The Economic and Social Review, Vol. 54, No. 1 Spring 2023, pp. 101-121

POLICY PAPER

Population Growth: Implications for Commuting

John Curtis*
The Economic and Social Research Institute, Dublin, Department of Economics, Trinity College Dublin, SFI MaREI Centre for Energy, Climate and Marine, Ireland

Elish Kelly
The Economic and Social Research Institute, Dublin, Department of Economics, Trinity College Dublin, Institute of Labor Studies (IZA), Bonn

Abstract: Planners and public policy decision-makers face many challenges in transport services provision. This research examines the impact of spatially concentrated versus dispersed residential development on transport in terms of congestion, expenditure, and emissions. The empirical modelling uses Galway city and its surrounding hinterland as a case study and provides scenario outcomes based on several planning development assumptions. Across the scenarios examined there is relatively little difference in total CO_2 emissions from public and private transport combined, even across scenarios with quite different assumptions on the location of new housing developments. Consequently, emissions outcomes may not be a singular critical motivating factor behind such planning scenarios, though other factors such as congestion are also relevant. A critical assumption underpinning the analysis is that mode shares across spatial zones remain like those in 2016. Consequently, the analysis suggests that in addition to planning decisions impacting on the location of new residential development, to minimise the impact of commuting emissions associated with envisaged population growth by the year 2040 will necessitate substantial behavioural change in terms of commuting patterns.

Acknowledgements: This research was completed under the Joint Research Programme on Housing Economics between the ESRI and the Department of Housing, Local Government, and Heritage. The views expressed in this paper are those of the authors and they should not be regarded as an official position of the Department of Housing, Local Government and Heritage. Results are based on analysis of strictly controlled the 2016 Place of Work, School or College Census of Anonymised Records (POWSCAR) Research Microdata Files provided by the Central Statistics Office (CSO). The CSO does not take any responsibility for the views expressed or the outputs generated from this research. We would like to thank the Central Statistics Office (CSO) for providing us with access to the data. The authors are solely responsible for the content and the views expressed.

* Corresponding author: John.Curtis@esri.ie

I INTRODUCTION

Population growth presents many challenges and opportunities for planners and government. In the area of transport services, the challenges include providing sufficient public transport and addressing congestion on transport infrastructure. Furthermore, with a transport sector largely reliant on fossil fuels, accounting for one-fifth of total emissions in the case of Ireland (EPA, 2021),[1] and given the existential threat of climate change, decarbonisation of transport is a principal public policy goal (DECC, 2021).

Transport policy measures to reduce emissions generally focus on mode or technology shifting. For example, the Climate Action Plan (DECC, 2021) includes targets to increase public transport and active travel (i.e. walking, cycling) by 14 per cent by 2030, representing 500,000 additional daily sustainable journeys; and to electrify the vehicle fleet, with 945,000 electric vehicles or low emitting vehicles (LEVs) on the road by 2030. An implicit assumption with mode and technology shifting policies is that they relate to the transport behaviours of the existing population, but a growing population implies new or additional levels of transport service demand. An opportunity exists that these new journeys become sustainable from the outset. A growing population, and possibly a younger population, may have stronger views towards sustainable transport options. What is particularly relevant in this context is that the location of population growth will impact on the nature of transport services required. Depending on whether population growth is concentrated in urban centres or follows more dispersed patterns will impact on several aspects of transport services (e.g. travel time, congestion, and emissions). While the primary focus of transport policy will be mode or technology shifting among the existing population, given that an additional one million people are likely to be living in Ireland by 2040 (DHPLG, 2018), roughly 20 per cent above 2016 levels, long-term planning can play a prominent role in delivering sustainable transport outcomes.

The National Planning Framework (NPF) is the Irish Government's high-level strategic plan for shaping the future growth and development of the country out to the year 2040 (DHPLG, 2018). Among the strategic outcomes envisaged within the framework are compact growth, which entails consolidating growth in urban areas, and sustainable mobility free of combustion engine driven transport systems. Given this, the objective of this paper is to demonstrate, using Galway city and its surrounding hinterland as a case study, the relative scale of the impact of concentrated versus dispersed new residential development on transport, in terms of congestion, expenditure and emissions. Such analysis will provide greater

[1] 20.4 per cent in 2019 but declining to 17.9 per cent in 2020 attributable to COVID-19 pandemic lockdowns.

support for decisions surrounding development plans, land zoning and planning decisions.

II LITERATURE REVIEW

The link between housing location and travel has been well established in the literature, mostly finding that bringing housing, workplaces, and retail locations closer together reduces travel. Cervero and Duncan (2006, p.488) are unequivocal when then say that:

> there is little ambiguity in our findings: linking jobs and housing holds significant potential to reduce vehicle miles travelled and vehicle hours travelled.

Furthermore, they suggest that having plentiful jobs within four miles of home substantially reduces travel time and distance. But travel patterns are constantly evolving, with Hickman and Banister (2015) finding distinct travel behaviour patterns across cohorts of residents over time. Two findings of relevance here are that households in rural locations increase their average journey length and energy consumption over time, while households in locations with good public transport accessibility reduce their average journey length and energy consumption. Engebretsen *et al*. (2018) also note the heterogeneity of travel patterns and suggest that it is strongly context dependent and associated with urban structural characteristics (e.g. city size, population, public transport). Overall, Engebretsen *et al*. (2018) find strong support for polices of urban densification as a planning strategy to curb the growth in urban motoring. In an Irish context, Murphy (2012) investigates this issue of employment and housing locations for Dublin city using a linear programming methodology leading to several conclusions and policy recommendations. These include targeting a decentralisation of employment locations to aid future development, which would aid the sustainability of public transport networks. A more significant finding is a recognition of the radically different travel patterns between peak and off-peak periods and that land-use and transport planning should give greater consideration to the off-peak period. More recently, Carroll and O'Sullivan (2020) examine the potential impacts on Dublin city in the context of NPF and National Development Plan investment spending. They find that only relatively small journey time savings are likely except for public transport modes, and conclude that more ambition is needed to improve the accessibility and level of service of public and active transport modes.

There is also evidence that the scope for using the planning process (i.e. to decide where new residential units are built) to influence commuting behaviour may be waning. Elldér (2014) examined commuting patterns across two decades in Sweden and finds a growing variation in the home-work distance for workers living in the same neighbourhoods. Better transport infrastructure may have enabled longer commuting distances, though commuting travel time was not examined. Elldér (2014) concludes that spatial planning is a necessary but not sufficient measure to reduce congestion and promote sustainability.

Separate from the issue of the association between residential location and commuting distance there is also the relationship with mode choice. The obvious relationship is that in the absence of public transport options, car dependency is high. However, more generally, Lunke *et al*. (2021) find a strong relationship between public transport modal shares and travel time ratios (i.e. the relative travel time between car and public transport). Travel time by car tends to be lower than that of public transport or cycling, except for destinations closer to the city centre where density is higher (Lunke *et al*., 2021; Liao *et al*., 2020; Saunier and Chabin, 2020). In addition to efficient relative travel times, if public transport options do not have direct routes or few transfers, and high service frequencies, modal share is significantly reduced (Lunke *et al*., 2021). Paid parking also has a substantial impact on mode choice (Pritchard and Frøyen, 2019).

An important consideration often overlooked in transport policy is the impact of commuting on wellbeing. Shorter commutes are associated with increased job satisfaction, increased leisure time satisfaction and improved mental health (Clarke *et al*., 2020; Chatterjee *et al*., 2020). Among the recommendations to improve wellbeing are policies to encourage a greater range of housing, work and transport options, as well as policies to lessen the need for long duration commutes (Chatterjee *et al*., 2020). While transport polices will invariably attempt to reduce commuting times, public planning frameworks are also critically important to delivering sustainable transport options.

Motivated by the extensive numbers working from home during the COVID-19 pandemic, several recent studies have considered the impact of working from home on commuting. Some research findings are consistent with conventional wisdom, including that traffic congestion eases and travel times drop due to increased working from home, plus there is a switch in housing demand from the urban core to periphery locations (Delventhal *et al*., 2021; O'Keefe *et al*., 2016). However, several studies cast doubt on the widely held view that working from home saves energy. O'Brien and Aliabadi (2020) review 33 studies that quantify the environmental effects of working from home, alternatively termed teleworking. They conclude that while many studies indicate some benefit in terms of energy use and greenhouse gas emissions, several suggest working from home is associated with energy rebound effects including within the home (e.g. for heating, etc.) but also for transport. In a study based on UK data, Cerqueira *et al*. (2020) find that working from home is associated with longer average commuting distances and higher CO_2 emissions, as those working from home tend to reside in locations remote from workplaces. The research by Cerqueira *et al*. (2020) and others is based on pre-COVID-19 data and reflects small numbers working from home, approximately 6 per cent of workers. Therefore, the results might not be representative of a more extensive switch to working from home but nonetheless it mirrors the conclusion from O'Brien and Aliabadi (2020) that the question of net energy use from switching to working from home is complex.

Modelling the complexities of urban commuting patterns, including mode choice, has a long history. Development of integrated land use-transport (LU-T) models commenced in the 1950s. Among the most prominent models internationally is UrbanSim, which simulates the development of land parcels and the decisions of households and firms over time (Waddell, 2002). The framework underlying LU-T models about where people choose to live and work revolves around the trade-off between commuting and housing costs. For example, inadequate housing supply drives up rents, which is associated with longer commutes (Ahrens and Lyons, 2021). However, such models are rarely applied at detailed geographic scales due to the complexity of the interactions and the required resolution of supporting data. Instead, models are more likely to be available at the regional or country level. It is also worth noting that while transport factors, such as commuting distance or public transport access, are among the issues considered in deciding choice of resident location (including in LU-T models), often the transport element is a minor part of locational decisions which represents a challenge for transport policy (Hickman and Banister, 2015).

Within Ireland the National Transport Authority maintains a suite of regional transport models, that forecast future year transport demand based upon population and employment scenarios and assigns it to networks and services.[2] The models are used as a planning tool to support policymakers and planners especially in the appraisal of major transport infrastructure projects. The models have been less useful in the appraisal of policy mechanisms that either indirectly impact on transport decisions or attempt to change behaviours. Counterfactual or scenario analysis is more commonly used in such circumstances internationally, as the data and modelling capacity is less intense. Examples include assessing the impact of bicycle highways on commuter mode choice (Rayaprolu *et al*., 2020); the impact of city growth on commuting patterns (Marini *et al*., 2019); or the impact of planning initiatives on commuting patterns (Yang, 2020). A counterfactual scenario approach is undertaken here to examine residential development planning decisions on transport.

The evolution of commuting patterns occurs within the context of national and regional plans and regulations, not just related to transport, but also spatial planning. In the context of Galway these include a county development plan (Galway Co.Co., 2022), a Galway City development plan (Galway City Council, 2017), as well as local and national transport policies (NTA, 2018; Department of Transport, 2009).

[2] For further details see https://www.nationaltransport.ie/planning-and-investment/transport-modelling/.

III METHODS

To demonstrate the impact of concentrated versus dispersed new residential development on transport congestion, expenditure and emissions we develop a partial equilibrium scenario analysis based around some of the policy objectives within the National Planning Framework (NPF) (DHPLG, 2018). We use Galway city and its hinterlands as a case study to demonstrate how new settlement patterns impact transport outcomes. Galway is among one of four cities that is envisaged within the NPF to grow by at least 50 per cent by 2040, which is a population increase of up to 45,000 people. National Policy Objective 3b of the NPF aims to deliver at least half of the associated new homes within the existing built-up footprint of the city. In the case study Galway was not chosen to be representative of cities and towns across Ireland, rather the case study is to illustrate the impacts of residential development decisions. Each town and city will have their own unique circumstances that impact on future development plans, including factors such as geography or public transport infrastructure.

We examine several scenarios surrounding the geographical dispersion of an additional 45,000 population within 50km of Galway city. Without a detailed land use-transport model for Galway, we utilise data from the 2016 Census, including commuting information, to model potential commuting behaviours to Galway city. We divide Galway and its hinterland into zones based on distance to the city centre (0-18km, 18-35km, 35-50km) and a six-way urban/rural classification developed by the Central Statistics Office (CSO, 2019). A full definition of the urban/rural classification is outlined in CSO (2019) and is summarised in Table 1.

Table 1: Urban/Rural Classification

Urban/rural classification	*Definition*
Cities	Towns/settlements with populations greater than 50,000 – using Census 2016 definitions/breakdowns.
Satellite Urban Towns	Towns/settlements with populations between 1,500 and 49,999, where 20 per cent or more of the usually resident employed population's workplace address is in 'Cities'.
Independent urban towns	Towns/settlements with populations between 1,500 and 49,999, where less than 20 per cent of the usually resident employed population's workplace address is in 'Cities'.
Rural areas with high urban influence	Rural areas (i.e. a population less than 1,500 persons, as per Census 2016) are allocated to one of three sub-categories, based on their dependence on urban areas, as defined by weighted percentages working in each category of urban area.
Rural areas with moderate urban influence	
Highly rural/remote areas	

Source: CSO (2019).

IV DATA

The primary data source is the 2016 Place of Work, School or College Census of Anonymised Records (POWSCAR) microdata file, which is derived from the Census of Population. There were 4.76 million individuals and 1.76 million households enumerated in the 2016 Census. POWSCAR is a subset of the census data file comprising all workers resident in Ireland and all resident students aged 5 and upwards. The POWSCAR data file contains demographic and socio-economic characteristics of these residents along with information on the origin and destination of their journeys to places of work or education. There are 3.05 million individuals in the 2016 POWSCAR microdata file of which 200,872 reside within 50km of Galway city, or specifically within the CSO's small area administrative boundaries that fall either in full or in part within 50km of Galway city.

The main underlying assumption of the scenario analysis is that new residents within the distance and urban/rural category zones will commute to Galway city following the same patterns of existing residents within these zones, both by proportion of commuters to Galway city and mode of transport based on the data reported in Table 2 and Table 3. A significant limitation of this assumption is that new residents in these zones do not deviate from the mean 2016 commuting behaviour. Behavioural responses to changes in fuel prices, carbon taxes and public transport options are not incorporated. The analysis is not intended to forecast future commuting behaviour, rather illustrate outcomes without behavioural response. While there are 200,872 workers and students living within 50km of Galway city, only 60,117 are recorded as commuting to Galway city. The balance of commuters work and study in locations outside of Galway city. While there are 51,283 workers and students living within Galway city, 34,712 also work and study within the city with the balance travelling outside the city. Two-thirds of workers and students commute by private car either as driver or passenger. Active travel modes (bicycle, foot) is the next most popular commuting method at over 20 per cent of commuters, with just 10 per cent of commuters travelling by public transport into Galway city.

4.1 Congestion, Expenditure and Emissions

Traffic congestion metrics are challenging, as congestion depends on time and location. For this paper a simpler approach is taken. Aggregate commuting time is reported for each scenario, which illustrates how development location can impact on congestion. Average commuting times are taken from POWSCAR with a summary of times reported in Table 4. The average commuting time to Galway city from within Galway city is 18 minutes, slightly faster for car drivers at 17 minutes and slowest for public transport users at 28 minutes. Across the other modes and origin locations reported in Table 4 average commuting time exceeds 50 minutes. In general, commuting by public transport takes the longest time regardless of commuters' origin, either in terms of urban/rural location or distance from the city.

Table 2: Worker and Student Population Within 50km Galway City and Commuters to Galway City

	Worker and student population living within:				*Commuters to Galway city from:*			
	0-18km	*18-35km*	*35-50km*	*Total*	*0-18km*	*18-35km*	*35-50km*	*Total*
Galway city	51,283	0	0	51,283	34,712	0	0	34,712
Satellite town	8,996	8,493	0	17,489	3,292	1,326	0	4,618
Independent town	0	1,847	19,074	20,921	0	236	491	727
Rural: high urban influence	31,561	22,856	9,918	64,335	10,733	4,653	803	16,189
Rural: moderate urban influence	1,987	8,657	17,871	28,515	389	1,119	1,195	2,703
Rural: remote	493	6,632	11,204	18,329	41	571	556	1,168
Total	94,320	48,485	58,067	200,872	49,167	7,905	3,045	60,117

Source: Based on 2016 POWSCAR microdata.

Table 3: Commuters to Galway City – by Mode

	Unknown	*Foot/ Bike*	*Bus/ Train*	*Car/ Motorbike*	*Car Passenger*	*Van/ Lorry*	*Total*
Galway city	367	11,688	3,624	11,816	6,875	342	34,712
Satellite town	34	125	561	3,212	597	89	4,618
Independent town	2	91	109	473	30	22	727
Rural: high urban influence	96	301	1,339	11,678	2,255	520	16,189
Rural: moderate urban influence	19	184	262	1,921	215	102	2,703
Rural: remote	18	138	122	755	86	50	1,168
Total	536	12,526	6,017	29,855	10,058	1,125	60,117
Total %	0.9%	20.8%	10.0%	49.7%	16.7%	1.9%	100.0%

Source: Based on the 2016 POWSCAR microdata.

The highest mean commuting time at 67 minutes is by public transport from independent towns 35-50km from Galway city.

Table 4: Average Travel Time by Mode to Galway City Centre, Minutes

From:		*Bus/ Train*	*Car/ Motorbike*	*Car Passenger*	*All modes*
Galway city	0-18km	28	17	16	18
Satellite Town	0-18km	33	26	26	27
	18-35km	52	41	38	41
Independent Town	18-35km	55	44	43	45
	35-50km	67	59	61	53
Rural: High Urban Influence	0-18km	37	30	28	30
	18-35km	48	40	41	40
	35-50km	59	50	49	48
Rural: Moderate Urban Influence	0-18km	42	40	34	39
	18-35km	51	47	44	46
	35-50km	58	53	56	50
Rural: Remote	0-18km	33	51	-	48
	18-35km	60	50	54	48
	35-50km	62	58	56	51

Source: Based on the 2016 POWSCAR microdata.

Fuel consumption and emissions are calculated based on mean distance travelled, with the calculations based on commuters that are either car drivers or use public transport. Car passengers are excluded from these calculations to avoid double counting. Across diesel and petrol an assumed average of 4.75 litres of fuel is consumed per 100km distance (SEAI, 2020 p.74). Conversion factors to calculate associated emissions are also sourced from SEAI.[3] Public transport emission factors are based on the simple average of values for three types of Irish commuter bus at 18.7 gCO_2 per passenger kilometre (Walsh *et al*., 2008, Table 2).

The purpose of calculating fuel expenditure is to illustrate how various planning strategies for new residential locations can impact on transport outcomes. The use of future price forecasts would be preferable, as the expenditure will be realised in the future, but is outside the scope of the analysis. Diesel and petrol prices may be quite volatile into the future and therefore forecasts will subject to substantial error. For simplicity we use an average fuel price of €1.68/litre from November 2021.

4.2 Scenarios

Five scenarios are developed for the analysis, which vary in the spatial location of where the additional population will reside in the hinterland of Galway city. NPA

[3] See https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/.

(2018) envisages up to 45,000 additional population residing in the wider Galway area by 2040, and up to 50 per cent within the built-up footprint of the city. The scenarios are summarised in Table 5. Scenarios C and D assume 50 per cent of the additional population will reside within Galway city but differ in the distribution of the balance of population growth across town and rural areas. The other scenarios diverge from the NPF target. Scenario A is an extreme case and assumes all new residents live outside Galway city. Scenario B assumes the additional population follows the same spatial distribution as the POWSCAR/Census 2016 data, which entails 26 per cent of the additional 45,000 population residing within the built-up footprint of Galway city. The NPF target is exceeded in scenario E with 70 per cent in Galway city, 20 per cent in towns and 10 per cent in rural areas. A variant of each scenario that incorporates a large-scale switch to 'working from home' compared to the situation in 2016 is also included. For these working from home variants, we assume that, on average, commuters will work from home for two days each week. While the ability to work from home will differ by sector and job function, factors that are not incorporated into the analysis, the broad assumption of an average of two days will illustrate the potential impact of remote working on transport outcomes.

Table 5: Scenarios of the Residential Location of 45,000 Additional Population in the Galway Area

Scenario	*Residential locations of the 45,000 additional population*
A	Across all zones except Galway city in relative proportions to POWSCAR/Census 2016 (0% in Galway city)
B	Across all zones in same proportion as POWSCAR/Census 2016 (26% in Galway city).
C	50% in Galway city, 50% in towns and rural areas in relative proportion to POWSCAR/Census 2016
D	50% in Galway city, 25% in towns and 25% in rural areas in relative proportion to POWSCAR/Census 2016
E	70% in Galway city, 20% in towns and 10% in rural areas in relative proportion to POWSCAR/Census 2016

Source: Authors' analysis.

V RESULTS

The analysis is presented in two parts, the first of which comprises the outputs of the scenarios described above. We subsequently present multiple regression analysis of commuters into Galway city based on the 2016 data, which provides insights into the characteristics of commuters across the distance and urban/rural category zones.

5.1 Scenarios

Table 6 reports the scenario outcomes and for reference also includes the calculations for all existing commuters to Galway city in the first row. Of the 60,117 commuters into Galway city, 6,017 commuted by public transport, with 29,855 driving by private car. Car commuters emit an estimated 25,856 tonnes of CO_2 per annum, which on a per commuter basis is over seven times that of public transport commuters.

The proportion of commuters that commute into Galway city varies substantially across the zones described earlier, ranging between 3 per cent and 68 per cent, which are implicit in Table 2. The proportion of commuters that commute into Galway city generally declines as distance from the city increases. This reflects that people generally seek to live close to their work location, though the extent to which that is feasible depends on budget constraints and other preferences. In completing an analysis of the impact of the location of new residential development on commuting behaviour, assumptions are necessary on employment location, for which we take two approaches. First, we assume that there is no link between housing and work/school locations and that a constant proportion of commuters commute into Galway city across all zones. We assume a rate of 30 per cent, which is the overall commuter rate into Galway city (see Table 2), which is reflected in 13,500 additional commuters into Galway city in each of the scenarios A-E. The modal shares by zone differ so the number of public transport and car commuters differ slightly between scenarios, as reported across scenarios A-E in Table 3.

Moving through the scenarios from A to E, the proportion of the additional population living in Galway city increases (0 per cent in scenario A to 70 per cent in scenario E) and while the number of commuters is constant across scenarios (i.e. 13,500), the number reliant on the car declines. This reflects the fact that mode share for car (drivers only) in Galway city is roughly half that of other zones. The aggregate times spent commuting and total CO_2 emissions under scenario E are less than half those of scenario A. This is a clear illustration of how concentrating new development in the urban core has the potential to reduce the environmental impact of commuting in terms of lower emissions, reduced congestion (as reflected in aggregate commuting time), and lower fuel costs. It should be noted that given the methodological approach, fuel expenditure is proportional to emissions from private cars at a fixed rate of €652/tCO_2.

As noted in the literature earlier (e.g. Cervero and Duncan, 2006), the choices of residential and workplace locations are not independent. Scenarios A-E assume that people living 35-50km from Galway will commute into Galway city at the same rates as those living within Galway city, which is a relatively extreme assumption. Our second approach to deciding workplace locations is that we assume commuting into Galway city declines with distance based on the rates implicit in Table 2. In summary, 52 per cent of commuters within 0-18km of Galway city commute to work or education in Galway city, with the rate falling to 16 per cent in the 18-35km range, and to 5 per cent in the 35-50km range. This assumption is implemented in scenarios A*-E*. To illustrate the difference, in both scenario A and A*, it is assumed that 3,370 of the additional 45,000 population will reside in remote rural areas 35-50km distance from Galway city. Of these additional inhabitants, 1,011 are assumed to commute into Galway city in scenario A, whereas in scenario A* just 167 are assumed to commute into Galway city. Overall, in scenario A*, which assumes that none of the additional population resides in the built-up area of Galway city, the total number of commuters into Galway is just 7,642. Moving through the scenarios A* to E*, the total number of commuters into Galway city increases from 7,642 to 23,386. In scenario E* 52 per cent of commuters travel into Galway city with the balance commuting elsewhere, whereas in scenario A* it is just 17 per cent. While there are three times as many commuters into Galway city in scenario E* versus A*, emissions, congestion, and fuel costs are all lower. Comparing E* to A* the higher commuter numbers are offset by a lower average commuting distance. Like the prior set of scenarios, A*-E* illustrate how concentrating new development in the urban core has the potential to reduce the environmental impact of commuting.

What is clear across the two sets of scenarios is that where people live depends on where they work, or vice versa. This is reflected in the POWSCAR data by a lower share of commuters into Galway city from more distant locations. Therefore, implicit within the scenarios presented is that there will be matching job growth within Galway city.

The COVID-19 pandemic accelerated the move to increased levels of remote working, which is facilitated by improved broadband service and other technological developments. How remote working, or working from home, is likely to impact on future commuting patterns is still an open question. The potential impact of working from home is incorporated into the analysis by assuming an average of two days working from home (i.e. two days not commuting into Galway city). In practice this is reflected in outcomes (i.e. commuters, emissions, etc.) being 60 per cent of the scenarios without the working from home assumption, but are explicitly reported to illustrate its potentially large impact on commuting outcomes. In Table 6 these scenarios are reported with a suffix '-wfh'.

The share of electric vehicles (EV) in the car market is likely to grow considerably in the coming years following motorists' preferences for low carbon alternatives and subsidy support. Pillai *et al.* (2022) illustrate how existing technology EVs can adequately accommodate driving needs of almost 0.5 million Irish motorists without battery range anxiety concerns. In the coming years the prevalence of EVs among commuters is likely to increase considerably. In the context of the scenarios developed here, the primary impact will be on the emissions estimates, as exhaust emissions will cease. In a commuting context the growth of EVs is likely to result in a change in vehicle fuel composition rather than vehicle numbers.

Table 6: Scenarios of Commuter Activity

Scenario		*Public transport*				*Private cars*		
	Additional commuters	*Commuters*	*CO_2, tonnes*	*Commuting time, hours*	*Commuters*	*CO_2 tonnes ,*	*Commuting time, hours*	*Fuel costs, €m*
2016[1]	60,117	6,017	694	3,484	29,855	25,856	14,329	16.9
A[2]	13,500	1,433	369	1,263	9,367	14,991	6,801	9.8
B	13,500	1,427	303	1,111	8,149	11,784	5,406	7.7
C	13,500	1,421	239	964	6,981	8,711	4,069	5.7
D	13,500	1,502	266	1,056	6,903	8,787	4,065	5.7
E	13,500	1,498	214	937	5,947	6,276	2,972	4.1
A*[3]	7,642	720	124	534	5,427	5,898	3,277	3.8
B*	13,468	1,348	155	780	6,688	5,792	3,210	3.8
C*	19,051	1,950	186	1,017	7,897	5,691	3,146	3.7
D*	18,825	1,961	187	1,024	7,716	5,433	3,001	3.5
E*	23,386	2,453	211	1,218	8,702	5,347	2,947	3.5
A*-wfh	4,585	432	74	320	3,256	3,539	1,966	2.3
B*-wfh	8,081	809	93	468	4,013	3,475	1,926	2.3
C*-wfh	11,430	1,170	111	610	4,738	3,414	1,888	2.2
D*-wfh	11,295	1,176	112	614	4,630	3,260	1,801	2.1
E*-wfh	14,031	1,472	127	731	5,221	3,208	1,768	2.1

Source: Authors' calculations.
Notes: [1] The first row of the table is based on all commuters to Galway city in 2016. The remaining rows are based on scenarios of 45,000 additional population dispersed geographically within 50km of Galway and a subset of which commute into Galway city.
[2] The first set of scenario results (A-E) assume a constant 30 per cent of commuters commute into Galway city across all geographic zones.
[3] The second set of scenario results (A*-E*) assume commuting rates into Galway city vary across zones equivalent to the POWSCAR/Census 2016 data: 52 per cent in 0-18km range but differing by urban/rural category, 16 per cent in 18-35km, and 5 per cent in 35-50km category.

The scenarios with -wfh suffix assume that on average commuters work two days from home and the reported figures are 60 per cent of the values of the scenarios A*-E* in the previous five rows.

5.2 Commuter Composition: Regression Analysis

In Table 7 we examine the characteristics of those that commuted into Galway city for work/study in 2016. This analysis is undertaken using binary logistic regression, in which our dependent variable takes the value of 1 for those that commuted into the city for work/study and zero for those that commuted elsewhere. The results presented in Table 7, also known as odds ratios, give the change in the log odds of an individual commuting into the city for work/study for a one unit increase in each of the explanatory variables. If the reported odds ratio is above 1 (e.g. 1.448), this implies that an individual with the relevant characteristic (e.g. third-level education) has higher odds (i.e. 45 percentage points higher) of commuting into Galway city relative to the reference category (second-level education or lower), while characteristics with an odds ratio of less than 1 imply a lower odds.

Focussing on age first, we see that all the older age categories are less likely to commute into Galway city compared to the reference category of those between ages 5–24. People aged 25–54 are approximately half as likely to commute into Galway city compared to the reference category. Comparison across age categories is possible by taking the ratio of odds ratios with, for example, those aged 65+ about one-third as likely to commute into Galway city as 55–64-year-olds (0.450/0.157=0.349).

Those with a third-level qualification or higher have higher odds of travelling into Galway city for work/study compared to those with a qualification at second-level or lower (1.448 compared to 1.0). In relation to household composition, compared to those that are single, all other household types (i.e. lone parent, couples with and without children) have higher odds of commuting into Galway city for work/study, with the highest odds ratios being reported by couples with no children (1.193). Controlling for residential tenure we see that those in rental accommodation are 0.84 times as likely to commute into Galway city compared to those living in properties owned by the occupants.

After controlling for these main socio-demographic variables, the key variables of interest are the interaction of the variables related to commuting distance and urban/rural category zones. Odds ratios for these are also reported in Table 7 where the reference category is commuters that live within Galway city (i.e. urban/rural zone is Cities and commuting distance is 0-18km). The odds of commuting into Galway city are lower in all the other distance and urban/rural combinations. Residents in satellite towns within 0-18km are 0.25 times as likely to commute into Galway as the reference category. The odds drop to between 0.07 and 0.08 for residents in towns in the 18-35km range, whether defined as satellite or independent town. Residents in rural areas with a high urban influence have broadly similar commuting odds as those living in satellite urban towns. The odds of commuting from rural areas declines as the level of urban influence wanes, even within areas relatively proximate to Galway city (i.e. 0-18km distance).

The odds ratios are reported relative to the reference category of Cities within 0-18km of Galway city, i.e. Galway city. Odds ratios relative to other reference categories can be recovered by taking the ratio of the odds reported in Table 7. Across the distance and urban/rural category zones there are nine categories with a rural categorisation. With a few obvious exceptions (e.g. Highly rural/remote areas in the 0-18km and 18-35km zones) the odds of commuting to Galway city

Table 7: Logistic Regression Commuting into Galway City

	Odds ratios	*Standard error*	
Age (reference: 5-24)			
25-54	0.545***	(0.013)	
55-64	0.450***	(0.014)	
65+	0.157***	(0.009)	
Education (reference: NFQ 1-6)			
Third level or higher (NFQ 7-10)	1.448***	(0.023)	
Other	0.535***	(0.014)	
Household composition (reference: Single)			
Lone parent with resident children	1.140***	(0.036)	
Couple with resident children	1.031		(0.028)
Couple without resident children	1.193***	(0.036)	
Other	1.135***	(0.035)	
Tenure (reference: owned, incl. with mortgage)			
Rented	0.841***	(0.013)	
Other	0.553***	(0.017)	
Constant	2.018***	(0.062)	
Cities	*0-18km Reference*	*18-35km n.a.*	*35-50km n.a.*
Satellite urban towns	0.253*** (0.006)	0.086*** (0.003)	n.a.
Independent urban towns	n.a.	0.071*** (0.005)	0.012*** (0.001)
Rural areas with high urban influence	0.228*** (0.004)	0.114*** (0.002)	0.039*** (0.002)
Rural areas with moderate urban influence	0.107*** (0.006)	0.067*** (0.002)	0.032*** (0.001)
Highly rural/remote areas	0.042*** (0.007)	0.043*** (0.002)	0.024*** (0.001)

Source: Authors' calculations.
Note: Standard errors in parenthesis; *** $p<0.01$, ** $p<0.05$, * $p<0.1$ and relate to tests of difference from 1.

from most rural category pairs statistically differ from each other. Of the 36 possible rural/distance pairs, the odds of commuting into Galway city are statistically different from each other in 31 cases ($p<0.05$). While no test of causality is implied, there is not a homogeneous commuting pattern into Galway city from rural areas, with differences across the CSO's urban/rural classification, as well as by distance from the city centre.

VI DISCUSSION

The scenarios are intended to be illustrative of commuting impacts of residential planning decisions. Commuting activity and behaviour is the confluence of many areas of society and the economy, including the labour market, enterprise development, the residential property market, cultural and individual preferences. To develop forecasts of future commuting patterns would require research and modelling across all these areas. The scenario analysis presented here is intended to be a broad-brush estimate of the scale of commuting impacts associated with residential planning decisions.

What is clear from the process of developing the scenarios is that the commuting impacts associated with residential planning decisions cannot be considered in the absence of the location of employment growth, i.e. where will people be commuting to? Employment growth is likely to occur at a greater scale in the larger urban centres, which likely underpins the NPF's population growth targets for the four larger cities in the country and the objective to deliver at least half of the associated new homes within the existing built-up footprint of those cities. Within these cities the locations of employment growth and new residential locations will impact on transport outcomes. As noted earlier, Cervero and Duncan (2006) suggest that having concentrations of jobs within four miles of residential locations is a critical threshold for reducing commuting time and distance. To improve commuting outcomes this means that focusing development of new residential locations within existing built-up footprints might not be sufficient, as location of housing relative to employment centres may also be critical.

The two sets of scenarios, A-E and A*-E*, clearly illustrate the benefit of new housing developments being close to Galway city centre, at least for the people that commute to work or education within Galway city. Scenarios C* and D* are consistent with the NPF objectives, whereas scenario B* assumed residential development with the same spatial distribution as existing development within the wider city hinterland. These NPF scenarios assume a 40 per cent higher number of commuters into Galway city, with greater numbers using public transport. While there is a 15-18 per cent increase in the number of car commuters also, as their average commuting distance is lower, total associated CO_2 emissions are slightly lower compared to B*.

It is worthwhile restating that the proportion of commuters that commute into Galway city declines rapidly with distance. At 0-18km distance, 52 per cent of commuters commute into Galway city, declining to 16 per cent at 18-35km, and to 5 per cent at 35-50km. It is not clear from these statistics that a policy to discourage residential development further away from Galway city would improve overall commuting outcomes for Galway city, as most commuters beyond 18km from Galway city do not commute into the city.

The scenarios are based on constant modal shares based on 2016 data, which are not likely to hold true in the longer term. For instance, active travel modes are being strongly encouraged at present, with citizen engagement being the primary driver. However, a large-scale switch to public transport modes will necessitate strong infrastructural investment to deliver high frequency, time efficient services with direct routes or few transfers (Lunke *et al*., 2021). The availability of zero or low-cost parking also has a substantial impact on model choice (Pritchard and Frøyen, 2019). Analysis by Systra (2021) suggests the removal of free employee workplace parking spaces in Galway city could reduce car trips by 5 per cent and commuting times by up to 12 per cent.

Across the scenarios considered, the trend on impact of residential location on commuting is clear. But these scenarios represent quite dramatic differences in residential planning policy, from 0 per cent additional population in Galway city in scenario A to 70 per cent of the additional population in Galway city in scenario E. When the changes in planning targets are more modest, the associated impact on transport outcomes are quite small. For example, switching from scenario B* to scenario C* entails moving from 26 per cent of the additional population residing in Galway city to 50 per cent; there is just a 2 per cent reduction in CO_2 emissions from private car commuting from 5,792 tCO_2 to 5,691 tCO_2. The link between residential planning and commuting outcomes is complex and what this example shows is that even quite substantial changes in planning policy may have relatively small outcomes on commuting.

The greatest sustainable transport outcomes in the scenarios considered are associated with mode switching and working from home. The 29 per cent reduction in emissions from car commuting between scenario D and E is largely attributable to mode switching. In scenario D, 6,750 commuters to Galway city reside in Galway city. In scenario E that increases to 9,450, which reflects a 20 percentage point increase in population allocated to the city. In Galway city the mode share in private cars at 34 per cent is approximately half that of other zones. While residential planning influences where new homes are built and indirectly influences modal choice, it has much less impact on mode choice among the existing population. Working from home, as illustrated in the scenarios in Table 6, has the potential to make large-scale impact on commuting outcomes. The added attractiveness of this as a transport policy measure is that it is associated with negligible transport investment costs. However, there is no consensus in the literature that working from home is unambiguously associated with reduced energy use and greenhouse gas emissions (O'Brien *et al*., 2020). While there are potential benefits from a transport congestion perspective, there are energy rebound effects associated with working from home in heating, as well as transport. The latter arises because trips that might not have occurred previously due to commuting become feasible when working from home, such as school pickups or family errands. The question of net energy use from switching to working from home is complex and needs additional analysis that is beyond the scope of this study.

The regression analysis shows how commuting into Galway varies by both socio-demographic characteristics and spatial factors. What is clear is that a higher likelihood of commuting into Galway is associated with certain individual attributes (e.g. educational attainment) as well as proximity to Galway. The more distant or remote from the city, the lower the likelihood of commuting into Galway city. The same statistic also says that the more distant or remote from the city the higher the likelihood of commuting to workplaces or schools beyond Galway city. Rather than asking in the first instance where new residential developments should be located, instead the key issue is whether there will be sufficient housing within the primary commuting hinterland of employment growth hotspots, whether within Galway city or county.

VII CONCLUSION

The likelihood of commuting to a location for work or education declines as distance increases and is widely reflected in empirical analyses. Underlying this headline metric is a complex web of interactions and behaviours which, as discussed earlier, are also evolving over time as technology, infrastructures and the population change. What is evident from the scenarios is that the location of residential development is just one, albeit important, aspect of commuting outcomes. Mode choice is equally relevant. The literature is clear that the key to minimising commuting times and distance is the relative co-location of jobs and homes, but commuting is just one element of a wider decision set relevant for home location choices.

The objective of the research is to demonstrate the relative scale of the impact of concentrated versus dispersed new residential development on transport, in terms of congestion, expenditure, and emissions. Across the scenarios presented (A*-E*) with growing levels of residential development concentrated in Galway city, the number of public transport commuters increases more than three-fold with associated CO_2 emissions increasing less than two-fold. This can be advocated as a benefit of concentrating residential development within existing urban areas. In the same scenarios the number of commuters by private car increases 1.6-fold, although emissions from private cars decline by 10 per cent. The planning rules implicit in the two scenarios A* and E* are quite different. In A* zero per cent of the additional population resides in Galway city (i.e. no new homes), whereas in E*, 70 per cent of the additional population is in Galway city. Either scenario may have high levels of support from different stakeholders but the absolute difference in CO_2 emissions across the two scenarios (public and private transport) is relatively small and consequently there is little case for motivating such a policy solely from an emissions perspective. When comparing the same number of commuters (i.e. in scenarios A and E versus A* and E*) both total commuting time and total emissions decline by more than half, which is clear evidence that planning decisions can have a large impact. Whether these savings in commuting time and emissions are realisable will depend on behavioural responses, particularly with respect to mode choice.

The scenarios developed rely on the assumption that the commuting behaviours of the additional 45,000 commuters will not deviate from the mean 2016 commuting behaviour. In practice this is not a defensible assumption, but extensive additional research is necessary to enable adequate modelling of future preferences related to mode choice, residential location, and employment opportunities. Nonetheless, the scenarios do illustrate potential outcomes absent substantial behavioural response.

While the paper's objective is to demonstrate the relative scale of the impact of concentrated versus dispersed new residential development on transport outcomes, the analysis shows that the factor likely to have the greatest impact on transport outcomes is working from home. Planning decisions on new residential development will impact on commuting outcomes, but policy and supports to encourage working from home have the potential to make a markedly greater impact.

REFERENCES

Ahrens, A. and S. Lyons, 2021. "Do rising rents lead to longer commutes? A gravity model of commuting flows in Ireland", *Urban Studies*, 58(2):264-279. https://doi.org/10.1177/0042098020910698.

Carroll, P. and P. O'Sullivan, 2020. "Forecasting the impact of the Planning, Land Use and Transport Outlook (PLUTO) Project–a 2040 Ireland case study", *Transportation Research Procedia*, *49*, 70-82. https://doi.org/10.1016/j.trpro.2020.09.007.

Cerqueira, E.D.V., B. Motte-Baumvol, L.B. Chevallier and O. Bonin, 2020. "Does working from home reduce CO2 emissions? an analysis of travel patterns as dictated by workplaces", *Transportation Research Part D: Transport and Environment*, 83:102338. https://doi.org/10.1016/j.trd.2020.102338.

Cervero, R. and M. Duncan, 2006. "Which reduces vehicle travel more: jobs-housing balance or retail-housing mixing?", *Journal of the American Planning Association*, 72(4):475-490. https://doi.org/10.1080/01944360608976767.

Chatterjee, K., S. Chng, B. Clark, A. Davis, J. De Vos, D. Ettema, S. Handy, A. Martin and. L. Reardon, 2020. "Commuting and wellbeing: a critical overview of the literature with implications for policy and future research", *Transport Reviews*, 40(1):5-34. https://doi.org/10.1080/01441647.2019.1649317.

Clark, B., K. Chatterjee, A. Martin and A. Davis, 2020. "How commuting affects subjective wellbeing", *Transportation*, 47(6):2777–2805. https://doi.org/10.1007/s11116-019-09983-9.

CSO, 2019. *Urban and Rural Life in Ireland 2019*. Central Statistics Office. https://www.cso.ie/en/releasesandpublications/ep/purli/urbanandrurallifeinireland2019/.

DECC, 2021. *Climate Action Plan 2021 — Securing Our Future*. Department of Environment, Climate and Communications. https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/.

Delventhal, M.J., E. Kwon and A. Parkhomenko, 2021. "JUE insight: How do cities change when we work from home?", *Journal of Urban Economics*, p. 103331. https://doi.org/10.1016/j.jue.2021.103331.

Department of Transport, 2009. *Smarter Travel–A Sustainable Transport Future – A New Transport Policy for Ireland 2009-2020*, Department of Transport, https://assets.gov.ie/19854/37d829c9748446349ff586045bfbcaba.pdf.

DHPLG, 2018. *Project Ireland 2040 – National Planning Framework*. Department of Housing, Planning and Local Government. https://npf.ie/project-ireland-2040-national-planning-framework/.

Elldér, E., 2014. "Commuting choices and residential built environments in Sweden, 1990–2010: a multilevel analysis", *Urban Geography*, 35(5):715-734. http://dx.doi.org/10.1080/02723638.2014.916906.

Engebretsen, Ø., P. Næss and A. Strand, 2018. "Residential location, workplace location and car driving in four Norwegian cities", *European Planning Studies*, 26(10), 2036-2057.

EPA, 2021. *Ireland's Provisional Greenhouse Gas Emissions 1990-2020*. Environmental Protection Agency. https://bit.ly/3kuEBiH.

Galway City Council, 2017. "Galway City Council Development Plan 2017-2023", https://www.galwaycity.ie/development-plan-downloads-2017.

Galway County Council, 2022. "Galway County Development Plan 2022-2028", https://consult.galway.ie/en/consultation/adopted-galway-county-development-plan-2022-2028.

Hickman, R. and D. Banister, 2015. "New household location and the commute to work: Changes over time", in *Handbook on Transport and Development*. Edward Elgar Publishing. https://doi.org/10.4337/9780857937261.00011.

Liao, Y., J. Gil, R.H. Pereira, S. Yeh and V. Verendel, 2020. "Disparities in travel times between car and transit: Spatiotemporal patterns in cities", *Scientific reports*, 10(1):1-12. https://doi.org/10.1038/s41598-020-61077-0.

Lunke, E.B., N. Fearnley and J. Aarhaug, 2021. "Public transport competitiveness vs. the car: impact of relative journey time and service attributes", *Research in Transportation Economics*, p.101098. https://doi.org/10.1016/j.retrec.2021.101098.

Marini, M., A.P. Gawlikowska, A. Rossi, N. Chokani, H. Klumpner and R.S. Abhari, 2019. "The impact of future cities on commuting patterns: An agent-based approach", *Environment and Planning B: Urban Analytics and City Science*, 46(6):1079-1096. https://doi.org/10.1177/2399808317751145.

Murphy, E., 2012. "Urban spatial location advantage: The dual of the transportation problem and its implications for land-use and transport planning", *Transportation research part A: policy and practice*, *46*(1), 91-101. https://doi.org/10.1016/j.tra.2011.09.017.

NTA, 2018. "Local Link Rural Transport Programme Strategic Plan 2018-2022", National Transport Authority, https://www.nationaltransport.ie/wp-content/uploads/2020/10/ll_rural-transport-programme_online.pdf.

O'Brien, W. and F.Y. Aliabadi, 2020. "Does telecommuting save energy? a critical review of quantitative studies and their research methods", *Energy and Buildings*, p. 110298. https://doi.org/10.1016/j.enbuild.2020.110298.

O'Keefe, P., B. Caulfield, W. Brazil and P. White, 2016. "The impacts of telecommuting in Dublin", *Research in Transportation Economics*, 57:13-20. http://dx.doi.org/10.1016/j.retrec.2016.06.010.

Pillai, A., J. Curtis and M.A.T. Reaños, 2022. "Spatial scenarios of potential electric vehicle adopters in Ireland", *Case Studies on Transport Policy*, 10(1), 93-104.

Pritchard, R. and Y. Frøyen, 2019. "Location, location, relocation: how the relocation of offices from suburbs to the inner city impacts commuting on foot and by bike", *European Transport Research Review*, 11(1):1-20. https://doi.org/10.1186/s12544-019-0348-6.

Rayaprolu, H.S., C. Llorca and R. Moeckel, 2020. "Impact of bicycle highways on commuter mode choice: A scenario analysis", *Environment and Planning B: Urban Analytics and City Science*, 47(4):662-677. https://doi.org/10.1177/2399808318797334.

Saunier, N. and V. Chabin, 2020. "Should I bike or should I drive? Comparative analysis of travel speeds in Montreal", *Transport Findings*, p. 11900. https://doi.org/10.32866/001c.11900.

SEAI, 2020. *Energy in Ireland, 2020 report*. Sustainable Energy Authority of Ireland. https://www.seai.ie/publications/Energy-in-Ireland-2020.pdf.

Systra, 2021. *Five Cities Demand Management Study Recommendations Report Phase Two Updates November 2021*. Government of Ireland. https://assets.gov.ie/205399/270ba219-4693-48b1-bef4-7a36e9126c85.pdf.

Waddell, P., 2002. "UrbanSim: Modeling urban development for land use, transportation, and environmental planning", *Journal of the American Planning Association*, 68(3):297-314. https://doi.org/10.1080/01944360208976274.

Walsh, C., P. Jakeman, R. Moles and B. O'Regan, 2008. "A comparison of carbon dioxide emissions associated with motorised transport modes and cycling in Ireland", *Transportation Research Part D: Transport and Environment*, 13(6):392-399. https://doi.org/10.1016/j.trd.2008.07.002.

Yang, T., 2020. "Understanding commuting patterns and changes: Counterfactual analysis in a planning support framework", *Environment and Planning B: Urban Analytics and City Science*, 47(8):1440-1455. https://doi.org/10.1177/2399808320924433.