

Investigating the link between carbon dioxide emissions and transport-related social exclusion in rural Northern Ireland

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Received: 18 April 2014/Revised: 8 January 2015/Accepted: 27 January 2015/Published online: 17 February 2015
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Abstract Carbon dioxide (CO₂) is considered the most harmful of the greenhouse gases. Despite policy efforts, transport is the only sector experiencing an increase in the level of CO₂ emissions and thereby possesses a major threat to sustainable development. In contrast, a reduced level of mobility has been associated with an increasing risk of being socially excluded. However, despite being the two key elements in transport policy, little effort has so far been made to investigate the links between CO₂ emissions and social exclusion. This research contributes to this gap by analysing data from 157 weekly activity-travel diaries collected in rural Northern Ireland. CO₂ emission levels were calculated using average speed models for different modes of transport. Regression analyses were then conducted to identify the socio-spatial patterns associated with these CO₂ emissions, mode choice behaviour, and patterns of participation in activities. This research found that despite emitting a higher level of CO₂, groups in rural areas possess the risk of being socially excluded due to their higher levels of mobility.

Keywords Activity participation · Carbon dioxide (CO₂) emissions · Northern Ireland · Sustainable transport · Sustainable development · Transport disadvantage · Travel behaviour

Introduction

Two policy themes that have featured heavily in UK transport strategy include the reduction in greenhouse gas emissions and the reduction in transport-related social exclusion (Department for Transport 2011; Department of the Environment Transport and the Region 1998). The first theme has been influenced by the need to meet the global policy agenda requirements such as the 1997 Kyoto protocol (Chapman 2007; Loo and Li 2012), whereas the UK has played a leading role in developing policy responses to transport disadvantage and social exclusion (Currie et al. 2009). Despite the intensity of research on both themes, little effort so far has been made to explore the interplay between these two key policy areas (Begg and Gray 2004; Rassafi and Vaziri 2005). An understanding of this relationship is an important first step to the development of future policy responses such as downstream carbon permit trading in the personal road transport sector, which has the potential, for example, to allocate carbon permits without forcing groups/individuals into immobility (Fawcett 2010; Wadud et al. 2008).

According to the Climate Change Act 2008, the UK government is committed to a reduction of 80 % greenhouse gases on the 1990 levels by 2050 (Committee on Climate Change 2008). In addition, it has set three intermediate carbon budgets for 2008–2012, 2013–2017, and 2018–2022, and in May 2011, the coalition government committed the UK to further radical reductions for the fourth budget period 2023–2027. More specific targets have been set for transport sector, which include a 26 % reduction (relative to 2008) by 2020 and 44 % by 2030 (Committee on Climate Change 2010). Carbon dioxide (CO₂) is considered the most harmful amongst the greenhouse gases (e.g. carbon dioxide, nitrous oxide, water

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vapour, methane) in terms of the contribution to global climate change that would be essentially irreversible (Brand and Preston 2010; Nocera et al. 2012; Simpson 2006; Solomon et al. 2009). Road transport alone produces about 28 % of CO₂ in UK (Department for Transport 2010a), and 12 % of global CO₂ is produced from the personal road transport sector and is the only sector in which this trend is increasing (Anable et al. 2012; Meyer et al. 2007; Simpson 2006; Wadud et al. 2008). As a result, the reduction in CO₂ emissions from the transport sector has been identified as a major challenge to these targets being met (Chapman 2007; Fudge and Peters 2011).

Although the reduction in car use has been highlighted as a means to reduce CO₂ emissions from personal travel, the car is considered a lifeline for those living in rural areas due to the declining nature of both public transport services and locally available goods and services (Banister 2008b; Farrington et al. 1998; Gray et al. 2006; Higgs and White 2000; McDonagh 2006; Moseley 1979; Nutley 1985, 1986; Shucksmith and Chapman 1998; Shucksmith and Philip 2000). In Northern Ireland (NI), for example, 78 % of individuals who live in urban areas have a bus stop within 6-min walking distance from their home in comparison with 49 % in rural areas. Only 5 % of individuals have train stations within 26-min walking distance from their home in rural areas, whereas this is 35 % in urban areas (Department for Regional Development 2008). This suggests that rural dwellers are structurally dependent on the car (Ahern and Hine 2012; Howarth and Polyviou 2012; McDonagh 2006; Shergold and Parkhurst 2012). Therefore, the question remains as to what extent any carbon reduction policy will be socially sustainable in rural areas. In addition, despite the contemporaneous nature of the transformative shift to low carbon mobility, very little has been published academically from a socio-economic perspective, with the research literature to date tending to focus on technical challenges and solutions (Berkeley and Jarvis 2012).

This research aims to: first, identify socio-spatial patterns of CO₂ emissions in rural areas; second, examine the travel behaviour patterns of low CO₂ emitters in order to understand why certain groups emit a lower level of CO₂ and why others do not; and third, assess the extent to which any CO₂ reduction policies could be implemented without forcing groups into being at risk of social exclusion. This research was conducted in three rural areas of NI (i.e. Doagh, Moira, and Saintfield), using weekly activity-travel diary data collected in 2009–2010 from a representative sample. A detailed review of the literature on the concept of transport-related social exclusion, CO₂ emissions reduction policies, and the methods used to measure CO₂ emissions is conducted in “[Materials and methods](#)” section. It also highlights the methodological limitations

associated with measuring the concept of transport-related social exclusion and also the challenges of making assessments of the link between travel choices and the measurements of CO₂ emissions. “[Methods](#)” section also discusses the methodology used to derive: a) CO₂ emission levels from personal travel, based on eight different modes; b) an individual’s mode choice behaviour; and c) their level of participation in society (activity patterns). “[Results and discussion](#)” section presents the results of such analyses. The impacts of alternative land use patterns in reducing CO₂ emission levels were also investigated by selecting three case study areas with differential levels of area accessibility and area mobility options in this research. Based on study findings, “[Conclusion](#)” section discusses their implications in policy terms and presents the conclusions from this research.

Materials and methods

Literature review

Personal travel and CO₂ emissions reduction policies

A multiplicity of factors can influence the level of CO₂ emissions from personal road transport such as fuel efficiency/economy (e.g. kilometres driven per litre), emission standard of fuels (e.g. amount of carbon content within a litre of fuel), travelled distance (e.g. the longer people drive, the more fuel they consume and consequently emit more CO₂), and chosen mode of transport (e.g. car emits higher per capita emissions compared to public transport). These factors have been classified as technological efficiency (e.g. the first two factors) and human travel behaviour (e.g. the last two factors) categories in the literature (Anable et al. 2012; Ketelaer et al. 2014). Policy efforts to date have sought to target both categories in order to reduce CO₂ emissions from road transport.

The European Union considers that the development of new technologies provides the main possibility for reducing transport emissions (Torres and Pinho 2011). Evidence is slowly becoming available that technological efficiency (e.g. new vehicle, fuel economy) has stagnated/slowed down the rate of CO₂ emissions in many European and US cities (Schipper 2011). More importantly, technological changes are easy to implement because these are often regulated by national/international bodies (Garren et al. 2011). At the same time, a shift to low carbon mobility presents societal challenges. Policy makers need to ensure that the transformative shift already underway does not exclude sections of society less able to afford new technologies entering the market, particularly in the short to medium term when their cost is high (Berkeley and Jarvis

2012). Wells (2012) has highlighted that within regions the privileges accorded to those owning and using electric vehicles will further exacerbate mobility disadvantage for those excluded from ownership or use.

Despite the technological improvements, numerous studies have found that CO₂ emissions from personal road transport are increasing and which are driven by changes in travel behaviour including high car dependency, declining levels of private car occupancy, increases in per capita trip rates, and longer motorised trip distances (e.g. vehicle kilometres travel—VKT) (Darido et al. 2014; O’Mahony et al. 2012). Consequently, various studies have argued in favour of behavioural shift policy measures indicating that technology has very little to do because an increasing technological efficiency means more people will be attracted to use it and also people will be using it more (Anable et al. 2012; Chapman 2007; Wadud et al. 2008). For example, Kelly et al. (2009) have shown that newer cars produced a higher share of CO₂ emissions than older cars in the vehicle fleet in Ireland between 2000 and 2005. Similarly, Marques et al. (2012) have shown that the recent reduction in CO₂ emissions through dieselisation has been surpassed by the increased kilometres driven in Europe. Consequently, a growing urgency in policy circles on the need for more effective strategies to reduce carbon emissions has seen the development of a stronger focus on behaviour change in the UK (Fudge and Peters 2011). For example, the UK Government’s Community Action 2020—Together We Can encapsulated the increased focus on behaviour change, and in this regard, a Framework for Behaviour Change has also been developed (HM Government 2005). The Department for Environment, Food and Rural Affairs has also published a Pro-Environmental Behaviours Framework in this regard (DEFRA 2008).

Policy interventions aimed at a behavioural shift towards low carbon mobility has been classified into push (e.g. travel behavioural changes by reducing the attractiveness of the car through higher taxes) and pull (e.g. travel behavioural changes by improving the attractiveness of public transport services by lowering fares and designing walkable roads) measures (Yigitcanlar and Kamruzzaman 2014). These measures are again classified as soft or psychological (e.g. campaign, individualised travel planning, teleworking, and car pooling) and hard/structural (i.e. modification in infrastructure or legislation—congestion charging) interventions (Department for Transport 2009). Although the effectiveness of such interventions has been assessed in various contexts, they are sporadic in nature (Avineri and Waygood 2013; Department for Transport 2004, 2009).

Research has shown that following the implementation of a number of soft-policy options in three UK towns between 2004 and 2009, car travel was reduced by 9 % and

the use of more sustainable transport options increased substantially—i.e. bus 10–22, cycling 26–30, and walking 10–13 % (Department for Transport 2010b). In addition to these soft measures, research has also highlighted the need for hard (physical) measures such as the allocation of land uses according to the needs of travellers (Frank et al. 2000; Santos et al. 2010). This is due to the fact that travel is a derived demand and the location of available opportunities will shape the demand for travelling (Banister 2008a). However, research findings to date are contradictory in nature. Wang et al. (2014) found that changing urban form between 2000 and 2009 significantly impacted on commuting CO₂ emission levels in Beijing. In contrast, Brand and Preston (2010) did not find any significant relationship between CO₂ emissions and land use patterns or household locations in the UK context. Little is known about the socio-spatial patterns of CO₂ emissions from personal travel and in turn which policy interventions can be targeted to encourage more behavioural change (Anable et al. 2012; Brand and Boardman 2008; Brand and Preston 2010; Frank et al. 2000). This is particularly true in rural areas despite the rate of car use being higher and longer distance trips being made when compared to urban trips¹ (Department for Regional Development 2008; NISRA 2001). This means that per capita CO₂ emissions are much higher in rural areas (Brand et al. 2013), and as a result, rural areas deserve more policy attention in order to meet the stated targets and also to reduce spatial disparities in the CO₂ emissions level (Glaeser and Kahn 2010; Tian et al. 2012).

Measures of CO₂ emissions from road transport

The methodology used to calculate CO₂ emissions from road transport can broadly be classified into aggregate (top-down) and disaggregate (bottom-up) measures (Garren et al. 2011; Kok et al. 2011; Li 2011). Our review shows that most studies to date have used the aggregate measures in which CO₂ emissions from road transport are calculated for a geographic area (e.g. country, state, city, and municipalities). Within aggregate measures, three approaches to estimate CO₂ emissions have commonly been used and included: (a) fuel consumption, (b) vehicle registration, and (c) travel distance method (e.g. VKT) (Kennedy 2010). The

¹ For instance, the 2012 National Travel Survey data show that 45 % households in London (or 20 % in small/medium towns) have no car, whereas this is only 9 % in rural areas. 52 % of the households in rural areas own two or more cars in comparison with 16 % in London (or 34 % in small/medium towns). In addition, although both urban and rural households made almost an equal number of trips (983 per person per year), 78 % of the trips were made by using the car in rural areas compared to 40 % in London (or 66 % in small/medium towns) and also the average journey length is much higher in rural areas (9.7 miles in rural areas versus 4.6 miles in London (or 7.2 miles in small/medium towns).



fuel consumption method is usually used for larger geographic areas (e.g. nation, state). In this method, total CO₂ emissions are calculated based on total sales of fuel (different types) in a geographic area and their associated emission factors. A weakness of this method is the assumption that all fuels sold within a geographic area are also consumed within that area, and therefore, the method may produce a misleading result for smaller geographic areas. As a way forward, the vehicle registration method is used to calculate CO₂ emissions for smaller geographic areas (e.g. municipalities). This method, first, calculates the total CO₂ emissions for a larger geographic area (e.g. state) using the fuel consumption method. Then, the total emissions are proportionately scaled down based on the percentage of registered vehicles which reside within the smaller areas. The third method calculates CO₂ emissions based on total distance travelled (e.g. VKT) by all individuals living in a particular area. This is the most widely used method because of the availability of VKT data for local areas. In this method, the VKT data are used to estimate total fuel consumption based on a nationally averaged fuel economy value for different modes of transport (cars and/or trucks). Total fuel consumption is then converted into a total CO₂ emissions level based on the emission factor of specific fuel type.

Andrews (2008) has simplified the VKT method by generating a weighted total fuel economy factor for all modes (e.g. car and light trucks). In this method, the mode-specific weights were generated based on modal split (e.g. proportion of trips made by different modes). In addition, this method has not taken into account fuel-specific emission factors for the calculation of CO₂ emissions. Some researchers have, however, differentiated total VKT based on nationally averaged driving conditions such as highway driving (45 %) and city driving (55 %). A specific fuel economy is then applied to each condition in order to calculate the total fuel consumption within a geographic area. This uniform differentiation of driving condition for all geographic areas has also been criticised in the literature, particularly in areas with a mismatched share of highways and urban roads. In response, Garren et al. (2011) developed a local condition methodology that takes into account the actual VKTs of urban areas and highway conditions for different areas. In the absence of real VKT data, researchers have also used different modelling techniques (e.g. regression, gravity, simulation) to estimate VKT and consequently CO₂ emissions within an area (see, for example, Wang et al. 2014).

Whilst the aggregate approaches are useful for devising top-down policy measures, they provide little evidence on how these measures will impact on individuals who are at risk of being excluded from society due to immobility—an issue that has been far less well researched (Lucas and

Jones 2012). In addition, O'Mahony et al. (2012) have highlighted that an understanding of the factors behind CO₂ emissions (why some groups emit more than others) is essential to formulating climate change mitigation policy and the development of applicable targets. As a result, researchers have started using disaggregate measures in order to understand the complexity and patterns of CO₂ emissions associated with personal travel. The use of household travel survey data (HTSD) has been identified as the most effective way of modelling the complexity of CO₂ emissions in these studies (see Brand and Preston 2010; Darido et al. 2014; Ko et al. 2011; Mathez et al. 2013).

Ko et al. (2011) have identified groups of high CO₂ emitters in the Seoul Metropolitan Area using the 2006 HTSD. This work used published emission factor data as used in Japan and calculated CO₂ emission levels for passenger car, taxi, bus, and subway. This work reported that the top 10 % of emitters in Seoul were responsible for 63 % of emissions with adult males being the largest emitters in the city (3.9 kg/day). Using the characteristics of the last trip made (mode, distance, speed) to McGill University and associated emission factors, Mathez et al. (2013) identified socio-temporal patterns of CO₂ emitters. The study then used these identified patterns and generated a number of CO₂ emission scenarios (e.g. what if all drivers switch to transit). McNamara and Caulfield (2011) calculated CO₂ emissions of commuting trips based on VKT and emission factors by mode in Dublin. This work then examined the impact of introducing a 20 % CO₂ reduction cap on national average emissions and identified commuters who are above the cap likely to drive to work over long distances, have dependent children in their household, and own more than one car. Using disaggregate measures, Brand and Preston (2010) found groups that potentially emit a lower level of CO₂ include those on low income, are of non-working occupational status, older in age, and without their own cars.

The evidence from above studies shows that a number of factors are important in the calculation of CO₂ emissions from personal travel including the choice of travel mode, distance travelled (VKT), carbon content in fuel (e.g. fuel type), fuel economy, driving condition. Despite the development of various models (see Boulter et al. 2007 for a review), most of the disaggregate studies have used the average speed model to calculate CO₂ emissions. A number of software tools have also been developed over the years to calculate emission levels based on the average speed models including MEET (Methodologies for Estimating air pollutants Emissions from Transport), COPERT (Computer Programme to Calculate Emissions from Road Transport), NAEI (National Atmospheric Emissions Inventory), and ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) (see



Barlow and Boulter 2009; Ntziachristos and Samaras 2009). Most of the disaggregate studies have, however, overlooked many of the above factors that may potentially contribute to CO₂ emissions—probably for the reason of simplification. Research has shown that CO₂ emissions can be generated in two different ways from road transport hot exhaust emissions when any vehicle operates at normal temperature and cold start emissions when a vehicle starts after certain period of rest (Boulter et al. 2007; Joumard and Andre 1990; Ntziachristos and Samaras 2009; Tchepel et al. 2012).

Measures of transport-related social exclusion

Social exclusion is a process, the key outcome of which is a lack of participation in daily activities (Burchardt et al. 1999, 2002). Studies have found evidence which indicates that transport plays a central role in this process as it enables people to reach essential opportunities (Currie and Stanley 2008; Hine and Mitchell 2003; Social Exclusion Unit 2003). Accessibility planning has been advocated as a key policy tool aimed at reducing transport-related social exclusion in the UK (Cass et al. 2005; Currie and Stanley 2008; Department for Transport 2006). A recent study has examined the impacts of different accessibility planning initiatives in the UK and found differential levels of impacts (from providing a “degree of access to basic services” to “life changing”) and that has directly contributed to the promotion of social inclusion (Kilby and Smith 2012). Consequently, this study has advocated that “accessibility planning can and should be recognised as key to localism” in the recent changing policy context of accessibility planning (p. 34). Other policy initiatives with a significant impact in reducing transport-related social exclusion are the concessionary fare schemes for younger and older age people (Jones et al. 2013).

An assessment of transport-related social exclusion generally follows a two-step process: first, an identification of transport disadvantaged groups/areas that possess a lower level of accessibility and/or mobility and generally referred to as transport disadvantaged and second, an evaluation of the nature of exclusion or non-participation of the identified disadvantaged groups (Kamruzzaman and Hine 2011). Although some of the studies have used a quantitative technique to identify transport disadvantage, a majority have used qualitative data (e.g. focus groups, interviews) to identify the nature of exclusion or non-participation in activities. As a result, the evidence presented in these studies is inadequate for assessing the relationship between CO₂ emissions and social exclusion. Church et al. (2000) have mentioned that in the absence of an objective

assessment, qualitative investigation will provide only a limited appreciation of the extent of transport-related social exclusion.

Traditionally used measures to identify transport disadvantage are aggregated in nature such as service deprivation measure within the multiple deprivation-based measures and accessibility planning approach within the many local transport plans in the UK (Department for Communities and Local Government 2008; NISRA 2005; Scottish Executive 2006; Welsh Assembly Government 2008). Despite its usefulness, studies have highlighted a number of weaknesses to this approach in identifying transport disadvantage. Methodology has been identified as one of these barriers, particularly where it has been unable to identify people’s actual patterns of travel and participation in activities (Department for Transport 2006; Lucas 2006). The policy challenge therefore relates to the ability to identify those groups and individuals in society who face transport disadvantage in order to address their needs, because both transport and opportunities remain unequal both within and between areas (Hine and Mitchell 2003; Hodge et al. 2002; Knowles 2006). This suggests the need for a more disaggregated approach in the identification of transport disadvantage as well as their non-participation in activities.

Various groups have been identified in the literature that possess the risk of being excluded from society due to their immobility and included low incomes, elderly, unemployed, disabled, women with children, non-car-owning households (Hine and Mitchell 2001; Kamruzzaman and Hine 2011; Social Exclusion Unit 2003). Most of these groups have also been identified as the low CO₂ emitters in various geographic contexts. However, most of these studies have been conducted in urban areas. The patterns of transport disadvantage and CO₂ emissions could be distinctly different in the context of rural areas. For example, Shergold and Parkhurst (2012) found that car availability is not a strong indicator of overall inclusion in rural England. In contrast, as shown earlier (see footnote 1), car-owning individuals are likely to drive more in rural areas and have different CO₂ emission levels. Therefore, a critical assessment is necessary to identify the linkage between CO₂ emissions levels and social exclusion in rural areas so that the social impacts and distributional effects of any future policy decision aimed at reducing CO₂ emissions can be evaluated (Gough 2013; Lucas and Jones 2012; Wadud et al. 2008; Wells 2012). This issue has clearly been acknowledged in NI which has stated that “sustainable transport may mean different things in urban and rural areas—one policy does not fit all” (Northern Ireland Assembly 2011).



Methods

Data

The NI government committed to reduce CO₂ emissions in order to meet the targets as set out in the UK Climate Change Act 2008 (Northern Ireland Assembly 2011). The government has also recognised that the challenge to sustainable transport is more severe in NI compared to other parts of the UK due to greater levels of rural driving and consequently a relatively higher level of emissions per capita. The Northern Irish government has undertaken a series of policy initiatives aimed at reducing CO₂ emissions levels including attitudinal change towards sustainable transport, utilisation of more sustainable transport technologies, investment in public transport, and investment in rural roads. The latter is seen as being important because the government recognises that public transport services are not available at all times, and therefore, the reliance on private car is inevitable. Many of these policy options have also been echoed in other policy documents aimed at reducing transport-related social exclusion in NI (Department for Regional Development 2001, 2002, 2005). The question, however, remains as to what extent these unique policies contribute to CO₂ reduction and reductions in transport-related social exclusion. This issue was investigated in this research using individual level activity-travel data collected during the summer of 2009 and 2010 through an activity-travel diary survey from three case study areas located in rural NI: Moira, Saintfield and Doagh (Fig. 1). The three case study areas were selected using differential levels of area accessibility and area mobility criteria:

- Moira: A self-contained village (in terms of locally available opportunities) located within walking distance from the motorway and train station but located away from urban areas.
- Saintfield: A self-contained village located away from the motorway, train station, and urban areas.
- Doagh: Not a self-contained village, located away from the motorway and train station, but located close to urban areas (e.g. Ballyclare).

Respondents for the activity-travel survey were selected from those in the sample who took part in a questionnaire survey conducted in an earlier phase of this research and those who provided consent for their participation in the activity-travel survey. Although 85, 77, and 96 respondents provided consent; 45, 62, and 50 activity-travel diaries were collected from Moira, Saintfield, and Doagh, respectively (an average return rate of 60 %). Therefore, a total of 157 activity-travel diaries were analysed in this research. Details about sampling, survey design

framework, and the representativeness of the sample to the wider population have been published elsewhere and are not discussed here in detail (Hine et al. 2012; Kamruzzaman and Hine 2011). These diaries contained a seven consecutive days of out-of-home travel and the activity details of respondents including trip origin, trip destination, trip start time, trip end time, trip day, trip purpose, travel mode, and roads/routes travelled for 3,057 individual trips. Respondents' socio-economic data were collected through the questionnaire survey and were used as the explanatory variables to identify differences in the levels of CO₂ emission, travel behaviour, and activity participation (outcome variables) in this research (Table 1). Due to area accessibility and area mobility differences between the case study areas, an individual living area profile was also used as a spatial explanatory variable (rural form) in this research in order to model contextual influence on the outcomes. Note also that originally the research was designed to investigate transport-related social exclusion in rural NI with no intention to analyse CO₂ emissions patterns. Consequently, the datasets do not necessarily contain all the factors to precisely derive CO₂ emissions level data. The data in this paper, however, do represent a serious attempt to calculate CO₂ emissions and explore the linkages with patterns of travel behaviour.

Calculation of CO₂ emissions

This research derived both hot exhaust and cold start CO₂ emissions. The average speed model was used to calculate hot exhaust CO₂ emissions level for each trip in this research. An analysis of the collected data shows that individuals used eight different modes in the 7 days surveyed (Table 2). Individuals' reported trip origin, trip destination, and travelled routes were geo-referenced, and consequently, trip distances were derived. Travel time associated with each trip was derived by subtracting trip start time from trip end time. Using the trip distances and travel times, average travel speed (km/h) for each trip was also derived. Stop over times between trips were calculated by subtracting the trip end time of a trip from the trip start time of the subsequent trip.

Equation 1 was used to calculate hot exhaust CO₂ emissions level for each trip (Ntziachristos and Samaras 2009). We have restricted the equation by excluding the engine size and fuel type factors due to limitations in our dataset.

$$E_{\text{HOT};i,j,k,n}(\text{g}) = e_{\text{HOT};i,j,k,n}(\text{gm}/\text{mode} - \text{km}) \times \text{trip distance}(\text{km}) \quad (1)$$

where E_{HOT} = hot exhaust emissions (in gram) of trip i ; using transport mode j , driving condition k , and emission

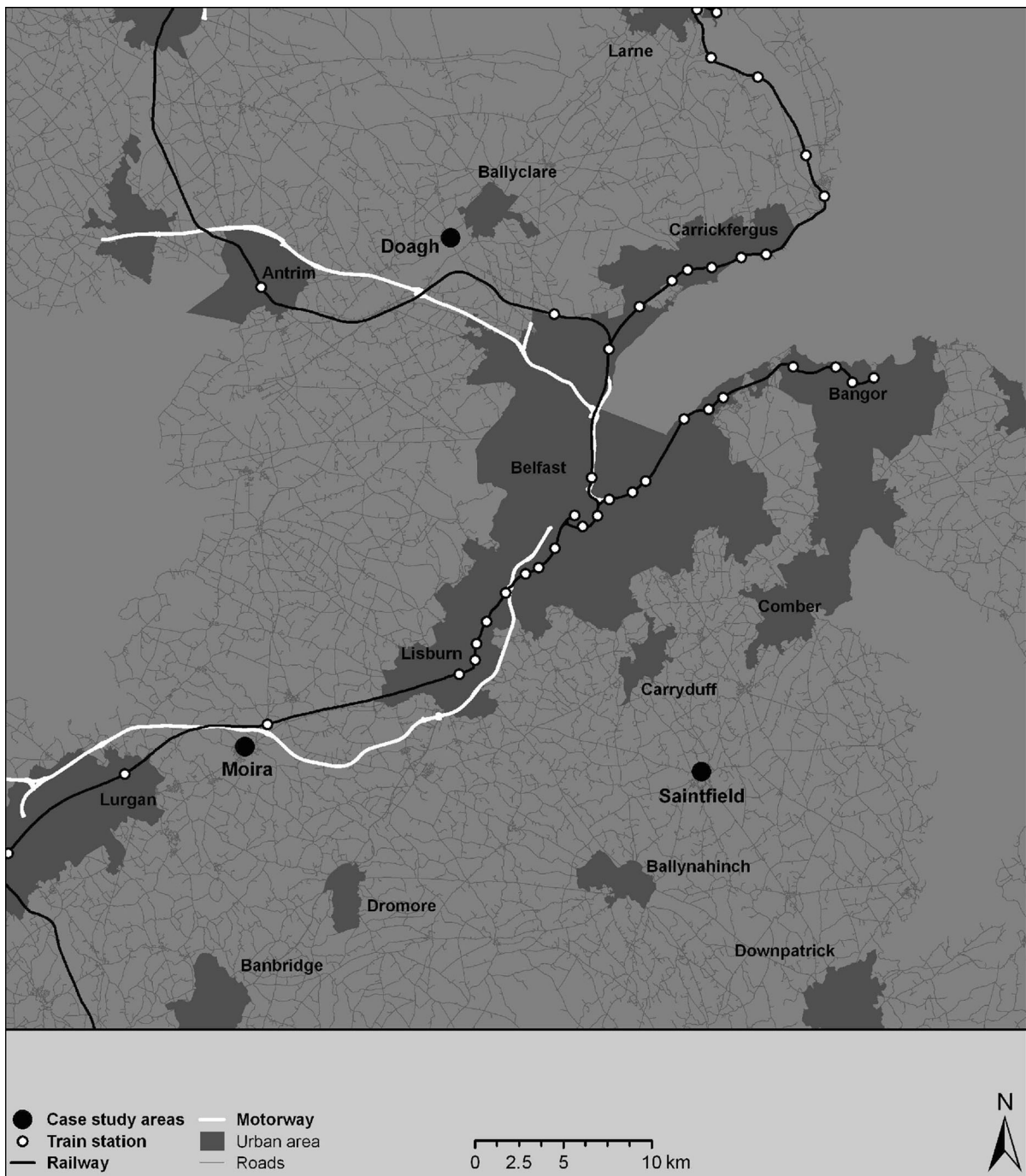


Fig. 1 Location of the case study areas in wider geographic context in Northern Ireland

standard n ; and e_{HOT} = associated emission factor under these conditions.

Therefore, E_{HOT} scores were calculated for each of the 3,057 trips separately. The associated emission factor (e_{HOT}) of each trip was selected based on its characteristics (e.g. mode, driving condition) from published sources (Boulter et al. 2009; Brand 2005; Ntziachristos and Samaras 2009). The driving conditions of each trip

made by respondents were classified into either urban, or rural, or motorway based on the derived average speed of that trip.² The associated emission factors for bus trips were divided by 10—given that the average occupancy of

² Urban < 40 km/h, 40 km/h ≤ rural < 77 km/h, motorway > 77 km/h. These standards were also found to be consistent with the speed limit proposed in the different types of road networks in Northern Ireland.

Table 1 Variables used in the empirical modelling and their definitions

Variable names	Coded categories and definition	Variable used as in the model	Statistical model used for analysis
Area profile	1 = Moira (good area accessibility and area mobility options); 2 = Saintfield (good area accessibility and poor area mobility); 3 = Doagh (poor area accessibility and poor area mobility)	Explanatory	–
Gender	1 = Male; 2 = Female	Explanatory	–
No. of car	Number of car in household	Explanatory	–
Income	1 = Low income (income level below the average income of rural NI); 2 = High income (income level above the average income of rural NI)	Explanatory	–
Age	1 = Young (18–59 years); 2 = Older (60 years and above)	Explanatory	–
Occupation	1 = Working (full/part time employed, business); 2 = Non-working (retired, unemployed, household management, student)	Explanatory	–
Home ownership	1 = Household owning a house; 2 = otherwise	Explanatory	–
CO ₂ emission	Continuous data type measured by gram (g) in a week	Dependent	General linear model
Mode choice behaviour	Number of trips made using different modes of transport	Dependent	Multinomial logit model
Activity participation	Number of trips made to perform different activities	Dependent	Multinomial logit model

rural transport services (Ulsterbus) in NI is 10 people³ (Department for Regional Development 2008, 2010). Equation 1 was, however, not used for the calculation of CO₂ emissions level associated with the train trips. There are no light rail, electric rail, and tram services operational in NI. The only form of train that is operational in NI is the regional train powered by diesel. As a result, the emission levels from the train trips were calculated using 73.7 g/passenger-km as an emission factor (Brand 2005). The hot exhaust emission level was considered as zero (0) when trips were made using the bicycle or foot because these modes do not produce any tailpipe emissions (Santos et al. 2010).

Cold start CO₂ emissions were calculated only for trips undertaken by using the car. Car trips that were made after 60 min stop over time between the trips were considered as a cold start trip (Frank et al. 2000). The fraction of trip

length that was made under cold engine conditions was calculated using Eq. 2 (Brand 2005).

$$\beta = 0.6474 - 0.02545 \times l_{\text{trip}} - (0.00974 - 0.000385) \times t_a \quad (2)$$

where β = fraction of trip length travelled under cold start condition, l_{trip} = average length of trips under consideration, and t_a = average ambient temperature. The average trip length of all cold start trips using the car was calculated, and it was found to be 15 km in this research.

Table 2 Descriptive statistics showing the trip characteristics of the data

Mode	Number of trips	% of total trips	Average trip length (km)
Driving car	2,002	65.5	14.41
Bus	168	5.5	15.73
Train	12	0.4	29.02
Lift	208	6.8	13.30
Walk	610	20.0	0.71
Taxi	35	1.1	14.95
Bicycle	20	0.7	10.94
Motorcycle	2	0.1	16.99
Total	3,057	100.0	11.71

³ This occupancy figure was calculated for the survey period. In 2009–2010, 41.9 million passenger journeys were made using the Ulsterbus services. Total bus-kilometres figure stood at 58.1 million. The Northern Ireland Travel Survey data show that the average journey length using the Ulsterbus services is 13.4 km (8.3 miles). Therefore, the calculated passenger-kilometres for this period is 578.22 million (41.9 × 13.4). Bus occupancy = 10 (i.e. passenger-km/bus-km).

As mentioned earlier, the activity-travel diaries were collected during the summer and the average temperature in NI varies between 11 and 18 °C in the survey period (BBC 2010). Therefore, 15 °C was used as a value for t_a in this research. Using the derived value for β coefficient, the cold start emission level was calculated for each trip using Eq. 3 (Brand 2005).

$$E_{\text{COLD};i} = \beta \times E_{\text{HOT};i} \times (e^{\text{COLD}}/e^{\text{HOT}} - 1) \quad (3)$$

where $E_{\text{COLD};i}$ = cold start emissions (in gram) for trip i ; β and $E_{\text{HOT};i}$ as above; and $e^{\text{COLD}}/e^{\text{HOT}}$ = cold/hot emission quotient which was calculated using Eq. 4 (Ntziachristos and Samaras 2009).

$$e^{\text{COLD}}/e^{\text{HOT}} = 1.9 - 0.03 \times t_a \quad (4)$$

The cold start emission and hot exhaust emission levels were aggregated to derive total emissions associated with each trip. This emission level was further aggregated for each person to derive individual level weekly CO₂ emission level data. Using these scores as a dependent variable, a seven factor ANOVA with a full factorial interaction between the explanatory variables was conducted based on the general linear model (GLM) in SPSS in order to identify patterns of CO₂ emissions for different socio-spatial groups.

Generating activity-travel patterns

As the policy emphasis has been placed on behavioural change and the choice of transport mode in order to reduce the CO₂ emission levels, this research analyses the mode choice behaviour of different groups in order to understand why certain groups emit a higher level of CO₂, whereas others do not. In addition, as a lack of participation in activities has been identified as the key outcome of the social exclusionary process, individual activity patterns were also analysed to identify whether the low CO₂ emitters possess the risk of being excluded from society. In transport terms, such participation implies the proportion of trips made to participate in different activities compared to other groups. However, train trips and trips that were undertaken using the motorcycle were excluded from this analysis. This is due to the fact that the train was not available to respondents living in Doagh and Saintfield. Whilst none of the respondents living in Moira and Doagh used the motorcycle as a mode of transport.

A coding list of 29 trip purposes was provided to the respondents participating in the activity diary phase of the research. These trip categories were subsequently grouped into eight main categories: work, social, shopping, recreational, health, food, returning home, and other (e.g. to drop off) for this research. However, return home trips

were excluded from this analysis, which is due to the fact that social inclusion means the ability to participate in out-of-home activity. As a result, a total of 1,704 individual trips were analysed which finished at locations other than the home (1,353 return home trips). Two multinomial logit models were estimated in STATA: one to identify mode choice behaviour, and the other to identify the rate of participation in different activities. The models computed the relative risk ratios (RRRs) for each explanatory variable that indicated a measure of how much more likely one group (e.g. male) used a certain mode of transport (e.g. bus) (or participated in an activity e.g. social) against the reference category (e.g. car/work) when compared to its counterpart (e.g. female).

Results and discussion

Socio-spatial patterns of CO₂ emitters

Table 3 shows that on average each individual emitted 32 kg CO₂ in a week. No other comparable data are available to verify this level of CO₂ emissions in a rural context. In addition, previously reported data are also not consistent across urban areas. For example, Ko et al. (2011) have reported that on average, each person emits about 1.6 kg CO₂ a day in Seoul. In contrast, this level of CO₂ emission was reported for a single trip to McGill University for different groups (Mathez et al. 2013). Our weekly finding was found to be slightly higher than the previously reported rates, which suggests that people in rural areas emit more CO₂ per capita.

A significant model emerged from the GLM test using the weekly CO₂ emission level as a dependent variable with good explanatory power (Table 4) (Xing et al. 2010). This means that a significant difference exists in the levels of CO₂ emissions between the different groups considered. Area profile, car ownership and occupation variables were found to have a significant effect in the model (Table 4). The post hoc analysis using the area profile variable shows that individuals living in Doagh emitted a significantly higher level of CO₂ (39 kg) compared to individuals living in Moira (37 kg) and Saintfield (23 kg) (Table 3). There could be a number of possible explanations for these differences. For instance: (1) individuals living in Doagh travelled mostly by car. The emission factor associated with the car is higher per passenger kilometre and as a result, despite travelling a shorter distance, this mode could represent a group which is a higher emitter; (2) despite no differences in the mode choice behaviour between the case study areas, individuals living in Doagh travelled longer distances; (3) individuals living in Doagh travelled shorter distances but participated in activities more frequently than

Table 3 Levels of CO₂ emission (g) by different groups in a week

Variables	Categories	All areas			Moira		Saintfield		Doagh	
		N	Mean	% change from reference	N	Mean	N	Mean	N	Mean
Area profile	Moira	45	36,834.96	Reference	–	–	–	–	–	–
	Saintfield	62	23,190.39	–37.04	–	–	–	–	–	–
	Doagh	50	39,278.88	6.63	–	–	–	–	–	–
Gender	Male	71	31,157.99	Reference	18	38,477.03	29	18,949.44	24	40,420.71
	Female	86	33,105.86	6.25	27	35,740.24	33	26,917.29	26	38,224.88
Car ownership	Non-car-owning	24	15,819.70	Reference	7	16,347.16	11	17,292.79	6	12,503.67
	Car owning	133	35,185.33	122.41	38	40,609.03	51	24,462.43	44	42,930.04
Income	Low income	88	31,200.73	Reference	30	36,177.31	30	23,502.34	28	34,116.96
	High income	69	33,531.26	7.46	15	38,150.25	32	22,897.95	22	45,848.59
Occupation	Working	91	32,892.43	Reference	28	39,259.04	35	25,544.45	28	35,710.80
	Non-working	66	31,304.70	–4.823	17	32,842.36	27	20,138.84	22	43,820.07
Age	Young	95	32,958.21	Reference	24	35,802.08	45	25,825.39	26	42,678.38
	Older	62	31,101.47	–5.63	21	38,015.39	17	16,215.41	24	35,596.09
Home ownership	Owner	119	32,692.79	Reference	32	40,630.91	45	21,846.54	42	38,265.67
	Rented	38	30,759.99	–5.91	13	27,491.07	17	26,747.65	8	44,598.22
Total		157	32,224.98		45	36,834.96	62	23,190.39	50	39,278.88

Table 4 GLM test results showing the variations in the levels of weekly emission of CO₂

Source	F	Partial Eta squared
Corrected model	2.251 ^a	0.623
Intercept	173.846 ^a	0.659
Area profile	2.781 ^a	0.058
Gender	0.642	0.007
Car ownership	14.231 ^a	0.137
Income	0.197	0.002
Occupation	6.536 ^a	0.068
Age	0.007	0.000
Home ownership	0.753	0.008
Interactions		
Area profile × occupation	4.281 ^a	0.087
Income × age	4.125 ^a	0.044
Area profile × gender × income	6.643 ^a	0.069

^a Coefficients are significant at the 0.05 level

the other spatial groups; and (4) any combination of these. Therefore, it is clear that the causes of CO₂ emissions cannot be explained by only looking at the explanatory factors, but that they need to be analysed along with mode choice behaviour and trip patterns. For that reason, findings from this section are elaborated on further in the next sections of the paper.

Consistent with other studies (Druckman and Jackson 2008), Table 3 also shows that car-owning individuals emitted a significantly higher level of CO₂ (35 kg)

compared to their non-car-owning counterparts (16 kg) in a week. This difference clearly reflects the high levels of car dependency in rural areas and also signifies the potential for the reduction in CO₂ if appropriate policy measures are introduced. Individuals who were in employment also emitted a significantly higher amount of CO₂ (33 kg) compared to their non-working counterparts (31 kg). This is surprising given that non-working individuals had more available time to travel. However, disaggregation of the data found that this was only in the case of Moira and Saintfield. The interaction between area profile and occupation variables was found to have a significant effect in the model, further analysis shows that non-working individuals living in Doagh emitted a significantly higher amount of CO₂ (44 kg) than their working counterpart (36 kg). Therefore, it appears that despite Moira and Saintfield having more opportunities locally, these settlements are inadequate for facilitating employment opportunities and as a result, individuals living in these areas travel to other urban centres. In Doagh, on the other hand, where individuals are living closer to urban areas have shorter commuting distances. However, since Moira and Saintfield provide a basic level of opportunity, non-working individuals were perhaps able to meet their requirements locally as opposed to those non-working individuals living in Doagh.

Although the main effects of the income and age variables are not significant in the model, the interaction of these two variables was found to have a significant impact in the model. Analysis shows that low-income young



individuals emitted more CO₂ (33 kg) than their low-income older counterparts (30 kg) in a week. On the other hand, older individuals with a higher level of income emitted a higher amount of CO₂ (34 kg) than high-income individuals who were younger (33 kg). An analysis of the interaction between area profile, gender, and income variables indicates that high-income males living in Saintfield emitted a significantly lower level of CO₂ (16 kg) than any other combinations of factors. Analysis shows that high-income males living in Saintfield also tended to have more business locally. As a result, this group rarely travelled outside of their areas. However, high-income females living in Doagh emitted a significantly higher amount of CO₂ (48 kg) than other groups.

In summary, this analysis shows that groups which have a lower level of CO₂ emission in rural areas include: (1) an area with a higher level of area accessibility and mobility options, non-car-owning individuals, non-working individuals, low-income and older people, and high-income and younger age groups; and (2) high-income males living in an area with a higher level of accessibility. However, this section raised more questions in terms of the travel behaviour patterns of these low CO₂ groups. An attempt was made to answer these questions by analysing the mode choice behaviour of these groups in the following section.

Mode choice behaviour

This section investigates the mode choice patterns of those groups identified as having a lower level of CO₂ emissions. It is clear from Table 5 that individuals who live in an area with a lower level of area accessibility and mobility options

(e.g. Doagh) were less likely to use the bus (4 times), take lifts (3 times), walk (5 times), and cycle (4 times) than when compared to their car use. Table 5 also shows that car-owning individuals relied mostly on the car for making all types of trips. As a result, their associated RRRs were found to be significantly reduced for making trips using the bus (20 times), taking lifts (2 times) (lower emissions on the grounds of occupancy), using the taxi (2 times) (lower emissions on the basis of no cold start emissions associated with this mode), and walk/cycle (3 times) (zero CO₂ emissions) when compared to their non-car-owning counterparts. In a similar way, high-income individuals were significantly less likely to make trips using the bus (5 times), take lifts (2.5 times), and walk (2 times) when compared to their car usage. Older individuals were found to be more likely to make trips using the bus (1.8 times) and on foot (1.5 times). Unlike older individuals, non-working individuals were found to be less likely to use the bus (3 times) and active transport (2 times). Note, however, that this group was identified as low-emitters despite not using more sustainable mode of transport. The finding implies that although working individuals used more sustainable modes of transport, they had to participate in their activities more frequently than their non-working counterparts. In addition, on average, work trip length was found to be the longest (16.9 km) amongst the different activity categories in this research. As a result, the aggregated level of emissions over a week increased significantly for working individuals. The above analysis clearly reflects the location of available opportunities and the choice of transport mode acts as a major factor in reducing the level of CO₂ emissions. These findings are

Table 5 Multinomial logistic regression analyses results showing the RRRs of mode choice for different groups

Explanatory variables	Dependent variables: chosen transport modes (reference: car)				
	Bus	Lift	Taxi	Walk	Bicycle
Area profile (ref: Moira)					
Saintfield	3.32 ^a	2.76 ^a	2.24	2.50 ^a	1.95
Doagh	0.29 ^a	0.378 ^a	0.45	0.20 ^a	0.31 ^a
Gender: female (ref: male)	1.22	1.61 ^a	1.31	1.24 ^a	0.14 ^a
Number of cars in household	0.05 ^a	0.45 ^a	0.02 ^a	0.37 ^a	0.45 ^a
Income: high (ref: low)	0.22 ^a	0.40 ^a	1.93	0.61 ^a	1.53
Age: older (ref: young)	1.80 ^a	1.08	0.86	1.56 ^a	1.43
Occupation: non-working (ref: working)	0.31 ^a	0.99	1.87	0.64 ^a	0.53
Home ownership: rented (ref: owner)	0.30 ^a	0.81	0.82	0.99	1.49
Log likelihood					-2,520.30
LR Chi ²					1,210.88 ^a
Pseudo-R ²					0.19
N (number of trips made using different modes)					3,043

^a Coefficients are significant at the 0.05 level

Table 6 Multinomial logistic regression analyses results showing the RRRs of activity participation for different groups

Explanatory variables	Dependent variables: types of activity participated in (reference: work)					
	Social	Recreation	Shopping	Taking a meal	Other	Health
Area profile (ref: Moira)						
Saintfield	0.90	0.60 ^a	0.78	1.47	1.90 ^a	0.83
Doagh	0.97	0.82	0.81	0.37 ^a	1.75 ^a	0.29 ^a
Gender: female (ref: male)	1.24	1.29	1.32 ^a	1.12	3.70 ^a	1.79 ^a
Number of cars in household	0.78 ^a	0.96	0.78 ^a	0.95	0.82 ^a	0.67 ^a
Income: high (ref: low)	1.43 ^a	2.26 ^a	1.40 ^a	1.15	1.46 ^a	1.62
Age: older (ref: young)	1.08	1.16	1.13	0.53	0.70	0.78
Occupation: non-working (ref: working)	48.08 ^a	45.74 ^a	42.61 ^a	70.12 ^a	56.11 ^a	64.10 ^a
Home ownership: rented (ref: owner)	0.91	0.81	0.90	1.13	0.99	0.77
Log likelihood						-2,693.38
LR Chi ²						643.47 ^a
Pseudo-R ²						0.11
N (number of different types of activity participated in)						1,704

^a Coefficients are significant at the 0.05 level

consistent with the policy initiatives of the government as discussed earlier. However, questions still remain as to whether these low CO₂ emitter groups are able to participate in activities as much as those groups who are high CO₂ emitters.

Activity patterns

Table 6 shows that despite being a high producer of CO₂, individuals living in Doagh were not able to participate in activities as much as individuals living in Moira and Saintfield particularly for dining out and health-related activities (a 3 times lower participation rate). However, individuals living in Saintfield were found to lack the ability to participate in recreational activities when compared to individuals living in Moira (around a 2 times lower participation rate). Table 6 also shows that the RRRs of making other types of trip (e.g. to drop off, to pick up) were doubled when individuals were found to live in Saintfield and Doagh compared to those respondents residing in Moira. These findings therefore indicate the need for the development of area-based policy interventions through the provision of local goods and services in order to keep the emission level lower in rural areas. Although the non-car group was identified as having a lower level of CO₂ emission, Table 6 shows that a higher level of car ownership at household significantly reduced the level of participation in some type of activities (e.g. social, shopping). In contrast, individuals were more likely to participate in different types of activities when the income level is increased. Despite working individuals emitting a significantly higher level of CO₂, they were found to be less likely to participate in different types of activities.

These findings, therefore, clearly produce evidence to suggest that individuals do not necessarily need to be high polluters in order to be socially included.

Conclusion

Excessive emission of CO₂ is a global threat (Chapman 2007). Despite a high level of policy concern, there are increases in the level of CO₂ emissions from road transport (Anable et al. 2012), which jeopardises realisation of the sustainable development policy goal. As a result, an identification of strategies that could reduce CO₂ emissions from road transport is a critical policy challenge worldwide. Researchers have agreed that policy interventions influencing a behavioural shift from car-based travel to more sustainable transport options would be a way forward in addition to improving the technological efficiency of the vehicles/fuel used for personal travel (Anable et al. 2012; Chapman 2007; Kelly et al. 2009). However, very little is known about the CO₂ emission behaviour in rural areas despite CO₂ emissions per head of population being higher in rural areas than in urban areas (Brand et al. 2013). This research has contributed to this knowledge gap in the literature. It has calculated CO₂ emission levels of individuals living in three rural areas in NI using their weekly activity-travel diary data. This research has also investigated the travel behaviour of these individuals to help understand why certain groups emit a lower level of CO₂ than others. This research then goes on to evaluate whether a lower level of CO₂ emissions results in a lower level of participation in activities.



Evidence from this research clearly indicates that there is a need for hard policy intervention measures such as encouraging the provision of local opportunities in order to encourage and underpin behavioural changes in travel behaviour in rural areas (Santos et al. 2010). For instance, individuals living in Moira and Saintfield were found to be more likely to make trips on foot due a higher level of area accessibility option. On the other hand, these individuals were also found to make more trips using the bus due to a higher level of area mobility options. As a result, their levels of CO₂ emission were found to be significantly lower than those living in an area with a lower level of area accessibility and area mobility options (e.g. Doagh). Although this finding runs against the findings reported by Brand and Preston (2010) in the context of UK, this finding is, however, similar to that reported by other researchers (Frank et al. 2000; Santos et al. 2010; Wang et al. 2014). Therefore, the decline in local services (both in public transport and local goods and services opportunities) in rural areas needs to be reversed even though it may require a greater subsidy (Banister 2008b; Higgs and White 2000; McDonagh 2006). The findings of this research, however, also demonstrate that rural people like to use local services if they are available, which would suggest that a temporary subsidised service can achieve financial viability in the long run (Department for Transport and Greater Manchester Passenger Transport Executive 2004).

This research has found that despite using sustainable transport options (e.g. bus), certain groups (e.g. working individuals) may emit a significantly higher level of CO₂ in rural areas particularly when their activity locations are in more dispersed places. Promotion of alternative soft measures such as teleworking, therefore, has a greater role to play in reducing CO₂ emissions in rural areas together with the physical measures for some jobs (Banister 2008a; Santos et al. 2010). Evidence in this research shows that although certain groups emitted a higher amount of CO₂, their level of participation in society is significantly lower than their counterparts (e.g. working individuals, individuals living an area with a lower level of accessibility and mobility). This means that these groups were excluded from society due to their higher level of mobility (Cass et al. 2005). These groups spent a considerably larger amount of time travelling which they otherwise could have spent in their local neighbourhoods if both soft and physical measures were implemented. A significantly higher level of CO₂ emission from the car-owning group was found to exist mainly due to the existence of these travelling patterns. This group was more likely to use the car for making their journeys although their participation in society was found to be significantly lower when compared to their counterparts using other modes.

Sustainable development is a well-recognised concept in today's society, which highlights the need to integrate economic, environmental, and social dimensions within development and policy. In this paper, two of the dimensions (e.g. social and environmental) were jointly investigated with an aim to understand whether one dimension is detrimental to the other in the transport sector. The findings of this research clearly show that these two dimensions are not necessarily conflicting at all; rather the sustainability in one dimension can enhance the sustainability in other dimension (e.g. a shorter travel distance is associated with both a reduction in CO₂ emissions and a higher level of participation in society). However, to achieve this, transport policies need to incorporate both soft (e.g. travel demand management) and hard (e.g. the arrangement of land uses to foster walking and cycling, transit oriented development) interventions.

Acknowledgments We acknowledge and cordially thank the Editor-in-Chief and the two anonymous reviewers for their constructive comments and insightful suggestions, which helped us to improve the manuscript.

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