

# Opportunities to Decarbonise the Irish Transportation Sector

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## ENVIRONMENTAL PROTECTION AGENCY

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- 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.

**EPA RESEARCH PROGRAMME 2014–2020**

# **Opportunities to Decarbonise the Irish Transport Sector**

**(2014-CCRP-MS.24)**

## **EPA Research Report**

Prepared for the Environmental Protection Agency

by

Science Foundation Ireland MaREI Centre for Energy, Climate and Marine Research,  
Environmental Research Centre, University College Cork

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This report is based on research carried out/data from January 2015 to April 2018. More recent data may have become available since the research was completed.

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# Executive Summary

In 2017, the energy sector was responsible for 60% of Ireland's greenhouse gas (GHG) emissions. The largest contributor to Ireland's energy-related GHG emissions, at 33%, is the transport sector. The transport sector thus has a vital role to play in the decarbonisation of the Irish energy system and subsequent protection of the climate system. Despite national efforts to curb transport emissions, the proportion of transport-related energy demand and, consequentially, GHG emissions, have increased consistently in the past 5 years.

The continued rise in transport activity, energy consumption and emissions can be attributed to economic, technological and societal factors. Therefore, a range of technoeconomic and socioeconomic analytical tools and models were developed and employed in this project to generate an evidence base that can inform decarbonisation-focused transport sector decision-taking and policymaking.

This report describes the findings from these tools and models, outlining some of the options for long-term decarbonisation in the Irish transport sector, with a focus on private cars, light commercial vehicles and heavy-duty vehicles (which together constitute 93% of final energy consumption in the transport sector).

## Private Cars

In 2017, private cars accounted for 61% of the energy consumed in the non-Emissions Trading System (non-ETS) transport sector and 27% of emissions across all non-ETS sectors. Three policy areas have been identified to assist in decarbonising private cars, with varying time periods of effectiveness:

1. *Continued policy support for biofuel blending (short-term measure – 2020).* Increased use of biofuels is projected to be the main contributor to Ireland's 2020 renewable energy in transport target (RES-T) of 10%. A biofuel obligation of approximately 13% is required to achieve a 10% RES-T target due to differences in energy content. Higher levels of blending can be achieved using advanced biofuels, such as hydrotreated

vegetable oil (HVO – also known as renewable diesel). The first commercial production globally of HVO was in the Whitegate Oil Refinery in Cork Harbour.

2. *Promoting the purchase of energy-efficient vehicles (medium-term measure – 2030).* Regulations set by the European Commission limit the average CO<sub>2</sub> performance of new cars to 95gCO<sub>2</sub>/km by 2021 and below 60gCO<sub>2</sub>/km by 2030, which is projected to reduce total energy consumption and emissions between 2017 and 2030 by 6% relative to a business as usual scenario. Irish policy measures that incentivise the purchase of more efficient vehicles through varying tax rates have been successful in the past and should continue to be part of a portfolio of measures.
3. *Incentivising the switch to electric vehicles (EVs) (long-term measure – 2050).* Shifting the private transport fleet from fossil fuel-powered vehicles to electrified transport is identified as a viable means of decarbonisation through to 2050. Two barriers limiting the large-scale uptake of electric-fuelled vehicles have been identified as (1) a lack of variation of vehicles available for sale and (2) range anxiety. Imposing a ban on the sale of fossil fuel-powered vehicles, increasing the variety of available EV models and improving the public charging network are projected to contribute to a well-to-wheel emissions reduction of 56% by 2050 and a 48% reduction in final energy consumption relative to a baseline. The annual loss to the Exchequer through reductions in value-added tax, excise duty and annual motor tax is projected to be €2.04 billion per year by 2050.

## Light Commercial Vehicles

Just over 220,000 light commercial vehicles were registered in 2017, which accounted for 10% of transport energy-related non-ETS CO<sub>2</sub> emissions and 4% of total non-ETS CO<sub>2</sub> emissions. This report identifies two measures that may assist in bridging this knowledge gap:

1. *Energy efficiency improvements (short- to medium-term measure – 2020/2030)*. Light commercial vehicle manufacturers have been regulated to limit vehicle emissions performance to, at most, 147 gCO<sub>2</sub>/km in 2020. Reinforcing this regulation through a change in the taxation bands from the current unladen weight bands to specific carbon emissions bands is projected to reduce emissions by 13% in 2025 relative to a baseline.
2. *Incentivising alternative fuelled vehicles (long-term measure – 2050)*. Natural gas vehicles fuelled by biomethane are identified as the cost-optimum approach towards decarbonising the light commercial vehicle sector of transport. Ceasing the sale of diesel light commercial vehicles in 2030 and encouraging the sales of biomethane fuelled light commercial vehicles would result in a 99.6% reduction in light commercial vehicle emissions by 2050 relative to a baseline.

### **Heavy-duty Vehicles**

In 2017, 100,000 heavy-duty trucks accounted for 22% of the energy consumed in the non-ETS transport sector and 9% of non-ETS emissions. Truck activity (in ton-kilometres) is projected to double between 2017 and 2050. The following three measures are suggested to assist in curbing the levels of emissions from the heavy goods vehicle sector:

1. *Improving the efficiency of road freight systems (medium- to long-term measure – 2030/2050)*. Reducing road freight ton-kilometres through logistic operational measures such as optimised routing, platooning, improving vehicle utilisation, back-hauling and co-loading has the potential to reduce activity by up to 36% and to reduce emissions by 17% by 2050 relative to a baseline.
2. *Adopting energy-efficient truck technologies (medium- to long-term measure – 2030/2050)*. Advances in aerodynamics, low rolling resistance tyres, light-weighting, transmission and drivetrain, engine efficiency, idling-reducing technologies and hybridisation are identified as areas of improvement for truck manufacturers, which have a combined potential to reduce emissions by 19% by 2050 relative to a baseline.
3. *Promoting the deployment of alternative fuels and the vehicles that use them (long-term measure – 2050)*. Promotion of conventional and advanced biofuels (biodiesel, HVO and biomethane) for deployment in the heavy-duty vehicle fleet has the greatest potential reduction contribution of all measures, at 24% by 2050 relative to the baseline. Electrified trucks, through hybridisation for urban freight and overhead catenary lines, could provide a further 16% reduction.

# 1 Introduction

There is a growing need for Irish energy policy to build momentum towards decarbonising the transport sector. This sector was the greatest consumer of final energy demand in 2016, accounting for 42% of final energy demand, and is expected to remain so until 2030 (SEAI, 2017a,b). The transport sector also had the highest growth rate of all energy-consuming sectors between 1990 and 2016, increasing by 145%. To adhere to a future in which global temperature rise is kept in line with the outcome of the 21st Conference of Parties, significant long-term decarbonisation is required in all energy-consuming sectors by all signatories. This is a considerably difficult task in the Irish transport sector as this sector is highly dependent on the importation of liquid fossil fuels – in 2016, consumption of diesel, gasoline and kerosene amounted to 5.5 billion litres, equating to emissions of 12.3 million tonnes of CO<sub>2</sub> (NORA, 2017; EPA, 2018). In contrast, the consumption of liquid biofuels in the same year was 0.2 billion litres, amounting to

2.39% of the final energy demand, whereas renewable electricity in transport amounted to an even lower percentage of the final energy demand, at 0.02% (SEAI, 2017a).

To assist in the transition to renewable transport, a number of national and European-wide policies have been adopted in the short term (2020), medium term (2030) and long term (2050). The impending 2020 target to achieve a 10% renewable energy share in transport (RES-T) remains a significant challenge for Ireland, despite receiving double weightings towards biofuels produced from wastes, residues, non-food cellulosic material and ligno-cellulosic material, and 2.5 times weightings towards renewable electricity used in transport. Compared with other European Union (EU) Member States, Ireland is slightly above average with regard to the use of renewable energy in transport (Figure 1.1) (Eurostat, 2017), although it will still struggle to meet its RES-T target.

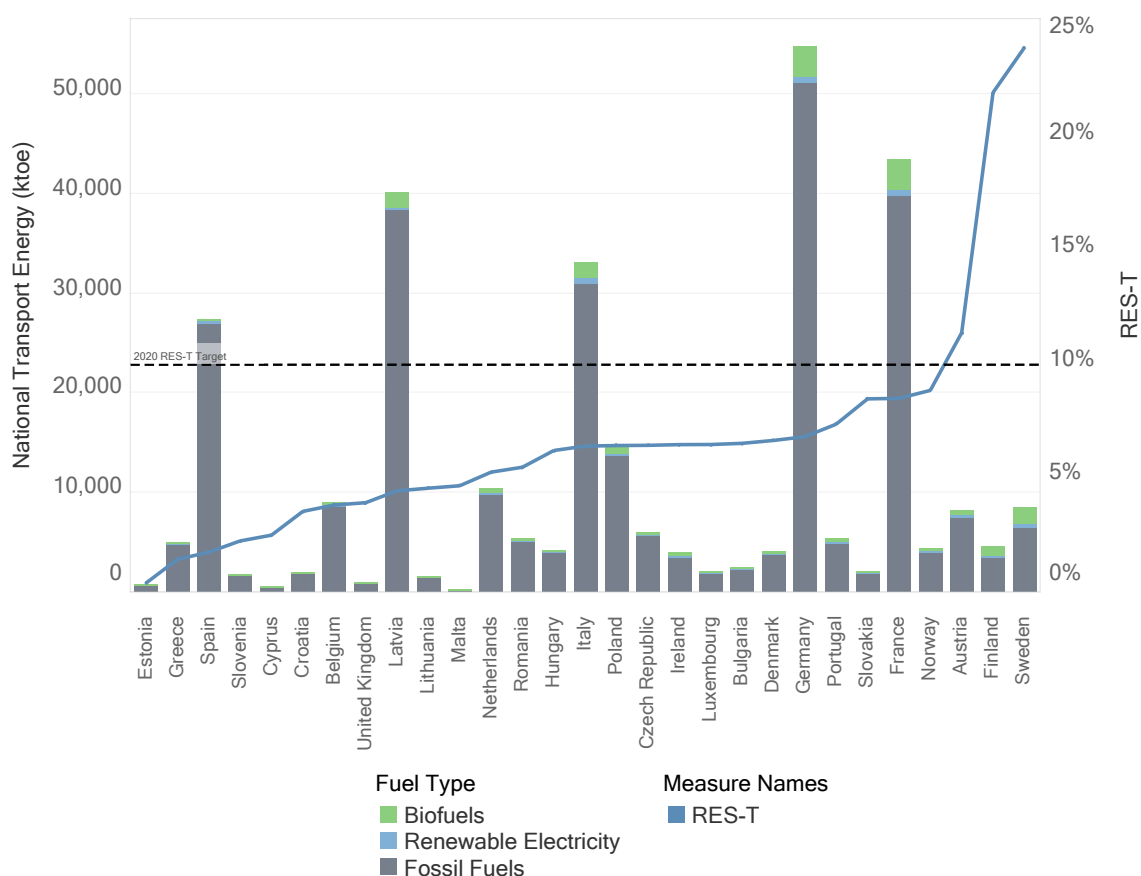


Figure 1.1. Share of renewable energy in transport in Europe in 2015.

Several international and national policies/ambitions are in place that affect the level of emissions from transport in Ireland (Table 1.1), which, if achieved, will contribute momentum towards long-term and sector-wide decarbonisation. Some of these policies directly affect the role of energy in transport in Ireland (e.g. the Biofuels Obligation Scheme, which mandates the level of liquid biofuels in Ireland), whereas some act on an indirect basis (e.g. the European-wide mandate on specific private car emissions means that there will be more emission-efficient cars in Ireland, although, as Ireland does not manufacture cars, it does not directly affect the state). Furthermore, not all targets are legally binding, meaning that a greater incentive may be needed to ensure compliance.

There are also numerous non-transport-specific policy measures that will indirectly affect energy consumption and greenhouse gas (GHG) emissions in the transport sector. For example, the Irish national policy position on climate change declares a long-term vision guided by “an aggregate reduction in carbon dioxide (CO<sub>2</sub>) of at least 80% (compared with 1990 levels) by 2050 across the electricity generation, built environment and transport sectors”. Although the focus is not entirely on the transport sector, the target would be unachievable without a significant transformation in the current transport network.

These policies and ambitions lay the groundwork for a decarbonised transport system in Ireland, but they will be unachievable without considerable intervention. A number of technical and social barriers prevent the uptake of low-carbon fuels; for example, the primary barrier to higher biofuel adoption lies with the blending limitations imposed by European-wide regulations and the availability of the feedstock for the fuel, whereas the barrier to higher use of electric transport is mainly the vast changes required at a societal level. To achieve long-term decarbonisation, considerable technological and societal change is required within the sector.

## 1.1 Objectives

The aim of this project is to outline a variety of opportunities for decarbonising the Irish transport sector at least cost. To achieve this aim, this project uses a combination of technoeconomic and socioeconomic sectoral simulation and optimisation transport models to provide valuable policy insights into methods of moving the Irish transport sector towards a low-carbon future. The main focus of this project is on road transport, specifically private cars and road freight vehicles, which, when combined, constituted 74% of the national transport final energy consumption in 2016, excluding fuel tourism

**Table 1.1. Transport-specific policies and ambitions**

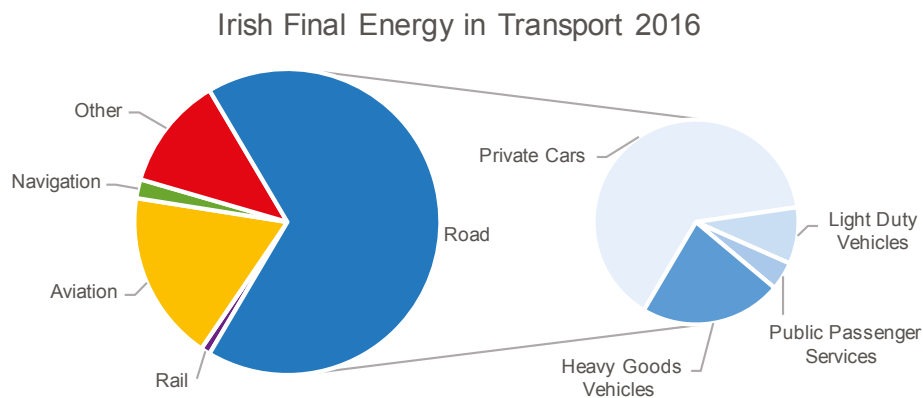
Policy/ambition	Target year	Binding
The Irish Biofuels Obligation Scheme places an obligation on suppliers of mineral oil to ensure that 8.695% (by volume) of the motor fuel (generally gasoline and motor diesel) that they place on the market in Ireland is produced from renewable sources, e.g. ethanol and biodiesel	2017	Yes
The EU Renewable Energy Directive (2009/28/EC) mandates all EU Member States to achieve a 10% share of energy from renewable sources in transport energy consumption	2020	Yes
The EU Fuel Quality Directive (2009/30/EC) introduced a 6% supplier target for the reduction of lifecycle greenhouse gas emissions per unit of energy from fuels and electricity compared with a 2010 baseline	2020	Yes
EU Regulation 443/2009/EC mandates manufacturers of private cars to ensure that the average new car emissions performance does not exceed 95gCO <sub>2</sub> /km	2021	Yes
EU Directive 2014/94/EU mandates that the necessary average distance between compressed natural gas refuelling points should be approximately 150 km and between liquified natural gas refuelling points should be 400 km	2025	Yes
EU Regulation 2015/525 requires non-ETS sectors to cut emissions by 20% (compared with 2005)	2020	Yes
The Irish National Development Plan aims to have at least 100,000 electric vehicles on the road by 2025	2025	No
The Irish Climate Action Plan aims to have at least 950,000 electric vehicles on the road by 2030	2030	No
EU Regulation 2018/842 requires non-ETS sectors to cut emissions by 30% (compared with 2005)	2030	Yes
EU Regulation 525/2013 standardises the reporting of Member States to the UNFCCC, verifying commitments to this Secretariat	–	Yes

**ETS, Emissions Trading System; UNFCCC, United Nations Framework Convention on Climate Change.**

(Figure 1.2) (SEAI, 2017a). This project utilises a variety of existing modelling methodologies and applies newly developed and unique techniques to analyse transport. These modelling techniques identify a combination of technology pathways and policy roadmaps with the potential to break the barriers opposing penetration of low-carbon road vehicles from both a technical and a social viewpoint. The focus of this research is therefore threefold: first, to use and build on current technoeconomic methodologies for modelling the transport sector and to understand the limits of these methods; second, to review socioeconomic modelling methods and integrate them into traditional technoeconomic models; and, third, to

develop robust knowledge-based policies capable of informing policymakers of the effectiveness and cost (both monetary and social) of certain policy packages within the transport sector using the former two focus points.

This report is presented as follows: Chapter 2 briefly discusses the methodology behind the modelling techniques used in this project, Chapter 3 provides the outlook for decarbonisation in the private car sector, Chapter 4 provides the outlook for decarbonisation in the light commercial vehicle (LCV) sector, Chapter 5 focuses on the heavy-duty vehicle sector and, finally, Chapter 6 concludes with policy recommendations.



**Figure 1.2. Breakdown of final energy consumption in transport by mode in Ireland.**

## 2 Models

To analyse the potential impact of transport-specific policies on assisting long-term decarbonisation, a variety of models were employed, predominantly a mixture of simulation and optimisation models. Simulation models tend to use a bottom-up approach whereby a range of technical and policy measures may be simulated throughout to generate the specific impact of such measures. Although this technique may be considered to give a more realistic representation of the system being modelled, it might not give an optimal solution to a certain measure. Optimisation models, on the other hand, may be used to generate least-cost pathways given a certain constraint on the system under analysis, e.g. identifying the least-cost method of limiting CO<sub>2</sub> emissions to comply with Ireland's ambition of achieving an 80% reduction in GHG emissions by 2050 relative to 1990. With this methodology, the model selects from a range of technology options available that have the potential to adhere to the system constraints imposed, while minimising the net present value (NPV) from an energy planner's perspective. Although this method provides a least-cost result, traditional optimisation models have failed to represent a high level of societal behaviour, leading to irregularities such as very sudden shifts in the system towards new technologies capable of meeting the system constraints, also known as the "winner takes all" phenomenon. Integration of both simulation and optimisation techniques has the potential to combat the weaknesses of both models and thus features heavily throughout this report. The CarSTOCK model, the Irish TIMES model, the consumer choice model and the LCV stock model, used across this project, are described in this chapter.

### 2.1 CarSTOCK Model

The CarSTOCK model (Daly and Ó Gallachóir, 2011, 2012; Mulholland *et al.*, 2017) is a technoeconomic private car sectoral simulation model that is used to calculate the final stock, energy consumption and emissions of the Irish private car sector. This stock model draws on detailed national statistics relating to the composition of the market, sales, average mileage, efficiency and lifetime of vehicles, with a

disaggregation by vintage, fuel type and engine size, to produce a long-term evolution of the private car stock, energy use and related CO<sub>2</sub> emissions to 2050 based on the ASIF methodology developed by Schipper *et al.* (2000). This is summarised in equation 2.1. In brief, total private transport-related CO<sub>2</sub> emissions are calculated as a sum of the product of vehicle activity ( $A$ ), private car stock ( $S$ ), energy intensity ( $I$ ) and emission factors ( $F$ ) for fuel type ( $f$ ) and vintage ( $v$ ). Aggregate emissions for the private transport sector are obtained using this methodology for each of the 15 technologies analysed.

Activity data were accessed through the Sustainable Energy Authority of Ireland (SEAI), which processes raw data from the National Car Test into technology-specific data. Stock data in Ireland are obtained from the Vehicle Registration Unit (VRU), which provides a detailed list of vehicles, accounting for fuel type, engine size and vehicle vintage.

$$\text{Transport-related CO}_2 = \sum_{f,v_i} A_{f,v_i} * S_{f,v_i} * I_{f,v_i} * F_f \quad (2.1)$$

The specific energy consumption (SEC) of the historical fleet in Ireland disaggregated by engine band was obtained from the SEAI, which links national sales data for each vehicle type to the manufacturer's specified energy consumption per km. A comparison of the SEC of each vehicle type is shown in Table 2.1.

The fuel emission factors for petrol and diesel were taken from Dineen *et al.* (2014). With regard to electricity emissions, Ireland has made recent strides towards a low-carbon power sector, aiming for 40% renewable electricity by 2020 (DCCAE, 2010). Projections of electricity-specific CO<sub>2</sub> emissions were taken from the EU PRIMES (Price-induced Market Equilibrium System) reference scenario, which assumes an emissions intensity in 2050 of 0.13 tCO<sub>2</sub>/MWh in Ireland (down from 0.41 tCO<sub>2</sub>/MWh in 2015) (European Parliament, 2016).

### 2.2 Irish TIMES

The Irish TIMES model (Chiodi *et al.*, 2013) is a partial equilibrium optimisation model of the Irish



**Table 2.1. SEC by class of car technology for Ireland in 2015**

Class of car technology	SEC (MJ/km)
Small petrol	1.83
Medium petrol	2.22
Large petrol	2.70
Small diesel	1.60
Medium diesel	1.62
Large diesel	2.19
Small hybrid	1.38
Medium hybrid	1.37
Large hybrid	1.89
Small plug-in hybrid	0.68
Medium plug-in hybrid	0.68
Large plug-in hybrid	0.77
Battery electric vehicle	0.64

energy sector, initially developed to build a range of medium- and long-term scenarios that provide insights into the technology requirements for energy system decarbonisation. The model was built to provide a technology-rich least-cost linear optimisation basis for the estimation of energy dynamics over a long-term, multi-period time horizon (Loulou *et al.*, 2005). The model simultaneously solves for the least-cost solution subject to emission constraints, resource potentials, technology costs, technology activity and capability to meet individual energy service demands across all sectors (equation 2.2). The model minimises the NPV through the selection of technologies with resulting energy consumption and CO<sub>2</sub> emissions output.

$$NPV = \sum_{t=1}^{NbPer} \left[ (1+\delta)^{1-t} * \text{annual cost}(r,t) \right. \\ \left. * \sum_{a=1}^{NbYrsPerPer} (1+\delta)^{1-a} \right] \quad (2.2)$$

where  $\delta$  is the discount rate; *NbPer* is the number of periods over the horizon; *NbYrsPerPer* is the number of years per period; the annual cost is the sum of all costs; *r* is the set of regions in the area of study; and *t* is the time period.

The Irish TIMES model was built by applying localised data and assumptions to the Pan European TIMES (PET) model, a model of 36 regions of Europe (the EU27, Iceland, Norway, Switzerland and six Balkan countries) (Gargiulo and Ó Gallachóir, 2013). The model represents the potential long-term evolution of the Irish energy system through a network of

processes that transform, transport, distribute and convert energy from its supply sector to its power generation and demand sectors. Energy demands are driven by a macroeconomic scenario covering the period to 2050, which is based on the Economic and Social Research Institute (ESRI) Harmonised Econometric Research for Modelling Economic Systems (HERMES) model of the economy underpinning the 2013 edition of ESRI's medium-term review (Bergin *et al.*, 2013a). This has recently been retired with the emergence of the ESRI COre Structural Model (COSMO) of the Irish economy.

### 2.3 Consumer Choice Model

The consumer choice model is a socioeconomic simulation model that estimates the influence of various policies on the Irish private vehicle market. The heterogeneity of private vehicle preferences is accounted for by splitting transport users into 18 segments, divided geographically (urban/rural), by driving profile (modest driver, average driver, frequent driver) and by adoption propensity (early adopter, early majority, late majority), inspired by McCollum *et al.* (2016) and Wilson *et al.* (2014). Five technologies divided into three categories are represented in the model – petrol internal combustion engine (ICE), diesel ICE, natural gas (NG) ICE, battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) – disaggregated into the classes small, medium and large for ICEs, based on engine size, and into short, medium and long range for BEVs (< 125 km, 125–175 km and > 175 km, respectively).

The consumer choice model of the private transport sector for Ireland includes the tangible costs faced by consumers (such as investment costs and vehicle-related taxes), along with a monetised representation of the intangible costs related to model availability, namely risk-related disutility, range anxiety and refuelling infrastructure. Policy measures can be integrated into the model by either varying the tangible costs, such as derogating vehicle registration tax (VRT), or manipulating the variables affecting intangible costs, such as model availability.

The market uptake of new technologies is calculated using the CIMS market share algorithm (equation 2.3). CIMS is a hybrid energy–economy model developed at Simon Fraser University, BC, Canada, that simulates capital stock turnover through time as technologies

are acquired, retired and replaced (Jaccard, 2009). This equation uses capital costs ( $CC$ ), maintenance costs ( $MC$ ), energy costs ( $EC$ ), intangible costs ( $i$ ) and a discount rate ( $r$ ) to calculate the market share of a technology  $j$  in year  $n$  when competing against  $K$  technologies.

$$MS_j = \frac{\left( CC_j * \frac{r}{1+(1+r)^{-n}} + MC_j + EC_j + i_j \right)}{\sum_{k=1}^K \left( CC_k * \frac{r}{1+(1+r)^{-n}} + MC_k + EC_k + i_k \right)} \quad (2.3)$$

More detail on the construction and operation of the consumer choice model can be found in Mulholland *et al.* (2018a).

## 2.4 Light Commercial Vehicle Stock Model

The LCV stock model uses the same mode of operation as the CarSTOCK model, with GHG emissions projected using the ASIF methodology defined in section 2.1.

Vehicle-kilometres (vkm) are projected using data from the Commercial Vehicle Roadworthiness Test (CVRT), which Irish LCVs are required to undergo annually. Gross national product (GNP) and fuel prices are used as drivers for vkm and are projected exogenously to 2050 by the ESRI and the European Commission, respectively (Bergin *et al.*, 2013a; Capros *et al.*, 2013). These projections are used in tandem with an income elasticity of demand ( $\gamma_I$ ) and a fuel elasticity of demand ( $\gamma_{FP}$ ). A mean long-run income elasticity of demand of 0.93 was chosen based on a review of traffic-related elasticities of demand, using a combination of 150 published values from a range

of international studies (Graham and Glaister, 2011). A fuel elasticity of demand of  $-0.1$  was chosen from the National Road Authority (NRA, 2013), implying that a change in fuel price will have a minute effect on total LCV energy demand.

At the time of writing, a limited number of data were available regarding the SEC of Irish LCVs. The SEAI creates estimates of the SEC of LCVs by linking the database of the makes and models of LCVs licensed in Ireland (accessed from the VRU) with the UK Vehicle Certification Agency's database of official vehicle fuel consumption test results. However, the fuel consumption of new LCVs has been recorded in this database only since 2011, creating a data gap for LCVs manufactured before 2011. The LCV stock model uses a portfolio of all vintages and therefore, to provide an accurate depiction of energy consumption in the base year, the model requires the SEC for LCVs of all ages. To address this gap, a Finnish study dedicated to unit emissions of traffic was used to estimate the SEC of LCVs by unladen weight. The study determines that the energy consumption and emissions are "to a certain extent linearly dependent on the mass of the vehicle" (Mäkelä and Auvinen, 2007). The SEC of LCVs for all seven unladen weight bands was determined through linear interpolation and extrapolation using the unladen weight  $m$  and the SEC of the goods-carrying vehicles used in Mäkelä and Auvinen (2007). This methodology was used to determine the SEC of vehicles in Ireland between 1988 and 2010. Table 2.2 shows the calculated SECs using equation 2.4, where  $a$  and  $b$  represent two unladen weight bands, as in Table 2.2, and  $x$  represents an unladen weight band that falls between  $a$  and  $b$ :

$$SEC_x = SEC_a + \left( \frac{m_x - m_a}{m_b - m_a} \right) * (SEC_b - SEC_a) \quad (2.4)$$

**Table 2.2. Historical SEC (MJ/km) of LCVs**

Euro LCV standard	Unladen weight band (kg)						
	0–610	611–813	814–1016	1017–1270	1271–1524	1525–1778	1779–2032
Euro 5 (>2009)	2.87	3.08	3.19	3.31	3.44	3.57	3.70
Euro 4 (2007–2008)	2.82	3.05	3.17	3.30	3.45	3.6	3.74
Euro 3 (2001–2006)	2.89	3.12	3.24	3.37	3.52	3.67	3.82
Euro 2 (1997–2000)	2.69	2.98	3.13	3.29	3.48	3.66	3.84
Euro 1 (1994–1996)	2.65	2.93	3.07	3.22	3.40	3.57	3.75
< 1993	2.59	2.88	3.02	3.19	3.37	3.55	3.73

The deterioration of an LCV engine is accounted for by increasing annual SEC by a factor of  $1.003^v$ , where  $v$  is the vintage of the LCV; this is assumed from Van den Brink and Van Wee (2001). This equates to a progressive reduction in the fuel economy of the vehicle in a year-on-year basis.

More detail on the construction and operation of the LCV stock model can be found in Mulholland *et al.* (2016).

## 3 Private Cars

Total private car final energy consumption was 2088 ktoe and CO<sub>2</sub> emissions were 6045 ktCO<sub>2</sub> in 2017 (SEAI, 2017a). Liquid fossil fuels are by far the most dominant means of powering private cars in Ireland, with diesel cars holding a greater share of total stock relative to gasoline cars (52% vs 46.5% at the end of 2017). Despite considerable efforts at a governmental level, the uptake of alternative fuelled vehicles (AFVs) has been low – in the same year hybrids accounted for 1% of total stock, petrol and ethanol vehicles for 0.3% and BEVs (including plug-in hybrid vehicles) for the remaining 0.2% (DTTAS, 2017a). Adhering to long-term decarbonisation goals will require a significant change in the method of fuelling private transport, such as a switch to BEVs or increasing the use of advanced biofuels, although a number of short-term measures can assist in meeting targets for 2020 and 2030, such as increasing the use of conventional biofuels and improving the efficiency of vehicles. These measures are discussed in detail in this chapter, with indications presented of their potential for decarbonising the private transport sector in Ireland.

### 3.1 Energy Efficiency

Energy efficiency improvements have the potential to offer significant reductions in energy consumption and emissions in the Irish car fleet, although Ireland has very limited influence over these measures because of its being a “technology taker” rather than a “technology maker”. Ireland does, however, have the ability to influence the purchase of vehicles through policy. The most noteworthy policy attempt to steer consumer choice of private cars towards more efficient vehicles was a change in the basis of taxation on motor vehicles in 2008, from taxation based on the size of a vehicle’s engine to taxation based on the level of vehicle emissions (in gCO<sub>2</sub>/km), which resulted in a significant migration in the private car fleet to more efficient vehicles (Rogan *et al.*, 2011). This policy measure acted as a supplement to the formal adoption of CO<sub>2</sub> performance standard regulations as decreed by Regulation 443/2009/EC of the European Parliament, which sets a target for specific emissions

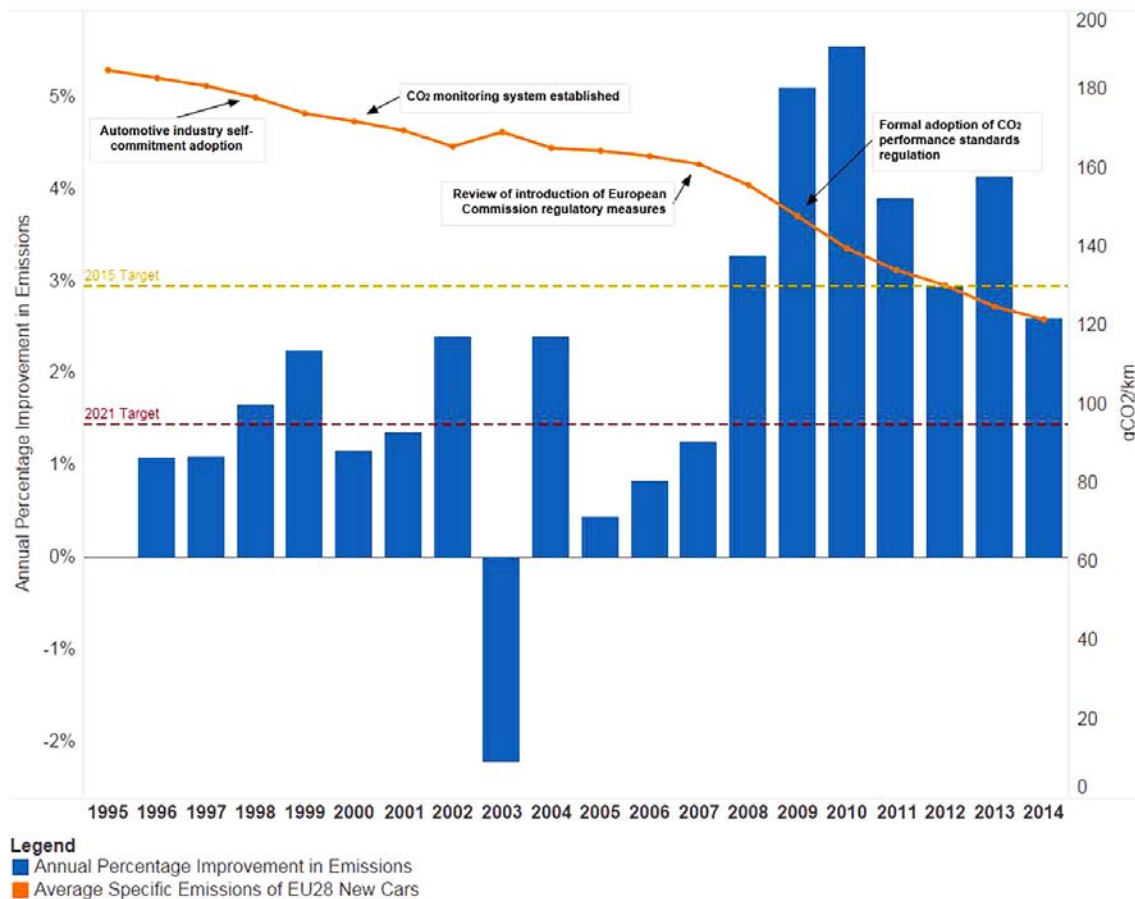
of lower than 95 gCO<sub>2</sub>/km to be in effect by 2021 (EU, 2009a). Supplementary to this target, a further 10 gCO<sub>2</sub>/km reduction is to be achieved through “additional measures”, met largely through national biofuel blending targets (see the following section). A significant reduction in new car test emissions was experienced across the 28 EU Member States in the years following the adoption of these targets (Figure 3.1) (EEA, 2015).

Discussions on implementing further CO<sub>2</sub> standards in the coming decade are under way and targets of 68 gCO<sub>2</sub>/km and 40 gCO<sub>2</sub>/km have been identified as plausible for 2025 and 2030, respectively (in contrast, the average specific emissions of new Irish cars in 2015 were 114 gCO<sub>2</sub>/km). However, these figures are subject to some degree of inaccuracy because of the gap between real-world driving and the test driving used to obtain them. The New European Driving Cycle was widely criticised for not representing real-world driving cycles and was subject to inaccuracies of up to 39% in testing for specific car emissions (ICCT, 2017).

The New European Driving Cycle was replaced with the World Harmonised Light Vehicles Test Procedure in September 2017, with the intention of reducing this on-road factor, although this will probably only half the gap between type-approval and real-life figures (Pavlovic *et al.*, 2018). Increasing the standards for private car specific emissions will inevitably increase cost-competitiveness between ICE vehicles and AFVs because of the increased cost of manufacturing required to reduce energy consumption and emissions. As standards become harder to meet, manufacturers will be incentivised to focus on AFVs.

### 3.2 Biofuel Blending

There has been an increase in the level of bioethanol and biodiesel blending with petrol and diesel in Ireland, respectively, since the introduction of the Biofuels Obligation Scheme (BOS), which has obliged suppliers to derive at least 8.695% of motor fuels placed on the market from a renewable source as of 1 January 2017 (White, 2016). This statutory instrument serves as a



**Figure 3.1. EU28 new car emissions in gCO<sub>2</sub>/km (right) and annual percentage improvement (left). Reprinted from *Energy*, Vol. 138, Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., From technology pathways to policy roadmaps to enabling measures – a multi-model approach, pp. 1030–1041, copyright 2017, with permission from Elsevier.**

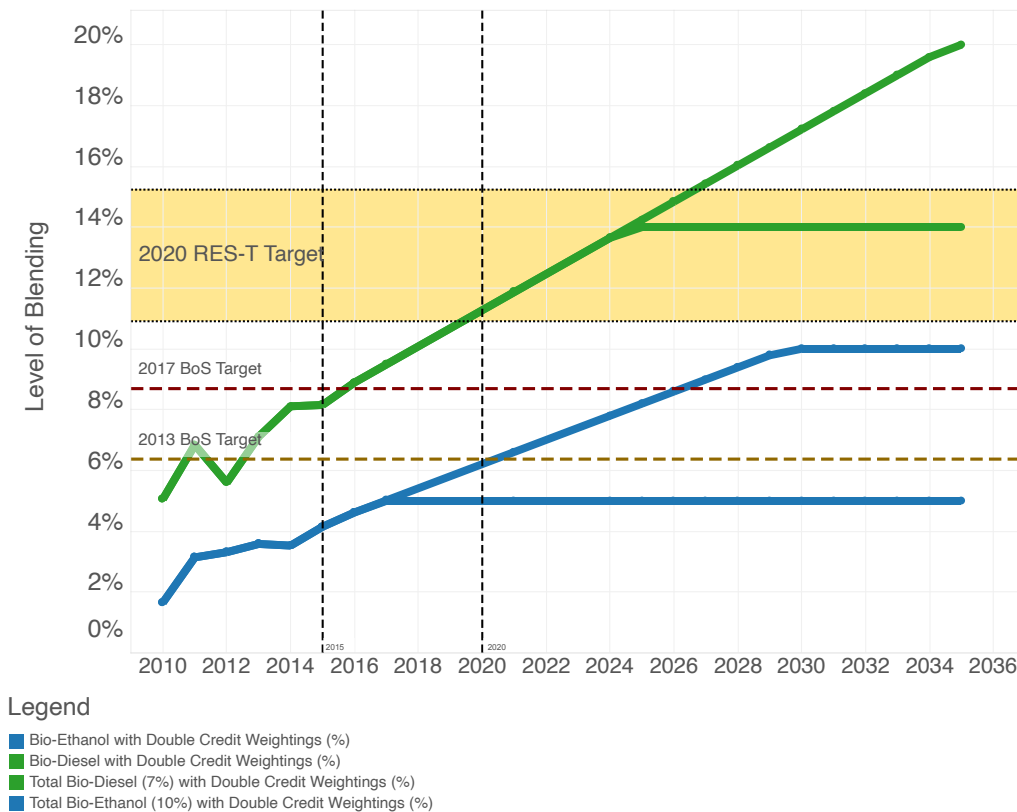
response to the binding 10% RES-T target introduced by the Renewable Energy Directive in 2009 and, to date, has proved effective at increasing the level of blending in transport in recent years (Dineen *et al.*, 2014).

Biofuels are effective at contributing towards short-term targets, although the relatively lower energy density of bioethanol and biodiesel with respect to their petroleum-based counterparts renders achieving the RES-T target solely through the use of biofuel blending very difficult.<sup>1</sup> The yellow band in Figure 3.2 represents the range of possibilities for the RES-T target if it is to be met solely through biofuel blending, with the lower limit representing a case whereby the target is met through biodiesel alone (which has a calorific value of

33 MJ/l compared with 36 MJ/l for diesel) and the upper limit representing a case whereby the target is met through bioethanol alone (which has a calorific value of 21 MJ/l compared with 32 MJ/l for gasoline), with the centre representing a combination of the two scenarios (NORA, 2016).

The level of blending of biofuels with petrol and diesel is limited for conventional ICEs to 5% and 7% according to European fuel standards EN 228:2004 and EN 590:2009, respectively, although allowances have been made for both to reach a value as high as 10% at both national and regional levels for use in conventional ICEs in accordance with the Fuel Quality Directive (2009/30/EC), provided sufficient information is made available to the consumer

<sup>1</sup> The RES-T target is an energy-based target, meaning that a 10% blend of biofuels with fossil fuels will not be enough to achieve the 10% RES-T because of the lower calorific value of biofuels relative to petrol and diesel.



**Figure 3.2. Historical and projected bioethanol and biodiesel blending by volume in Ireland. Reprinted from *Energy*, Vol. 138, Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., From technology pathways to policy roadmaps to enabling measures – a multi-model approach, pp. 1030–1041, copyright 2017, with permission from Elsevier.**

regarding the fuel blend (EU, 2009b). This analysis uses a linear extrapolation of historical bioethanol and biodiesel blending in the primary scenario, with growth capped at the limits imposed by these European fuel standards, and a limit placed on the use of biofuels of 10% in the secondary scenario, with the green and blue bands in Figure 3.2 representing the potential of blending using biodiesel and bioethanol, respectively.<sup>2</sup>

The use of hydrotreated vegetable oil (HVO) (also referred to as renewable diesel) has the potential to overcome the limitations imposed by the European fuel standards outlined previously. HVO is a diesel-based fuel traditionally produced from vegetable oils, but recently derived more commonly from waste and residue fat fractions from food, fish and slaughterhouse industries. These are hydrogenated and are used in an isomerisation process to produce a fuel that can entirely substitute for diesel

(Neste Oil, 2016). The requirement for hydrogen in the hydrogenation process limits the economics of HVO production; therefore, this study also uses a scenario development based on a range of HVO blending rates to determine its potential long-term decarbonisation effect.

### 3.3 Alternative Fuelled Vehicle Penetration

Incentivising BEV and PHEV purchasing through policy measures is considerably more cumbersome to enable compared with biofuel blending and efficiency improvement mandates, as the last two can be enforced on the supply side of the chain whereas the former relies solely on consumer behaviour. Despite this, a multitude of countries have invested in a myriad of incentivising schemes, with the hope of shifting

<sup>2</sup> Article 21 of the Renewable Energy Directive allows for double weightings to be counted towards biofuels produced from wastes, residues, non-food cellulosic material and ligno-cellulosic material. Figure 3.2 considers only the weighted value.

consumer transport preferences towards electrification. Norway currently benefits from the highest electric vehicle market share in the world (23% in 2015) (IEA, 2016). There is a range of contributing factors to this market share – Norway’s high gross domestic product (GDP) per capita, membership of the Electric Vehicles Initiative board and strong incentives in the form of registration tax reduction, e.g. value-added tax (VAT) exemption, waivers on road tolls and ferries, and access to bus lanes (IEA, 2016).

Figure 3.3 summarises the level of initiatives required for Ireland to meet its self-imposed targets, as laid out by the 2019 Climate Action Plan, to achieve 950,000 electric vehicles on Irish roads by 2030 (840,000 of which are private cars). The uptake required is notably ambitious and sees a growth in market share greater than that experienced in Norway to date.

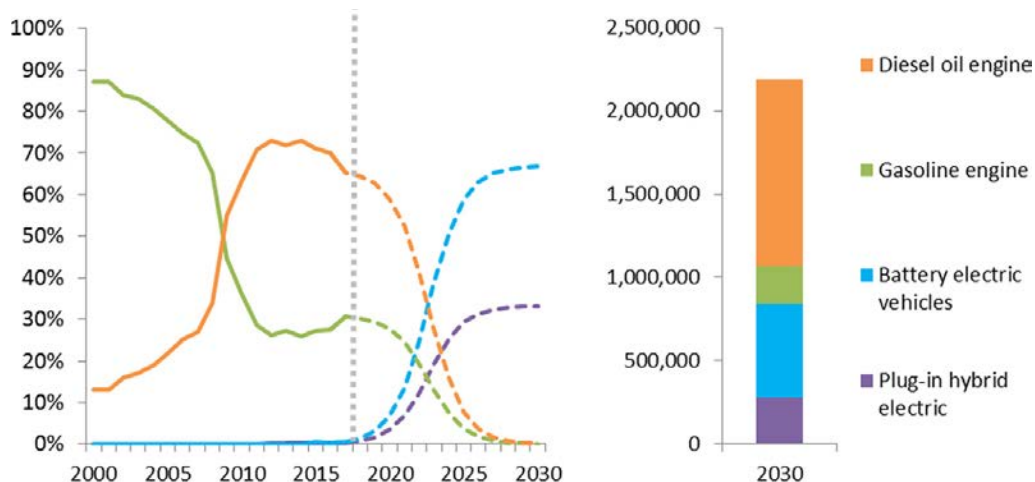
The consumer choice model (described in section 2.3) was used to determine the effect that both monetary and non-monetary policies at a governmental level would have on the uptake of alternative fueled private cars in Ireland.

Under a business as usual (BaU) scenario, with no variation in the number of models available for sale, the market share of BEVs in Ireland rises from 0.39% in the base year to 1.2% in 2021 and then falls to 0.3% once the VRT subsidy is removed in 2022. The market share then rises steadily to 4.5% by 2050, driven by the assumed reductions in the costs of BEVs and cost increases in ICEs (Moawad *et al.*, 2016). The

market share of PHEVs is largely unchanged. The market share in the base year is 0.002% of all vehicles bought and, following the removal of the VRT subsidy in 2019, this is reduced to 0.001%. Despite reductions in technology costs, there is no change in the market share by 2050 because of the low number of PHEV models available. The total AFV stock reaches 91,000 vehicles by 2050, compared with 3.46 million ICEs.

Emission reductions are still evident despite the low uptake of AFVs, driven by ICE efficiency improvements. These efficiency improvements are in line with current European standards mandating manufacturers to achieve maximum emissions of 95gCO<sub>2</sub>/km per vehicle produced by 2021 (EU, 2009a) and a regulatory proposal to set this standard to between 68 and 78gCO<sub>2</sub>/km for 2025 (Mock, 2013). Efficiency improvements beyond this are assumed at a year-on-year value of 0.75%, in line with the total long-range potential efficiency improvements of ICEs by 2050 according to the International Energy Agency (IEA) (IEA, 2008). These efficiency improvements, coupled with the marginal electrification of transport, provide a 19% reduction in well-to-wheel CO<sub>2</sub> emissions by 2050 relative to 2015.

A linear increase in the model availability of BEVs and PHEVs from their current standing to match the number of ICE models currently available reduces the intangible costs of these technologies significantly and, by 2050, increases their combined market share to 49%. This corresponds to approximately 1.4 million BEVs and 75,000 PHEVs in the private vehicle stock



**Figure 3.3. Market share (left) required to achieve a stock (right) of 840,000 electric vehicles by 2030. Dashed coloured lines denote projections.**



by 2050 and a 44% reduction in well-to-wheel CO<sub>2</sub> emissions relative to 2015.

The purpose of policies that act in favour of AFVs is, in general, to incentivise the sale of this new technology to a point at which it overcomes the initial barriers associated with purchasing and begins to achieve a greater market share. The scenarios for this analysis are divided into both monetary policy levers – offering a derogation of VRT, VAT and annual motor tax (AMT), and offering free recharging for AFVs – and non-monetary policy levers – banning the sale of ICEs in 2030, with a 5-year phase-in period. This latter policy lever is chosen to be in line with the Irish stated national ambition that, by 2030, all new cars and vans sold in Ireland will be zero emission capable (DTTAS, 2017b), which roughly follows recent ambitions by France and the UK to ban the sale of petrol and diesel cars by 2040 (Defra, 2017; Ministère de la Transition Écologique et Solidaire, 2017). An externality to the model is the number of AFV models available for sale, as Ireland are vehicle “takers” rather than vehicle “makers”. Analysis showed this variable to be a key determinant of consumer uptake, and its effect is examined at different levels in the four scenarios examined. The “low” scenario has no change to the number of AFV models available compared to the base year of 2015, the “medium” scenario assumes that there are half of the number of AFV models available as there are currently ICEs by 2050, and the “high” scenario assumes parity between the number of AFVs and ICE models available in 2050 (Ministère de la Transition Écologique et Solidaire, 2017).

Placing an early ban on the sale of ICEs was found to have the cost optimal impact on the uptake of AFVs. In the case when no incentives are offered, there is generally a loss in revenue relative to the BaU scenario because of the relatively cheaper nature of AFVs. In the scenario without any incentives offered, high AFV model availability and a ban on the sale of ICEs, the average annual loss in tax to the Exchequer is €169.7 million per year in Ireland (resulting in an 89.3% AFV penetration). Figure 3.4 presents the market share and associated cost to the Exchequer for the following four scenarios:

1. S1 – low AFV model availability, no ban on the sale of ICEs, no further incentives offered (BaU scenario);

2. S2 – high AFV model availability, no ban on the sale of ICEs, no further incentives offered;
3. S3 – medium AFV model availability, ban on the sale of ICEs in 2030, no further incentives offered;
4. S4 – medium AFV model availability, no ban on the sale of ICEs, derogation of VAT, VRT and AMT, and no refuelling costs.

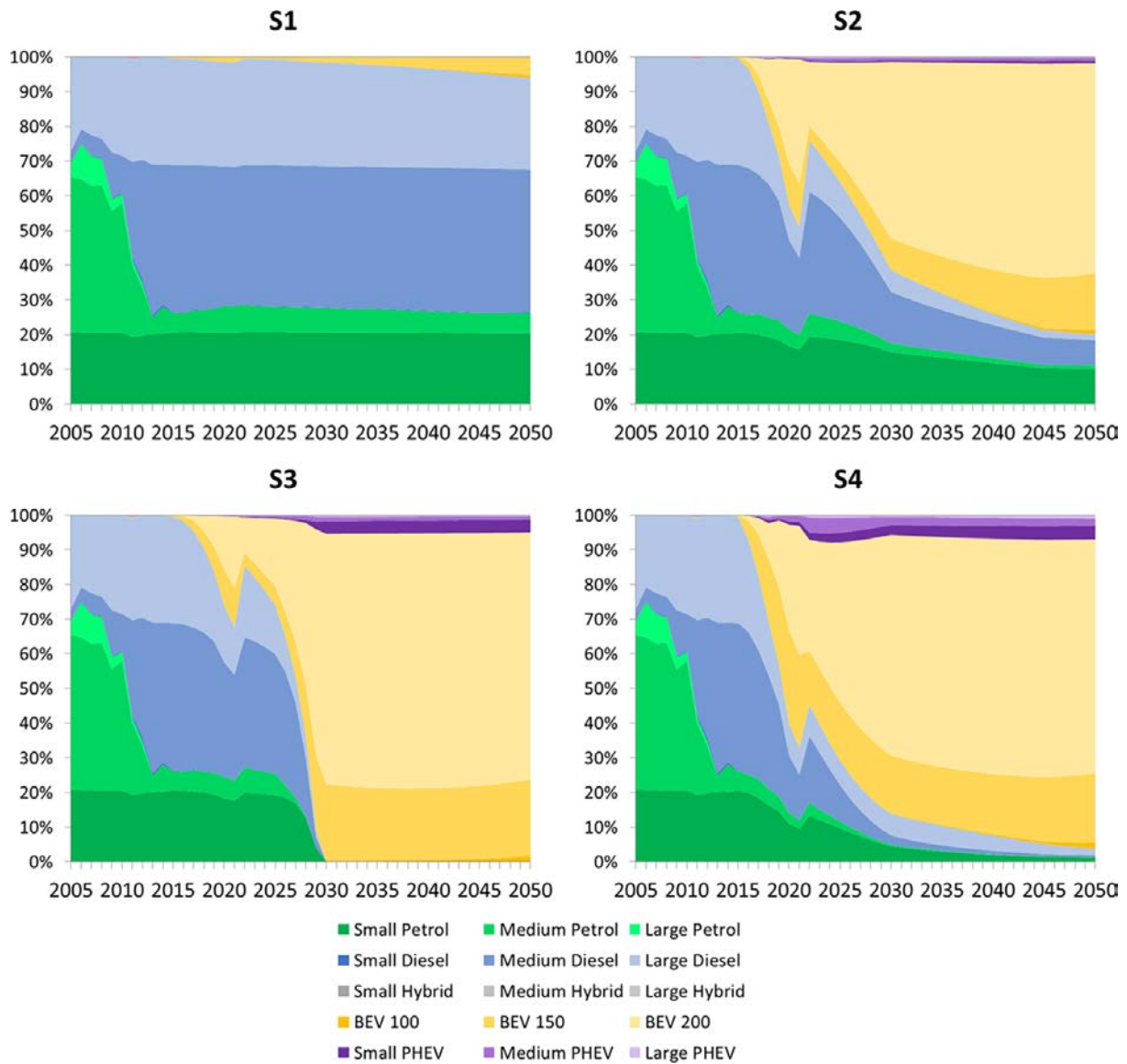
The resulting energy consumption and CO<sub>2</sub> emissions are further presented in Table 3.1.

Scenario S1 in Ireland represents the effect of the VRT subsidy retraction in the long term. The cost and effect of further incentivisation of AFV purchasing are represented by scenarios S2–S4. In scenario S2, although the VRT subsidy retraction for BEVs causes a reduction in market sales in 2022, BEVs start to emerge strongly in the market through to 2050. In scenario S3, in which a ban is placed on the sale of ICEs and there are half as many AFVs available for sale in 2050 as ICEs, a much faster emergence of AFVs is seen. Finally, in the most costly scenario, S4, in which there is no ban on the sale of ICEs and there is a derogation of VRT, VAT and AMT and no refuelling costs, there is a fast uptake of AFVs in Ireland.

Under the current taxation regime, the Irish Exchequer is set to experience a net revenue loss in scenarios S2–S4 compared with the baseline scenario S1. Revenue from private car taxation amounted to €4 billion in 2015, generated from VRT (€0.39 billion), VAT on vehicle purchases (€0.45 billion), VAT on fuel (€0.99 billion), excise fuel duty (€1.5 billion), carbon tax (€0.12 billion) and AMT (€0.55 billion). Most notably, the income related to fuel purchases accounted for over half of this income. With a shift away from fossil fuels, a large portion of income generated from fossil fuel taxation will be lost. The current excise fuel duty on electricity (€0.28/GJ) is low in comparison with that on petrol and diesel (€17.19/GJ and €12.41/GJ, respectively), indicating that there is a necessity to prepare a tax system for the expected penetration of electric vehicles that can fill this gap.

Figure 3.5 summarises the projected losses from scenarios S2–S4 relative to the baseline scenario S1. Annual losses by 2050 vary from €4.3 billion to €5.3 billion, with the bulk difference attributed to reductions in excise duty and fuel VAT.





**Figure 3.4. Market share for select scenarios from the multinomial logit consumer choice model.**

**Table 3.1. Energy consumption and CO<sub>2</sub> emission projections for the four policy scenarios**

Scenario	Energy consumption (TJ)			ktCO <sub>2</sub> emissions		
	2015	2030	2050	2015	2030	2050
S1	95,956	83,754	78,594	6379	5449	5112
S2	95,956	74,052	51,384	6379	4875	2611
S3	95,956	73,557	45,338	6379	4853	1989
S4	95,956	68,531	45,186	6379	4568	2044

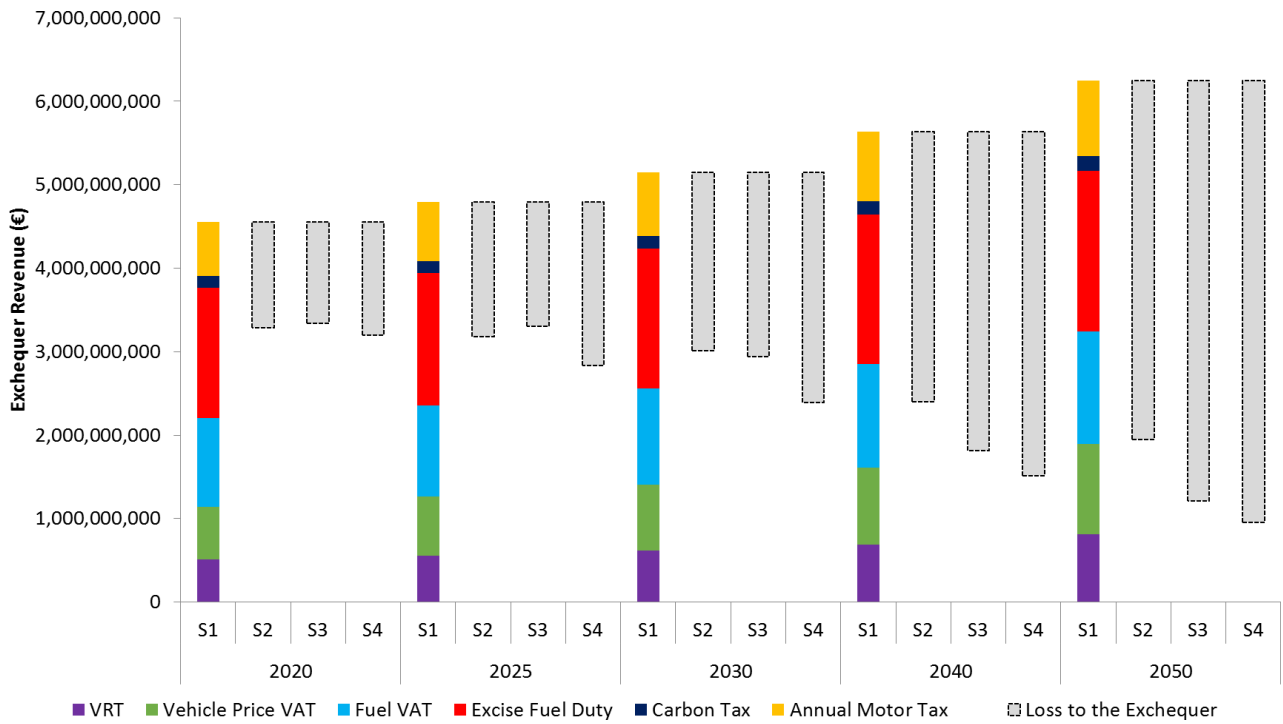


Figure 3.5. Exchequer revenue from scenario S1 and the relative losses in scenarios S2–S4.

## 4 Light Commercial Vehicles

Three scenarios were analysed to quantify the range of possible emission reductions associated with a combination of efficiency improvements, fuel switching and bio-gas deployment (Table 4.1). Initially, a BaU scenario was developed, which assumes no improvement in the energy efficiency of LCVs from now to 2050, with no switch to renewable fuel vehicles. The BaU scenario sets a baseline for all other scenarios, indicating what may happen in the absence of any policies.

The second scenario quantifies the potential emissions reduction from focusing on the efficiency improvements of LCVs, with no penetration of renewable vehicles. A focus is placed on three individual efficiency measures. The first limits the average specific emissions of all new LCVs to 147 gCO<sub>2</sub>/km, as required by EU Regulation No. 510/2011 (EU, 2011). The second simulates the switch to more efficient vehicles following the simulation of a policy in 2021 that bases LCV tax on emissions rather than unladen weight, as is the case currently. This simulation uses the same percentage change in efficiency as in the private car fleet for the 5 years following the change in taxation from engine size to specific emissions in 2008 (3.8% improvement per year), which saw a drop in the emissions of the new car fleet (Rogan *et al.*, 2011). Finally, an improvement in the fuel economy of LCVs up to 2050 is assumed based on the *Energy Technology Perspectives* report released by the IEA, which identifies a potential 47% improvement in the efficiency of LCVs relative to a baseline gasoline vehicle (IEA, 2008).

The final scenario combines the improved efficiency scenario with the penetration of renewable LCVs

– compressed NG (CNG) LCVs fuelled by biomethane. To simulate this technology, data from the six gasoline- and gas-fuelled vans owned by Gas Networks Ireland (GNI) were used. The purpose of this scenario was to assess the feasibility of a high penetration rate of biofuels in the LCV stock, i.e. >90%.

The European Commission has proposed a maximum distance of 150 km between publicly accessible refuelling points to allow the circulation of CNG vehicles by the beginning of 2021 at the latest (EC, 2013). Because of the lack of any further planning post this operation, this scenario assumes a moderate penetration of 2000 CNG LCVs by 2025, which is in line with the GNI target of at least 5% penetration of CNG or renewable gas for heavy-duty transport. Complementary to this, a recent 10-year development plan by GNI proposes a target to achieve a contribution of renewable NG of 12% of the gas network by 2024 (GNI, 2015).

The three scenarios created – BaU, improved efficiency and improved efficiency with renewable vehicles – allow for an insight into policy measures in Ireland that may contribute towards a low-carbon LCV sector.

The BaU scenario is intended to provide a baseline against which all other scenarios are compared. LCV stock experiences a 36% increase by 2050 relative to 2013, which satisfies the total energy services demand of 8357 million vkm – calculated using GNP as a driver – with an average of 25,925 vkm/LCV/year. The SEC of new LCVs is held constant at the 2013 value, with a weighted average of 2.16 MJ/km. This is lower than the current average SEC of the LCV fleet of 3.37 MJ/km, allowing for an overall improvement in the fuel economy of LCVs as older inefficient LCVs

**Table 4.1. Scenario summary**

Scenario	Description
BaU	Baseline
Improved efficiency	<ul style="list-style-type: none"> <li>• 147 gCO<sub>2</sub> by 2020</li> <li>• Switch of carbon tax bands in 2021</li> <li>• 47% improvement in efficiency by 2050</li> </ul>
Improved efficiency + renewable vehicles	As above + high penetration of CNG

are replaced by more efficient vehicles. When linked with the growing stock out to 2050, there is a 12.06% increase in the total emissions by 2050 relative to the base year.

The improved efficiency scenario focuses on the effect of a number of individual policy measures on improving the energy efficiency of new LCVs and reducing fleet emissions. Meeting the 147 gCO<sub>2</sub>/km target for new LCVs by 2020, as laid out in EU Regulation No. 510/2011, leads to only a slight reduction in emissions, 3% relative to the BaU scenario, because of the short time span. This is a result of the small number of new LCVs entering the transport fleet between now and 2020 relative to the total LCV fleet, resulting in a slight impact on the level of emissions in the short term. However, this has a sufficient impact in the long term because of the continuous introduction of new LCVs every year.

Using the change in taxation policy for private cars in 2008 as an example (from being based on the engine size to being based on specific emissions, which resulted in an improvement in the fuel economy of new private cars in Ireland), a similar policy was simulated in LCVs. A change in the policy for taxation of LCVs from being based on unladen weight to being based on specific emissions resulted in a 13% reduction in emissions by 2025 relative to the BaU scenario, following an improvement in fuel economy, assuming that LCVs will experience the same improvement in fuel economy as private cars.

The highest potential of fuel economy gains come from efficiency improvements made to engine and non-engine components, as identified by the IEA (47% improvement in the efficiency of LCVs relative to a baseline gasoline vehicle by 2050). These efficiency improvements are projected to contribute to a total reduction in emissions of 41% by 2050 relative to the BaU scenario. This highlights the total potential for emissions reduction of focusing solely on energy efficiency improvements of conventional ICE engines without considering the adoption of alternative or renewable fuel.

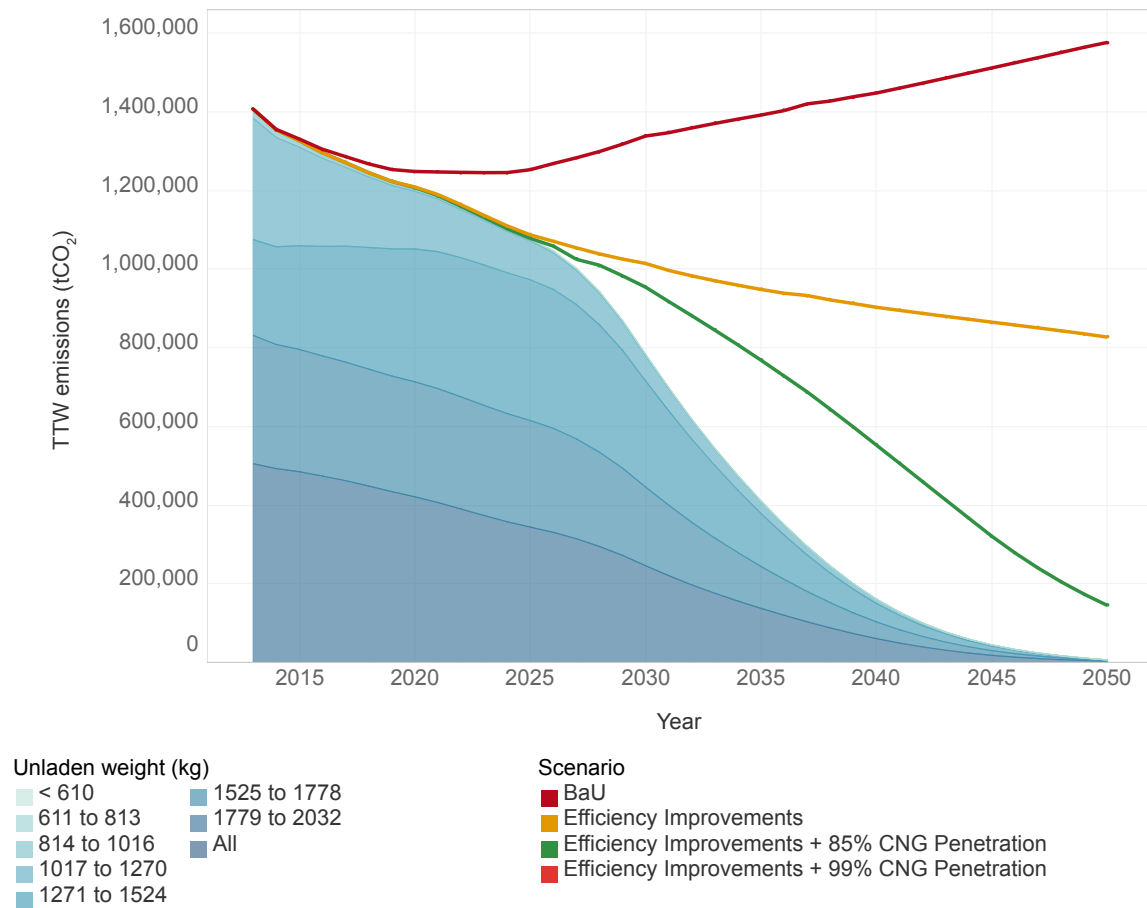
The final scenario considers the level of effort required to decarbonise LCVs through the penetration of biomethane-fuelled LCVs. This decarbonisation is modelled using an initial introduction of LCVs fuelled solely by biomethane; in reality, there will be an introduction of CNG LCVs and a gradual penetration

of biomethane into the gas grid whereas this analysis considers only the end goal of providing enough biomethane to fuel the required number of LCVs. At present, biomethane has been identified to have the potential to satisfy 30% of Ireland's gas demand by 2030. A target has been proposed by GNI of 20% renewable NG on the gas network by 2030 (GNI, 2015). The percentage level of sales of ICEs and biomethane-fuelled LCVs is varied in the LCV stock model to simulate the stock levels laid out in the CO<sub>2</sub>-80 and CO<sub>2</sub>-80 NoBioImp scenarios (Mulholland *et al.*, 2016). A moderate penetration of 2000 biomethane-fuelled LCVs is assumed out to 2025. To achieve an 85% penetration rate of biomethane in freight by 2050, CNG LCVs require an annual increase of 5% of the share of all LCV sales from 2026 onwards, with 100% of all LCV sales from 2045 onwards being CNG LCVs. In an extreme scenario in which a 99% CNG penetration rate is required, a much faster increase in CNG LCV sales is necessary. This scenario requires a linear increase from 2026 to 2030 in the rate of CNG LCV sales up to 100%, which is then held constant out to 2050.

Figure 4.1 shows the combined tank-to-wheel (TTW) emission reduction based on these four scenarios.

The SEC of the biomethane-fuelled LCV stock is taken as the average performance of the on-road performance of four dual fuel vans (petrol and gas) operated by GNI. The vans selected were chosen to obtain an accurate representation of the average van size in Ireland, which had an unladen weight of approximately 1500 kg. The same fuel efficiency improvement in diesel engine vans used in the improved efficiency scenario described above was assumed for the dual fuel vans to 2050. Compared with diesel LCVs, the dual fuel vans have a higher rated SEC: a diesel LCV in 2050 has an average SEC of 1.15 MJ/km whereas CNG LCVs have an average SEC of 1.57 MJ/km. No on-road factor was taken into account (the difference between actual and test emissions) for diesel LCVs whereas "real-world" data were used for biomethane LCVs.

Replicating the CO<sub>2</sub>-80 scenario in the LCV stock model resulted in a final energy consumption of 307 ktoe for biomethane-fuelled LCVs. In replicating the CO<sub>2</sub>-80 NoBioImp scenario (increasing the penetration rate of biomethane-fuelled LCVs from 85% to 99% by 2050), the total biomethane demand reached 363 ktoe.



**Figure 4.1. Potential TTW emissions reduction from efficiency improvements in LCVs.**

The calculated emissions from LCVs in 2013 were 1,406,639 tCO<sub>2</sub> whereas the improved efficiency scenario results in emissions of 827,024 tCO<sub>2</sub> (41% reduction). An 85% penetration rate of biomethane-fuelled LCVs results in estimated emissions of

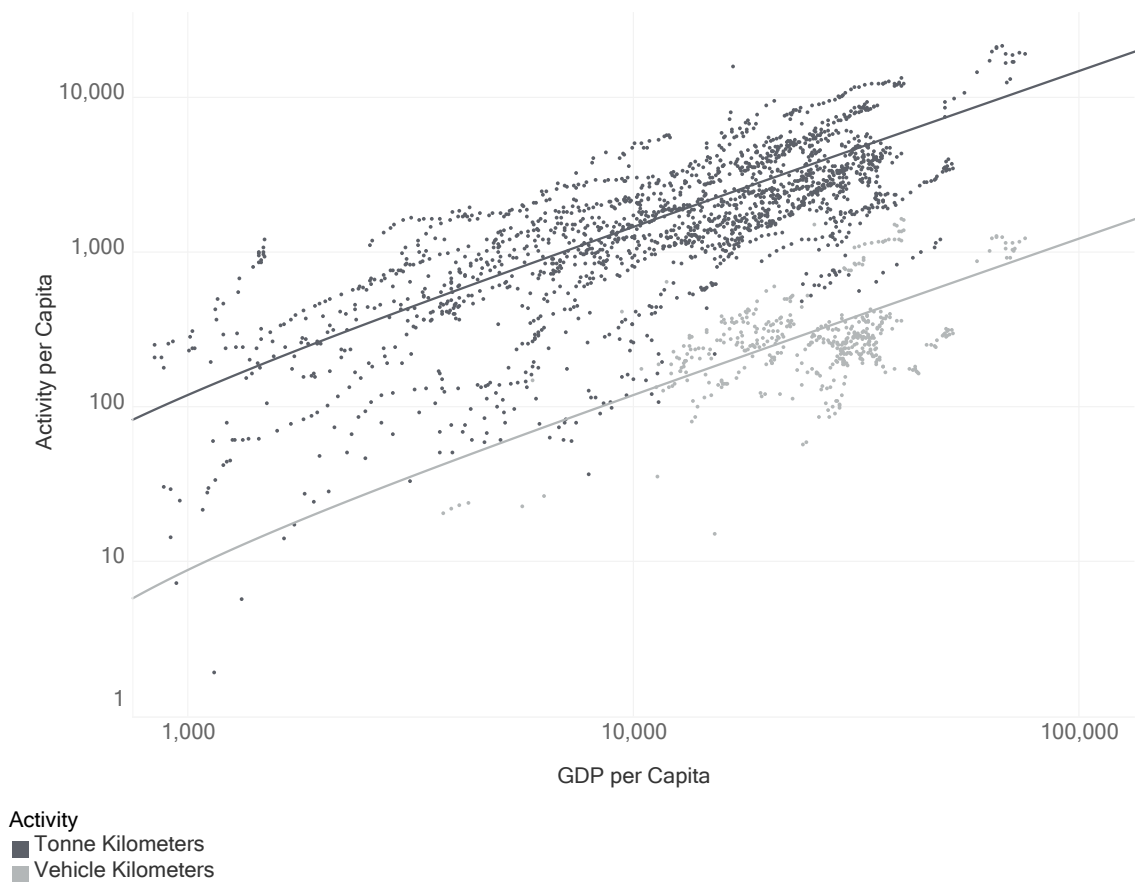
144,854 tCO<sub>2</sub> by 2050 (89.7% reduction) and a 99% penetration rate has estimated emissions of 6311 tCO<sub>2</sub> (99.6% reduction). More detail on these results can be found in Mulholland *et al.* (2016).

## 5 Heavy-duty Vehicles

The road freight network acts as the arteries for global economic activity. As such, it is strongly linked to globalisation and economic development within nations – as a country's economy develops, so does its level of infrastructure, freight logistics and demand for goods, all of which tend towards an increase in freight demand. This trend has become most prominent in developing countries in recent decades. For example, according to national statistics, road freight activity in India – measured in tonne-kilometres (tkm) – increased by more than 9-fold over the period 1975–2015 (Ministry of Road Transport and Highways, 2016), whereas road freight activity in China grew by more than 30-fold over this same period (National Bureau of Statistics, 2015). Road freight activity in

developed regions has not been as extreme, but is still significant: in the USA, for example, road freight tkm increased by 2.5-fold (BTS, 2015) over the same 40-year period. Ireland is no exception, with heavy-duty freight activity rising from 5493 million tkm in 1995 to a high of 19,147 million tkm in 2007 before the economic crash and returning to 9844 million tkm in 2015. A regression between activity per capita and GDP per capita, with 1900 observations between 1974 and 2014, showed a strong link between the two metrics (see Figure 5.1).

Creating a long-term projection forecast of road freight tkm in Ireland using the ESRI's economic drivers suggests a continuing rise in the activity of heavy-duty vehicles, with activity trebling between 2015 and 2050



**Figure 5.1. Road freight activity link to econometrics. Reprinted from *Applied Energy*, Vol. 216, Mulholland, E., Teter, J., Cazzola, P., McDonald, Z. and Ó Gallachóir, B.P., *The long haul towards decarbonising road freight – a global assessment to 2050*, pp. 678–693, copyright 2018, with permission from Elsevier.**

and reaching 30,135 million tkm. The projections and the drivers are shown in Figure 5.2. Considering that heavy-duty vehicles are almost entirely fuelled by liquid fossil fuel and that switching to AFVs may prove difficult to achieve, a combination of energy efficiency measures, measures to improve the efficiency of road freight systems and a switch to AFVs are necessary to adhere to a low-carbon future.

## 5.1 Energy-efficient Technologies

Aerodynamics, low rolling resistance tyres, light-weighting, transmission and drivetrain, engine efficiency, idling-reducing technologies and hybridisation are identified as areas for improvement for truck manufacturers, which have a combined potential to reduce emissions within the Irish heavy-duty vehicle sector by 19% by 2050 relative to a baseline. The baseline presents the outlook for future energy demand and GHG emissions growth to 2050 based on all policies affecting the outlook for road freight transport and those that have been announced and are expected to take effect in the near future. Table 5.1 outlines engineering literature estimates for the range of commercially available energy-efficient technology options for road freight vehicles.

Vehicle design improvements that reduce energy needs include improvements in aerodynamics, reduced rolling resistance for tyres and truck weight reduction. Enhanced powertrain efficiency can be realised via improvements to the engine, transmission and drivetrain – powertrain controllers that integrate transmission and engine controls can bring additional

fuel savings. Battery-powered electric auxiliary power units can provide on-demand power for climate control and other cabin devices while saving fuel.

## 5.2 Measures to Improve the Efficiency of Road Freight Systems

Achieving deep decarbonisation in the road freight sector, along a trajectory consistent with the IEA Energy Technology Perspective's Beyond 2°C Scenario (B2DS) (IEA, 2017a), will require the near complete realisation of all of the systemic improvements available for road freight, which are outlined in this section. In addition, measures that require closer external collaboration across firms, including the sharing of assets and services between and among companies, as well as more radical re-envisioning of how logistics systems operate, are needed to bring road freight emissions in line with B2DS emissions targets. Policies that reward efficiency and collaboration, as well as regulations and/or pricing measures to discourage “just-in-time” and same- or next-day deliveries and other similar practices that constrain the flexibility of supply chain operations, will be needed to drive the radical changes needed to reduce the GHG footprint of road freight. A list of methods for systems efficiency improvements is outlined in Table 5.2.

Reducing road freight tkm through logistic operational measures such as those described in Table 5.2 has the potential to reduce Irish heavy-duty freight activity by up to 36% and to reduce emissions by 17% by 2050 relative to a baseline.

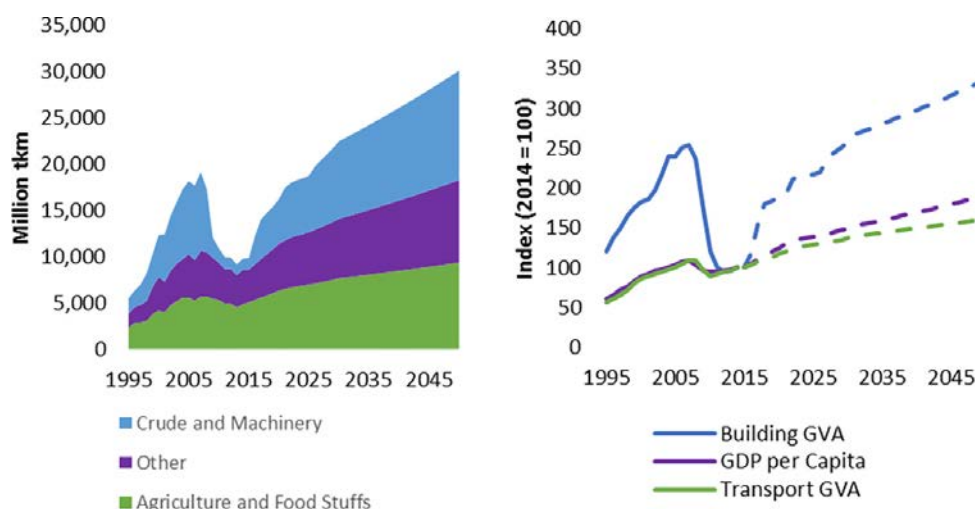


Figure 5.2. Irish HGV tkm projections to 2050 (left) and key drivers (right). GVA, gross value added.



**Table 5.1. Energy efficiency measures for road freight**

Measure	Description	Potential energy savings	Source
Aerodynamics	A wide range of aerodynamic fittings can reduce the drag coefficient, thereby reducing road load	Individual vehicle components reduce fuel use by 0.5–3%, depending on the truck type and aerodynamic retrofit	Schroten <i>et al.</i> (2012); Mannix (2015)
LRR tyres/TPS	LRR tyres can be designed with various specifications, including dual tyres or wide-base single tyres with aluminium wheels and next-generation designs	Ranges from about 0.5% to 12% in the tractor-trailer market. TPS alone could reduce fuel use by 0.5–2%	Schroten <i>et al.</i> (2012); Hill <i>et al.</i> (2015); Mannix (2015); Meszler <i>et al.</i> (2015)
Light-weighting	Broadly, all heavy-duty vehicle types except utility trucks could cost-effectively reduce weight by upwards of 7% within the next 10 years	The CO <sub>2</sub> savings potential is about 1% by 2020, 2–3% by 2030 and 2.7–5% by 2050	Hill <i>et al.</i> (2015)
Transmission and drivetrain	Moving from manual to automatic/ automated manual transmission can greatly improve efficiency. Adding gears, reducing transmission friction and using shift optimisation in manual automated or fully automated transmissions can also improve drivetrain efficiency	Automatic/automated transmissions reduce fuel consumption by 1–8%, depending on truck type; other improvements lead to fuel savings of about 0.5–2.5%	Schroten <i>et al.</i> (2012)
Engine efficiency	Engine improvements include increasing injection and cylinder pressure, both of which typically improve incrementally on a yearly basis	Improvements in the coming decade could lead to fuel savings of approximately 4% in service/delivery vehicles and 18% in long-haul vehicles	Schroten <i>et al.</i> (2012)
Idling reducing technologies	These include auxiliary power units and generator sets, battery air conditioning systems, plug-in parking spots at truck stops and thermal storage systems	As much as 2.5% of the fuel consumed by road trucks may be the result of idling operations. As such, this is an upper threshold for the potential fuel savings (energy savings are less)	Van Lier <i>et al.</i> (2010); ANL (2013)
Hybridisation	Electric hybridisation tends to be the best option for urban small and medium-sized freight vehicles	Dual-mode hybrid: 8–30%; parallel hydraulic hybrid: 15–25%; parallel hybrid: 6–35%. All ranges depend on vehicle type	Law <i>et al.</i> (2011); Schroten <i>et al.</i> (2012)

For further details, see (Mulholland *et al.*, 2018b).

LRR, low rolling resistance; TPS, tyre pressure systems.

### 5.3 Alternative Fuels and Fuel Technologies

Alternative fuels act as a means of addressing the many near- and long-term economic, societal and environmental dilemmas posed by the continued reliance of road transport in general, and heavy-duty vehicles in particular, on oil. Promotion of conventional and advanced biofuels (biodiesel, HVO and biomethane) for deployment in the heavy-duty vehicle fleet has the greatest potential reduction contribution of all measures, at 24% by 2050 relative to a baseline. Electrified trucks, through hybridisation for urban freight and overhead catenary lines, provide a further 16% reduction. Notwithstanding the opportunities provided by alternative fuels and powertrains to diversify from petroleum-derived fuels as the dominant energy sources for road freight and to decarbonise the sector, there are many challenges, such as high abatement costs (Malins, 2011; Holland

*et al.*, 2015). Although biofuels and electric power trains are predicted to have the greatest impact on decarbonisation of Irish heavy-duty vehicles, this section also highlights the additional alternative energy carriers that could be used in road freight in a low-carbon future: NG and hydrogen.

#### 5.3.1 Natural gas

Medium and heavy-duty compression ignition engines can be designed to run on a blend of diesel fuel and methane, with methane typically mixed with small volumes of diesel to provoke ignition. Alternatively, engines can be manufactured to run solely on methane, using positive (also known as spark) ignition systems. NG is the main source of methane currently available and used in dual fuel and dedicated engines. However, the GHG mitigation potential of switching to NG trucks is limited – even if upstream leakage issues are addressed and the best available vehicle



**Table 5.2. Improvements in road freight logistic measures**

Measure	Description	Truck type affected	Parameters affected	Global potential realised in 2050 (%)	Source
Optimised routing	Optimising delivery routes using GIS plus real-time routing data enables both time and fuel savings for both intra-city trucking and long-haul missions	All LCVs, MFTs and HFTs	Activity (vkm)	4.5	Carbon War Room (2012)
Platooning	Gaps between trucks driving on highways can be reduced using smart vehicle communication and automation technologies, which reduce drag and thereby reduce fuel consumption	Non-urban MFTs and HFTs	Energy intensity (MJ/vkm)	11.3	Tsugawa <i>et al.</i> (2016)
Improved vehicle utilisation	Optimisation of loads carried can be achieved both via internal logistics improvements and through external (i.e. across-firm) collaboration	All LCVs, MFTs and HFTs	Utilisation (load factor)	9.0	Collaborative Concepts for Comodality (2013)
Backhauling	Backhauling is a specific case of improving vehicle utilisation through delivering cargo on return trips, thereby offsetting other trips	All MFTs and HFTs	Utilisation (load factor)	3.8	Greening <i>et al.</i> (2015)
Last-mile efficiency	The allocation and prediction of dynamic demand can help to prepare for seasonal and daily peaks. Particularly in congested urban regions, there is a potential for logistics service companies to capitalise on ICT and the sharing economy to more cheaply and efficiently ship goods over the last mile	Urban LCVs and MFTs	Activity (vkm)	3.8	IEA (2017b)
Urban consolidation centres	By grouping shipments from multiple shippers/retailers and consolidating them onto a single truck for delivery to a particular locality, vehicle activity and emissions within urban centres can be reduced	Urban LCVs and MFTs	Activity (vkm)	3.8	Allen <i>et al.</i> (2012)
Re-timing urban deliveries	A shift to off-peak deliveries leads to a reduction in local pollutants and improved fuel economy, because of the reduction in congestion	Urban LCVs and MFTs	Energy intensity (MJ/vkm)	3.8	Holguín-Veras <i>et al.</i> (2016)
Co-modality	Operational efficiency gains come from extending the operations of not only private citizens' trips but also public transit and taxi operations to deliver goods in urban settings	Non-urban MFTs and HFTs	Activity (vkm)	3.8	Ronald <i>et al.</i> (2016)
Crowd-sourced logistics	Crowd-shipping is a means of translating the concept of crowd-sourcing to freight and is intended to accommodate last-mile delivery through deploying a large number of individual citizens as couriers	Urban LCVs and MFTs	Activity (vkm)	3.8	McKinnon (2016a,b)
Co-loading	Co-loading is a means of increasing vehicle utilisation through bundling shipments across product categories with similar shipment parameters (e.g. destination and time constraints)	All MFTs and HFTs	Activity (vkm) and utilisation (load factor)	7.5	Vernon and Meier (2012)
Physical internet	The physical internet describes an open, shared and modular global logistics system inspired by the movement of data on the internet, in contrast to the proprietary logistics systems that are common today	All LCVs, MFTs and HFTs	Activity (vkm) and utilisation (load factor)	18.8	Sarraj <i>et al.</i> (2014)

For further details, see Mulholland *et al.* (2018b).

GIS, geographic information system; HFT, heavy freight truck; ICT, information and communication technology; MFT, medium freight truck.

technologies are adopted, well-to-wheel reductions in emissions relative to diesel ICE trucks are limited to about 20% (JRC, 2014; DBI, 2016; Dominguez-Fauz, 2016). Biomethane, with similar physical and chemical properties to fossil NG, can be used in the form of CNG or liquified NG and, when produced by upgrading raw biogas produced via anaerobic digestion of high moisture content organic wastes, can deliver substantial GHG benefits on a well-to-wheel basis.

### **5.3.2 Biofuels**

A range of biofuel options have the potential to reduce oil demand from heavy-duty road transport, with the case for their use strengthened as a result of their high energy densities and, for several fuels, also their compatibility with existing vehicle fleets and fuel distribution infrastructure. Production processes for biofuels are technically mature, with heavy-duty vehicles suitable for using biofuels available from major original equipment manufacturers. A variety of low-carbon, advanced biofuel feedstocks and production pathways may serve as potential fuel sources for freight in the future. The most promising are summarised here:

- Biodiesel can be produced from a range of feedstocks and is most commonly blended with fossil fuels at a level below 20% (B20). Higher blends such as B50 or pure biodiesel (B100) can also be used but require technical modifications to be made to freight vehicles.
- HVO, also known as renewable diesel, can be produced from a similar range of feedstocks as biodiesel and can be used unblended (HVO100) without modifications being made to heavy-duty diesel engines or changes to fuelling infrastructure.
- As outlined above, biomethane can be used in NG-fuelled vehicles.

The main barrier facing biofuel adoption is its long-term economic competitiveness relative to highly volatile oil prices (which translates, albeit imperfectly, to volatile pump prices for automotive gasoline and diesel fuels). Even if certain biofuel pathways manage to become economically viable, from a climate and sustainability perspective there is likely to be a limited volume of feedstock that does not compromise food, land, water and soil resource availability (Slade *et*

*al.*, 2014). Moreover, in a context of commitment to decarbonisation targets, competition for use of biomass resources within the energy sector is likely to favour their adoption not only in road freight, aviation and the maritime sector, but also in industrial and power applications (i.e. bioenergy with carbon capture and storage) (IEA, 2017a). Despite these considerations, advanced and low-carbon biofuels are likely to be needed, particularly in the coming few decades, to act as a bridge from the current fossil-dependent infrastructure undergirding road freight to the new infrastructures needed for ultra-low and zero emission energy carriers, such as hydrogen, electricity and power-to-X.

### **5.3.3 Electric trucks**

Relative to a typical ICE engine, the efficiency of battery electric motors is significantly higher, although the greater size and weight of trucks relative to LCVs substantially increases the barriers to batteries serving as a substitute for diesel in the road freight sector. The key performance considerations for batteries designed for use in electric trucks are gravimetric and volumetric energy density, the specific power (W/kg), the durability and number of discharge cycles that a battery can undergo before losing too much capacity, temperature management requirements and safety. The hurdles to electrification are lower for trucks with a lower gross vehicle weight and shorter annual mileage and so plug-in and battery electric LCVs and medium freight trucks in urban contexts are beginning to move into the early deployment phase. There are greater barriers to be overcome for heavy freight trucks because of their size.

Because of the cost implications of large battery requirements, the challenge for the electrification of trucks, particularly in the heavy freight truck segment, is how to reduce battery needs through the supply of electricity to vehicles while in motion. Electric road systems (ERSs) enable vehicles to receive electricity from power transfer installations along the roads on which they are driving. Vehicles using ERSs can be hybrid, battery electric or hydrogen fuel cell vehicles and can conduct normal driving operations, such as overtaking and driving autonomously, outside of ERS-enabled lanes. The main infrastructure concepts for ERS are:

- conductive power transfer, which may take the form of overhead catenary lines, which require the installation of an overhead retractable pantograph on trucks, or of in-road conductive charging, which requires the installation of a connection arm under or behind the truck;
- inductive transfer of power, requiring the installation of coils that generate an electromagnetic field in the road, as well as receiving coils for electricity generation on the vehicle.

## 6 Conclusions

Decarbonisation of the Irish transport sector is undoubtedly challenging because of its dependence on liquid fossil fuels. Despite this dependence, it is imperative for long-term decarbonisation to stay in line with the current European-wide target of a 30% reduction in non-Emissions Trading System (ETS) emissions by 2030 relative to 2005 and the ambition of achieving an 80–95% reduction in GHG emissions by 2050 relative to 1990. This project has identified a combination of decarbonisation measures targeted at the Irish transport sector, specifically for private cars, LCVs and heavy-duty vehicles, covering 93% of the non-ETS transport sections.

For private cars in the short term, and based on the current diesel–gasoline share, mandatory biofuel blending obligations imposed on suppliers can be increased to 10.13% (which is in keeping with the current fuel quality standards laid out by the European Commission in the Renewable Energy Directive) to stabilise national private car emissions out to 2025. This blend would have to be further increased to 13.21% to meet the current 10% RES-T target for 2020, which exceeds the guidelines for conventional ICE diesel and gasoline blends.

In the medium term, imposing European-wide technology-specific improvement targets on car manufacturers, trending towards 80 gCO<sub>2</sub>/km in 2040 and 75 gCO<sub>2</sub>/km in 2050, stabilises CO<sub>2</sub> emissions in private cars out to 2050 and is sufficient to provide a 4.5% reduction in emissions by 2050 relative to 2015 when combined with the aforementioned blending mandates.

In the long term, an array of incentives can be introduced to promote the use of pure electric vehicles and plug-in hybrids. A high penetration of AFVs in Ireland could be achieved by placing a ban on the sale of ICE vehicles by 2030, although this comes at a loss to the Exchequer in the form of tax forgone, as AFVs, in general, are expected to cost less than ICEs in the future and therefore to bring in less tax revenue. Putting in place such a ban would achieve an 80%+ penetration of AFVs by 2050, but this comes with an opportunity cost through tax forgone in the range of €162–170 million per year, the precise amount being

dependent on the availability of AFV models for sale. Without regulating the sales of ICEs, Ireland could still achieve a substantial market penetration through a derogation of VAT on AFVs, but this comes at a higher average opportunity cost of €826 million per year. HVO provides a viable means of producing a carbon-neutral diesel substitute, allowing for an effective “plan B” in a low-preference shift towards electrification.

Complete decarbonisation of the LCV sector in Ireland, which would contribute towards an 80% reduction in CO<sub>2</sub> emissions by 2050 relative to 1990, is technically feasible through the combination of efficiency improvements and the use of biofuels. An overall 41% reduction in CO<sub>2</sub> emissions relative to a BaU scenario is possible through improvements in the fuel economy of LCVs. To help contribute to emissions reduction in the short term, a change in the policy of taxation for LCVs, from one based on unladen weight to one based on specific emissions, would improve the fuel economy of new LCVs by 13% relative to the baseline, if the same market response is mimicked in the LCV sector as has taken place in the private car sector.

Regarding LCVs, a penetration rate of 85% for renewable NG LCVs by 2050 would contribute to an 80% CO<sub>2</sub> emissions reduction by 2050, whereas a 99% penetration rate would be required if Ireland was to source all biofuels indigenously because of a lack of availability of ethanol and bio-dimethyl ether locally. This would be achievable through a linear increase in the percentage share of CNG LCVs, from 0% in 2025 to 100% in 2045 for an 85% penetration level and an increase from 0% in 2025 to 100% in 2030 for a 99% penetration level.

Finally, regarding heavy-duty vehicles, activity is expected to treble between 2015 and 2050 in Ireland, although three main measures can be used to decouple activity growth and related emissions. Adopting policies targeting vehicle efficiency, including fuel economy standards and differentiated taxes on vehicle purchases, would ensure that all new truck sales achieve a minimum efficiency performance and that fiscal measures favour the best-performing models, pushing further improvements. Fuel economy standards for heavy-duty vehicles need to

be broadened far beyond their current application in only four countries to cover all of the heavy-duty vehicle main markets. Once heavy-duty fuel economy policies are in place, their stringency needs to be successively raised, accounting for cost reductions delivered by technological progress. Supporting widespread data collection and information sharing are key prerequisites to realising some of the potential that underlies systemic improvements in freight logistics, including the sharing of assets and services. Policymakers should take a proactive role in supporting data collection and sharing platforms by promoting closer collaboration among all stakeholders, including government, citizen groups and corporate actors operating across the supply chain. Open data protocols that protect proprietary data while enabling supply chain collaborations could unlock an operational efficiency potential of large but uncertain magnitude. Finally, promoting the deployment of alternative fuels and the vehicles that use them

requires different types of policy involvement, depending on the fuel in question (NG, biofuels, electricity or hydrogen) and the state of technological maturity. Their deployment typically requires support across four areas: research, design and development (RD&D); market uptake of AFVs; adequate access to charging or refuelling infrastructure; and the availability of alternative fuels.

Although this report has focused on the current energy-intensive sectors of transport and the potential means of decarbonising them, it is important to note that other methods of mitigation, such as transport smoothing through modal shift, have not been explored here. The results from this study stand as a starting point for mitigation options available for the Irish transport sectors from a technological and societal standpoint, but there are many other areas for potential research that can contribute towards the 2030 and 2050 ambitions of decarbonisation.

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# Abbreviations

<b>AFV</b>	Alternative fuelled vehicle
<b>AMT</b>	Annual motor tax
<b>B2DS</b>	Beyond 2°C Scenario
<b>BaU</b>	Business as usual
<b>BEV</b>	Battery electric vehicle
<b>CNG</b>	Compressed natural gas
<b>ERS</b>	Electric road system
<b>ESRI</b>	Economic and Social Research Institute
<b>ETS</b>	Emissions Trading System
<b>EU</b>	European Union
<b>GDP</b>	Gross domestic product
<b>GHG</b>	Greenhouse gas
<b>GNI</b>	Gas Networks Ireland
<b>GNP</b>	Gross national product
<b>HVO</b>	Hydrotreated vegetable oil
<b>ICE</b>	Internal combustion engine
<b>IEA</b>	International Energy Agency
<b>LCV</b>	Light commercial vehicle
<b>NG</b>	Natural gas
<b>NPV</b>	Net present value
<b>PHEV</b>	Plug-in hybrid electric vehicle
<b>RES-T</b>	Renewable energy share in transport
<b>SEAI</b>	Sustainable Energy Authority of Ireland
<b>SEC</b>	Specific energy consumption
<b>tkm</b>	Tonne-kilometres
<b>TTW</b>	Tank-to-wheel
<b>VAT</b>	Value-added tax
<b>vkkm</b>	Vehicle-kilometre
<b>VRT</b>	Vehicle registration tax
<b>VRU</b>	Vehicle Registration Unit

## Appendix 1    Consumer Choice Model Cost Assumptions

ICE tangible cost assumption in 2015 (€)	Petrol car, engine size < 1300 cc	Petrol car, engine size 1300–1700 cc	Petrol car, engine size > 1700 cc	Diesel car, engine size < 1300 cc	Diesel car, engine size 1300–1700 cc	Diesel car, engine size > 1700 cc
Capital costs excl. tax	11,512	13,542	20,296	11,319	16,322	22,002
VAT	2648	3115	4668	2603	3754	5061
VRT	2407	2998	6740	2228	3212	4871
Incentives	–	–	–	–	–	–
AMT	200	270	390	190	200	390

AFV tangible cost assumption in 2015 (€)	Plug-in hybrid car, engine size < 1300 cc	Plug-in hybrid car, engine size 1300–1700 cc	Plug-in hybrid car, engine size > 1700 cc	EV range < 125 km	EV range 125–175 km	EV range > 175 km
Capital costs excl. tax	28,525	37,414	50,054	25,656	28,245	34,204
VAT	6561	8605	11,512	5901	6496	7867
VRT	4912	6443	8619	4418	4864	5890
Incentives	7500	7500	7500	10,000	10,000	10,000
AMT	200	270	390	120	120	120

## Appendix 2 Contributions to Academia

The findings and methodology of this project have been established in collaboration with a wide range of leaders in transport energy modelling teams and, as a result, this project has generated a number of scientific publications. A list of these publications is presented here, indicating the collaborators over the course of the project.

### A2.1 Journal Papers

- Mulholland, E., O Shea, R., Murphy, J.D. and, Ó Gallachóir, B.P., 2016. Low carbon pathways for light goods vehicles in Ireland. *Research in Transportation Economics* 57: 53–62.
- Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., 2017. From technology pathways to policy roadmaps to enabling measures – a multi-model approach. *Energy* 138: 1030–1041.
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- Venturini, G., Tattini, J., Mulholland, E. and Ó Gallachóir, B.P., 2019. Improvements in the representation of behaviour in integrated energy and transport models. *International Journal of Sustainable Transport* 13: 294–313.
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*Transportation Research Part D: Transport and the Environment* 62: 584–603.

### A2.2 Book Chapter

- Tattini, J., Mulholland, E., Venturini, G., Ahanchian, M., Gargiulo, M. and Karlsson, K., 2017. Long term strategy to decarbonise the Danish transportation sector. In Giannakidis, G., Karlsson, K., Labriet, M. and Ó Gallachóir, B. (eds), *Limiting Global Warming to Well Below 2°C: Energy System Modelling and Policy Development*. Lecture Notes in Energy Vol. 64. Springer, Cham, Switzerland.

### A2.3 Conference Proceedings

- Mulholland, E., Teter, J., Cazzola, P., McDonald, Z. and Ó Gallachóir, B.P., 2017. The long haul towards decarbonising road freight – a global assessment to 2050. Paper presented at the 36th International Energy Workshop, University of Maryland, College Park, MD, 12–14 July.
- Mulholland, E., Tattini, J., Ramea, K., Yang, C. and Ó Gallachóir, B.P., 2017. The cost of electrifying transport. Poster presented at the STEPS Symposium, UC Davis, CA, 23–24 May.
- Mulholland, E., Chiodi, A., Teter, J., Cazzola, P. and Ó Gallachóir, B.P., 2016. Development of a global freight transport demand tool. Poster presented at the Energy Systems Conference, London, 14–15 June.
- Mulholland, E., Teter, J., Cazzola, P. and Ó Gallachóir, B.P., 2016. Development of a global freight transport demand tool. Paper presented at the Irish Transport Research Network Conference, Dublin, 2 September.
- Mulholland, E., O Shea, R., Murphy, J.D. and Ó Gallachóir, B.P., 2015. Low carbon pathways for light goods vehicles in Ireland. Paper presented at the Irish Transport Research Network Conference, Galway, Ireland, 27 August.
- Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., 2015. Top-down and bottom-up policy evaluation – a multi-model approach. ECEEE Summer Study, Toulon, France, 2 June.

## **A2.4 Reports**

- Teter, J., Cazzola, P., Gul, T., Mulholland, E., Le Feuvre, P., Bennet, S., Lagarde, Z., Kraayvanger, V. and Rulz, P., 2017. *The Future of Trucks – Implications for Energy and the Environment*. International Energy Agency, Paris.
- Kunze, R., Gomez, J., Keles, D., Haasz, T., Fahl, U., Dobbins, A., Fraboulet, D., Coffineau, L., Deane, P. and Mulholland, E., 2016. *Renewable Energy for Transport*. INSIGHT-E report prepared for the European Commission.

## **A2.5 Invited Talks/Presentations**

- Mulholland, E. and Ó Gallachóir, B.P., 2017, The long haul towards the decarbonisation of freight. International Council of Clean Transportation, San Francisco, CA, 20 June.
- Mulholland, E. and Ó Gallachóir, B.P., 2017. The past, present and future – an analysis of the Irish transport sector from 1900 to 2050. STEPS Seminar, University of California, Davis, Davis, CA, 22 February.
- Mulholland, E. and Ó Gallachóir, B.P., 2017. Stock Simulation Modelling in Transport. Technical University of Denmark (DTU) Transport Workshop, Copenhagen, 26 January.
- Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., 2016. Low carbon options for transport in Ireland. Scientific Advisory Council, Cork, Ireland, 13 December.
- Mulholland, E. and Ó Gallachóir, B.P., 2015. What will contribute more to emissions reduction in Ireland in 2020 – 50,000 EVs or improving the efficiency of petrol and diesel cars? Economic and Social Research Institute (ESRI)–University College Cork (UCC) Energy Research Workshop, Economic and Social Research Institute, Dublin, 9 June.
- Mulholland, E. and Ó Gallachóir, B.P., 2015. The effect of vehicle efficiency improvements and electric vehicle penetration on the energy sector in Ireland. ENVIRON 25th Annual Consortium, Institute of Technology Sligo, Ireland, 8–10 April.
- Mulholland, E., Rogan, F. and Ó Gallachóir, B.P., 2014. Soft-Linking a TIMES model and sectoral simulation model for individual policy measures. 66th Semi-annual International Energy Agency (IEA) Energy Technology Systems Analysis Program (ETSAP) Workshop, Copenhagen, 17–18 November.

**AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL**  
Tá an Gníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaoil a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaoil 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 comhlionta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.

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

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

**Ár bhFreagrachtaí**

**Ceadúnú**

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaoil:

- 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 Dhrámhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídionn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaoil.

**Bainistíocht Uisce**

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uisce idirchriosacha agus cósta na hÉireann, agus screamhuisc; 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 gComhshaoil**

- 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 Chomhshaoil 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 shainaitheint, 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 gcomhshaoil in Éirinn (*m.sh. mórfhleananna 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 gcomhshaoil ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaoil (*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 chosaint 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 inní agus le comhairle a chur ar an mBord.

# EPA Research Report 321

## Opportunities to Decarbonise the Irish Transportation Sector



Authors: Eamonn Mulholland, Fionn Rogan,  
Tomás Mac Uidhir and Brian Ó Gallachóir

### Identifying Pressures

The energy sector is responsible for 60% of Ireland's greenhouse gas (GHG) emissions. The largest contributor to Ireland's energy-related GHG emissions is the transport sector. Ireland faces mandatory targets for GHG emissions reductions in the sectors that are outside the European Union Emissions Trading System (ETS) for the periods 2013–2020 and 2021–2030. Private cars account for more than one-quarter of all energy-related non-ETS GHG emissions. The share of transport-related energy demand and, consequentially, GHG emissions have increased consistently in the past 5 years. The continued rise in transport activity, energy consumption and emissions can be attributed to economic, technological and societal factors. Therefore, a range of technoeconomic and socioeconomic analytical tools and models was developed and employed in this project to generate an evidence base that can inform decarbonisation-focused transport sector decision-taking and policymaking. This report describes the findings from these tools and models, outlining some of the options for long-term decarbonisation in the Irish transport sector, with a focus on private cars, light commercial vehicles and heavy duty vehicles (which together comprise 93% of final energy consumption in the transport sector).

### Informing Policy

The results of the research point to a series of policy recommendations. For private cars, the increased use of biofuels will be the main contributor to meeting Ireland's mandatory 2020 renewable energy in transport target of 10%. In the medium term (to 2030), Irish policy measures that incentivise the purchase of more efficient vehicles through varying tax rates should continue to be part of a portfolio of measures. In the longer term (to 2050), a key recommendation is incentivising the switch to electric vehicles. For light goods vehicles, the results point to a change in the taxation bands from the current unladen weight bands to specific carbon emissions bands. In the medium to long term, banning the sale of diesel light commercial vehicles in 2030 and encouraging the sale of biomethane-fuelled light commercial vehicles would result in a 99.6% reduction in light commercial vehicle emissions by 2050 relative to a baseline scenario (i.e. a scenario without long-term emissions reduction targets). For heavy goods vehicles, the results indicate that optimised routing, platooning, improving vehicle utilisation, back-hauling and co-loading have the potential to reduce activity by up to 36% by 2050. Adopting energy-efficient truck technologies is another key policy option with significant potential (nearly 20% GHG emissions reduction by 2050 relative to the aforementioned baseline scenario). Promoting the deployment of alternative fuels (in particular, advanced biofuels but also some electrification potential) and the trucks that use them is the final policy recommendation.

### Developing Solutions

In the short term, a biofuel obligation of approximately 13% is required to achieve the 2020 10% renewable energy share in transport (RES-T) target because of differences in energy content. Moving beyond 2020, higher levels of blending can be achieved using advanced biofuels, such as hydrotreated vegetable oil (HVO, also known as renewable diesel). The first commercial production globally of HVO was in the Whitegate Oil Refinery in Cork Harbour. In the medium to long term, the results of this research point to a shift to electric vehicles for car transport, with a number of options for light and heavy goods vehicles, with a greater focus on liquid and gaseous fuels. Imposing a ban on the sale of fossil fuel-powered vehicles, increasing the variety of available electric vehicle models and improving the public charging network are projected to contribute to a well-to-wheel emissions reduction of 56% and a reduction in final energy consumption of 48% by 2050 relative to a baseline. Promotion of conventional and advanced biofuels (biodiesel, HVO and biomethane) for deployment in the heavy duty vehicle fleet has the greatest potential reduction contribution of all measures, at 24% by 2050 relative to a baseline.