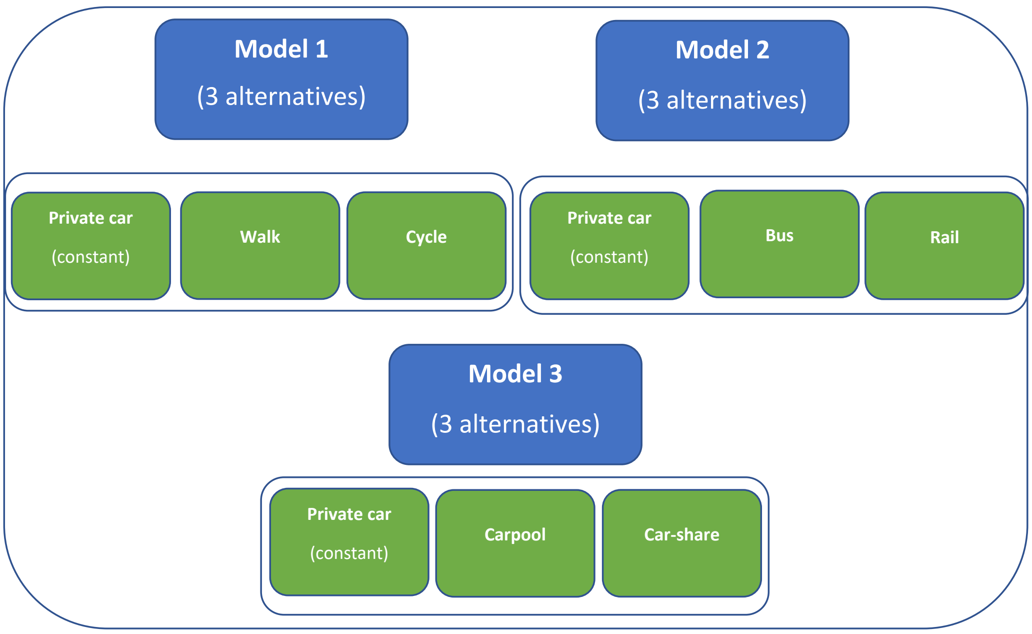

Figure 3.2. SP experiment design structure.

to the literature. As the attributes were determined by the resultant impacts of the mode-specific policy incentives, it was necessary to first consider what elements of each mode included in the SP experiment could be improved to increase their utility.

3.4.1 Model 1 – active modes

In their research on active modes of transport, Short and Caulfield (2014) and Pooley *et al*. (2013) examined the challenge of ensuring safety along cycling routes and identified speed and available infrastructure as factors contributing to the perceived risk of cycling. Increased segregation from motorists is seen as more attractive and could result in an increase in cycling numbers. This is supported by evidence from Caulfield *et al*. (2012), who concluded that segregated cycling infrastructure was preferred from the results of an SP experiment. This was followed by a preference for routes through residential streets and parks, where lower speed limits and traffic levels are the norm. Lowering urban speeds was also found to be associated with lower serious injury rates and this was correlated with accident severity, which increases with speed (Nilsson, 2004; Caulfield *et al*., 2014). It was similarly determined here that only 5% of collisions are severe in 30 kmph zones, thus adjacent traffic speed is a main policy variable to be considered with cycling and walking.

As a result of this, it was decided to include infrastructure and adjacent traffic speed as the mode-specific attributes to include in the active modes model, as shown in Table 3.1.

3.4.2 Model 2 – public transport (bus, rail)

Bus and rail are commonly reflected upon by commuters in terms of time, cost and reliability of timeliness, which is linked to the frequency or level of service. These factors have been widely examined in the SP literature. Deliverable 3.1 discusses these attributes and the attributes of Model 2 in this study are displayed in Table 3.2.

3.4.3 Model 3 – smarter car use (carpooling and car-sharing)

It was identified from the literature that convenience, time and cost were the main attributes affecting mode choice behaviour for carpooling and car-sharing. The attribute levels in Model 3 relate to the levels of convenience, time and cost at which an individual might be willing to choose carpooling or car-sharing

Table 3.1. Active modes model – alternatives, attributes and attribute levels

Mode	Attribute	Attribute level
Private car (drive alone)	Cost	Gradual increase in the ownership costs of a car
Walking	Infrastructure improvements: more even surface, wider foot paths and separated from traffic	20% of trip with these improvements 40% of trip with these improvements 60% of trip with these improvements
	Travel time reduction	Reduced by 2 minutes Reduced by 4 minutes Reduced by 6 minutes
	Adjacent traffic speed reduced to 30 kmph	50% of trip with lower speed limit 75% of trip with lower speed limit 100% of trip with lower speed limit
Cycling	Infrastructure improvements: fully segregated from traffic	For 20% of trip For 40% of trip For 60% of trip
	Travel time reduction	Reduced by 2 minutes Reduced by 4 minutes Reduced by 6 minutes
	Adjacent traffic speed reduced to 30 kmph	50% of trip with lower speed limit 75% of trip with lower speed limit 100% of trip with lower speed limit

Table 3.2. Public transport model – alternatives, attributes and attribute levels

Mode	Attribute	Attribute level
Bus	Frequency	25% more often 50% more often Twice as often
	Travel time reduction	15% reduction 25% reduction 35% reduction
	Cost	15% reduction 25% reduction 35% reduction
Private car (drive alone)	Cost	Gradual increase in the ownership costs of a car
Train/Luas	Frequency	25% more often 50% more often Twice as often
	Travel time reduction	15% reduction 25% reduction 35% reduction
	Cost	15% reduction 25% reduction 35% reduction

over the other two alternatives in the hypothetical scenario.

Time and cost have a direct effect on the perceived convenience for the carpool/car-share driver, as convenience is closely linked to the time attribute in terms of access and waiting times. For example, as the access and waiting times increase as a result of pick-up delays and the number of carpool members in a car, the inconvenience of the trip also increases. The attributes and attribute levels of Model 3 are displayed in Table 3.3.

3.5 Survey Design and Data Collection

The SP survey was conducted online in March 2017 and was distributed randomly to a sample of the population resident in and who work or study in the area of interest for this experiment (the GDA). The survey was organised into four sections:

1. introductory questions;
2. perceptions of policy measures;
3. SP scenarios;
4. demographic characteristics.

The SP experiment itself motivated respondents to decide which trip characteristic/“deal breaker” or combination of attributes (i.e. time, cost, convenience, etc.) was most important to them in terms of their commute and then asked respondents to rank their mode choice in order of preference from the three modes given. For instance, if their trip were to become 35% cheaper and 15% quicker by taking the bus to their place of work/education as a result of various policy tools being implemented, relative to the trip attributes that the current bus service provides, would this spur them to switch to this mode of transport or would they simply continue using their current mode of transport (i.e. no change)?

The sample for this study was selected from the population of the GDA. The target sample was defined as those working and studying within the GDA, as the SP survey in this study specifically concerned the commuting population. To calculate the required sample size based on the population of the GDA, the following equation was used (Dillman, 2000):

$$Ns = \frac{(Npp)(pp)(1-pp)}{(Npp-1)\left(\frac{B}{C}\right)^2 + (pp)(1-pp)} \tag{3.1}$$

Table 3.3. Smarter car use model – alternatives, attributes and attribute levels

Mode	Attribute	Attribute level
Carpooling	Convenience (reduction in access/waiting time)	10% reduction
		30% reduction
		50% reduction
	Time (reduction in trip time)	15% reduction
		25% reduction
		35% reduction
	Cost (reduction in trip cost)	15% reduction
		25% reduction
		35% reduction
Car-sharing (GoCar/Toyota Yuko)	Convenience (reduction in access/waiting time)	10% reduction
		30% reduction
		50% reduction
	Time (reduction in trip time)	15% reduction
		25% reduction
		35% reduction
	Cost (reduction in trip cost)	15% reduction
		25% reduction
		35% reduction
Private car (drive alone)	Cost	Gradual increase in the ownership costs of a car

where *Ns* is the sample size required for the desired level of precision, *Npp* is the size of the population, *pp* is the proportion of the population expected to choose one of the three response categories – to allow for maximum variation in the sample, a 50–50 split was utilised (i.e. 50% of respondents choose an option and 50% do not) – *B* is the acceptable amount of sample error and *C* is the *Z*-statistic associated with the response level.

Therefore, for the experiment, the above equation was written as:

$$Ns = \frac{(1{,}907{,}332)(0.5)(1-0.5)}{(1{,}907{,}332)\left(\frac{0.05}{1.65}\right)^2 + (0.5)(1-0.5)} = 272 \quad (3.2)$$

From the equation above, it can be seen that 272 was found to be a satisfactory number of respondents for the survey, based on the population of the GDA (1,907,332), a 95% confidence level and a 5% margin of error, and an associated *Z*-statistic of 1.65. The sample was recruited online with the aid of Delve Research, an independent survey research company that uses a panel of respondents nationally. The panel utilised by Delve Research in this study was first recruited from Delve Research's own database of respondents, and later this was extended to include an external pool of respondents to meet the required target sample size. The panellists were given a number of chances to be entered into a draw for a prize, in exchange for fully completing the survey provided (Delve Research, 2017). Delve Research ensured the receipt of a representative sample with a 50–50 gender split, with respondents being accepted only if they were living and working in the GDA counties. This was achieved by filtering out those residing outside the GDA by means of a pre-survey question. To finalise the sample, responses from only those who completed the socio-demographic section of the survey were considered for the modelling in this study.

A total of 552 survey responses were recorded, of which 432 were fully complete and therefore could be used for modelling purposes.

3.6 Sample Characteristics

A summary of the characteristics of the sample is presented in Table 3.4, where they are compared with 2016 census data. From this, it can be observed that a greater percentage of the sample was in the 35–44 years and 45–54 years cohorts than in other age groups, with most having at least a secondary school

Table 3.4. Sample characteristics

Characteristic	Survey		Census 2016 (GDA)	
	N	%	*N*	%
Gender				
Male	193	44.5	935,849	49
Female	239	55.5	971,483	51
Total	432	100	1,907,332	100
Age				
18–24 years	38	8.8	168,686	11.7
25–34 years	84	19.4	304,968	21.1
35–44 years	114	26.4	315,207	21.8
45–54 years	109	25.2	242,078	16.8
55–64 years	67	15.5	186,756	12.9
65+ years	20	4.6	226,362	15.7
Total	432	100	1,444,057	100
Education				
No formal education	3	0.7	16,711	1.5
Primary education	8	1.8	113,325	9.9
Secondary education	130	29.9	369,637	32.4
Technical or vocational	46	10.6	99,092	8.7
Advanced certificate/apprenticeship	26	6	63,322	5.5
Higher certificate	49	11.3	59,886	5.2
Ordinary bachelor degree/diploma	66	15.2	99,679	8.7
Honours bachelor degree	55	12.6	156,350	13.7
Postgraduate diploma/degree	48	11	147,700	12.9
Doctorate (PhD) or higher	4	0.9	15,550	1.4
Total	435	100	1,141,252	100
Income				
€24,999 or less	110	25.3	NA	NA
€25,000–49,999	129	29.7	NA	NA
€50,000–74,999	74	17	NA	NA
€75,000–99,999	27	6.2	NA	NA
€100,000 or more	17	3.9	NA	NA
Rather not say	78	17.9	NA	NA
Total	435	100	NA	NA
Marital status				
Single	179	41.5	1,055,977	55.4
Married	215	49.9	693,749	36.4
Separated	19	4.4	46,127	2.4
Divorced	15	3.5	41,373	2.2
Widowed	3	0.7	70,106	3.7
Total	431	100	1,907,332	100
Children/dependants				
None	199	46	140,349	29.2
One	65	15	136,252	28.3
Two	98	22.6	124,728	25.9
Three	49	11.3	57,916	12.0

Table 3.4. Continued

Characteristic	Survey		Census 2016 (GDA)	
	N	%	*N*	%
More than three	22	5.1	21,817	4.5
Total	433	100	481,062	100
Economic status				
Working for payment or profit	267	61.8	853,116	56.4
Looking for first regular job	8	1.9	12,771	0.8
Unemployed	24	5.6	99,248	6.6
Student	24	5.6	175,321	11.6
Looking after home/family	40	9.3	115,164	7.6
Retired	36	8.3	197,761	13.1
Unable to work because of permanent sickness or disability	17	3.9	53,890	3.6
Other	16	3.7	5350	0.4
Total	432	100	1,512,621	100
Living location				
Dublin City	55	12.7	NA	NA
Inner suburbs	141	32.6	NA	NA
Outer suburbs	101	23.3	NA	NA
Commuter town	78	18	NA	NA
Rural area	58	13.4	NA	NA
Total	433	100	NA	NA
Working location				
Dublin City	135	33.8	NA	NA
Inner suburbs	116	29	NA	NA
Outer suburbs	67	16.8	NA	NA
Commuter town	53	13.3	NA	NA
Rural area	29	7.3	NA	NA

NA, not available from the 2016 census.

education, being married with no children, having an average household income of between €24,999 and €49,999 per annum, living in the inner suburbs of Dublin and working in Dublin city centre. It must be noted that a considerably higher percentage of the sample was in employment than in education. The gender split as well as the age, number of children/dependants, education, marital and economic status characteristics of the survey were found to be consistent with the population of the GDA when compared with the 2016 census results for the GDA (CSO, 2017).

In terms of the trip attributes of the respondents, Table 3.5 shows that 39.5% of the sample drove to places of work or education, followed by 14% commuting by bus, 11% walking, 9% taking the train, DART[1] or Luas,[2] and 5% cycling. Four per cent of the respondents stated that they regularly or only telecommuted (i.e. worked from home), and 2.4% carpooled to commute to places of work or education. This modal split of the sample was ideal for this experiment, as it presented us with a real challenge in terms of shifting the mode chosen by many of those who drove by car alone to other more sustainable modes such as walking, cycling, public transport or riding as a passenger in a car (i.e. carpooling). Table 3.5 displays these modal share values among various other trip characteristics of the sample such as trip

1 The DART (Dublin Area Rapid Transit) is a rail service in the Dublin area.

2 Luas is Dublin’s light rail/tram service.

Table 3.5. Trip attributes of survey respondents compared with 2016 census data

Attribute	Survey		Census 2016 (GDA)	
	N	%	*N*	%
Mode				
Not at work/education	67	12.1	NA	NA
On foot	61	11.1	217,912	18.1
Bicycle	27	4.9	60,454	5.0
Bus	78	14.1	162,818	13.6
Rail	51	9.2	73,005	6.1
Motorcycle or scooter	7	1.3	5566	0.5
Driving a car	218	39.5	441,147	36.7
Passenger in a car	13	2.4	176,265	14.7
Van	6	1.1	35,594	3.0
Other, including taxi or truck	2	0.4	2746	0.2
Work mainly from home	22	4	25,782	2.1
Total	552	100	1,201,289	100
Distance travelled				
< 2 km	92	17.4	NA	NA
2–4 km	85	16.1	NA	NA
4–6 km	74	14	NA	NA
6–8 km	57	10.8	NA	NA
> 8 km	221	41.8	NA	NA
Total	529	100	NA	NA
Trip time				
10 minutes or less	75	14.7	300,944	33.0
11–20 minutes	112	21.9	355,748	39.0
21–30 minutes	106	20.7		
31–40 minutes	88	17.2	255,094	28.0
40 minutes or more	130	25.4	208,463	22.9
Total	511	100	911,786	100
Cost of commute				
€0	164	30.4	NA	NA
€1–10 per day	196	36.4	NA	NA
€5–10 per day	122	22.6	NA	NA
€10–15 per day	39	7.2	NA	NA
> €15 per day	18	3.3	NA	NA
Total	539	100	NA	NA
Cars owned per household				
One	246	46	272,687	42.5
Two	177	32.4	205,332	32.0
Three	26	4.8	33,760	5.3
Four or more	9	1.6	10,249	1.6
None	89	16.3	119,180	18.6
Total	547	100	641,208	100

NA, not available from the 2016 census.

times and distances travelled to work and education by the respondents. These attributes are also compared with data from the 2016 census. It can be observed that, in the sample, 25% of the respondents' commute to places of work or education took 40 minutes or more, closely followed by 11 to 20 minutes and 21 to 30 minutes on average. The distances travelled are linked to the time travelled, which showed that, by a larger margin, 41.8% of the sample travelled 8 km or more to places of work or education. Similarly, of interest is the number of cars available to each household, with 46% of the sample stating that one car was available, followed by 32% stating that two cars were available. Table 3.5 also shows that these figures were similar to those from the 2016 census.

3.7 Stated Preference Model Results

3.7.1 Model 1 – active modes model

Table 3.6 presents the results estimated for a range of socio-demographic variables. The results indicate that, unlike the results from the base model, the *Walkinfrai* (improved walking infrastructure) variable is significant at a 90% confidence level and the coefficient is positive, indicating that, as policy measures increase the percentage of evenly surfaced, wide footpaths, separated from traffic, the utility of the walking mode rises. In relation to predictors, females were more likely to walk to places of work or education than males, and older age groups were more likely to walk than younger age cohorts. Furthermore, possessing a driving licence, owning more than one car and having free parking available at places of work or college/university dramatically decrease the chances of individuals opting to walk to places of work or education, which makes intuitive sense. For cycling, this was also the case, although the results also suggest that those not in full-time employment, i.e. the unemployed, students, the retired, etc., were more likely to report cycling to places of work or education, as it was stated in the survey that, if the respondent was not currently in employment or studying, they should respond in accordance with how they used to travel when they were. Finally, having one child or more significantly decreased the chances of commuting by bike.

Table 3.6. Output from Model 1

Variable		Coefficient	Z-statistic
Walkinfra	Infrastructure	0.0077*	1.74
Walktime	Time	–0.0124	–0.28
Walkadjs	Adjusted traffic speed	0.0027	0.78
Walkgen	Gender	–0.2778***	–3.17
Walkage	Age	0.2374***	3.30
Walkedu	Education	0.0912**	2.19
Walklic	Driving licence	–1.3091***	–6.02
Walkown	Car ownership	–0.3765***	–3.27
Walkpark	Free parking	–0.3800**	–1.98
Cycleinfra	Infrastructure	0.0021	0.49
Cycletime	Time	0.0363	0.84
Cycleadjs	Adjusted traffic speed	0.0028	0.83
Cycleedu	Education	0.0907**	2.22
Cycleemp	Employment status	0.1416***	3.76
Cyclechil	No. of children	–0.1109*	–1.66
Cyclelic	Driving licence	–0.5030**	–2.26
Cyclepark	Free parking	–0.5168***	–2.80

Log likelihood: –992.623; constants only log likelihood: –1060.040; AICc (Akaike information criterion, corrected for small sample size): 2041.2; pseudo-rho-squared: 0.063; chi-squared: 0.000.

***Significant at 90% confidence level.**

****Significant at 95% confidence level.**

*****Significant at 99% confidence level.**

3.7.2 Model 2 – public transport model

Model 2, consisting of the bus and rail alternatives, produced noteworthy results in the context of the aims of the experiment (i.e. encouraging a shift away from solo driving to alternative modes of travel).

As in Model 1, Model 2 was similarly extended to include various socio-demographic variables, the output from which is presented in Table 3.7. Many of the variables were shown to be statistically significant. For example, some of the main attributes in the model displayed increased significance in the extended model, such as the *Bustime* (bus travel time) and *Buscost* (bus fare) variables. The socio-demographic variables provide greater detail on the profile of the individuals choosing between the alternative modes of transport. Those with a higher level of education were more likely to choose the bus and rail modes than those with lower levels of education. This is also true for those of lower economic status and unmarried people. As strong positive coefficients are estimated for the *Busempl* and *Trainempl* variables, this model's results suggest that there is a higher likelihood of unemployed people, home carers and retired people opting to use private cars over the bus or train, which is largely due to differing transportation requirements throughout the day (i.e. commuter services would not address all of the transport needs of these individuals). Similarly, those who were married were more likely to travel by car than by bus or rail, which was perhaps influenced by the higher income levels of these individuals given their socio-demographic characteristics (i.e. being married).

The fact that the *Buschild* (reflecting bus users with children) coefficient is negative suggests that individuals with one or more children are much less likely to commute to places of work or education by bus. Older age groups were more likely to travel to places of work or education by rail, increasing the utility of this mode.

Table 3.7. Output from Model 2

Variable		Coefficient	Z-statistic
Busfreq	Frequency	0.0038	1.10
Bustime	Time	0.0147*	1.71
Buscost	Cost	0.0307***	3.70
Busedu	Education	0.1116**	2.51
Busempl	Employment status	0.1092**	2.07
Busmari	Marital status	0.5686***	3.48
Buschild	No. of children	–0.1116*	–1.86
Buslic	Driving licence	–1.6312***	–5.44
Busown	Car ownership	–0.4931***	–4.00
Trainfreq	Frequency	0.0019	0.54
Traintime	Time	0.0316***	3.52
Traincost	Cost	0.0165*	1.92
Trainage	Age	0.2264**	2.57
Trainedu	Education	0.1743***	3.70
Trainempl	Employment status	0.1370**	2.52
Trainmari	Marital status	0.2936*	1.75
Trainlic	Driving licence	–1.4228***	–4.62
Trainown	Car ownership	–0.5399***	–4.19
Trainpark	Free parking	–1.0903***	–4.49

Log likelihood: –872.445; constants only log likelihood: –971.709; AICc (Akaike information criterion, corrected for small sample size): 1800.9; pseudo-rho-squared: 0.102; chi-squared: 0.000.

***Significant at 90% confidence level.**

****Significant at 95% confidence level.**

*****Significant at 99% confidence level.**

3.7.3 Model 3 – smarter car use model

Model 3 considers carpooling and car-sharing as alternative transport modes. This model is particularly important in the context of this project, as it directly relates to the sustainable usage of the private car to encourage car-shedding behaviour, by means of reducing the number of people driving alone to work, rendering the car less important for commuting proposes. It is predicted that ultimately, by attracting more people to commute by carpool or taking up a car-share membership through various policy incentives, a reduction in car use and potentially car ownership could transpire.

Table 3.8 shows that all the coefficients are statistically significant at various confidence levels, with the exception of the *Cartime* (car travel time) variable. This may suggest that individuals who chose to carpool or car share did not place much importance on the time attribute. Various predictors in the model produced significant results, with gender, age and education level being similarly significant variables for both the carpool and car-share alternatives. These coefficients indicate that females, within the higher age cohorts and with higher levels of education were more likely to carpool or car share than younger males with lower levels of education. Those living in areas in the outer suburbs or peripheral locations of the GDA were more likely to choose to carpool, which makes sense given their longer commuting distances to places of work or education. In addition to this, unmarried people were distinctly more likely to carpool than married individuals. Yet, those working in closer proximity to Dublin city centre in full-time employment were more likely to car share, perhaps because of the greater availability of car-sharing vehicles in Dublin city centre. Having a driving licence and owning more cars, as in Models 1 and 2, reduced the chances of people commuting by carpool and car-share to places of work or education.

Table 3.8. Output from Model 3

Variable		Coefficient	Z-statistic
Carpconv	Convenience	0.0131***	3.06
Carptime	Time	0.0126	1.47
Carpcost	Cost	0.0246***	2.86
Carpgen	Gender	–0.2023**	–2.23
Carpage	Age	0.3678***	4.68
Carpedu	Education	0.1824***	4.38
Carplive	Living location	0.1904**	2.25
Carpmari	Marital status	–0.2210**	–2.01
Carplic	Driving licence	–0.9395***	–3.91
Carpown	Car ownership	–0.3005***	–2.71
Carsconv	Convenience	0.0098**	1.97
Carstime	Time	0.0187*	1.86
Carscost	Cost	0.0209**	2.07
Carsgen	Gender	–0.3260***	–3.08
Carsage	Age	0.2589***	2.89
Carsedu	Education	0.0836*	1.65
Carswork	Working location	–0.2381**	–2.27
Carsempl	Employment status	–0.0952*	–1.72
Carschil	No. of children	0.1786**	2.16
Carslic	Driving licence	–0.5606**	–2.05
Carsown	Car ownership	–0.3135**	–2.40

Log likelihood: –856.938; constants only log likelihood: –925.384; AICc (Akaike information criterion, corrected for small sample size): 1773.9; pseudo-rho-squared: 0.074; chi-squared: 0.000.

***Significant at 90% confidence level.**

****Significant at 95% confidence level.**

*****Significant at 99% confidence level.**

3.8 Discussion of Stated Preference Model Results

This experiment was conducted with the principal aim of analysing the impact of strategically designed policy plans on the commuting population of the GDA. The tool used, having been determined to be the type most commonly applied to experiments in this field of research, was an SP survey that incorporated these policy plans into hypothetical choice scenarios.

In analysing the results of this survey, it became apparent that individual commuters do need a proper incentive to disrupt commuting habits that may have been in place for a considerable amount of time. However, if such incentives are able to lead to tangible time and cost savings for the commuter, then extensive shifts to more sustainable mode choices can result. The scenarios were constructed to encourage the respondents to deliberate on which attributes were of real importance to them and from this they were prompted to consider trade-offs between three modes of transport in each scenario. If a respondent was not attracted by the incentives presented or if, given their socio-demographic characteristics, the sustainable modes could not be realistically considered, then the status quo “drive alone” option could be selected as a no-choice alternative, as no incentives or disincentives were applied to this option. From examining the results, it was found that, with the exception of Model 1, the sample responded very positively to the incentives included in the experiment, to the extent that the car (drive alone) option was often placed second or even third in order of preference. This provides robust evidence for the benefits of paying more attention to providing commuters with more incentives to switch to modes of transport other than the private car.

4 Examining Emission Reductions Resulting from Changes in the Private Car Fleet and the Public Transport Bus Fleet

4.1 Introduction

This chapter of the report examines emission information related to the private car and public transport bus fleets in Ireland. In addition to electric vehicles (EVs) accounting for 10% of the private car fleet in 2020, Ireland's target was to derive 16% of its final energy use and 10% of its transport energy use from renewable sources (SEAI, 2016). This target was not reached. However, transport emissions were projected to show a strong growth over the 2015–2020 period, resulting in a 10–12% increase in GHG emissions. A 12% increase was projected based on measures that are already in place (i.e. existing measures), such as vehicle registration tax (VRT) and motor tax (introduced in 2008), carbon tax (imposed on fuels since 2010) and improvements to the fuel economy of private cars. Under an additional measures scenario, which assumes that 8% of the transport energy demand will be met by renewables and 10,000 EVs will be deployed by 2020, emissions from the transportation sector were expected to increase by 10%, to 13 Mt CO_2eq (megatonnes of carbon dioxide equivalent). GHG emissions from road transport alone are expected to increase by 14% by 2030, relative to 2005 levels, with existing measures.

4.2 Examining Emission Reductions Resulting from Changes in the Private Car Fleet

In 2008, it was announced that 10% of the private car fleet (approximately 230,000 vehicles) would be electric by 2020 (SEAI, 2014). The electrification of the transportation sector has become necessary considering the growth in transport demand, resulting in higher GHG emissions, urban air pollution and fossil fuel depletion (Weldon *et al*., 2016). EVs have zero tailpipe emissions, which is particularly important in dense urban areas. They are the most promising alternative to internal combustion engine vehicles (ICEVs) in terms of moving towards a cleaner transportation sector (Casals *et al*., 2016). The net emission savings from EV use have always been a concern though, as they largely depend on the fuel the electricity is produced from. Thus, while evaluating the environmental benefits of EVs over conventional vehicles, one must consider the emissions resulting from the energy production. Well-to-wheel (WTW) methodology is commonly used to estimate the fuel efficiency of a vehicle in its use phase, and can be considered a combination of the well-to-tank and tank-to-wheel (TTW) methodologies (Campanari *et al*., 2009; Hawkins *et al*., 2012). The WTW phase comprises the emissions resulting from the fuel extraction, refining and distribution activities needed to fill the vehicle tank. The TTW emissions include the emissions produced by fuel combustion to generate traction power. The environmental impact of an ICEV mostly depends on the TTW phase. Whereas, in the case of EVs, the TTW emissions are zero. Thus, in the carbon footprint assessment of EVs, the WTW phase, i.e. the emissions resulting from electricity generation, is analysed (Nicolay, 2000). It is very difficult to determine the amount of electricity consumed by EVs, as it depends on many factors, such as driving behaviour, the use of auxiliaries and weather conditions (Badin *et al*., 2013; De Vroey *et al*., 2013). Therefore, a wide range of electricity consumption levels, varying from 0.10 kWh/km to 0.24 kWh/km, has been reported by researchers (Campanari *et al*., 2009; Helms *et al*., 2010; Hawkins *et al*., 2012; De Vroey *et al*., 2013; Strecker *et al*., 2014). In addition to consumption level variability, the emissions resulting from the electricity production and distribution have also been assessed by researchers (Helms *et al*., 2010). Thus, unlike ICEVs, the environmental impacts of EVs are largely variable, depending on the source of electricity and the electricity consumption while in use (Campanari *et al*., 2009). It should be noted that EVs do still have an air quality impact and that PM emissions are still an issue because of braking (Grigoratos and Martini, 2014).

4.2.1 Methodology and data

This section describes the methodology used to assess the emission levels and the data used, along with sources. The emission levels of the pollutants were calculated using COPERT 5. This transportation emission modelling tool follows tier 3 methodology, which requires a detailed level of environmental information, fleet data and activity data, in addition to requiring trip information and annual fuel consumption data for different fuel types. Table 4.1 presents the input data needed to calculate vehicular emissions using COPERT.

The fleet data for 2015 were extracted from the Society of the Irish Motor Industry (SIMI, 2016) and DTTaS (2016a). COPERT 5 requires a detailed classification of fleet data with respect to engine class, i.e. small (< 1.4 L), medium (1.4–2.0 L) and large (> 2.0 L), fuel type and technology class, i.e. Euro 1, Euro 2, etc.

Average speeds on urban roads, rural roads and highways were taken as 40 kmph, 60 kmph and 100 kmph, respectively (RSA, 2015), and the driving mode shares as 30% (urban), 50% (rural) and 20% (highways). The estimated emission levels from private car fleets in 2020, 2025, 2030, 2040 and 2050 with respect to the BaU situation were calculated using COPERT 5. The future fleet composition was determined using Systra's rolling fleet projections. The BaU scenarios were named as BaU_2020, BaU_2025, BaU_2030, BaU_2040 and BaU_2050. Table 4.2 shows the car ownership levels forecasted for the years for which estimated emission levels have been calculated.

It can be observed that the population in Ireland is predicted to increase by 8.4% by 2030, compared with the 2015 level, but the number of cars is predicted to increase by 28.7%. By 2050, the population is predicted to increase by 15.7%, with car ownership predicted to increase by 54.2%. Car compositions for future years under the BaU situation were

Table 4.1. COPERT input data and respective sources

Data type	Source
Fuel consumption	SEAI (2016)
Fleet data	Motorstats: the official statistics of the Irish Motor Industry (SIMI, 2017)
	DTTaS (2016a)
Fuel information	Motorstats: the official statistics of the Irish Motor Industry (2016)
	DTTaS (2016a)
Mileage	CSO (2014)
	SEAI (2013)
Relative humidity	Met Éireann: the Irish Meteorological Service Online (2016)
Temperature	Met Éireann: the Irish Meteorological Service Online (2016)
Speed	Road Safety Authority (RSA, 2015)
Trip length	CSO (2014)
Mileage share	Brady and O'Mahony (2011)

CSO, Central Statistics Office of Ireland; SEAI, Sustainable Energy Authority of Ireland.

Table 4.2. Prediction of car ownership

Year	Population (million)	Percentage change (%)	Car population	Percentage change (%)
2015	4.677	–	1,985,130	–
2016	4.773	2.1	2,023,752	1.9
2020	4.80	2.6	2,132,532	7.4
2025	4.91	5.0	2,312,610	16.5
2030	5.07	8.4	2,555,280	28.7
2040	5.30	13.3	2,906,264	46.4
2050	5.41	15.7	3,062,060	54.2

calculated using Systra's_rolling_fleet_v7 model. The compositions predicted are shown in Table 4.3. Systra's rolling fleet model predicts that battery electric vehicles (BEVs) and PHEVs will account for only 1.6% of new car registrations in 2025 and 2030; however, this percentage will increase to 50.8% by 2040, and by 2050 EVs will account for 100% of new car registrations. It is noted that Systra's rolling fleet model assumes a BaU forecast scenario and in this way continues historical trends as hypothetical, rather than modifying any underlying relationships.

4.2.2 Emissions from the 2015 private car fleet

This section presents the emissions from the 2015 private car fleet in Ireland as calculated using COPERT. Table 4.4 shows the total emission levels (in the GDA) from the private car fleet disaggregated with respect to fuel type and engine class.

It can be observed that private cars alone contribute about 6.1 Mt of CO_2 and 13.8 kt of NO_x to total emission levels, which has a severe impact on human health, especially in urban areas.

Table 4.3. Private car fleet compositions under a BaU scenario

Year	Petrol (%)	Hybrid (%)	Electric (%)	Diesel (%)
2015	55.4	0.51	0.05	44.40
2020	33.1	1.5	0.1	65.3
2025	24.8	1.4	0.1	73.7
2030	24.0	1.3	0.2	74.5
2040	20.2	1.2	15.2	63.4
2050	9.0	1.0	61.0	29.0

Table 4.4. Total GDA emissions for different pollutants for the 2015 fleet

		Emissions (t), by fuel type		
Pollutant	Engine size (L)	Petrol	Diesel	Hybrid petrol
CO_2	< 1.4	1,087,881	212,876	1601
CO	1.4–2.0	1,512,624	2,690,937	8647
	> 2.0	130,530	446,053	4595
NO_x	< 1.4	713	752	0.5
	1.4–2.0	1049	9986	2.6
	> 2.0	72	1189	1.3
$PM_{2.5}$	< 1.4	70	31	0.1
	1.4–2.0	83	510	0.6
	> 2.0	6	73	0.3
PM_{10}	< 1.4	120	41	0.2
	1.4–2.0	142	635	1.2
	> 2.0	10	88	0.6
N_2O	< 1.4	16	9	0.02
	1.4–2.0	23	118	0.11
	> 2.0	2	15	0.05
NMVOCs	< 1.4	986	6	1
	1.4–2.0	1470	139	7
	> 2.0	76	28	4
VOCs	< 1.4	1123	6	1
	1.4–2.0	1649	150	7
	> 2.0	89	29	4

NMVOCs, non-methane volatile organic compounds; $PM_{2.5}$, fine particular matter; PM_{10}, coarse particular matter; VOCs, volatile organic compounds.

4.2.3 Emission levels in 2020, 2025, 2030, 2040 and 2050 from the private car fleet under a BaU scenario

This section presents time series results for the years 2020, 2025, 2030, 2040 and 2050 under the BaU situation. The changes in emission levels of all the major air pollutants predicted in these future years under a BaU scenario with respect to 2015 are presented in Table 4.5. CO_2 emissions from electricity generation were taken as 582 gCO_2/kWh and the electricity requirement per kilometre was taken as 0.15 kWh (SEAI, 2017a). Thus, WTW emissions for BEVs in 2015 are calculated as 87.30 gCO_2/km. Taking into account the combined measures of increasing the share of renewable generation and improvements in the overall efficiency of the electricity supply, it is assumed that the carbon intensity of the electricity supply would be 393 gCO_2/kWh in 2020 and, therefore, the WTW emissions would be 58.95 gCO_2/km. WTW emissions for BEVs were calculated and the differences in CO_2 emission levels are shown in Table 4.5.

It can be observed from the results that, by 2020, CO_2 emissions from the private car fleet are expected to be 22% higher than in 2015 under a BaU situation, whereas they are expected to increase by 39% by 2030. Even with renewable electricity production, emission levels are not expected to decrease because of the increase in car ownership and no significant increase in the uptake of EVs. Thus, three hypothetical scenarios were designed to examine the differences in emission levels if the EV purchase trend does not follow Systra's prediction and there is an increase in EV uptake.

4.2.4 Emission levels in 2020 and 2030 from the private car fleet under alternative scenarios

Three alternative scenarios were designed, with low (2030_low), medium (2030_medium) and high (2030_high) levels of market penetration by EVs, assuming that EVs will account for 10%, 15% and 25% of new registrations in 2025, respectively, and 50% new EV deployment in 2030. The emission levels for 2030 under these three scenarios and percentage differences from baseline were calculated. Emission levels under the current target (2020_10000 EVs), which is to have 10,000 EVs in the car fleet by 2020, were also calculated. Table 4.6 shows the potential emission reductions that would result from increased EV uptake under these scenarios, compared with the BaU emission scenarios for 2020 and 2030.

It can be seen that, under the BaU scenario, CO_2 emission levels are expected to increase by about 39% by 2030 relative to 2015 (Table 4.5); however, under the high level of market penetration scenario, the increase in CO_2 emission levels would be brought down by 20%. However, they are still expected to increase by 19% compared with 2015 CO_2 emission

Table 4.5. Emission changes in future years under a BaU scenario

Pollutant	2015 emissions (t)	Percentage change from 2015 (%)				
		BaU_2020	BaU_2025	BaU_2030	BaU_2040	BaU_2050
TTW CO_2	6,095,743	22	28	39	28	–39
WTW CO_2		22	28	39	41	13
WTW CO_2 (with renewable electricity)		22	28	39	37	–4
CO	35,558	–49	–65	–63	–67	–84
NO	8858	28	52	65	54	–27
NO_2	4908	53	44	35	23	–42
$PM_{2.5}$	772.1	4	–19	–22	–28	–66
PM_{10}	1039	10	–5	–4	–11	–58
N_2O	182.18	28	36	41	30	–38
NMVOCs	2717	–50	–66	–65	–68	–84
VOCs	3058	–49	–64	–63	–66	–84

NMVOCs, non-methane volatile organic compounds; $PM_{2.5}$, fine particular matter; PM_{10}, coarse particular matter; VOCs, volatile organic compounds.

Table 4.6. Emission reductions in future years with incentivised optimistic scenarios

Pollutant	2015 emissions (t)	Percentage change from 2015 (%)			
		2020_10000 EVs	2030_ low	2030_ medium	2030_ high
TTW CO_2	6,095,743	21	27	24	19
WTW CO_2		33	32	29	22
WTW CO_2 (with renewable electricity)		31	29	26	22
CO	35,558	–50	–72	–76	–81
NO	8858	28	60	63	61
NO_2	4908	53	31	35	35
$PM_{2.5}$	772.1	4	–28	–29	–32
PM_{10}	1039	10	–12	–13	–17
N_2O	182.18	28	36	38	37
NMVOCs	2717	–50	–74	–78	–83
VOCs	3058	–49	–72	–77	–82

NMVOCs, non-methane volatile organic compounds; $PM_{2.5}$, fine particular matter; PM_{10}, coarse particular matter; VOCs, volatile organic compounds.

levels. This indicates that it is also important for people to use sustainable modes of transport and public transport, so that car ownership levels reduce, to help Ireland to move towards its emission goals. It can be seen that, because of technological improvements in ICEV engines (i.e. more Euro 6 vehicles in the fleet), other pollutant levels are expected to decrease by 2030; however, no reductions in NO or NO_2 levels are expected because of the projected increase in the number of diesel cars in the overall fleet.

4.3 Examining Emission Reductions Resulting from Changes in the Public Transport Fleet

In this study, alternative fuel and technology options that are currently available for the bus fleet and their potential in reducing GHGs and exhaust air pollutants are examined. This task was achieved by designing hypothetical alternative scenarios and calculating the emission levels corresponding to each of these scenarios. The buses that are currently in use are of Euro 3, 4 and 5 technology classes, all of which have different emission standards. The scenarios were designed by considering the replacement of the present bus fleet with a fleet composed of different percentages of vehicles that use various available technology options (e.g. Euro 6, enhanced environmentally friendly vehicle – EEV) and fuel alternatives, such as CNG, bio-CNG and battery electric buses. The levels of all the major air pollutants, namely CO, CO_2, NO_2, NO, fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), volatile organic compounds (VOCs), N_2O and non-methane volatile organic compounds (NMVOCs), emitted by the current public transport bus fleet as well as for the alternative scenarios were estimated using COPERT. COPERT was developed to calculate emissions from road transport in European countries (EMISIA, 2014) and has been used by researchers to calculate emissions from buses in Ireland (Ryan and Caulfield, 2010; Alam *et al*., 2015).

This study considered Dublin Bus and Bus Éireann, which are the main public bus service operators in Ireland with a total of 1441 buses in their current fleets (NTA, 2016). The emission levels from CNG, bio-CNG and electric buses were modelled and the emission savings were compared with conventional diesel-fuelled buses. The final energy consumption levels under these scenarios have been reported in outputs from this project. CO_2 emissions can be reduced by 94% by using CNG and bio-CNG, and savings in emission levels of 57% can be achieved by replacing urban public service buses with electric buses.

4.3.1 Methodology and data

This section presents the methodology used to calculate the emission levels from the public transport bus fleet and the reductions possible with the use of alternative fuel options and technologies, and also the resulting damage costs and feed stock required for the use of bio-CNG buses. This study considers the entire Dublin Bus and Bus Éireann fleets. The potential of the public transport bus fleet to reduce emissions was assessed by designing four alternative scenarios in addition to the base scenario, which uses diesel and older engine technology classes for the entire bus fleet. The emission levels of CO_2, CO, NO_x, $PM_{2.5}$, PM_{10}, N_2O, VOCs and NMVOCs were calculated in tonnes using COPERT, which uses a top-down approach. Emission calculations using COPERT require detailed input data (Dey *et al*., 2017) in terms of fuel consumption, trip information (trip length, trip duration), activity (speed, mileage and mileage share), fleet configuration (number of buses of each fuel type and technology class) and environmental information (monthly average relative humidity and monthly average minimum and maximum temperatures). COPERT can be used to calculate emissions from diesel, biodiesel and CNG buses for all the Euro technology classes. Table 4.7 presents a summary of the five scenarios that were examined in this study. The scenarios are also described below:

- **Scenario 1:** in this scenario, emissions were calculated for the base year fleet, 2015 being taken as the base year. The public transport bus fleet in Ireland is diesel powered and comprises buses of older Euro technology classes, which have higher EFs. Dublin Bus and Bus Éireann, being the dominant public service bus operators in Ireland, were considered in this study. The fleet data were obtained from Dublin Bus (2016) and the NTA (NTA, 2016). For Dublin Bus, the mileage share was assumed to be 15% from rural journeys and 85% from urban journeys (NTA, 2016). COPERT provides the scope to specify the peak and off-peak driving percentages and corresponding speeds separately. The urban share of the mileage was further split into 50% for peak and 50% for off-peak hours, with average peak speed taken as 13 kmph and average off-peak speed taken as 26.5 kmph (Ryan and Caulfield, 2010; CSO, 2014; Alam et al., 2015; RSA, 2015). For Bus Éireann, average rural speed was assumed to be 40 kmph. Annual average mileages were taken as 57,288 km and 71,074 km for Dublin Bus and Bus Éireann, respectively (NTA, 2016).
- **Scenario 2:** this scenario presents the emission levels that would result if all the buses were to be replaced by Euro 6 diesel buses. Euro 6 buses use improved technology, especially in terms of lower EFs for NO_x, PM and VOCs. Emissions in this scenario were calculated using COPERT assuming that the entire fleet comprised Euro 6 buses. The rest of the input parameters were the same as those described for scenario 1.
- **Scenario 3:** this scenario presents the emission levels that would result if all buses in the public transport fleet were to be replaced by EEV/Euro 6 CNG buses. EEV and Euro 6 buses were found to have the same EFs. This scenario assesses the emission reductions that would result from replacing both fuel and technology. Emission levels in this scenario were also calculated using COPERT. All other input parameters were the same as those for scenario 1.
- **Scenario 4:** in this scenario, emissions were calculated assuming that all public transport buses would be replaced by bio-CNG Euro 6/EEV buses. Therefore, this scenario also assumed the replacement of both fuel and engine types, as considered in scenario 3. Grass silage was chosen as the optimum feedstock for producing bio-CNG in Ireland, and the carbon neutrality of

Table 4.7. Scenario descriptions for the public transport bus fleet

Scenario	Technology class	Fuel type	Number of buses
Scenario 1	Euro 3	Diesel	666
	Euro 4	Diesel	218
	Euro 5	Diesel	557
Scenario 2	Euro 6	Diesel	1441
Scenario 3	Euro 6/EEV	CNG	1441
Scenario 4	Euro 6/EEV	Bio-CNG	1441
Scenario 5	Euro 6	Diesel	72
	Electric	–	1369

bio-CNG was taken as 60% (Ryan and Caulfield, 2010).

- **Scenario 5:** this scenario evaluates the emission savings that would be possible by replacing all buses in urban fleets with electric buses. In this scenario, the WTW emissions, i.e. the emissions due to electricity generation, were calculated for two cases. The first case assumes the energy source to be electricity generated from renewable sources, which has WTW emissions of 20 gCO_2eq/km, and the second case assumes that the electricity required would come from the EU energy mix, with a GHG emission rate of 720 gCO_2eq/km (Mahmoud et al., 2016).

4.3.2 Results and discussion

This section presents the emission levels resulting from the existing public transport bus fleet in Ireland and potential emission savings resulting from changing to alternative fuels and technologies. Table 4.8 presents the emissions from the existing bus fleet (base scenario) and the percentage changes possible under the various scenarios, with respect to the base scenario.

Table 4.9 presents the energy consumption expected under the scenarios in this study. Electricity requirements for buses under scenario 5 were calculated taking the WTW energy consumption levels as 18.66 MJ/km and 10.33 MJ/km, the energy sources being electricity from the EU energy mix and renewables, respectively.

It can be seen that bio-CNG buses have the highest energy requirement, whereas a substantial reduction in energy consumption would be possible under scenario 5, with the use of renewable-based electricity. Scenario 4, which considers the use of an alternative fuel, namely bio-CNG, and the technology class Euro 6/EEV for public transport bus services, would be a very suitable option for Ireland, as it would utilise agricultural grass silage as feedstock in producing biomethane (Smyth *et al.*, 2009).

The cost of health and other (biodiversity, crop, building) damages caused by the pollutants discharged by the bus fleet were calculated by

Table 4.8. Emissions under the various bus fleet scenarios and differences from base

Pollutants	Emissions (t), scenario 1	Difference from base under each scenario (%)			
		Scenario 2	Scenario 3	Scenario 4	Scenario 5
CO	244.86	–88	–61	–61	–97
CO_2	99,185.35	–5	+8	–57	–94[a] (–35[b])
NO	786.31	–94	–53	–53	–97
NO_2	114.26	–96	–87	–87	–97
N_2O	1.47	+137	–100	–100	–100
VOCs	29.71	–85	216	+216	–97
NMVOCs	25.46	–84	–42	–42	–97
$PM_{2.5}$	16.07	–77	–74	–74	–99
PM_{10}	19.44	–64	–61	–61	–98

[a]Percentage decrease in CO_2 levels when a renewable source of electricity is used.
[b]Percentage decrease in CO_2 emissions when electricity from the EU energy mix is used as the source of electricity.

Table 4.9. Energy consumption under the various bus fleet scenarios

Scenario	Fuel consumption (TJ)	Electricity consumption (TJ)	
		EU energy mix	Renewables
1	1875	–	–
2	1809	–	–
3	2602	–	–
4	3411	–	–
5	75	1568	868

multiplying the quantity of pollutants emitted (in tonnes) by unit damage cost per tonne of pollutant, as obtained from the *Update of the Handbook on External Costs of Transport* (Korzhenevych *et al*., 2014) and DTTaS (2016b). Damage costs per tonne of pollutant were taken as €13.22, €5851, €19,143, €1438, €1398, €200,239, €48,779 and €16,985 for CO_2, NO_x, PM_{10}, VOCs, NMVOCs, $PM_{2.5}$ (urban), $PM_{2.5}$ (suburban) and $PM_{2.5}$ (rural), respectively.

The damage costs caused by these emissions are shown in Table 4.10, along with the savings that would be possible if alternative fuel and technology options were implemented.

It can be observed that the pollutants emitted from the public transport bus fleet alone caused damages worth €10.09 million in 2015. Scenario 5 offers the highest possible annual savings in damage costs and scenario 3 offers the lowest possible savings.

4.4 Emission Projections and Proposed Fleet Compositions

There is no separate emission target for the road transport sector in Ireland; therefore, this study assumes that the target for road transport is the same as the overall target, which is to reduce emission levels by 30% by 2030, relative to 2005. The level of emissions from road transport in 2005, which was approximately 12,554,873 t, was obtained from the EPA (2017b). The passenger car CO_2 emission share was taken as 67.5% of total road transport emissions, and the emission share for the Dublin Bus and Bus Éireann fleets was taken as 1% (Alam *et al*., 2015). This value was then reduced by 30% to determine the target for 2030. The emission levels were then backcast to propose the fleet composition, with percentages of BEVs, hybrid electric vehicles (HEVs), PHEVs and ICEVs, that would be required to meet this target. Two separate approaches were taken:

- approach 1: based on the car and bus fleet compositions required to meet the target combined with estimated car ownership and number of buses in 2030;
- approach 2: based on the car and bus fleet compositions required to meet the target separately.

In the first approach, the proposed car and bus fleet compositions would jointly reduce CO_2 emissions by 30%. While, in the second approach, the car and bus fleet compositions required to reduce CO_2 emissions by 30% were evaluated individually.

4.4.1 *Approach 1 – meeting the target using a combined target for the car and bus fleets*

This section presents the private car and public transport fleet compositions that together would help to meet the 2030 emission goal. It was found that the car fleet required to meet the EU 2030 emission target would be as follows:

- HEVs: 50%;
- ICEVs: 23%;
- BEVs: 14%;
- PHEVs: 13%.

It has been assumed that, by 2030, there will be a 15% increase in the number of public transport buses. Assuming the life of a public service bus as 15 years,

Table 4.10. Damage costs from pollutants emitted in the base scenario and possible savings under alternative scenarios

	Cost of emissions (€)	Potential cost savings relative to damage costs under scenario 1 (€)			
Pollutant	Scenario 1 (base)	Scenario 2	Scenario 3	Scenario 4	Scenario 5
CO_2	1,311,230	63,688	105,172	744,669.2	1,259,118
NO_x	5,269,213	4,968,777	3,017,719	3,017,719	5,108,574
VOCs	42,719.81	36,101	92,288.5	92,288.5	41,479.65
NMVOCs	35,593	29,789	15,084	15,084	34,388
$PM_{2.5}$	3,055,587	2,354,735	2,272,714	2,272,714	3,020,654
PM_{10}	372,206.2	236,862	228,596	228,595.8	365,193.5
Total	10.09 million	7.69 million	5.34 million	6.19 million	9.83 million

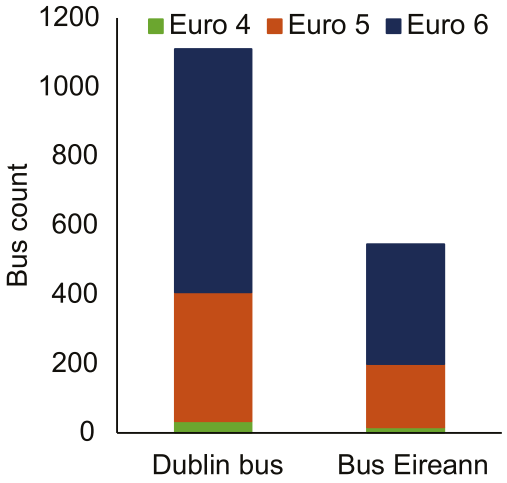

Figure 4.1. Public transport bus fleet composition, per technology class, required to meet 2030 target.

the fleet composition for 2030 was estimated. Figure 4.1 shows the projected 2030 public transport bus fleet (Dublin Bus and Bus Éireann) composition with respect to technology class. It was estimated that, to reduce the combined emissions from private car and public transport bus fleets by 30%, the urban bus fleet should be replaced by electric buses.

CO_2 emission levels in 2005, target emission levels for 2030 and potential reductions in emissions from private car and public transport bus fleets are presented in Table 4.11.

4.4.2 Approach 2 – meeting targets separately

This section presents the private car and public transport fleet compositions that will be required to reduce CO_2 emissions individually from the private car and public transport sectors by 30% by 2030, compared with 2005.

Passenger car fleet

The results presented in the previous section show that, with the expected increase in car ownership levels, the only way to achieve the emission goals is through a high level of electrification of the private car fleet. This section examines the reduction in car ownership levels that would result in fulfilling the target and a more practical breakdown of the private car fleet. To estimate the EV share, this scenario assumes a high level of EV market penetration. The desired CO_2 emission levels were then backcast to determine the car ownership and fleet composition required.

Table 4.12 shows the estimated fleet composition and car ownership levels required to meet the 2030 target.

The CO_2 emission levels in 2005 from the private car fleet and the potential private car fleet emission levels in 2030 are also presented, in Table 4.13, along with the emission target for 2030, relative to 2005, and the percentage reduction needed to achieve this target.

Public transport bus fleet

The public transport bus fleet required to meet the 2030 target and possible emission reductions are presented in this section. As mentioned in section 4.3, depending on the source and method of electricity production, TTW emissions can vary from 20 gCO_2/km to as high as 720 gCO_2/km. Therefore, two cases were considered: case 1 determined the public transport bus fleet composition assuming that the electricity produced was renewable based (i.e. TTW CO_2 emissions being 20 gCO_2/km) and case 2 calculated the public transport bus fleet breakdown assuming that the source of electricity was the EU energy mix (i.e. TTW CO_2 emissions being 720 gCO_2/km). Table 4.14 presents the fleet composition required in 2030 to meet the emission target.

Based on the fleet composition estimated for case 1 and case 2, Table 4.15 lists the separate emission levels from diesel, bio-CNG and electric buses for the proposed fleet.

Table 4.16 presents the CO_2 emission levels from the public transport bus fleet in Ireland in 2005, and the CO_2 emission levels and possible reductions in emissions from the fleets proposed for 2030 in both cases.

4.5 Conclusions

This research has examined, through a comprehensive analysis, the potential emission reductions from changes in the private car fleet and the public transport bus fleet in Ireland. In 2015, the CO_2 emission levels from the private car fleet alone were 6.1 Mt of CO_2, whereas NO_x and $PM_{2.5}$ levels were 13.8 kt and 774 t, respectively. NO_x and $PM_{2.5}$ have been linked to a series of health effects such as stroke, lung cancer, and chronic and acute respiratory diseases, including asthma (WHO, 2018). NO_x, which comprises NO_2 and NO, is a key air pollutant, which

Table 4.11. Emission levels and potential reductions in 2030 relative to 2005 with the proposed fleet composition

	2005	Target year: 2030	
Road transport mode	CO_2 emissions (t)	CO_2 emissions (t)	Decrease relative to 2005 levels (%)
Car	8,474,539	5,982,034	–29
Bus	118,330	7913	–93
Total	8,592,869	5,989,947	–30

Table 4.12. Car ownership levels and fleet composition required to meet 2030 target

	Number of cars by engine size		
Fuel type	<1.4 L	1.4–2.0 L	>2.0 L
Petrol	191,312	66,328	3917
Diesel	61,860	993,535	78,751
Petrol hybrid	17,653	222,486	93,080
EV	351,710		
Total	2,080,632		

Table 4.13. Emission levels and reduction in 2030 relative to 2005 with the proposed private car fleet

		Emissions in 2030 (t)			
Pollutants	Emissions in 2005 (t)	WTT	TTW	WTW	Emission target 2030 (t)/per cent reduction
CO_2	8,474,000	374,005	5,506,600	5,880,605	5,932,000/30.6%
CO		0	37,857	37,857	
NO		0	9010	9010	
NO_2		0	4055	4055	
$PM_{2.5}$		0	399	399	
PM_{10}		0	670	670	
N_2O		0	164	164	
NMVOCs		0	924	924	
VOCs		0	1004	1004	

Table 4.14. Bus fleet composition required to meet 2030 target

	Case 1, by fuel type (%)			Case 2, by fuel type (%)		
Euro class	Diesel	Bio-CNG	Electric (renewable)	Diesel	Bio-CNG	Electric (EU-mix)
Euro 4	2	–	–	1	–	–
Euro 5	22	–	–	15	–	–
Euro 6	41	25	10	29	30	25
Total	65	25	10	45	30	25

Table 4.15. Emission levels in 2030 with the proposed public transport bus fleet

	Case 1			Case 2		
	Emission levels (t), by fuel type			Emission levels (t), by fuel type		
Pollutant	Diesel	Bio-CNG	Electric (renewable)	Diesel	Bio-CNG	Electric (EU energy mix)
CO	79.21	27.74		54.70	33.22	
CO_2	70,038	12,343	205	48,454	14,782	18,477
NO	206.62	106.40		142.69	127.42	
NO_2	23.60	4.43		16.30	5.31	
N_2O	2.38	0.00		1.64	0.00	
VOCs	3.90	27.04		2.70	32.38	
NMVOCs	3.57	4.23		2.47	5.06	
$PM_{2.5}$	4.19	1.19		2.90	1.42	
PM_{10}	6.72	2.16		4.64	2.59	

Table 4.16. Emission reductions in 2030 relative to 2005 from public transport bus fleet

CO_2 emissions (t) in 2005	CO_2 emissions (t) in 2030		Decrease (%) by 2030 relative to 2005 levels	
	Case 1	Case 2	Case 1	Case 2
118,330	82,587	81,713	30.21	30.94

contributes to atmospheric levels of NO_x, $PM_{2.5}$ and ground-level ozone (USEPA, 2016), currently one of the air pollutants of most concern in Europe (WHO, 2018). Diesel cars are one of the major sources of these deadly pollutants. Ireland has the highest share of newly registered diesel cars in Europe (72% of the total of newly registered cars in 2015). As calculated in the previous section, in 2020, with 10,000 EVs in the fleet, CO_2 emissions are estimated to increase by 31–33% depending on the source and efficiency of the electricity production and supply (see Table 4.6), whereas resulting NO_2 emissions are expected to increase by 53%. In 2030, under a BaU scenario and with a high level of EV deployment, CO_2 emission levels are expected to increase by 39% and 19%, respectively, compared with 2015 levels. Thus, looking at the solution, substantial electrification of the car fleet is imperative to satisfy Ireland's sustainable goals. Despite the fiscal incentives provided by the Irish government for EV purchase, the uptake is not significant. Therefore, it is necessary to look into the existing policies and consider what revisions are needed and, also, the implementation of new policies and measures.

The potential of the alternative fuel options available for the public transport bus fleet to reduce emissions was evaluated. The results show that all the scenarios considered could offer a significant reduction in emission levels. The use of Euro 6 buses, being the cleanest of the technologies, would result in a considerable reduction in CO, PM, NO, NO_2 and VOC emissions, but would not significantly reduce CO_2 emissions. This indicates that alternative fuels must also be incorporated to move towards meeting Ireland's GHG targets for 2020 and 2030. In this regard, CNG is also not a suitable option, as the results show that the use of CNG as a bus fuel would increase CO_2 emissions by 8%. However, when the emission levels resulting from the use of bio-CNG were compared with 2015 levels, a 57% reduction in CO_2 emissions was observed, with reductions in CO, NO_2 and $PM_{2.5}$ emission levels being 61%, 87%, and 74%, respectively. Given the availability of grassland in Ireland, bio-CNG offers a convenient and feasible option as an alternative fuel for public transport buses. Scenario 5, which examined the emission reductions from replacing only the urban bus fleets by battery electric buses, shows the highest potential for reducing both GHGs and other harmful pollutants. The emission levels of all the pollutants could be reduced by more than 90%. With the electricity source being based on renewable energy, which has high energy efficiency, the energy demand could be reduced by 49% relative to the base scenario.

It can be concluded that electric buses offer the most attractive option. The public transport bus services studied in this study mainly operate in cities such as Dublin, Cork and Galway where the population density is relatively high. The renewal of the fleet would not only reduce emission levels but also improve public health. Thus, replacing the urban public service bus fleets with electric buses is highly recommended, especially if the electricity used is produced from renewable energy sources.

This analysis of the private car and public transport bus fleet compositions indicates that a reduction in estimated future car ownership will also be essential if Ireland is to meet its 2030 GHG emission target. In addition, the increased use of renewable energy and improved efficiency in electricity production will play a major role in reducing emissions.

5 Modelling the Impacts of Policy Incentives on Mode Shares and Emissions

5.1 Introduction

This chapter examines the travel demand modelling of the policy scenarios that were assessed in the SP experiment. These policies were represented in the NTA Regional Modelling System (RMS) for Ireland, which predicts all-day travel demand and patterns for all modes of transport and "allows for the appraisal of a wide range of potential future transport and land use alternatives" (NTA, 2017a). More specifically, the ERM was consulted, which considers the GDA and the Leinster province. However, in accordance with the findings from the SP experiment in Chapter 3, only the GDA will be considered in the results produced from the ERM in this study.

The ERM was chosen to complement the results of the SP analysis and to provide a detailed policy evaluation of the potential "real life" impacts of incentives that encourage car-shedding behaviour. The outputs from the ERM were then used to estimate mode shares and emission reductions, to measure the potential behavioural and environmental impacts of implementing the policy incentives. The rationale for using the NTA RMS in this report was based on an extensive review of a range of economic, environmental, land use and transportation models available in Ireland that was one of the main deliverables of the Greening Transport project (Carroll *et al*., 2016).

Ultimately, this chapter builds upon the results explored in the SP study and offers further empirical evidence that examines the effect of policy incentives on encouraging a reduction in single-occupancy vehicle trips and that may provide valuable recommendations for policymakers. Such recommendations could be considered in the context of encouraging a sustainable shift from private car use to alternative modes such as public transport, active modes (walking and cycling) and the sustainable usage of the private car through carpooling and car-sharing. The results of this work can also be found in Carroll *et al*. (2016).

5.2 The Regional Modelling System

The NTA RMS is Ireland's chief national transport modelling framework tool, providing a vital instrument for policy and project appraisal to transport planners and modellers, urban planners and policymakers. It comprises the National Demand Forecasting Model, five large-scale multi-modal regional transport models and a suite of appraisal modules.

These models are used primarily to accurately predict and forecast mode choice behaviour and complex travel patterns, by modelling all-day travel demand. They are valuable tools that can be utilised as a means of assessing the response of travellers to various transport policies and schemes by analysing the potential changes to travel demand and flows on certain routes in the network. The main features of the models are as follows: they provide comprehensive coverage of the country through the use of five independent models; they offer in-depth depictions of the road, public transport and active modes networks and have the capability to estimate demand for modes in these networks; the regional models also consider four main journey purposes (employer business travel, commuting trips, education trips and other), four time periods (AM, lunchtime, school run, PM and off-peak); and finally they can "predict change in trip destination and mode choice through changes to traffic conditions, transport provision and/or policy" (NTA, 2017b).

The year in the base model scenario of the ERM is 2012, based on data from the 2011 POWSCAR (Place of Work, School or College – Census of Anonymised Records) (CSO, 2012) and the National Household Travel Survey (NTA, 2013a) datasets. The year 2012 was used in this report, as it was based on the latest available Ireland census data. The 2012 base scenario was used as the foundation for the various parameter changes made in the ERM, and acted as a base case/comparison year for the examination of the effects that the policy changes could have on mode shares if implemented.

The NTA's 2016–2035 transport strategy for the GDA (NTA, 2016) – the 2035 GDA Strategy hereafter – is the forecast scenario that was modelled in this study. This strategy "provides a framework for the planning and delivery of transport infrastructure and services in the GDA over the next two decades" (NTA, 2016).

The key elements proposed by this strategy are:

- to reduce traffic congestion, particularly in relation to bottlenecks and public transport priority, along busy routes;
- to avoid further increases in the private car mode share and provide additional support for schemes that aim to reverse this trend, paying particular attention to short-distance and commuter trips;
- to address issues of pedestrian priority and the walkability of urban areas;
- to accelerate and maintain increases in the mode share of active modes;
- to reduce the risk associated with cycling and prevent road accidents involving cyclists by investing in the GDA Cycle Network Plan (NTA, 2013b; NTA, 2016).

The array of policy incentives/interventions explored in the SP were tailored to represent the objectives set out in this strategy. However, it must also be noted that the ERM parameter changes made in this study considered modifications that were beyond those of the infrastructure projects already planned in the 2035 GDA Strategy.

The large-scale transport infrastructure projects included in the 2035 GDA Strategy, include the following:

- Heavy rail: this project aims to expand the DART (Dublin Area Rapid Transit) to the north and west of the GDA.
- Light rail: this project involves creating a new metro line (MetroLink) from Dublin city centre to Dublin Airport, and two new tram (Luas) lines.
- Bus: the Bus Connects project proposes to develop a number of initiatives on bus corridors in the GDA that aim to make bus journeys faster, more reliable and more frequent (Bus Connects, 2017). A key feature of this project is the focus on the development of the core bus network – representing the most important bus routes in the Dublin area, providing high frequency services and serving high passenger volumes. The introduction of a bus rapid transit service will be included as part of Bus Connects, which will consist of a service delivering higher speeds through improved road infrastructure and enhancements to the quality of service by means of faster boarding/alighting and more appropriate vehicles (NTA, 2016).
- Cycling: an expansion of the GDA cycle network and development of more segregated facilities are planned to address cycle lane continuity along routes and cyclist safety.
- Walking: reducing traffic signalling times for pedestrians at crossings in Dublin city centre, thus leading to shorter waiting times, is planned. The provision of dedicated pedestrian crossings and footpath widening, in addition to providing better surfacing and removing street clutter, are also planned (NTA, 2016).

5.2.1 Parameter modifications in the Eastern Regional Model

Changes to the active mode network

In this report, the cycle network in the active modes assignment model was first modified to account for the proposed provision of an improved cycling infrastructure in the GDA, as examined in the SP survey. In the NTA RMS, levels of cycling infrastructure provision are represented by coded cycling speeds in the model, with higher speeds signifying higher levels cycle lane segregation. Thus, in order to represent an improvement in cycling infrastructure, coded cycling speeds were increased in line with the SP policy scenarios, on certain links in the network, to act as a proxy for the provision of segregated cycle lanes. Pedestrian speeds coded in a comparable fashion were similarly increased to account for walking mode improvements, such as signalling changes at pedestrian crossings, widening footpaths (i.e. more street space assigned to pedestrians to increase the flow of pedestrians) and decluttering footpaths to remove obstacles that may hinder pedestrian flows.

Changes to the public transport network

In the public transport assignment model, headways were reduced as a directly modelled proxy for increased public transport service frequency in the network for all routes in the GDA serviced by bus operators, Dublin Bus (Dublin Bus, 2018) and Bus Eireann (Bus Eireann, 2018), and rail operators of the DART and the Luas, Irish Rail (Irish Rail, 2018) and Transdev (Transdev, 2018). In addition to this, fares associated with these services, which are coded in CUBE Voyager scripting language, were also modified to represent staged decreases in the cost of bus and rail services. These parameter changes acted as proxies for improvements made to bus and rail service frequency, leading to shorter waiting times, and lower trip costs for public transport commuters.

The assignment model runs in a CUBE Voyager module through a two-step process that allots trips to their respective routes. The first step (enumeration) calculates all reasonable routes between zone O–D (origin and destination) pairs, in addition to calculating the probabilities of certain routes being chosen. The second step (evaluation) uses choice models to allocate trips to these routes based on the "probabilities of use", considering crowding and fares (NTA, 2017b).

Changes to the road network (i.e. car occupancy level values)

In the road assignment model, car-sharing and carpooling are not explicitly modelled as discrete modes. Carpooling is, however, represented by modifying the car occupancy level values or car-user-to-car-driver values. Thus, in order to account for increases in carpooling behaviour for commuting purposes in the GDA, it was decided to code an increased car occupancy value for private vehicles in the ERM for commuting and education trip purposes, as a proxy for individuals responding to carpooling incentives such as free tolls, free parking, high-occupancy vehicle (HOV) lanes and economic rewards. The road assignment model is somewhat different from the active and public transport assignment models, as the supply and demand components of the model draw upon more detailed road and highway data. For example, the supply component of the road model is determined by the road network, which includes link and junction capacities, link speeds, vehicle restrictions and tolls, coded in a SATURN network model (Atkins, 2017). The demand for the road model is defined as a series of vehicle O–D matrices prepared using data from POWSCAR and Dublin City Council's SCATS[3] (DPER, 2018) dataset. When the supply and demand data are fed into the model, the O–D vehicle trips are assigned to the road or highway network to determine route choice and the generalised costs for motorised road vehicles.

Methodology

The objective of this work was to more accurately predict the potential real-life responsiveness of commuters in the GDA to a range of policy incentives by employing the NTA ERM. To achieve this aim, a number of scenarios were devised to simulate the introduction of the policy interventions explored in the SP experiment and to capture the effect of these policies on mode shares.

To account for the attribute levels included in the SP study, three overarching modelling scenarios were examined: the Do Nothing/base scenario, the Do Something scenario and the Do Maximum scenario. In each of these scenarios, changes to the network were introduced in multiple model runs. The organisational structure of the parameter changes made in the ERM is outlined in Table 5.1.

Emission estimation

In order to estimate the emission savings or changes in emissions that would result from implementing the range of policy scenarios tested in this study, the recommended approach outlined in the DTTaS Common Appraisal Framework (CAF) report (2016a) was adopted. The CAF provides guidance on evaluating a range of aspects related to the transport sector in Ireland including economic appraisal, risk and uncertainty analysis, and cost–benefit analysis, in addition to recommending approaches for project assessment, monitoring and implementation.
The purpose of the CAF is to "develop a common framework for the appraisal of transport investments that is consistent with the Irish Public Spending Code, to assist scheme promoters in constructing robust and comparable business cases for submission to Government" (DTTaS, 2016a). One of the central factors included in the CAF project appraisal criteria

3 The Sydney Coordinate Adaptive Traffic System (SCATS) is an intelligent transport system that coordinates traffic.

Table 5.1. Policy incentives and model parameter changes

Mode	Policy incentives/ measures	Effects of incentives on trip attributes		Justification for model changes
		Infrastructure	Time and/or cost	
Cycling	Increase cycle lane continuity, number of fully segregated cycle lanes Priority given to cyclists over motorists at junctions	Increase in the number of fully segregated cycle lanes	Reduction in trip times from improved cycling infrastructure	Increase in cycling speeds on certain links act as a proxy for increased segregation of cycling infrastructure
Walking	Improved pedestrian priority at junctions, signalling changes, greater amount of street space assigned to pedestrians	Reclaiming street space for pedestrians, priority over motorised traffic	Reduction in trip times from shorter waiting times at junctions, reduction in pedestrian congestion	Increase in pedestrian speeds acts as a proxy for pedestrian priority at junctions
Bus/rail	Scheduling improvements to ensure reliability, punctuality and increased frequency of services Reduction in bus and rail fares	Improvement in frequency of public transport services (reductions in headways of public transport modes)	Reduction in door-to-door trip times due to reduced waiting times Reduction in trip cost from lower fares	Reduction in public transport headways and fares acts as a proxy for changes in service efficiency affecting time and cost parameters Change to headways to act as proxy for improvements in service frequency
Carpooling/car-sharing	Free on-street and private parking for HOVs and those who car share HOV lanes, exemption from road tolls Guaranteed ride home for carpoolers	Reduction in access and/or waiting time from home to place of work or education	Reduction in trip times Reduction in trip costs from sharing the cost of carpooling or avoiding car ownership costs	Increase in occupancy level values to account for an increase in the mode share of carpooling as a result of the range of policy incentives/interventions implemented

is related to evaluating the impact of transport on the environment, such as air, noise, and ecological pollution and architectural impacts. In reference to air quality, the CAF recommends the approach for estimating road-based emissions outlined in Figure 5.1.

Under this approach, emissions of CO_2, NO_x and $PM_{2.5}$ are estimated by applying the following equation (McNamara and Caulfield, 2013; CAF, 2016a):

$$CO_2 = \sum (EF_i * VKM) \tag{5.1}$$

where *VKM* is the number of VKTs for the motorised modes modelled and EF_i represents the emission factor, estimated in kilograms per kilometre.

The VKTs were calculated based on the distance of each link in the network and the load of the user classes travelling on the links, per time period. These results were generated from SATURN (Atkins, 2017) and CUBE Voyager (Citilabs, 2017) for the following user classes: car employer business, car commute, car education, car other, bus and rail. Factors were first applied to the VKTs for each of the peak hours to estimate the passenger car unit (PCU) kilometres for bus and rail. Hour-to-period factors were then applied to calculate VKTs for all modes in the time periods. These factors are outlined in Tables 5.2 and 5.3. When the PCU and hour-to-period VKTs were calculated, the EFs included in the 2016 CAF report (DTTaS, 2016a) were applied to the VKTs to estimate the daily mode-specific emissions for private cars and buses in kilograms per kilometre for the 2012 base scenario and 2035 GDA Strategy scenario. The EFs for private vehicles and buses, listed in Table 5.4, were sourced from the default values contained in the COPERT (EMISIA, 2018) road transport emission model in the Irish context. The CO_2 EF for the DART was obtained from a European research project (PEACOX; see Brazil *et al*., 2013) and the Luas EF was developed by the Veolia Transport Group Eco-efficient Travel Assessment Methodology (Luas, 2017). The factors for DART and Luas are also included in Table 5.4. For private cars, separate factors were applied to petrol cars and diesel cars, based on a fuel split in the private car fleet of 53.6% diesel and 46.4% petrol, which was outlined in the National Mitigation Plan (DCCAE, 2017). A decision was made, in discussion with the

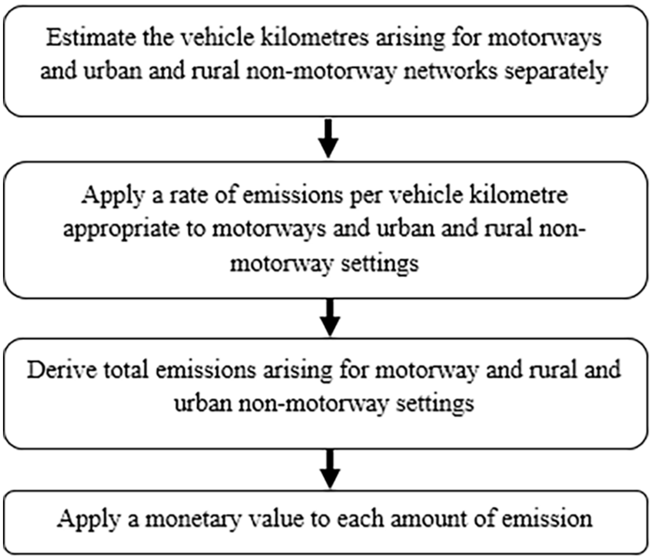

Figure 5.1. CAF-recommended method for evaluating road-based emissions. Based on the approach recommended in DTTaS (2016a).

Table 5.2. PCU factor for public transport modes (bus and rail)

Mode	PCU factor
Public service vehicle, i.e. public transport	3.0

Table 5.3. Hour-to-period factors per time period

Time period	Car	Public transport
AM	2.09	2.17
Lunchtime	3.00	3.00
School run	2.63	3.00
PM	2.35	2.50

Table 5.4. EFs in kilograms per kilometre

Vehicle category	CO_2	NO_x	$PM_{2.5}$
Petrol car	0.1923	0.0001	0.000002
Diesel car	0.1811	0.0007	0.000035
Bus	1.1393	0.0092	0.000081
DART	0.0110		
Luas	0.0706		

Sources: based on data in Brazil *et al.* (2013), DTTaS (2016a) and Luas (2017).

Table 5.5. Monetary values applied to emissions

Emission type	Emission value (€ per tonne)
CO_2	13.22
NO_x	5851
$PM_{2.5}$	200,239

Source: based on data from DTTaS (2016a).

NTA, to employ consistent EFs for both the 2012 and 2035 scenarios because of the unavailability of reliable forecast EFs for the public transport modes analysed.

Applying a monetary value to the emission estimations is outlined as the final stage in the approach set out by the CAF (DTTaS, 2016a). Accordingly, the CAF provides a range of emission values per emission type to calculate the cost of road transport emissions. The values that were employed in this project to estimate the potential cost savings generated from emission reductions are shown in Table 5.5. It should be noted that a full cost–benefit analysis was not conducted in this study and as such the discounting of these values was not conducted. If a subsequent cost–benefit analysis was to be conducted, discounting is recommended, following the guidelines in the CAF (DTTaS, 2016a).

It is noted that, since the CAF guidance was published in 2016, the monetary cost associated with CO_2 emissions will probably be higher by 2020. This is acknowledged by the authors; however, at the time that this research was conducted, no official national resources were available to indicate that a higher monetary value should be applied to CO_2 estimations for 2020.

5.3 Eastern Regional Model Mode Share Results

This section outlines the mode share changes estimated from the ERM following the stepwise modification of parameters in the model. The parameter changes were carried out in accordance with the Do Something and Do Maximum scenarios. Separate tables are provided for the 2012 base scenario results and the 2035 GDA Strategy scenario results, which compare the mode shifts under the Do Nothing/base scenario with those under the Do Something and Do Maximum scenarios. Only trips made within the GDA are considered in the analysis of mode shares. The behavioural responses measured as a result of introducing the policy incentives are analysed from changing mode shares, calculated from the total number of trips taken by each mode, first for all trip purposes and then for the commute purpose alone. The emission savings or changes in emissions estimated from changes in VKTs by different modes, in addition to the cost savings associated with the changes in emissions, are estimated in this section.

Figure 5.2 sets out the order in which the modelling results will be presented for each of the modelled scenarios (public transport, active mode and smarter car use) in this section.

5.3.1 Results from changes to the active modes model

The alterations made to the walking and cycling network in the ERM were centred on increases in pedestrian and cycling speeds as proxies for improvements made to infrastructure for pedestrians and cyclists, in addition to increasing pedestrian and cycling priority at junctions. These results can be found in Carroll *et al.* (2019a). The results set out in Table 5.6 show the mode shares in the GDA produced from the ERM-based changes in the 2012 base scenario. The results produced from the model based on the 2035 GDA Strategy are then shown in Table 5.7.

Under the Do Something scenario, shown in Table 5.14, the 25% increase in pedestrian speeds and 40% increase in cycling speeds, compared with the 2012 base scenario, resulted in a 4.42% increase in the mode share of walking for all trip purposes as a result of improving cycling and pedestrian infrastructure (i.e. addressing pedestrian and cyclist priority at junctions, increasing the number of widened and decluttered footpaths and fully segregated cycle lanes). Of this increase, 1.33% was accounted for by a mode shift from private cars, 2.12% from public transport and 0.97% from cycling. The walking mode share increased by a further 1.53% under the Do Maximum scenario, bringing the share to 29.85%, with a 1.91% decrease in private car use, a 2.81% decrease in public transport use and 1.23% of cyclists switching to walking. The key result from this particular modelling exercise was that it resulted in the largest decrease in the private car mode share achieved for all trip purposes, which was 1.91%. This suggests that investing in pedestrian infrastructure in particular could be an effective means of encouraging a mode shift away from private car usage in the GDA.

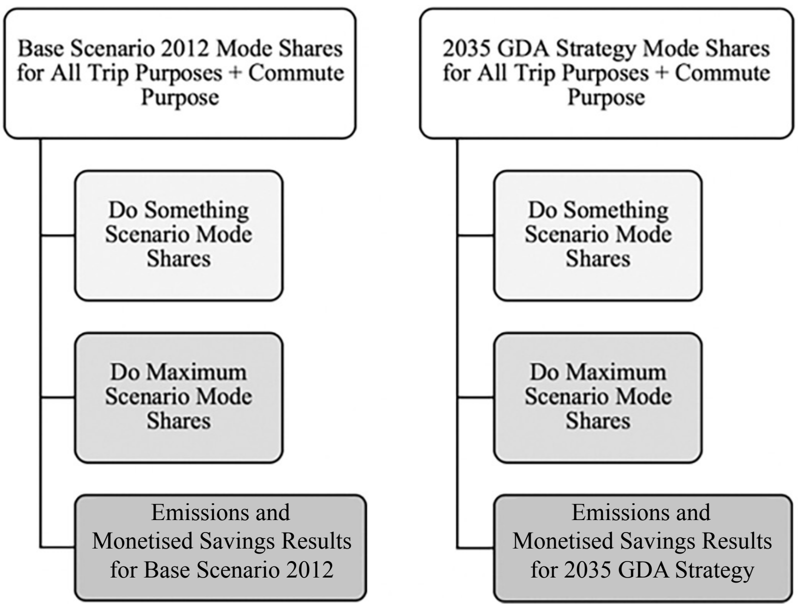

Figure 5.2. Order of model results presented in sections 5.4 and 5.5.

Table 5.6. Results from changes to the active modes model under the 2012 base scenario

Base scenario		Do Something scenario: 25% increase in pedestrian speeds and 40% increase in cycling speeds		Do Maximum scenario: 35% increase in pedestrian speeds and 60% increase in cycling speeds	
Mode	**Mode share (%)**	**Mode share (%)**	**Difference from base (%)**	**Mode share (%)**	**Difference from base (%)**
All trip purposes					
	5,048,523 trips	5,050,470 trips		5,050,691 trips	
Car	62.23	60.90	–1.33	60.32	–1.91
Public transport	9.69	7.57	–2.12	6.88	–2.81
Walking	23.90	28.32	+4.42	29.85	+5.95
Cycling	4.18	3.21	–0.97	2.95	–1.23
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,046,797 trips	1,047,419 trips		1,047,515 trips	
Car	72.89	72.08	–0.81	72.14	–0.75
Public transport	10.58	9.58	–1.01	8.91	–1.67
Walking	12.78	15.16	+2.38	15.95	+3.17
Cycling	3.75	3.19	–0.57	3.00	–0.76
Total	100.00	100.00	–	100.00	–

By isolating commute trips estimated in the model, it was also possible to observe the mode choice behaviour of commuters in the GDA. The private car mode share was markedly higher for commute trips than for all trip purposes, at 72.89%, under the base scenario, and fell only marginally, to 72.08%, under the Do Something scenario. Walking was found to be the only mode that increased for commute trips, with an increase of 2.38% under the Do Something scenario and 3.17% under the Do Maximum scenario. Of this 3.17% increase under the Do Maximum scenario, 1.67% was accounted for by a shift from public transport use, 0.76% from cycling and 0.75% from private car use. These results show that, given infrastructure improvements to both the pedestrian and cycling networks, pedestrians could be more sensitive to improvements than cyclists, as indicated by the mode share increases for walking and decreases for cycling. This suggests that, if walking trip times were reduced as a result of shorter waiting times at junctions and wider and decluttered footpaths, cyclists (who were also incentivised by these changes), along with public transport users and private car drivers, would be attracted to shifting their transport modes to walking.

The model based on the 2035 GDA Strategy assumes the completion of large-scale public transport projects such as the MetroLink, new Luas lines and Bus Connects projects. This increase in the availability of public transport modes is reflected in the base scenario mode shares shown in Table 5.7, that is, mode shares of 58.40% for car, 16.18% for public transport, 22.18% for walking and 3.24% for cycling. This equated to an increase in the public transport mode share of 6.49% under the 2035 GDA Strategy base scenario, compared with the 2012 base scenario. The private car mode share under the 2035 scenario was also found to be noticeably lower than under the 2012 scenario, as a result of the range of projects introduced in the period covered by the 2035 GDA Strategy, falling by 3.83%, from 62.23% to 58.40%.

However, the aim of the changes applied to the active modes model under the 2035 scenario was to investigate the effects of further incentivising walking and cycling over other modes in the model. This was represented by the 2035 mode shares under the Do Something and Do Maximum scenarios: the walking mode share rose by 6.30% under the Do Maximum scenario for all trip purposes and 3% for the commute trip purpose only. Pedestrians were again more sensitive to changes in speed than cyclists, as the cycling mode shares decreased by up to 0.96% for all trip purposes and up to 0.51% for the commute trip purpose. Nevertheless, the modifications made

Table 5.7. Results from changes to the active modes model under the 2035 GDA Strategy base scenario

Base scenario		Do Something scenario: 25% increase in pedestrian speeds and 40% increase in cycling speeds		Do Maximum scenario: 35% increase in pedestrian speeds and 60% increase in cycling speeds	
Mode	Mode share (%)	Mode share (%)	Difference from base (%)	Mode share (%)	Difference from base (%)
All trip purposes					
	5,984,781 trips	5,987,783		5,991,301 trips	
Car	58.40	57.68	–0.72	57.07	–1.33
Public transport	16.18	13.20	–2.98	12.11	–4.07
Walk	22.18	26.83	+4.65	28.48	+6.30
Cycle	3.24	2.29	–0.96	2.35	–0.89
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,268,512 trips	1,266,550 trips		1,266,948 trips	
Car	68.76	68.20	–0.56	68.26	–0.50
Public transport	18.75	17.58	–1.17	16.64	–2.12
Walk	10.35	12.59	+2.25	13.35	+3.00
Cycle	2.14	1.63	–0.51	1.76	–0.38
Total	100.00	100.00	–	100.00	–

to cycling and pedestrian speeds in the model came at the cost of a significant mode shift away from public transport modes, as also shown for the 2012 scenario. Under the 2035 scenario, reductions in the public transport mode share under the Do Maximum scenario of 4.07% for all trip purposes and of 2.12% for the commute purpose alone were estimated. Under this scenario, this significant shift away from public transport would not necessarily be a negative consequence given the large increase in the walking mode shares and the reductions in private car trips. Overall, these results show that the introduction of incentives to use active modes could result in a 4.58% increase in the walking mode share from the 2012 base scenario to the 2035 GDA Strategy Do Maximum scenario.

Mode shares within the inner metropolitan area of the GDA were also examined under the active modes scenarios, as a means of comparison between the private car mode shares considering distances travelled by active mode users (Caulfield, 2014).

The 2012 base scenario mode share results for the inner metropolitan area of the GDA estimate that a reduction in the private car mode share of up to 2.69% for all trip purposes and 1.01% for the commuting purpose could be achieved under the Do Maximum scenario. These results were also in response to a 35% increase in pedestrian speeds and a 60% increase in cycling speeds as a result of upgrading the active mode infrastructure in this area. The results are notable, as they are the largest reductions in the private car mode share recorded as part of this study. This suggests that, as expected, incentives for walking and cycling could be most effectively implemented in inner metropolitan areas, where there is higher population density and an accumulation of centres of employment. The policy measures tested in this modelling exercise were predicted to result in an increase of up to 8.78% in the walking mode share for all trip purposes and 4.43% for commuting trips. This was shown to increase the walking mode share to 39.23% for all trip purposes. Of this increase in the walking mode share, 2.69% came from a shift from private car use, 4.26% from public transport and 1.84% from cycling.

For commuting trips, mode share shifts of 1.01% from car use, 2.37% from bus and rail and 1.05% from cycling were estimated. The reduction in cycling trips was again found to be an adverse effect of people favouring improvements made to the pedestrian network over improvements to the cycling network.

The walking mode share results estimated under the 2035 GDA Strategy scenario for the inner metropolitan area were higher: increases of 9.28% for all trip purposes and 4.61% for commuting purposes were found. These increases in walking were, however, coupled with large shifts away from public transport, of up to 6.28% for all trips and 3.07% for commute trips, under the Do Maximum scenario. Moreover, reductions in the private car mode share as a result of introducing active mode policy incentives were projected to be higher in the inner metropolitan area of the GDA under the 2035 scenario than in the rest of the GDA, with a 1.85% reduction in the private car mode share for all trip purposes and a 1.09% reduction for commute trips.

The results generated from modelling changes to pedestrian and cycling networks were found to be comparable to those produced by O'Fallon *et al.* (2004) and Mackett (2001), who determined that an increase in the number of cycle lanes did not have a statistically significant impact on cycling mode shares in relation to encouraging a mode shift from single-occupancy vehicle use to cycling. These studies concluded that only 2% of car drivers would be willing to shift to cycling given infrastructural improvements to the cycling network. The estimated changes in mode share as a result of changing only cycling speed, as opposed to changing both pedestrian and cycling speeds, suggest that only a 1.05% increase in the cycling mode share could be achieved in the GDA across the two years modelled, with the majority of this mode shift coming directly from a decrease in private car commute trips (1.08%).

5.3.2 Results from changes to the public transport mode

The network changes to the public transport (bus and rail) networks considered were reductions to service headways and fares, to analyse the effects of reducing the time and cost of travelling by bus or rail in the GDA. Under the 2012 base scenario, as shown in Table 5.8, changes to the public transport network were predicted to result in an increase in public transport trips of 1.34% under the Do Something scenario and 2.08% under the Do Maximum scenario for all trip purposes. Of the increase under the Do Maximum scenario, 0.52% came from a shift away from private car use, 1.03% from walking and 0.53% from cycling. These mode shifts were the result of decreasing the headways of and fares for bus and rail services in the GDA by 35% as proxies for quicker, more frequent and cheaper public transport trips. These results can also be found in Carroll *et al.* (2019b).

Table 5.8. Results from changes to the public transport model under the 2012 base scenario

Base scenario		**Do Something scenario: 25% decrease in headways and fares**		**Do Maximum scenario: 35% decrease in headways and fares**	
Mode	**Mode share (%)**	**Mode share (%)**	**Difference from base (%)**	**Mode share (%)**	**Difference from base (%)**
All trip purposes					
	5,048,523 trips	5,047,423 trips		5,064,850 trips	
Car	62.23	61.95	–0.28	61.71	–0.52
Public transport	9.69	11.03	+1.34	11.77	+2.08
Walking	23.90	23.22	–0.68	22.87	–1.03
Cycling	4.18	3.80	–0.38	3.65	–0.53
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,046,797 trips	1,046,850 trips		1,046,765 trips	
Car	72.89	71.41	–1.48	71.13	–1.76
Public transport	10.58	12.77	+2.19	13.45	+2.87
Walking	12.78	12.44	–0.34	12.24	–0.54
Cycling	3.75	3.39	–0.36	3.18	–0.57
Total	100.00	100.00	–	100.00	–

For commute trips, the changes to the public transport network were predicted to produce a 2.19% increase in the public transport mode share under the Do Something scenario and a 2.87% increase under the Do Maximum scenario. These mode share increases were largely due to shifts from private car use, with up to a 1.76% switch to public transport being predicted, followed by cycling at 0.57% and walking at 0.54%. Thus, these findings suggest that reductions in headways and fares could cause a direct mode shift from private car use to the use of bus and rail services by those commuting to work.

The 2035 GDA Strategy scenario results, outlined in Table 5.9, showed smaller increases in public transport mode shares than the 2012 scenario. However, these increases were in addition to the already higher public transport mode share in 2035 given the range of public transport projects included in the strategy. For all trips, the public transport mode share grew to 17.37% under the Do Maximum scenario, representing a 1.19% increase. Yet only 0.07% of this came from a mode shift from private cars, while there were larger mode shifts from cycling and walking to public transport, with reductions in these mode shares of 0.82% and 0.30%, respectively. For commute trips, there was an increase in the public transport mode share of 1.42% under the Do Maximum scenario (Table 5.9) to 20.17%, which represented the highest public transport mode share estimated across all the modelling exercises conducted as part of this research. The majority of this was accounted for by a shift from private car use, of 0.99%. Overall, the results presented for this scenario show an increase in public transport mode share of 7.68% from the 2012 base scenario to the Do Maximum scenario under the 2035 scenario.

5.3.3 Results from changes to the smarter car use mode

Mode share changes based on increasing private car occupancy level values are unique among the parameter changes tested in the ERM. In this case, an increase in the private car mode share would be a relatively positive outcome, if such an increase were to be accompanied by a reduction in the VKTs by private cars, as decreases in the VKTs by private cars would be accounted for by more commuters shifting to carpooling as a mode, as opposed to driving alone. Akin to the other parameter changes in this study, two levels of change were considered, one under the Do Something scenario – a 25% increase in car occupancy levels – and the second under the Do Maximum scenario – a 35% increase in occupancy levels. The Do Something scenario results under the 2012 base scenario, as outlined in Table 5.10, show

Table 5.9. Results from changes to the public transport model under the 2035 GDA Strategy base scenario

Base scenario		Do Something scenario: 25% decrease in headways and fares		Do Maximum scenario: 35% decrease in headways and fares	
Mode	**Mode share (%)**	**Mode share (%)**	**Difference from base (%)**	**Mode share (%)**	**Difference from base (%)**
All trip purposes					
	5,984,781 trips	5,987,610 trips		5,986,137 trips	
Car	58.40	58.53	+0.13	58.33	–0.07
Public transport	16.18	16.82	+0.64	17.37	+1.19
Walking	22.18	21.62	–0.56	21.36	–0.82
Cycling	3.24	3.03	–0.21	2.94	–0.30
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,268,512 trips	1,266,159 trips		1,266,313 trips	
Car	68.76	67.90	–0.86	67.77	–0.99
Public transport	18.75	19.82	+1.06	20.17	+1.42
Walking	10.35	10.25	–0.10	10.11	–0.24
Cycling	2.14	2.04	–0.10	1.95	–0.19
Total	100.00	100.00	–	100.00	–

Table 5.10. Results from changes to the smarter car use model under the 2012 base scenario

Base scenario		Do Something scenario: 25% increase in car occupancy values		Do Maximum scenario: 35% increase in car occupancy values	
Mode	**Mode share (%)**	**Mode share (%)**	**Difference from base (%)**	**Mode share (%)**	**Difference from base (%)**
All trip purposes					
	5,048,523 trips	5,048,587 trips		5,049,031 trips	
Car	62.23	62.84	+0.61	63.01	+0.78
Public transport	9.69	9.41	–0.28	9.31	–0.38
Walking	23.90	23.67	–0.23	23.63	–0.27
Cycling	4.18	4.08	–0.10	4.05	–0.13
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,046,797 trips	1,047,407 trips		1,047,289 trips	
Car	72.89	73.10	+0.21	73.47	+0.58
Public transport	10.58	10.39	–0.19	10.10	–0.47
Walking	12.78	12.75	–0.03	12.73	–0.05
Cycling	3.75	3.76	0.01	3.70	–0.06
Total	100.00	100.00	–	100.00	–

a 0.61% increase in the private car mode share for all trips, with shifts away from other modes, i.e. a 0.28% decrease for public transport, a 0.23% decrease for walking and a 0.10% decrease for cycling. The private car mode share then increased further, by an extra 0.17%, under the Do Maximum scenario to bring the mode share up to 63.01%. Under this scenario, the largest shift was the shift away from public transport at 0.38%, followed by walking at 0.27% and finally cycling at 0.13%. For commute trips, the mode share changes were not as high as they were for all trip purposes, meaning that those travelling for other trip purposes were also attracted to carpooling as a mode, given the incentives offered (i.e. free tolls and free parking, HOV lanes, etc.).

For commute trips, the increase in the private car mode share was estimated to be 0.21% under the Do Something scenario and 0.58% under the Do Maximum scenario. These increases were facilitated by marginal reductions in the shares of other modes, with the highest shift coming from public transport at 0.47% under the Do Maximum scenario.

Changes made to car occupancy level values under the 2035 GDA Strategy scenario, as presented in Table 5.11, resulted in higher mode shifts to private cars than under the 2012 base scenario. Under the Do Something scenario, for all trips, a mode shift to private car use of 1.19% was found, based on a 25% increase in car occupancy values. Under the Do Maximum scenario, this figure increased to 1.83%, based on a 35% increase in car occupancy values. More pedestrians were estimated to shift to carpooling (0.84%) under the Do Something scenario than under the Do Maximum scenario. Under the Do Maximum scenario, 1.12% of public transport users were estimated to shift away from bus and rail use to private car usage. For commute trips, the private car mode share changes were broadly in line with those for all trip purposes, although fewer pedestrians and cyclists were predicted to shift to private car use than they were for all trips. Finally, there was estimated to be a 1.75% mode shift from public transport to private cars, given the carpooling incentives, for commute trips.

5.4 Emission Results

To ultimately appraise the performance of the range of policy incentives suggested in this study, a technical evaluation of the emissions from transport resulting from the behavioural changes (i.e. mode shares) required to achieve the emission savings was conducted. The VKTs results taken from SATURN (Atkins, 2017) were used to estimate the

Table 5.11. Results from changes to the smarter car use model under the 2035 GDA Strategy base scenario

Base scenario		Do Something scenario: 25% increase in car occupancy values		Do Maximum scenario: 35% increase in car occupancy values	
Mode	**Mode share (%)**	**Mode share (%)**	**Difference from base (%)**	**Mode share (%)**	**Difference from base (%)**
All trip purposes					
	5,984,781 trips	5,984,605 trips		5,986,252 trips	
Car	58.40	59.59	+1.19	60.23	+1.83
Public transport	16.18	16.13	–0.05	15.06	–1.12
Walking	22.18	21.34	–0.84	21.65	–0.53
Cycling	3.24	2.94	–0.30	3.06	–0.18
Total	100.00	100.00	–	100.00	–
Commute trip purpose					
	1,268,512 trips	1,266,467 trips		1,266,514 trips	
Car	68.76	69.79	+1.03	70.57	+1.81
Public transport	18.75	18.04	–0.71	17.00	–1.75
Walking	10.35	10.19	–0.16	10.31	–0.04
Cycling	2.14	1.98	–0.16	2.12	–0.02
Total	100.00	100.00	–	100.00	–

daily emissions in kilograms per kilometre likely to be produced from the various scenarios modelled by applying the mode-specific EFs for CO_2, NO_x and $PM_{2.5}$.

5.4.3 Active modes model emission results

The emission results from the active modes model under the 2012 base scenario, presented in Table 5.12, show that daily emission savings of 10.93 t of CO_2, 0.03 t of NO_x and 0.0011 t of $PM_{2.5}$ for "car other" user class trips could be achieved under the Do Maximum scenario, as a result of introducing the active mode policy incentives set out in Table 5.12. These emission savings were accompanied by private car emission reductions in other user classes; for example, for private car use for work/business travel ("car employment/business"), savings of 4.94 t of CO_2, 0.011 t of NO_x and 0.0005 t of $PM_{2.5}$ were estimated under the Do Maximum scenario. However, as a consequence of the mode-shifting behaviour from public transport to active modes in this scenario, emission reductions were also associated with bus, DART and Luas. Bus, for example, experienced the largest reduction in VKTs, in total resulting in emission savings of 16.44 t of CO_2, 0.13 t of NO_x and 0.0012 t of $PM_{2.5}$ daily relative to the total emissions estimated under the base scenario. CO_2 emissions were also estimated to decline for DART and Luas, but to a lesser extent than for bus.

The monetised savings associated with these emission savings for the various car user classes under the 2012 base scenario were calculated using the CAF-recommended approach (DTTaS, 2016a). These findings are presented in Table 5.13. In contrast to all other trip types, there was found to be an increase in emissions (CO_2, NO_x and $PM_{2.5}$) between the 2012 base scenario and the two forecasted scenarios (i.e. Do Something and Do Maximum scenarios) from private cars for the "car commute" trip purpose. This is probably the result of more individuals opting to carpool as a mode of transport to work, given the range of incentives on offer. The increase in emissions from this activity, which is estimated to have an adverse effect on society, is accounted for by an associated increase in monetary costs of up to €2365 per day.

Under the 2035 GDA Strategy scenario, as shown by the emission results in Table 5.14, it was estimated that, for the "car education" user class under the Do Maximum scenario, a total of 2.01 t of CO_2 and 0.01 t of NO_x would be saved daily by encouraging a mode shift away from car use to walking and cycling. However,

Table 5.12. Results of changes to the active modes model under the 2012 base scenario: impact on daily emissions

	Base scenario	Do Something scenario		Do Maximum scenario	
User class	Total (t)	Total (t)	Difference from base (t)	Total (t)	Difference from base (t)
CO_2 emissions					
Car employment/business	293.45	290.31	–3.14	288.51	–4.94
Car commute	1269.41	1280.72	+11.31	1284.37	+14.96
Car education	19.15	17.38	–1.77	16.74	–2.41
Car other	1821.77	1817.18	–4.59	1810.84	–10.93
Bus	199.10	185.19	–13.91	182.66	–16.44
DART	2.04	1.86	–0.18	1.79	–0.25
Luas	13.02	11.18	–1.84	10.58	–2.44
NO_x emissions					
Car employment/business	0.643	0.636	–0.007	0.632	–0.011
Car commute	2.78	2.80	+0.02	2.81	+0.03
Car education	0.042	0.038	–0.004	0.037	–0.005
Car other	3.99	3.98	–0.01	3.96	–0.03
Bus	1.61	1.47	–0.14	1.48	–0.13
$PM_{2.5}$ emissions					
Car employment/business	0.0309	0.0306	–0.0003	0.0304	–0.0005
Car commute	0.1338	0.1350	–0.0012	0.1354	–0.0016
Car education	0.0020	0.0018	–0.0002	0.0017	–0.0003
Car other	0.1920	0.1915	–0.0005	0.1909	–0.0011
Bus	0.0142	0.0132	–0.001	0.0130	–0.0012

Table 5.13. Monetised savings from emission reductions, by car user class, under the 2012 and 2035 scenarios in the active modes model

User class	Pollutant	Daily emission savings (t)	Daily monetised savings (€)
2012			
Car other	CO_2	10.93	144.49
	NO_x	0.03	175.53
	$PM_{2.5}$	0.0011	220.26
Car employment/business	CO_2	4.94	65.31
	NO_x	0.011	64.36
	$PM_{2.5}$	0.0005	100.119
	Total		770.07
2035			
Car other	CO_2	14.08	186.14
	NO_x	0.03	176.53
	$PM_{2.5}$	0.01	2002.39
	Total		2365.06
Car employment/business	CO_2	2.01	26.57
	NO_x	0.01	58.51
	$PM_{2.5}$	0.00	00.00
	Total		85.08

Table 5.14. Results of changes to the active modes model under the 2035 GDA Strategy base scenario: impact on daily emissions

User class	Base scenario	Do Something scenario		Do Maximum scenario	
	Total (t)	Total (t)	Difference from base (t)	Total (t)	Difference from base (t)
CO_2 emissions					
Car employment/business	312.96	317.87	+4.91	316.17	+3.21
Car commute	1654.59	1669.11	+14.52	1668.67	+14.08
Car education	17.65	16.32	–1.33	15.64	–2.01
Car other	1928.89	1952.66	+23.77	1946.58	+17.69
Bus	1551.32	1408.33	–142.99	1345.89	–205.43
DART	11.10	9.73	–1.37	9.35	–1.75
Luas	21.97	17.61	–4.36	16.36	–5.61
NO_x emissions					
Car employment/business	0.69	0.70	+0.01	0.69	0.00
Car commute	3.62	3.66	+0.04	3.65	+0.03
Car education	0.04	0.04	0.00	0.03	–0.01
Car other	4.22	4.28	+0.06	4.26	+0.04
Bus	12.54	11.38	–1.16	10.88	–1.66
$PM_{2.5}$ emissions					
Car employment/business	0.03	0.03	0.00	0.03	0.00
Car commute	0.17	0.18	+0.01	0.18	+0.01
Car education	0.002	0.002	0.00	0.002	0.00
Car other	0.20	0.21	+0.01	0.21	+0.01
Bus	0.11	0.10	–0.01	0.10	–0.01

as for the 2012 base scenario results, incentivising the use of active modes resulted in a decrease in the use of public transport, as these modes remained constant or unaffected by the policies implemented under this scenario.

This fall in public transport usage led to a daily reduction of 205.43 t in CO_2, 1.66 t in NO_x and 0.015 t in $PM_{2.5}$ emissions from buses in the GDA. The reductions in emissions from buses along with reductions in emissions from DART and Luas were in line with the reductions in the public transport mode share.

5.4.4 Public transport model emission results

The changes in emissions estimated from the public transport model under the 2012 base scenario are presented in Table 5.15. These emissions were based on variations in VKTs as a result of modifications made to headways and fares in the ERM. The results in Table 5.15 show that reductions of 431.58 t in CO_2, 0.95 t in NO_x and 0.046 t in $PM_{2.5}$ emissions could be attained for commute trips in the GDA under the Do Something scenario. These emission savings were higher than those recorded under the 2012 base scenario for the active modes model, which assumed a reduction in VKTs for car commute trips as a result of public transport modes being incentivised. Car trips for employment or business purposes were also associated with emission reductions under this scenario, with 37.02 t of CO_2, 0.08 t of NO_x and 0.004 t of $PM_{2.5}$ being saved under the Do Something scenario. Under the Do Maximum scenario, the emissions generated from the various car user classes were lower than under the Do Something scenario, with the exception of the “car other” user class. However, in response to mode shifting from active modes and private cars to public transport under this scenario, a resultant rise in emissions from bus, train and Luas modes was found, as expected given the higher frequency of services required to meet the shorter headway times modelled for the network.

Table 5.15. Results of changes to the public transport model under the 2012 base scenario: impact on daily emissions

	Base scenario	Do Something scenario		Do Maximum scenario	
User class	**Total (t)**	**Total (t)**	**Difference from base (t)**	**Total (t)**	**Difference from base (t)**
CO_2 emissions					
Car employment/business	293.45	256.43	–37.02	290.54	–2.91
Car commute	1269.41	837.83	–431.58	1258.36	–11.05
Car education	19.15	507.29	+488.14	18.23	–0.92
Car other	1821.77	1811.48	–10.29	1805.98	–15.79
Bus	199.10	236.36	+37.26	324.61	+125.51
DART	2.04	2.38	+0.34	2.55	+0.51
Luas	13.02	14.56	+1.54	15.46	+2.44
NO_x emissions					
Car employment/business	0.64	0.56	–0.08	0.64	0.00
Car commute	2.78	1.83	–0.95	2.76	–0.02
Car education	0.04	1.11	+1.07	0.04	0.00
Car other	3.99	3.97	–0.02	3.95	–0.04
Bus	1.61	1.91	+0.30	2.62	+1.01
$PM_{2.5}$ emissions					
Car employment/business	0.031	0.027	–0.004	0.031	0.00
Car commute	0.134	0.088	–0.046	0.133	–0.001
Car education	0.002	0.053	+0.051	0.002	–0.00
Car other	0.192	0.191	–0.001	0.190	–0.002
Bus	0.014	0.017	+0.003	0.023	+0.009

The daily emission savings estimated for the "car commute" and "car employment/business" user classes under the 2012 base scenario were then used to estimate the daily cost savings, as shown in Table 5.16.

Under the 2035 GDA Strategy scenario, there were relativity minor reductions in emissions compared with the 2012 base scenario, given the mode shift to public transport between the 2012 base scenario and the 2035 GDA Strategy scenario with the inclusion of MetroLink, Bus Connects, and DART and Luas expansions. However, Table 5.17 shows that, in addition to these infrastructural changes, the policy incentives tested in this study were predicted to result in an additional reduction of 1.19 t in CO_2, 0.002 t in NO_x and 0.0001 t in $PM_{2.5}$ emissions per day for car business use trips, and 0.11 t in CO_2, 0.001 t in NO_x and 0.0001 t in $PM_{2.5}$ emissions for car education trips under the Do Maximum scenario. These two car user classes were the only classes to experience a reduction in emissions under both of the scenarios modelled (i.e. Do Something and Do Maximum) under the 2035 GDA Strategy scenario, which reflects the difficulty in encouraging a further reduction in car mode shares over that already achieved by the 2035 GDA Strategy.

5.4.5 Smarter care use model emission results

The 2012 base scenario emission results for the smarter car use model tested in this study are presented in Table 5.18. These results show the predicted effects of incentivising car users in the GDA to take up carpooling through various policy measures that lead to shorter trip times and lower costs and an enhancement in the convenience of carpooling, by increasing the occupancy of private cars. These findings indicate how individuals in the GDA could make more sustainable use of the car and, in this way, would also help to reduce emissions from shared-use trips. Table 5.18 shows that, under the Do Maximum scenario, emission savings of 235.47 t of CO_2, 0.88 t of NO_x and 0.025 t of $PM_{2.5}$ from car commute trips could

Table 5.16. Monetised savings from emission reductions, by car user class, under the 2012 and 2035 scenarios in the public transport model

User class	Pollutant	Daily emission savings (t)	Daily monetised savings (€)
2012			
Car commute	CO_2	431.58	5705.48
	NO_x	0.95	5558.45
	$PM_{2.5}$	0.046	9210.99
Car employment/business	CO_2	37.02	489.40
	NO_x	0.08	468.08
	$PM_{2.5}$	0.004	800.96
Total			22,223.36
2035			
Car commute	CO_2	1.19	15.73
	NO_x	0.002	11.70
	$PM_{2.5}$	0.0001	20.02
Car employment/business	CO_2	0.11	1.45
	NO_x	0.001	5.85
	$PM_{2.5}$	0.0001	2.02
Total			56.77

Table 5.17. Results of changes to the public transport model under the 2035 GDA Strategy base scenario: impact on daily emissions

	Base scenario	Do Something scenario		Do Maximum scenario	
User class	Total (t)	Total (t)	Difference from base (t)	Total (t)	Difference from base (t)
CO_2 emissions					
Car employment/business	312.96	312.92	–0.04	311.77	–1.19
Car commute	1654.59	1660.75	+6.16	1657.34	+2.75
Car education	17.65	17.77	+0.12	17.54	–0.11
Car other	1928.89	1944.70	+15.81	1937.90	+9.01
Bus	1551.32	1977.00	+425.68	1977.00	+425.68
DART	11.10	11.67	+0.57	11.77	+0.67
Luas	21.97	20.73	–1.24	22.10	+0.13
NO_x emissions					
Car employment/business	0.685	0.685	0.00	0.683	–0.002
Car commute	3.62	3.64	+0.02	3.63	+0.01
Car education	0.039	0.038	+0.001	0.038	–0.001
Car other	4.22	4.26	+0.04	4.24	+0.02
Bus	12.54	15.98	+3.44	15.98	+3.44
$PM_{2.5}$ emissions					
Car employment/business	0.0330	0.0330	0.00	0.0329	–0.0001
Car commute	0.174	0.175	+0.001	0.175	+0.001
Car education	0.0019	0.0019	0.00	0.0018	–0.0001
Car other	0.203	0.205	+0.002	0.204	0.001
Bus	0.11	0.14	+0.03	0.14	+0.03

Table 5.18. Results of changes to the smarter car use model under the 2012 base scenario: impact on daily emissions

	Base scenario	Do Something scenario		Do Maximum scenario	
User class	Total (t)	Total (t)	Difference from base (t)	Total (t)	Difference from base (t)
CO_2 emissions (t)					
Car employment/business	293.45	297.88	+4.43	298.88	+5.43
Car commute	1269.41	1086.51	–182.9	1033.94	–235.47
Car education	19.15	16.74	–2.41	15.93	–3.22
Car other	1821.77	1849.07	+27.3	1855.94	+34.17
Bus	199.10	199.09	–0.01	194.18	–4.92
DART	2.04	1.97	–0.07	1.94	–0.1
Luas	13.02	12.47	–0.55	12.39	–0.63
NO_x emissions (t)					
Car employment/business	0.64	0.65	+0.01	0.85	+0.21
Car commute	2.78	2.38	–0.40	3.66	–0.88
Car education	0.04	0.03	–0.01	0.05	+0.01
Car other	3.99	4.05	+0.06	5.25	+1.26
Bus	1.6095	1.6094	–0.0001	2.6241	+1.0146
$PM_{2.5}$ emissions (t)					
Car employment/business	0.0309	0.0314	0.0005	0.0315	+0.0006
Car commute	0.1338	0.1145	–0.0193	0.1090	–0.0248
Car education	0.0020	0.0018	–0.0002	0.0017	–0.0003
Car other	0.192	0.195	+0.003	0.196	+0.004
Bus	0.0142	0.0142	0.00	0.0138	–0.0004

result from increasing the occupancy levels of private vehicles by 35%. While for education trip purposes the same model parameter modifications resulted in lower daily emission savings, of 3.22 t CO_2, 0.01 t NO_x and 0.0002 t $PM_{2.5}$. As the incentives offered in the smarter car use model resulted in mode shifting from public transport and active modes to private car use in the form of carpooling, this, as intended, also had the effect of reducing emissions from public transport as a result of a decrease in bus and rail use and in VKTs. The public transport emission savings are also presented in Table 5.18: emissions from Luas trips were found to decrease more under the Do Something scenario and emissions from bus trips declined more under the Do Maximum scenario.

The cost savings associated with the emission savings for the "car commute" and "car education" user classes under the 2012 base scenario are presented in Table 5.19.

Under the 2035 GDA Strategy scenario, a similar trend in emission reductions was found for car commute and education trips as for the 2012 scenario. Table 5.20 shows that emission savings of up to 220.95 t CO_2, 0.48 t NO_x and 0.023 t $PM_{2.5}$ could be possible under the Do Something scenario as a result of increasing the occupancy levels of cars in the commuter user class by 25% in the GDA. This is in addition to the 1.38 t of CO_2, 0.003 t of NO_x and 0.0002 t of $PM_{2.5}$ being saved for education trips under the same scenario. However, under the Do Maximum scenario no such savings were recorded for private car trips, suggesting that increasing the occupancy level of private cars by 35% could result in a daily increase, rather than decrease, in the VKTs. As for the 2012 base scenario, the associated reduction in public transport VKTs under the 2035 scenario resulted in emission savings for bus, train and Luas, as shown in Table 5.20, with the highest emission reductions associated with bus trips.

Table 5.19. Monetised savings from emission reductions, by car user class, under the 2012 and 2035 scenarios in the smarter car use model

User class	Pollutant	Daily emission savings (t)	Daily monetised savings (€)
2012			
Car commute	CO_2	235.47	3112.91
	NO_x	0.88	5148.88
	$PM_{2.5}$	0.025	5005.97
Car education	CO_2	3.22	42.57
	NO_x	0.01	58.51
	$PM_{2.5}$	0.0002	40.04
Total			11,408.88
2035			
Car commute	CO_2	220.95	2920.95
	NO_x:	0.48	2808.48
	$PM_{2.5}$	0.023	4605.50
Car education	CO_2	1.38	18.24
	NO_x	0.003	17.55
	$PM_{2.5}$	0.0002	40.05
Total			10,410.77

Table 5.20. Results of changes to the smarter car use model under the 2035 GDA Strategy base scenario: impact on daily emissions

	Base scenario	Do Something scenario		Do Maximum scenario	
User class	Total (t)	Total (t)	Difference from base (t)	Total (t)	Difference from base (t)
CO_2 emissions					
Car employment/business	312.96	330.65	+17.69	351.33	+38.37
Car commute	1654.59	1433.64	–220.95	1905.08	+250.49
Car education	17.65	16.26	–1.38	22.57	+4.92
Car other	1928.89	2006.24	+77.35	2020.00	+91.11
Bus	1551.32	1532.87	–18.45	1505.62	–45.70
DART	11.10	9.96	–1.14	9.78	–1.32
Luas	21.97	19.57	–2.40	19.18	–2.79
NO_x emissions					
Car employment/business	0.69	0.72	+0.03	0.77	+0.08
Car commute	3.62	3.14	–0.48	4.17	+0.55
Car education	0.039	0.036	–0.003	0.049	+0.01
Car other	4.22	4.39	+0.17	4.42	+0.20
Bus	12.54	12.39	–0.15	12.17	–0.37
$PM_{2.5}$ emissions					
Car employment/business	0.033	0.035	+0.002	0.037	+0.004
Car commute	0.17	0.15	–0.023	0.20	+0.03
Car education	0.0019	0.0017	–0.0002	0.0024	+0.0005
Car other	0.203	0.211	+0.008	0.213	+0.01
Bus	0.110	0.109	–0.001	0.107	–0.003

5.5 Conclusions

This chapter has set out the rationale for, the methodology behind and the results produced from modelling travel demand under a range of scenarios based on policy incentives that were first tested in the SP study. The research presented in this chapter was conducted to complement the results produced from the SP experiment and to further appraise the policy scenarios by analysing the real-life impacts of introducing policies that aim to increase the use of active transport modes, public transport and smarter car use modes such as carpooling.

Section 5.2 provided an overview of the use of the RMS in Ireland, with particular attention being assigned to the ERM in the context of this research. Also in this section, the mathematical framework of the choice model and the structure of the assignment model in the ERM were discussed. Section 5.3 then delineated the methodology used to make the model parameter changes to each of the mode-specific scenarios that were run in accordance with the Do Something and Do Maximum scenarios. This was followed by an explanation of the methodology used for calculating the emission savings from reductions in VKTs and the monetised savings estimated to result from these emission savings. Section 5.4 presented the mode share results for each of the mode-specific scenarios under the 2012 base scenario and 2035 GDA Strategy scenario. These results suggested that pedestrians in the GDA were most sensitive to parameter changes made in the ERM. This was highlighted in the active modes and optimal car-shedding model results, where the walking mode share experienced the largest or, in some cases, the only increase. In addition to this, it was found that, in the smarter car use model, while there were increases in the private car mode share, an increase in carpooling was likely to have been the reason for this increase based on the reduction in VKTs under this scenario. Thus, it was estimated that, similarly, a sustainable mode shift occurred in this model.

The emission savings calculated based on the CAF (DTTaS, 2016a) methodology were presented. It was found that, for various private car user classes, emissions declined, particularly for the “car commute” and “car education” classes. These results were then used to estimate the monetised savings associated with the emission reductions. It was determined that up to €5705 could be saved from daily commutes as a result of estimated CO_2 emission reductions, up to €5558 as a result of NO_x emission reductions and up to €9210 as a result of $PM_{2.5}$ emission reductions.

6 Modelling Vehicular Emission Reductions with Alternative Policy Interventions

6.1 Introduction

Air pollution is linked to 491,000 deaths in Europe annually (EEA, 2016) and diesel vehicles are one of the major sources of two deadly air pollutants, $PM_{2.5}$ and NO_x. NO_x is typically generated through any process of high-temperature combustion, most commonly from the burning of fossil fuels in motor vehicles' combustion engines (EPA, 2016). It has been found that Euro 5 and Euro 6 diesel private cars and LCVs emit much higher levels of NO_x than Euro standard specifications (Transport and Environment, 2016). As mentioned earlier, Ireland has the highest number of newly registered diesel vehicles in Europe and the increase in diesel car purchases can be linked to a change in VRT from being based on engine size to being based on CO_2 emission levels. Moreover, this has led to a substantial increase in diesel vehicles of larger engine size (> 1.4 L). In addition, the Irish fleet has a relatively high number of older vehicles, which are more polluting than the newer technology classes. This in addition to "dieselgate" has resulted in significant health and economic consequences, especially in urban areas. Therefore, the introduction of new policies with the intention to reduce the use of ICEVs and increase the use of sustainable transport modes has become necessary. More information on this modelling can be found in Dey *et al.* (2017).

6.2 Policy and Scenario Design

This chapter presents the current and future scenarios designed in this study and the methodology developed to assess the environmental, health and economic impacts of diesel use in road transport in the GDA. More information on this study can be found in Dey *et al.* (2018a,b). Four scenarios were examined and evaluated in terms of assessing their impacts on the environment, public health and the economy. The first scenario considers the situation in 2015 (base scenario), and the current trend projected over the next 10 years is considered in the second scenario, the BaU scenario. The third scenario considers a diesel phase-out, where the possible outcomes of a set of proposed policy measures aimed at minimising the impacts of diesel use in road transport are explored until the end of 2024. Finally, the potential impacts in the year 2030 were assessed to quantify the long-term effects of introducing different policy measures, including introducing a ban on the sale of new diesel vehicles in 2025. This fourth scenario is referred to as the "diesel ban scenario". Detailed descriptions of the proposed policies and resulting scenarios are given in the following sub-sections.

6.2.1 Base scenario: emissions from the current diesel fleet in Dublin (2015)

In this scenario, emissions from the entire private car, LCV and bus fleets in Dublin were calculated using COPERT 5 (EMISIA, 2018) for the base scenario (2015). The COPERT model uses detailed data in terms of meteorological information. Since dieselgate has come to light, COPERT has been updated to take into account the discrepancy in NO_x EFs. The term dieselgate was used to explain the scandal caused by the discovery that Euro 5 and Euro 6 diesel private cars and LCVs were violating the NO_x emission standards for their engine classes with the help of a defeat device that turns on the full emission control system during the emissions test and emits higher levels of emissions by turning off the emission control system at other times. The emission levels of all the major pollutants – CO_2, NO_x, $PM_{2.5}$, PM_{10}, VOCs and NMVOCs – have been estimated in tonnes. The annual emissions and associated impacts in terms of health and cost were calculated for the base scenario.

Impact assessment

The damage costs due to these pollutants resulting from the private car, LCV and bus fleets in Dublin were calculated by multiplying the total GDA emissions (tonnes) by corresponding unit damage costs. Unit damage costs (€/t) from emissions were obtained from the *Handbook on External Costs of Transport* (Korzhenevych *et al*., 2014) and DTTaS (2016a). Health effects due to NO_x were calculated in terms of disability-adjusted life years (DALYs), which represent the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability (WHO Europe, 2016). In this study, the damage factor approach to estimate the health impacts of NO_x was followed to assess DALYs associated with NO_x and $PM_{2.5}$ from the diesel road transport fleet in Dublin. In Europe, NO_x and $PM_{2.5}$ emissions cause damage to health at the rate of 90 DALYs/kt (Tang *et al*., 2015) and 700 DALYs/kt (Hofstetter, 1998), respectively.

6.2.2 BaU scenario (2015–2024)

The BaU scenario presents information on the potential emissions that would be generated from diesel private cars, LCVs and buses in Dublin cumulatively over the years 2015–2024 if the current trend in fuel use continues. The associated cumulative damage costs and health impacts from NO_x and $PM_{2.5}$ in Dublin are also estimated under this scenario.

Future fleet determination

The main challenge in estimating emissions from the future fleet was obtaining the disaggregated future fleet compositions corresponding to each technology class. Total percentages of diesel private cars in future fleets were calculated using Systra's rolling_fleet_model (v.7.0) (DTTaS, 2015b). The compositions of the future car fleets per age were estimated based on the historical vehicle survival rate (Alam *et al*., 2015) and current fleet composition (DTTaS, 2015a). Here, survival rate refers to the chances of a vehicle staying in the fleet depending on its age. For example, if a 15-year-old vehicle has a survival rate of 0.3, it means that a vehicle purchased today would have a 30% chance of still being on the road after 15 years. The available historical survival rate of cars in Ireland is based on 1972–1984 data (Alam *et al*., 2015). Thus, the survival rate is updated by multiplying the historical survival rates by the fraction of cars in the 2015 fleet per age. This approach was followed, as it not only helps to classify the vehicles into Euro classes but also identifies vehicles older than 20 years. The future LCV fleet compositions were determined based on the past survival rate trend (DTTaS, 2015a, 2016b). The same approach was followed to sort the future bus fleet into Euro standard classes.

Impact assessment

The emission levels from the future fleets of diesel cars, LCVs and buses were calculated using COPERT 5 for each year separately and summed to obtain the cumulative emissions over the 2015–2024 period. The resulting damage costs for CO_2, PM_{10}, $PM_{2.5}$, NO_x, VOCs and NMVOCs were also calculated. A similar procedure as that used for the base scenario was followed in order to quantify the damage costs and health impact in terms of DALYs in the next 10 years under the BaU scenario.

6.2.3 Diesel phase-out scenario (2018–2024)

The diesel phase-out scenario considers a set of new policy measures but calculates the potential savings in cumulative emissions and subsequent impacts up to 2024, i.e. until such time that an older vehicle phase-out policy is in place, but a diesel ban is yet to be implemented. Therefore, the four policies considered in the diesel phase-out scenario are as follows:

1. Vehicles older than 20 years will be banned from 2018. This will imply that all Euro 1 (private car: 1992–1996; LCV: 1994–1997; bus: 1994–1996), Euro 2 (passenger car: 1997–2001; LCV: 1998–2001; bus: 1997–2001) and Euro 3 (private car, LCV and bus: 2002–2005) vehicles, which are more polluting than later technology classes, will be phased out by the end of 2024.
2. To discourage diesel car uptake, the diesel excise duty will be increased by 2.1 c/L per year from 2017 until 2021, when it will be equal to the petrol excise duty, which was 23% higher than for diesel at the time of writing (Department of Finance, 2017).
3. Motor tax based on CO_2 emissions will be changed back to being based on engine capacity from 2018 for newly registered cars.
4. Fiscal incentives will be given to consumers for scrapping their diesel vehicles to buy EVs.

Some of these policies, such as an increase in diesel excise duty, are planned for Ireland (Public Policy, 2016; RTÉ, 2016), and some are to be introduced elsewhere and are evaluated in the case of Ireland in this study. It is expected that there will be an increase in the market penetration of EVs in Ireland as a result of policy interventions. It is assumed that this market penetration will follow an S-curve. Three EV penetration scenarios, i.e. low, medium and high levels of market penetration, were considered here. The fleet configurations for 2030 are based on the high-level EV market penetration scenario. In the diesel phase-out scenario, the immediate impacts of the proposed policies until the end of 2024 in terms of the reductions in emissions and the resulting changes in health and fiscal damage are calculated. The cost savings from fewer risks to health will be given as an incentive to consumers who agree to scrap old diesel vehicles and replace them with EVs.

Impact assessment

The changes in emission levels and the resulting health and economic impacts under this scenario were calculated. The extra revenue generated from the increased diesel excise duty was calculated by multiplying the average annual mileage (AAM; km), the total number of cars and fuel consumption per kilometre (litres/km), and increased cost (cents/litre), as shown in the following equation (6.1):

$$R_{di} = FC * N_{di} * M_{di} * FT * 10^{-8} \tag{6.1}$$

where R_{di} is revenue from diesel sales in year i (€ million), FC is fuel consumption per kilometre (litres/km), N_{di} is the number of diesel cars in year i, M_{di} is the AAM of diesel cars in year i (km) and FT is the increase in fuel tax (cents/litre).

The extra revenue generated due to a change in the taxation system for diesel vehicles (see policy 3) was calculated. In Ireland, for LCVs and buses, motor tax is determined and imposed based on weight class. The extra revenue generated from changes in the motor taxation system was calculated by subtracting revenue generated from the CO_2 emissions-based taxation system, which is the present approach, from the revenue generated from the older engine capacity-based taxation system. There are 12 tax bands based on CO_2 emissions, namely A0, A1, A2, A3, A4, B1, B2, C, D, E, F and G, which correspond to the following CO_2 emission ranges: 0–1 g/km, 2–80 g/km, 81–100 g/km, 101–110 g/km, 111–120 g/km, 121–130 g/km, 131–140 g/km, 141–155 g/km, 156–170 g/km, 171–190 g/km, 191–225 g/km and 225–999 g/km, respectively. There are 21 tax classes based on engine size, with a 100 cc interval covering the range from 0 to 3000 cc and another separate tax band for vehicles with an engine size greater than 3000 cc. The CO_2 emissions-based and engine capacity-based annual tax values were obtained from DTTaS (2017) for each of the CO_2 bands and engine size classes. The numbers of cars in each CO_2 emissions-based tax class and each engine capacity-based tax class were obtained from DTTaS (2017) for the fleet in 2015. The same percentage shares in the future fleet were assumed in order to estimate the revenue that could be generated from this policy change over the 2018–2024 period. The revenues were calculated based on both approaches and are listed in Table 6.1 along with the taxation bands. Only the engine classes and CO_2 emission bands to which the future diesel car fleet is expected to belong are shown in the table. Increased excise duty on diesel fuel and the withdrawal of the CO_2 emissions-based tax incentive might discourage consumers from buying new diesel vehicles.

6.2.4 Diesel ban scenario (2030)

This scenario considers banning sales of new diesel vehicles starting from the year 2025 in addition to the continuation of all the policies mentioned in the diesel phase-out scenario and calculates annual emission levels from the overall road transport fleet in the year 2030. In this scenario, the changes in emission levels in 2030 compared with 2015 have been explored. It has been assumed that with increased market penetration of EVs, the share of EV in annual new car registrations will be 25% in 2025 and 50% in 2030. The remaining new registrations will comprise petrol and hybrid petrol vehicles. The electricity requirement of EVs was considered to be 150 Wh/km and CO_2 emissions from electricity generation to be 582 g/kWh (SEAI, 2017b). The car population in 2030 was estimated based on population, economic growth and economic stability and obtained from the *Demographic and Economic Forecasting Report* (NRA, 2014), Ireland. From 2025, new buses will be powered by bio-CNG and new LCVs will be petrol PHEVs. The changes in emission levels and resulting impacts in 2030 have been calculated based on the entire private car fleet, Dublin Bus fleet and the LCV fleet in the year 2030. While calculating the emissions from LCVs, it was assumed that 40% of the journey will be made in electric mode. CO_2 emissions from bio-CNG buses were considered to be 40% of those

Table 6.1. Revenues that could be generated under previous and current motor taxation systems, 2018–2024

Current approach			Previous approach		
CO_2 emission class	Annual tax rates (€)	Revenue (€), 2018–2024	Engine capacity bands (cc)	Annual tax rates (€)	Revenue (€), 2018–2024
A3	190	2,411,121	0–1000	199	1058
A4	200	5,089,924	1101–1200	330	117,556
B1	270	4,347,230	1201–1300	358	186,156
B2	280	6,693,707	1301–1400	385	2,507,972
C	390	4,397,745	1401–1500	413	6,849,332
D	570	2,858,580	1501–1600	514	16,490,649
			1601–1700	544	5,089,414
			1701–1800	636	97,388
			1901–2000	710	15,704,621
			2101–2200	951	4,790,367
			2201–2300	994	407,999
			2301–2400	1034	45,081
			2401–2500	1080	5742
			2701–2800	1391	4437
			2901–3000	1494	1,853,986
			3001–15,000	1809	11,542

from CNG-powered buses (Ryan and Caulfield, 2010). The bus fleet and the LCV fleet in 2030 were assumed to increase by 10% and 25% respectively compared with the 2015 fleet following the past trends in both the fleets.

6.3 Data Description

This section describes the data used in this study to assess the emission levels resulting from the diesel fleet in Dublin using COPERT. The main input data required by COPERT are fuel consumption data (TJ), fleet data disaggregated by each fuel type, Euro standard engine size class data, AAM (km) data, mileage share (%) data, monthly average minimum and maximum temperature (°C) data, monthly average relative humidity (%) data, average speed (km/h) data and average trip length (km) data. A sensitivity analysis of these parameters was also conducted as part of this project and can be found in Dey *et al.* (2019).

The private car, LCV and bus fleet data (Dublin Bus, 2016; SIMI, 2016) for Dublin in 2015 and AAM data are presented in Tables 6.2 and 6.3.

6.4 Results

The results of this study in terms of environmental, health and economic impacts as obtained from analysing the different scenarios are presented in this section.

6.4.1 Base scenario

The emission levels, and health and cost impacts, calculated following the methods described in section 6.2.1, are presented here. The total number of private cars, LCVs and buses was 514,000, 56,141 and 966, respectively, which together constitute about 91.31% of the entire road transport fleet (DTTaS, 2015a) in Dublin, while the rest of the road transport fleet comprises motorcycles, motor caravans, large public service vehicles, excavators, etc. (DTTaS, 2015a). The results for the base scenario are shown in Table 6.4.

It can be observed that the total damage costs of NO_x and $PM_{2.5}$ are significant, with these pollutants being estimated to have caused a total loss of €80 million in 2015.

Table 6.2. Disaggregated diesel car fleet in Dublin

Engine size	Euro class	No.	AAM (km)
Small (< 1.4 L)	4	5987	18,368
	5	10,764	
	6	64	
Medium (1.4–2.0 L)	1	637	22,862
	2	9427	
	3	25,032	
	4	57,899	
	5	87,453	
	6	1783	
Large (> 2.0 L)	1	64	19,802
	2	892	
	3	2293	
	4	13,694	
	5	7771	
	6	191	

Table 6.3. Disaggregated diesel LCV and bus fleets in Dublin

LCV				Bus		
Weight class	Euro class	No. of vehicles	AAM (km)	Euro class	No.	AAM (km)
N1 I (< 1305 kg)	2	346	22,344	3	447	57,288
	3	631				
	4	876				
	5	1459				
	6	68				
N1 II (1305–1760 kg)	2	501		4	147	
	3	914				
	4	1268				
	5	2113				
	6	99				
N1 III (1760–3500 kg)	2	5046		5	372	
	3	9202				
	4	13,093				
	5	19,464				
	6	1059				

Table 6.4. Annual emission levels from all cars, LCVs and buses with associated cost and health impacts in Dublin in 2015 (base scenario)

	Pollutants					
Impacts	CO_2	NO_x	$PM_{2.5}$	PM_{10}	VOCs	NMVOCs
Car: emissions (t)	1,458,903	2987.46	185.26	268.39	776.14	679.54
LCV: emissions (t)	301,831	1332.69	61.67	81.44	60.39	58.39
Bus: emissions (t)	62,513	571.84	10.14	12.23	18.91	16.11
Unit damage cost (€/t)	13.22	5851	200,239	19,143	1438	1398
Total damage cost (€ million)	24.10	28.62	51.48	6.93	1.23	1.05
Health damage (DALYs)	–	440	180	–	–	–

6.4.2 Diesel emissions under the BaU scenario during the 2015–2024 period

The potential environmental, economic and health impacts that will be caused by diesel cars, LCVs and buses in the 10 years from the base year of 2015 are presented in this section. Table 6.5 shows the cumulative emissions and associated impacts that could be caused by the diesel share of road traffic (cars, LCVs, and buses) in Dublin during the 2015–2024 period.

6.4.3 Diesel phase-out scenario

The possible reduction in emission levels and savings in damage costs between 2015 and the end of 2024 considering the policy changes proposed in section 6.2.2 are presented here. In addition, the revenues generated from increased excise duty on diesel and changing the motor vehicle tax system back to an engine capacity-based system from the current CO_2 emissions-based system for new cars are reported. Table 6.1 shows the CO_2 emission and engine capacity bands, to which the future diesel car fleet is expected to belong, with their corresponding tax amounts. Table 6.6 shows the reduction in pollution levels and damage costs expected by the end of 2024, and Table 6.7 shows the revenues generated from the changes in taxation policies. The revenue generated from diesel excise tax includes the revenue generated from cars, LCVs and buses due to the increased fuel price calculated over the 2018–2024 period, whereas the revenue values in the other columns of Table 6.7, namely revenue from CO_2 emissions-based tax and revenue from engine-based tax, include only private cars. It can be observed that, from the changes in taxation and the implementation of new policies, a significant amount of the burden can be reduced and will keep on reducing as these policies continue to be in place.

Table 6.5. Cumulative emission levels from diesel cars, LCVs and buses with resulting cost and DALYs in Dublin over the 2015–2024 period (BaU scenario)

	Pollutants					
Impacts	CO_2	NO_x	$PM_{2.5}$	PM_{10}	VOCs	NMVOCs
Car: emissions (t)	11,236,074	37,854	1271	1984	234	167
LCV: emissions (t)	2,999,432	12,649	472	669	342	332
Bus: emissions (t)	639,119	4582	80	102	133	114
Unit damage cost (€/t)	14,874,623	55,085	1823	2755	709	613
Total damage cost (€ million)	148.54	221.48	254.57	37.97	0.34	0.23
Health damage (DALYs)	–	4958	1276	–	–	–

Table 6.6. Potential changes in emissions and damage costs under the diesel phase-out scenario (2018–2024)

Pollutants	Emission reduction (t)	Damage savings (€ million)
CO_2	371,657	4.91
NO_x	1614	9.44
$PM_{2.5}$	114.90	23.00
PM_{10}	137.14	2.63
VOCs	65.62	94.37
NMVOCs	57.38	80.22

Table 6.7. Potential changes in revenues generated under the diesel phase-out scenario (2018–2024)

Diesel excise tax (€ million)	CO_2 tax (€ million)	Engine based tax (€ million)	Net revenue: CO_2 tax withdrawal (€ million)
490.74	25.80	54.16	28.36

6.4.4 Diesel ban scenario

This section presents the emission levels expected in 2030 as an after-effect of implementation of the policies proposed in sections 6.2.3 and 6.2.4. In Table 6.8, total emissions of CO_2, NO_x, $PM_{2.5}$, PM_{10}, VOCs and NMVOCs in the GDA from all cars, buses and LCVs are shown along with the change in emission levels, damage costs and DALYs compared with 2015 values.

With the new policy measures, the potential reduction in NO_x levels by 2030 is 2297 t, whereas for $PM_{2.5}$ it is 104 t, relative to 2015 levels. This could potentially lessen the health damage in 2030 by 300 DALYs as a result of decreases in NO_x and $PM_{2.5}$ pollution from road transport.

6.5 Discussion and Policy Implications

The main findings of this study, in terms of possible reductions in environmental (emissions), health (DALYs) and economic (damage cost of pollutants on health, materials, crops and biodiversity) burdens as a consequence of policy changes, have been discussed in this chapter. Private cars, LCVs and buses in Dublin were estimated to have discharged 1823 kt, 4.89 kt, 257 t, 362 t, 855 t and 754 t of CO_2, NO_x, $PM_{2.5}$, PM_{10}, VOCs and NMVOCs, respectively, under the base scenario. Cumulatively, this is estimated to have caused €113.42 million of damage.

It was estimated that the diesel fleet alone would cause health and other monetary damage of €663.1 million in the 10 years following the base year, of which approximately 72% is accounted for by NO_x and $PM_{2.5}$ emissions. It is possible that, as a result of the cumulative measures, including the phase-out of older vehicles from 2018 and banning new diesel vehicles from 2025, the annual emission levels of CO_2, NO_x, $PM_{2.5}$, PM_{10}, VOCs and NMVOCs could be reduced by 0.1%, 47%, 52%, 39%, 42% and 51%, respectively, by 2030 compared with 2015, even with increases in car ownership of 29%, in LCV numbers of 25% and in bus numbers of 10%. By 2025, CO_2 and NO_x emissions are expected to have risen by 8% and 17% from ICEVs, but $PM_{2.5}$ is expected to have declined by 33%. It can be observed from Table 6.8 that the CO_2 emissions from cars will increase in 2030 by 6% compared with 2015 levels, as a result of an increase in petrol-powered cars after the diesel ban. However, CO_2 levels will start to decrease and overall damage will be further reduced with increased EV uptake. The results from the proposed scenarios show that the proposed policy measures could generate annual savings of €43.8 million and an annual reduction in health damage of 300 DALYs in Dublin by 2030. With the implementation of the policy to ban older diesel vehicles, the damage costs could be reduced by €40.16 million by 2024. The money saved from this reduction in damage costs could be used to provide a scrappage incentive for consumers.

Table 6.8. Potential changes in annual emissions, health damage and costs by 2030 in the GDA compared with 2015 (under the diesel ban scenario)

Fleet		CO_2	NO_x	$PM_{2.5}$	PM_{10}	VOCs	NMVOCs
Car	Emissions (t)	1,544,846	2297	104	185	362	300
	Change (%)	+6	–23	–44	–31	–53	–56
	Cost savings (€)	–1,136,167	4,041,268	16,261,460	1,596,631	595,921	530,059
	DALYs	–	62	57	–	–	–
Bus	Emissions (t)	29,549	266	3	5	65	10
	Change (%)	–53	–54	–72	–58	243	–36
	Cost savings (€)	435,778	1,791,024	1,466,000	136,411	–66,124	8048
	DALYs	–	28	5	–	–	–
LCV	Emissions (t)	247,059	32	17	32	72	61
	Change (%)	–18	–98	–72	–61	19	5
	Cost savings (€)	724,076	7,609,214	8,877,380	943,978	–16,280	–4331
	DALY	–	117	31	–	–	–

Dublin has the highest population density in Ireland; therefore, like any other urban centre, the health effects of air pollution on the population are more pronounced. Emission standards are designed to protect air quality and human health. After dieselgate, which identified that Euro 5 and Euro 6 light-duty vehicles were not obeying emission standards, reducing pollutant levels became one of the major concerns of researchers and policymakers. It has been estimated that NO_x and $PM_{2.5}$ from road transport resulted in 620 DALYs in 2015, whereas with the proposed policies this number could be reduced by nearly 50% by 2030. It has also been calculated that NO_x and $PM_{2.5}$ emissions from the diesel fleet alone will cause about 6234 DALYs during the 2015–2024 period if the present trend continues. Therefore, like other countries, Ireland should consider implementing diesel ban policies in order to improve and protect air quality and health.

For cars, previously motor vehicle taxation was based on engine capacity, but this was changed to a system based on CO_2 emissions in 2008 with the aim of reducing GHG levels. The annual registration tax for a diesel car with an engine size of 1500 cc would have been €413 under the engine capacity-based taxation system, whereas, under the CO_2 emission-based taxation system, the annual tax of the same diesel vehicle is €200, assuming that the average diesel tailpipe CO_2 emissions would be 120 g/km. This has led to a rapid increase in diesel car ownership. This study proposes changing this taxation system back to an engine capacity-based approach, which, on one hand, would demotivate new diesel vehicle uptake and, on the other hand, would generate revenue that could be invested in improving the EV infrastructure, such as installing a greater number of fast-charging stations. There would not be much difference in tax generated from petrol, as most petrol cars are of a smaller engine capacity, with sizes less than 1400 cc, and require annual tax varying from €199 to €385. Under a taxation system based on CO_2 emissions, the tax would vary from €270 to €390 for an emission range of 121–155 gCO_2/km. As a result of these new policies, there would be an increase in the number of petrol car registrations until 2030, after which an increase in the market penetration of EVs is expected to offset the share of petrol cars. Consequently, this, along with the diesel ban policies, may also solve the problem Ireland faces with regard to low EV uptake.

The Sustainable Energy Authority of Ireland (SEAI) offers a grant of up to €5000 for every BEV or PHEV purchase. In addition to this grant, VRT relief, of €5000 for BEV and €2500 for PHEV (SEAI, 2017a), is available. The annual motor tax for an EV is €120. Despite these measures, EV uptake remains significantly low in Ireland. EVs have zero tailpipe emissions; therefore, the electrification of the fleet is important for mitigating overall emission levels. A limited number of EV models are available in Ireland presently, with only 85 fast-charging stations. As a result of the proposed fiscal policies, i.e. bringing diesel and petrol excise duty into parity by 2021 and changing CO_2 emissions-based tax system back to the previous engine capacity-based tax system, becoming effective from 2018 and applicable to all new cars, revenue of €519.10 million could be generated by 2024. This money could be utilised to improve the EV infrastructure, change the diesel bus fleet to bio-CNG-compliant buses and build facilities to encourage the use of active travel options such as walking and cycling. Active travel would not only be beneficial for the environment but also have major health benefits as a result of increased physical activity (RCP and RCPCH, 2016).

7 Limitations of Cost of Emissions Estimation Approach

The damage costs per tonne in DTTaS (2016a) were applied as the standard values used for Irish public policy appraisal of investment in transport projects and policies. This was done to use the national recommendations of both the DTTaS and the Department of Public Expenditure and Reform. These costs should be seen as indicative and may be underestimated. The CO_2 costs proposed in the DTTaS guidance are a lower rate cost as indicated by "traded prices" and not a damage cost. However, as outlined in Chapter 5, a full cost–benefit approach was not applied in this research, as this was not in the original scope of the project.

8 Conclusions

The principal objective of the Greening Transport project was to investigate the behavioural responses to introducing a range of policy measures that incentivise alternative modes of transport as a means of encouraging any subsequent reduction in emissions.

Preferences collected in the SP survey found that policy incentives offering tangible time and cost savings would lead to the greatest shift towards sustainable modes across the attributes modelled.

The results suggested that individuals with a driving licence who have access to free parking at places of work or university and at least one car per household were less likely to choose public transport, active modes, or carpooling and car-sharing. Individuals with more than one child also displayed a lower likelihood of choosing these modes, while those with a higher level of education showed a higher probability. Older individuals were more likely to walk and opt to use the train, carpooling and car-sharing, and females were more likely than males to walk or choose carpooling and car-sharing as modes for commuting purposes.

The travel demand modelling showed that various levels of car-shedding behaviour and emission reductions could be achieved as a result of implementing the three policy scenarios tested in the SP experiment. In the public transport model, under the 2012 base scenario, the results showed that a reduction in private car trips of up to 1.76% could be achieved as a result of a 2.87% shift towards public transport modes. This reduction in private car trips was estimated to result in a daily reduction in CO_2 emissions of 431.58 t, a 0.95 t reduction in NO_x emissions and a 0.046 t reduction in $PM_{2.5}$ emissions from car commute trips alone. These emission reductions combined with reductions in car use for education trips would result in a daily saving of €22,223 under the 2012 base scenario. The results produced for the 2035 GDA Strategy scenario for this public transport model were lower but a reduction in the private car mode share of up to 0.99% could be achieved on top of the 3.83% reduction already made between 2012 and 2035 as a result of the changes to public transport included in the 2035 GDA Strategy.

This shift away from private cars led to an increase in public transport use of up to 1.42%, which again was over the 6.49% increase in public transport made between 2012 and 2035 under base conditions.

The reduction in private car trips was higher in the active modes model, where up to a 1.91% reduction was estimated under the 2012 scenario and up to a 1.33% reduction under the 2035 scenario. Pedestrians were however more elastic to changes in infrastructure provision than cyclists, as the results showed a 5.95% increase in the walking mode share under the 2012 base scenario and a 6.30% increase under the 2035 GDA Strategy scenario. Cyclists were also found to shift to walking given infrastructure improvements, as were public transport users, which suggested that cyclists were relatively inelastic to the infrastructure improvements modelled in the experiment.

The changes in mode shares under the 2012 base scenario incentivised by the introduction of the active modes policy plan were found to result in emission reductions of 10.93 t CO_2, 0.03 t NO_x and 0.001 t $PM_{2.5}$, leading to a daily monetised saving of €770.07.

The smarter car use policy model found that, based on incentives offered to carpoolers and car-sharers, increases of 0.78% under the 2012 base scenario and 1.83% under the 2035 GDA Strategy scenario could be achieved, which was represented by a decrease in VKTs by private cars following the introduction of the measures. Under these scenarios, the increase in carpooling was also accounted for by marginal shifts away from other modes. The emission savings recorded from the shift to carpooling were higher than those estimated for the active modes model.

Emission levels of CO_2, CO, NO_x, $PM_{2.5}$, PM_{10}, VOCs, NMVOCs and N_2O resulting from the existing road transport fleets in Ireland were estimated using COPERT 5. Given the expected increase in car ownership levels, emission levels of all the major air pollutants for the predicted future car fleets in Ireland and potential emission reductions as a result of increased market penetration of EVs were estimated. In addition, potential emission reductions from changes in the public transport bus fleet were examined, as this would offer the opportunity to reduce emissions on a large scale.

The Greening Transport project examined the potential emission reductions from the future fleets with alternative fleet compositions. In other words, it examined what fleet Ireland would actually require to reduce the future emissions expected and meet its emission target. Emission mitigation is one of the prime concerns in Europe now and the targets set by the EU are strict. Therefore, the research findings contain very useful information showing the consequences of both a realistic scenario and an optimistic scenario. In addition, quantitative damage cost analyses are provided for all the scenarios, analyses that have not been performed before but are essential for informing policy decisions.

It was found that very large-scale electrification of the fleet is necessary to significantly reduce emission levels and meet the emission target for 2030, as car ownership levels are expected to notably increase. The results indicated that electric buses could offer substantial emission reductions, but only if the electricity is renewable-energy based. Bio-CNG-fuelled buses could also offer considerable improvements in terms of emissions, but a large amount of land area would be required to fulfil the feedstock demand. Therefore, a more feasible way of meeting 2030's emission goal is to reduce car ownership, and a mixed percentage of the various options was proposed by backcasting from the target 2030 emission level.

From this research and its findings, it can be said that, without a reduction in car ownership levels, the 2030 GHG emission target as set by the EU will not be met. Therefore, policies should be made that not only increase the uptake of alternative fuels in transport but also increase the usage of sustainable modes of transport through a shift from private car usage, especially for shorter distances.

The policies proposed in the Greening Transport project are designed to address the very cause of the increase in emissions, as mentioned in the previous section. The work also provides a timeline that could help in the implementation of those policies in a realistic and effective way. The study also reports the benefits that can be drawn from those policy implications. As a consequence of these policy measures, NO_x, PM, VOC and NMVOC emissions are expected to reduce significantly by 2030. However, CO_2 levels would not improve significantly because of the expected increase in car ownership and the huge percentage of petrol vehicles already in the fleet. Nonetheless, this will slowly get better as the percentage of EVs in the fleet increases. Through the additional policies, the monetary damage due to emissions could be prevented. In addition to this, a sizable amount of revenue could be generated as a result of the withdrawal or changing of fiscal incentives, which could be utilised to improve the EV infrastructure and thus encourage EV uptake and also for the betterment of the infrastructure for walking and cycling.

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Abbreviations

AAM	Average annual mileage
ARTEMIS	Assessment of Road Transport Emission Model
BaU	Business-as-usual
BEV	Battery electric vehicle
CAF	Common Appraisal Framework
CNG	Compressed natural gas
COPERT	Computer Programme to Calculate Emissions from Road Transport
DALY	Disability-adjusted life year
DART	Dublin Area Rapid Transit
DTTaS	Department of Transport, Tourism and Sport
EEA	European Environment Agency
EEV	Enhanced environmentally friendly vehicle
EF	Emission factor
EPA	Environmental Protection Agency
ERM	Eastern Regional Model
ESRI	Economic and Social Research Institute
EU	European Union
EV	Electric vehicle
GDA	Greater Dublin Area
GHG	Greenhouse gas
GIS	Geographic information system
HBEFA	Handbook of Emission Factors for Road Transport
HDV	Heavy-duty vehicle
HERMES	Harmonised Economic Research Models on Energy Systems
HEV	Hybrid electric vehicle
HOV	High-occupancy vehicle
ICEV	Internal combustion engine vehicle
ISus	Irish Sustainable Development Model
LCV	Light commercial vehicle
MOBILE	Mobile Source Emission Factor Model
MOLAND	Monitoring Urban Land Cover Dynamics
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
NTA	National Transport Authority
NTpM	National Transport Model
O–D	Origin and destination
PCU	Passenger car unit
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
PM_{10}	Coarse particulate matter
POWSCAR	Place of Work, School or College – Census of Anonymised Records
RMS	Regional Modelling System
RP	Revealed preference
SP	Stated preference

TII	Transport Infrastructure Ireland
TTW	Tank-to-wheel
UCD	University College Dublin
VKT	Vehicle-kilometre travelled
VOC	Volatile organic compound
VRT	Vehicle registration tax
WTW	Well-to-wheel

Appendix 1 Research Outputs

During the course of the project our research team has produced a number of publications that have made contributions to knowledge in this field. The team has also engaged in a number of outreach activities and has made presentations on the findings from the project.

A1.1 Journal Papers

Carroll, P., Caulfield, B. and Ahern, A., 2020. Appraising an incentive only approach to encourage a sustainable reduction in private car trips in Dublin, Ireland. *International Journal of Sustainable Transportation* 15: 1–12.

Carroll, P., Caulfield, B. and Ahern, A., 2019. Measuring the potential emission reductions from a shift towards public transport. *Transportation Research Part D: Transport and Environment* 73: 338–351.

Carroll, P., Caulfield, B. and Ahern, A., 2019. Modelling the potential benefits increased active travel, *Transport Policy* 79: 82–92.

Dey, S., Caulfield, B. and Ghosh, B., 2019. Modelling uncertainty of vehicular emissions inventory: a case study of Ireland. *Journal of Cleaner Production* 213: 1115–1126.

Dey, S., Caulfield, B. and Ghosh, B., 2018. Potential & economic benefits of banning diesel traffic in Dublin, Ireland. *Journal of Transport & Health* 10: 156–166.

Carroll, P., Caulfield, B. and Ahern, A., 2017. Examining the potential for car-shedding in the Greater Dublin Area. *Transportation Research Part A: Policy and Practice* 106: 440–452.

Dey, S., Caulfield, B. and Ghosh, B., 2017. The potential health, financial & environmental impacts of dieselgate in Ireland. *Transportation Planning and Technology* 41(1): 17–36.

A1.2 Conference Papers

Carroll, P., Caulfield, B. and Ahern, A., 2020. Modelling the introduction of incentives to encourage a reduction in private car use in Dublin, Ireland. 99th Annual Meeting of the Transportation Research Board, Washington, DC.

Carroll, P., Caulfield, B. and Ahern, A., 2018. Appraising the introduction of car-shedding incentives in the Greater Dublin Area. 46th European Transport Conference, Dublin Castle, Dublin.

Dey, S., Caulfield, B. and Ghosh, B., 2018. Quantification of diesel burden and the potential impact of diesel-ban in Dublin, Ireland. 97th Annual Meeting of the Transportation Research Board, Washington, DC.

Carroll, P., Caulfield, B. and Ahern, A., 2017. Exploring a case of car usership and ownership reduction in Dublin through car shedding interventions. 49th Annual Conference of the Universities' Transport Study Group, Trinity College Dublin.

Carroll, P., Benevenuto, R. and Caulfield, B., 2017. Transport disadvantage and car dependency in rural Ireland. Irish Transport Research Network, University College Dublin.

Dey, S., Caulfield, B. and Ghosh, B., 2017. Examining alternative fuel options and potential emission reductions from changes in public transport bus fleet in Ireland. Irish Transport Research Network, University College Dublin.

Carroll, P., Caulfield, B., Ahern, A. and Ghosh, B., 2016. Car shedding in Dublin. 48th Annual Conference of the Universities' Transport Study Group, Bristol, UK.

A1.3 Invited Talks

Caulfield, B., 2019. The future of low carbon transport. Transport Ireland Conference, Radisson Blu, Golden Lane, Dublin, 3 July.

Caulfield, B., 2017. Future of transport. Citizens Assembly on Climate Change, 7 November.

Caulfield, B., 2017. The car is dead – long live the car? EGNITE Talk, Electric Picnic, 2 September.

Caulfield, B., 2016. Greening Transport – reducing emissions from transport. Transport Ireland, Chartered Accountants Ireland, 21 April.

Caulfield, B., 2015. Potential of transport data use for behaviour change, environmental data: priorities and innovation. National Economic and Social Council, Wood Quay, 24 April.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Greening Transport: Final Report

Authors: Brian Caulfield, Paraic Carroll, Shreya Dey, Bidisha Ghosh and, Aoife Ahern

epaResearch
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Identifying Pressures

Our dependency on single-occupancy vehicles as a transport mode for commuting and other purposes has a number of costly economic and environmental consequences in urban areas. Moreover, because of the booming transport demand, reducing emissions from road transport has gained more attention over the past few years. Several targets are now being set and policies are being implemented aimed at decreasing fossil fuel use and increasing the uptake of low or zero emission transport modes, and thereby, reducing emission levels. Ireland has strict emissions targets to achieve by 2030 and beyond and, in order for transport to meet these goals, investment and planning are required.

Informing Policy

Project Ireland 2040 includes several ambitious strategic investment plans, totalling €21.8 billion, to accelerate Ireland's transition to a low-carbon and climate-resilient nation. It plans to have 500,000 or more electric vehicles on Irish roads by 2030, with essential improvements planned to the charging infrastructure to meet this demand. Project Ireland 2040 outlines the investment proposed to modernise and decarbonise transport in Ireland. The Greening Transport project examines a range of sustainable travel measures, designed to encourage a shift to alternative modes of transport and reduce dependency on private cars, and tests a number of policies to achieve these goals.

Developing Solutions

Sustainable travel measures seek to modify travel behaviour in favour of green alternatives such as active modes (walking and cycling), public transport and smarter use of private cars, namely car-sharing and carpooling. Our research offers a unique approach to the field of transport policy, entitled "car-shedding", which exclusively centres on incentivisation strategies for sustainable modes of transport. This seeks to stimulate voluntary travel behaviour change and encourage sustainable deliberation of transport mode choice. "Car-shedding" is defined in the research as a means of encouraging the reassessment of the need to use a private vehicle for certain trip purposes. Improving walking and cycling facilities, enhanced public transport services and car-sharing are all examined in this research to determine their benefits and potential emissions reductions.

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