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NOVEL METHODS FOR THE PLANNING AND DESIGN OF GREENWAYS FOR CYCLING

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A thesis submitted to the College of Engineering and Informatics in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Supervisor: Dr. Eoghan Clifford

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This thesis or any part thereof, has not been, or is not currently being submitted for anydegree at any other university.

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Richard Manton

The work reported herein is as a result of my own investigations, except whereacknowledged and referenced.

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Richard Manton

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“The gross and net result of it is that people who spent most of their natural lives riding iron bicycles over the rocky roadsteads of this parish get their personalities mixed up with the personalities of their bicycles as a result of the interchanging of the atoms of each of them and you would be surprised at the number of people in these parts who nearly are half people and half bicycle.

[…]

“Many a grey hair it has put into my head, trying to regulate the people of this parish. If you let it get too far it would be the end of everything. You would have bicycles wanting votes and they would get seats on the County Council and make the roads far worse than they are for their own ulterior motivation.

[…]

“How would you know a man has a lot of bicycle in his veins?

If his number is over Fifty you can tell it unmistakable from his walk. He will walk smartly always and never sit down and he will lean against the wall with his elbow out and stay like that all night in his kitchen instead of going to bed. If he walks too slowly or stops in the middle of the road he will fall down in a heap and will have to be lifted and set in motion again by some extraneous party.

[…]

“A little of it is a good thing and makes you hardy and puts iron on to you. But walking too far too often too quickly is not safe at all. The continual cracking of your feet on the road makes a certain quantity of road come up into you. When a man dies they say he returns to the clay but too much walking fills you up with clay far sooner (or buries bits of you along the road) and brings your death half-way to meet you.

It is not easy to know what is the best way to move yourself from one place to another.”

Flann O’Brien, *The Third Policeman*

Abstract

There is a crisis in transport internationally as the continuing proliferation of car-use undermines environment, society and economy. Cycling has gained considerable attention in policy and academia in recent years as one alternative mode of travel, yet conflict with motorised vehicles and resulting concerns for safety are inhibiting development of this mode. Greenways, as routes for non-motorised travel, offer extensive benefits for the environment, quality of life, tourism and transport; yet their planning and design for cycling has not been thoroughly researched. A review of cycling network planning (including discourse on segregation, vehicular cycling, the hierarchy and challenges facing route selection) highlighted the need for new methods for greenways to focus on safety, environmental impact and economic impact as well as integrating the unique design requirements of cyclists. To this end, the thesis comprises four empirical elements, which are subsequently distilled into a framework for the planning and design of greenways.

Firstly, a mental mapping and modelling approach was developed to identify the determinants of perceived cycling risk, considering both infrastructural and individual effects. A survey (n=104) of cyclists in Galway City (Ireland) collected mentally-mapped perceived risk observations (n=484) and these were matched in ArcGIS to road data extracted from a transport infrastructure inventory. Initial comparison between perceived risk hotspots and locations of cycling collisions showed somealignment between the perceived and objective environment. A Generalised Linear Mixed Model in SPSS revealed the infrastructural and individual determinants of perceived cycling risk to be segregation of infrastructure, road width and the volume ofmotorised traffic as well as gender and cycling experience. The results illustrate the potential for improved cycling experience in areas well-separated from traffic (e.g. greenways) and the added benefits that these environments can present for women and inexperienced cyclists.

Secondly, an international greenway survey was piloted and deployed online to determine end-user design preferences, receiving 1,002 responses from over 20 countries. Coded qualitative responses initially highlighted high-level user priorities for greenway functions and design priorities. Preferred design characteristics (surface, gradient, width, junctions), facilities (resting areas, food & drink) and other preferences (segregation, parking) were quantified and compared with best-practice. To account for variation in design preferences according to mode of travel, a logistic regression model was built for one design characteristic, surface materials, finding that cyclists, commuters and older people prefer asphalt. Building on existing matrices from engineering guidance, these preferences were incorporated into a framework for the route selection and design of greenways, including as elements: accessibility, safety, user experience, design, environment and economy. This framework facilitates the inclusion of quantitative metrics in a broad route selection methodology, which also allows scope for engineering judgement.

Thirdly, life cycle assessment was used to measure greenway embodied carbon and to develop a balance sheet for the environmental impact of greenways. This approach is predicated on the fact that while modal shift to cycling has the potential to reduce carbon emissions, the carbon footprint of constructing newcycling routes, particularly greenways, can negate these savings. Applying life cycle assessment to the Great Western Greenway (GWG; Co. Mayo, Ireland), embodied carbon due to materials, construction machinery, transport of materials and removal of vegetation and peat was calculated to be 67.6 tCO_2e/km.Furthermore, the carbon savings of shifting one passenger-kilometre travelled (PKT) from driving a car to cyclingwere found to average 134 gCO_2e. In this case study, a shift of 115 commutersper year (253,000 PKT) is required to ‘balance’ or offset the carbon footprint ofone 10 km asphalt greenway (over 20 year life cycle).

Fourthly, greenway spending data was derived from the international greenway survey and was used to develop some indicators for the economic impact of these routes. Greenways are comparatively expensive cycling routes to deliver (€100,000/km) and a strong emphasis is placed on demonstrating return on investment. Concentrating initially on the GWG, the average user spend per night was calculated to be €51, confirming earlier findings of economic consultants. Expanding the analysis to the international sample, it was found that the average spend for a greenway user is €47 per night, with accommodation and food & drink accounting for the largest proportions. A Travel Cost Model was then built in SPSS to measure the value of greenway recreation to cyclists showing that the consumer surplus retained by greenway users is particularly high: €77 or 83% of the total value. Meanwhile, the study found broad opposition to direct payment for greenway access. The results show the importance of greenways as a recreational and tourism resource.

Finally, the four empirical elements were combined as part of a framework for the planning and design of greenways and this framework was used to analyse the development of the burgeoning 2,000 km Irish National Cycle Network (NCN). The framework was tested against a case study of the Oranmore to Mullingar section of the Galway to Dublin Greenway, which hasrecently completed the route selection process, yet faces many engineering, economic and land acquisition challenges. Dividing the study area into three sections, route constraints/opportunities, route options and a preferred route were successfully identified and the result is compared with the output from engineering consultants. Overall, the guidance developed in this thesis will be a major asset to local authorities, engineering consultancies and community groups, enabling the design of safe, environmentally-friendly, cost-efficient and well-used greenways.

Publications derived from this thesis

1. Manton, R. and Clifford, E. (2016). Greenway route selection and design preferences: an international study. *Landscape and Urban Planning* (to be submitted for peer review).

2. Manton, R., Rau, H., Fahy, F., Sheahan, J. and Clifford, E. (2016). Using mental mapping to unpack perceived cycling safety. *Accident Analysis and Prevention*, 88, pp.138-149.

3. Manton, R., Hynes, S. and Clifford, E. (2016). Greenways as a tourism resource: a study of user spending and value. *Tourism Planning and Development,* DOI: 10.1080/21568316.2015.1136835

4. Manton, R., Duggan, A., Goggins, J. and Clifford, E. (2014). Carbon costs and savings of Greenways: creating a balance sheet for the sustainable design and construction of cycling routes. *International Journal of Environment and Sustainable Development*, 13(1), pp.3-19.

5. Manton, R., Clifford, E. (2013). Review of construction and maintenance guidelines for Greenways. *Proceedings of the ICE – Transport*, 167, pp.377-383.

6. Manton, R., Clifford, E. (2013). Identification and classification of factors affecting route selection of cycling routes in Ireland. *Cycling Research International*, 3, pp.136-153.

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Glossary

ABP	An Bord Pleanála (Planning Board)
BnaM	Bord na Móna (Peat Board)
CIÉ	Córas Iompair Éireann (Irish Transport System)
CnaT	Comhairle na Tuaithe (Countryside Council)
CPO	Compulsory Purchase Order
cSAC	Candidate Special Area of Conservation
CSO	Central Statistics Office
DAF	Department of Agriculture and Food *(now DAFM)*
DAFM	Department of Agriculture, Food and the Marine
DAHG	Department of Arts, Heritage and the Gaeltacht
DECLG	Department of Environment, Community and Local Government
DEHLG	Department of Environment, Heritage and Local Government (now DECLG)
DfT	Department for Transport (UK)
DMRB	Design Manual for Roads and Bridges
DMURS	Design Manual for Urban Roads and Streets
DoF	Department of Finance
DoT	Department of Transport *(now DTTAS)*
DPER	Department of Public Expenditure and Reform
DRD	Department for Regional Development (NI)
DTTAS	Department of Transport, Tourism and Sport
ECF	European Cyclists' Federation
ED	Electoral Division
EGWA	European Greenways Association
EIS	Environmental Impact Statement
EV	EuroVelo (European Cycle Route Network)
FI	Fáilte Ireland (Tourism Development Board)
GDA	Greater Dublin Area
GST	Great Southern Trail *(also known as Southern Heritage Trail)*
GWG	Great Western Greenway
HSE	Health Services Executive
ISC	Irish Sports Council
LA	Local Authority
MRA	Midlands Regional Authority
NCN	National Cycle Network
NCNAC	National Cycle Network Advisory Committee
NCPF	National Cycle Policy Framework
NHA	Natural Heritage Area
NPWS	National Parks and Wildlife Service
NRA	National Roads Authority *(now TII)*
NRDO	National Road Design Office
NSTO	National Sustainable Travel Office *(now Sustainable Transport Division)*

NTA	National Transport Authority
NTAC	National Trails Advisory Committee
NTO	National Trails Office
OSi	Ordnance Survey Ireland
PMG	Project Management Guidelines
pNHA	Proposed Natural Heritage Area
POWSC	Place of Work, School or College
QoS	Quality of Service
RMP	Registered Monuments and Places
RPA	Railway Procurement Agency *(now TII)*
RSA	Road Safety Authority
SA	Small Area
SAC	Special Area of Conservation
SAPS	Small Area Population Statistics
SPA	Special Protection Area
TII	Transport Infrastructure Ireland
WRA	Western Regional Authority

1 Introduction

1.1 Overview

Cycling is increasingly recognised as a key tool in improving sustainability in transport, public health and tourism. This mode of travel requires physical activity for propulsion, thereby reducing sedentary behaviour and leading to improved physical and mental health. It emits almost no noise or air pollution, can have a negligible effect on flora and fauna and is the most energy-efficient mode of transport. To cycle costs substantially less than driving a car and providing infrastructure is much more cost-effective for the exchequer. Choosing to cycle also leads to greater social interactions, an enriched sense of community and is more equitable. Yet cycling levels around the world declined significantly during the proliferation of the private motor vehicle (Buehler & Pucher, 2012) and this decline has had far-reaching social, environmental and economic consequences. As traffic speeds and volumes increased, roads became more dangerous for cyclists who did not switch to driving.

This risk, combined with the desire for generally more aesthetic and comfortable places to cycle, has led to the segregation of cyclists from motorised traffic and the design of dedicated infrastructure. In recent years there has been a cycling renaissance in many countries and a collection of authors has linked this to greater infrastructural provision for the mode (Pucher & Dijkstra, 2000). Reflecting the known benefits of cycling, the development of cycle networks has entered national, regional and international policy for numerous reasons, including: (i) reducing the carbon footprint of the transport sector, (ii) the potential for health benefits, (iii) improving quality of life and (iv) the development of sustainable tourism. This has led to major investment in cycling infrastructure in both urban and rural areas, for example EuroVelo envisages a European trans-border cycling network of which more than 45,000 km has been completed.

Against this backdrop, this thesis examines the case of greenways for cycling. These off-road cycling routes have shot to prominence in recent years, not least due to the work of organisations, such as the European Greenways Association and Sustrans, and the popularity of the term in countries such as Ireland. The term ‘greenway’ likely derives from a combination of ‘greenbelt’ and ‘parkway’, demonstrating its origins in the landscape architecture and landscape ecology fields (Little, 1995). According to this approach, greenways act as corridors for wildlife and as part of a greenbelt for landscape planning and resource protection. However, the greenway concept has evolved in recent years to become multi-objective, fulfilling three major roles: (i) nature protection, (ii) recreation and tourism provision, and (iii) heritage protection (Fabos, 2004).

Greenway-based research and practice "brings together a range of formerly divergent disciplines such as civil engineering, landscape architecture and wetland ecology to address complex problems posed by expanding human development" (Searns, 1995). This thesis approaches greenway planning and design from a civil engineering and transport planning perspective, while drawing on other disciplines for useful principles and methods. A focus is placed on the benefits of these routes for cycling, although it is recognised that greenways' functions extend far beyond that of corridors for cyclists.

'High-cycling' countries such as The Netherlands, Denmark and Germany have developed extensive cycle and greenway networks over the course of decades, which 'low-cycling' countries, such as Ireland and the UK, have been trying to emulate more recently. Indeed greenways for cycling have received considerable policy and investment focus, but limited attention has been paid to developing planning and design methods to ensure maximum benefits of these routes to the environment, economy and society. Furthermore, while the cycling planning and design field has expanded rapidly in the past five to ten years (concentrating on urban networks), minimal literature exists on the planning and design of rural, inter-urban cycling routes – the form taken by most greenways. One of the main challenges of this research is therefore to bring together diverse aspects of the cycling, transport and environment fields – from planning for a wide variety of users and statutory obligations to designing for the unique characteristics of cyclists in terms of geometric design and exposure to risk (Parkin & Koorey, 2012).

1.2 Structure of the thesis

Chapter 2 reviews the relevant international scientific and engineering academic literature and planning and design guidance to identify background, gaps and challenges to the proposed research. **Chapter 3** plots the research objectives and method. **Chapter 4** unpacks the determinants of perceived cycling risk using an innovative combination of mental mapping, geographic information systems and statistical analysis. **Chapter 5** describes the methods and findings of an international greenway user survey, focusing on user preferences and priorities, and develops a framework for greenway planning and design. **Chapter 6** presents a new methodology for the measurement of the embodied carbon of a greenway and the potential for offset against modal shift. **Chapter 7** derives typical greenway spending data from the international user survey and measures the value of greenway recreation to cyclists using a travel cost model. **Chapter 8** explores the development of the Irish National Cycle Network, drawing on the lessons of previous chapters to identify opportunities and challenges for the network. **Chapter 9** applies the principles, methods and findings of each chapter to the planning and design of the Mullingar to Oranmore section of the Irish NCN. **Chapter 10** outlines conclusions, recommendations and proposed further research.

2 Literature Review

This chapter establishes the background and the challenges addressed by this research. The chapter reviews the principles for the design of infrastructure and the role of safety perceptions and bicycle suitability. A suite of greenway design and maintenance guidance is also analysed as part of an extensive review of the safety, economic and environmental impacts of such routes. The review finally addresses the lack of standardised planning and design for cycling infrastructure, particularly greenways, and points towards new methods for greenway planning and design.

2.1 Introduction

2.1.1 Benefits of cycling

The benefits of cycling have been well established and are found across the three pillars of sustainability: social, environmental and economic. Regular cycling has been shown to reduce the risk of coronary heart disease, stroke, cancer, diabetes. A reduction in these conditions may result in a reduction in mortality, morbidity, absenteeism as well as general savings to the health service (Cavill et al, 2008; Demers, 2006). Furthermore, the 'Safety in Numbers' theory holds that increased levels of cycling result in a lower risk of collisions and fatalities for all cyclists (Jacobsen, 2003). Planning which promotes walkability and bikeability improves social capital, provides passive security and leads to a greater sense of community (Leyden, 2003).

The only carbon emissions associated with cycling derive from the embodied carbon of the bicycle, human exhalation and the embodied carbon of increased food consumption (Walsh et al, 2008). Furthermore, as cycling infrastructure occupies less space and calls for higher density development, fewer habitats are negatively impacted, air quality is improved and there is less urban sprawl (McDonald & Nix, 2005). Cycling infrastructure is more cost-effective to build than car-based infrastructure, results in a greater benefit-cost ratio and is a cheaper transport system for users (Sustrans, 2010). Also, cycle tourism is a growing industry worth billions of Euro in Europe alone (Weston et al., 2012).

Table 2.1 summarises the current walking and cycling modal shares for nine European countries and the USA. The most up-to-date data available is used, however, in some cases this dates back to 2005. The 'high cycling' countries, Germany, Netherlands and Denmark, all exhibit cycling levels of 15% or over, and a combined active travel share over one third of all trips. In the Netherlands, the majority of journeys are made on foot or by bicycle. 'Low cycling' countries, such as USA, Ireland and the UK, have cycling modal shares in the range of 1-5%.The ECF has proposed a cycling modal share target of 15% for the EU and several countries also have national walking and cycling targets.

Table 2.1 - Walking and cycling (all journeys) in selected countries (data year)

Country	% Walk	% Cycle	*Combined %*
Netherlands (2008)	25	26	*51*
Germany (2011)	21	15	*36*
Denmark (2008)	16	18	*34*
Sweden (2006)	23	9	*32*
Norway (2009)	22	4	*26*
Austria (2005)	21	4	*25*
France (2008)	22	3	*25*
UK (2008)	22	2	*24*
Ireland (2012)	20	2	*22*
USA (2009)	11	1	*12*

Sources: Buehler & Pucher (2012); CV (2012); NTA (2013a)

2.1.2 Road space and cycling

Despite the benefits of cycling, the key trend in transport internationally has been nearly constantly increasing reliance on the private car or 'car dependency' (Wickham, 2006). This has resulted in environmental damage (carbon emissions, air quality, habitat destruction), economic cost (road-building, sprawl, parking) and threats to human health (road collisions, sedentary lifestyles, road rage).Taking Ireland as an example (Figure 2.1), between 1960 and 2014, there have been 1.7 million private cars added to the roads – an increase of 1000% – while population grew by 60% (in 1960 there was one car for every 12 adults, today there is one car for every second adult). These 1.9 million private cars and 500,000 other vehicles travel 31.6 billion and 41.7 billion kmper year respectively (CSO, 2000; 2009; 2013a; 2015; Dargay et al., 2007).In these trends, Ireland has broadly followed the US, UK and other western countries (Garceau et al., 2014). Meanwhile, developments in vehicle technology have increased vehicle speeds, thereby posing greater danger to cyclists who share the roads with motorists.

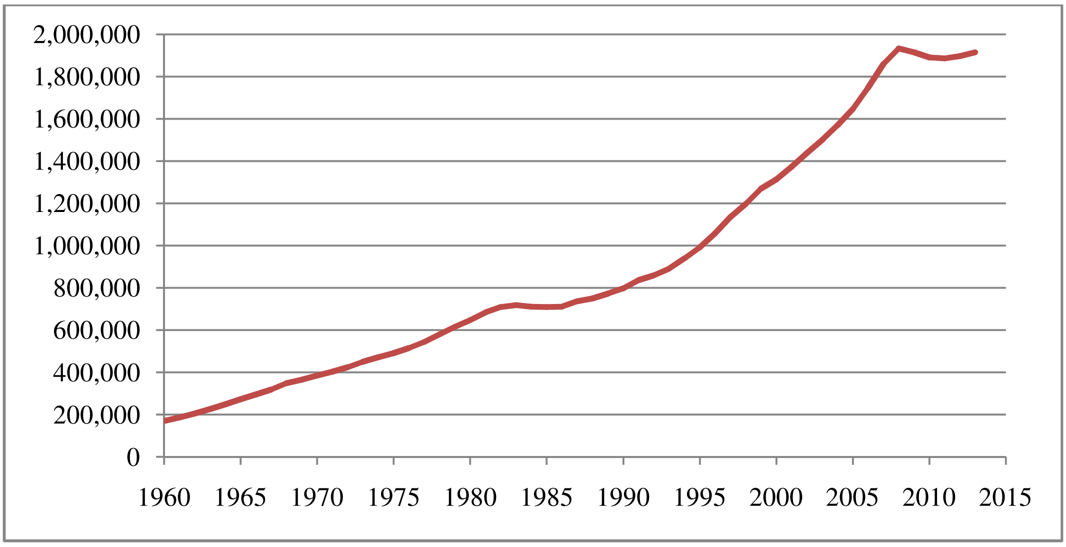

Figure 2.1 - Number of private cars under current licence 1960-2014 (CSO, 2015; 2000)

Furthermore, since the popularisation of the car, the built environment has increasingly been planned and engineered around this vehicle, rather than at a human scale. Roads became larger in size and number as the traffic engineering profession evolved around the 'predict and provide' concept, marginalising walking, cycling and public transport at the same time (Kay, 1998; Vigar, 2002; McDonald & Nix, 2005;Norton, 2008; Vanderbilt, 2009; Duany et al., 2010). This situation led Jacobsen et al. (2009) to pose their titular question 'Who owns the roads?' in an examination of the effect of motorised traffic on cycling in Europe and USA. The authors concluded that motorised traffic speed and volume discourages cycling due to real and perceived danger and discomfort (Jacobsen et al., 2009). This question of *where* pedestrians and cyclists 'belong' is therefore a major challenge for engineers, policy-makers and a source of daily 'war' between cyclists and motorists (BBC, 2013). Most road users appear to conceptualise road space as the historical reserve of the car and little attention is paid to the role of early cyclists in achieving better paved roads and the pneumatic tyre in the 1890s (CROW, 2007; Horton et al., 2007; Furth, 2012). According to Reid (2014), 'roads were not built for cars'.

Dutch engineers began to tackle this issue after the Second World War: following a rapid increase in motorisation and cyclist deaths in the Netherlands, they decided to build networks of separated cycle tracks (CROW, 2007). Between 1973 (oil crisis) and 1988, the Dutch cycle track and cycle path network increased from 9,000 km to 16,000 km (Wardlaw, 2014) (today the network is over 30,000 km). Cycling boomed in the Netherlands and today exhibits the largest cycling modal share in the world (Buehler &Pucher, 2012). Although the debate on integration versus segregation will be discussed in more detail in Section 2.3, suffice it at this point to conclude that issues of road space, motorised traffic and the actual and perceived risks posed to cycling deserve greater research attention in the context of promoting cycling as an everyday mode of travel (Noland, 1995; Pucher & Dijkstra, 2000; Whannell et al., 2012).

2.2 Safety concerns as a barrier to cycling

Cycling safety, as shown in the previous section, is receiving increased attention as researchers, transport planners and cycling advocates seek to increase uptake of the mode. A Stop Killing Cyclists protest (or 'die in') by more than 1,000 cyclists in London in November 2013 dramatically highlighted the continued risk of fatalities (The Guardian, 2013), calling on more suitable roads for cycling. Cyclists are classed as 'vulnerable road users': in 2010, 1994 cyclists were killed on the roads of 20 EU countries. Although there has been a reduction in the number of cyclist fatalities in Europe over the last decade, cyclists remain among the most vulnerable road users. Furthermore, the decline in cycling fatalities has not been as steep as for other road users and cyclists now account for a greater proportion of overall road fatalities at 7% (ERSO, 2012).

In Ireland, for example, between 2013 and 2014, there was a 27% increase in vulnerable road user deaths; there were 12 cyclists killed in 2014, compared to 5 in 2013. Cyclists represent 6% of all road fatalities despite accounting for 2% of road users (RSA, 2014). Issues surrounding cycling safety are gaining attention in the Irish media as shown in the title of one recent current affairs show: ‘The growing war between cyclists and motorists, what’s happening on our streets?’ (RTÉ, 2015). This discourse has centred on the behaviour of cyclists (jumping red lights, cycling on footpaths) and the behaviour of motorists (aggression, verbal abuse, speeding, overtaking) and how the two come into conflict. Short & Caulfield (2014) discuss the safety challenge of increased cycling, particularly in Dublin (Figure 2.2). In such a discussion, it is also important to bear in mind the reduction in all-cause mortality related to cycling infrastructure and increases in cycling levels (Schepers et al., 2015; Cavill et al., 2008).

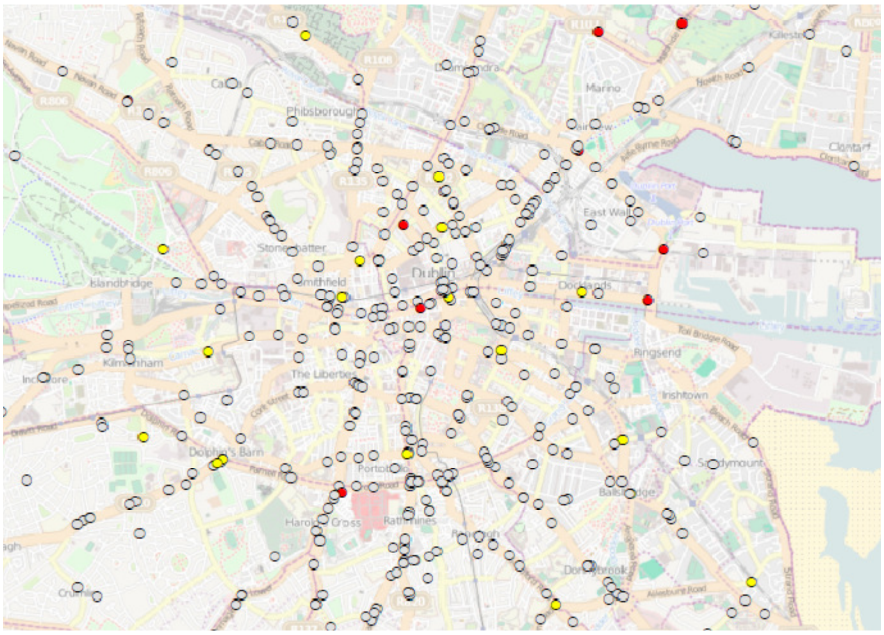

Figure 2.2 - Cycling collisions in Dublin City Centre 2005-2010 (red: fatal, yellow: serious injury, grey: minor injury) [based on RSA (2014) data]

Perceived cycling safety is a also major challenge to increasing cycling, as highlighted by many studies in the field (Pucher & Dijkstra, 2000). According to Parkin et al. (2007a): “While actual, or objective, risk is relatively high for cycling compared with other modes, the perceived risk, that is the risk that is assumed to exist by existing and would-be mode users, is the important criterion in terms of behavioural response”. Consideration of perceived safety has been described as paramount in the cycling design process (Parkin & Koorey, 2012), yet there has been a lack of research into the relationship between the objective and perceived cycling environment (Ma et al., 2014). The fact that barriers to cycling are based to a greater degree on perception and habit is a challenge to engineers to design attractive and comfortable infrastructure that encourages cycling (Gallagher & Parkin, 2014). This challenge thus involves drawing on interdisciplinary transport research on attitudes, habits and perceptions in order to design suitable infrastructure.

2.2.1 Environmental perceptions and travel behaviour

In the field of transport, a small, but emerging, body of literature contends that attitudes, perceptions, and preferences strongly influence individual's travel behaviour (Spears et al., 2013; Gehlert et al., 2013). Indeed, recent studies have indicated that attitudes towards public transport as well as concerns about personal safety and traffic, all play a significant role in the decision to use public transport (Elias & Shiftan, 2012). Within transport studies, researchers have applied attitude and behavioural theories from environmental and cognitive psychology, such as Fishbein & Ajzen's (1975) *Theory of Reasoned Action* (TRA) and later Ajzen's (1991) *Theory of Planned Behavior* (TPB), to explore the psychological dimensions of travel behaviour and modal choice. The TRA and related models from the field of cognitive psychology assume that individual variables such as attitudes and perceptions are the dominant drivers of behaviour (this approach has been advocated for promoting bicycle use by Bamberg (2012)). A number of empirical studies support this contention, for example Thogerson's (2006) research with Danish residents found that attitude towards public transport, car ownership and perceptions about whether public transport could meet travel needs all predicted public transportation use.

While often contested, the influence of perceptions cannot be ignored. Geographical and sociological studies of crime in cities and perceptions of neighbourhood safety (Rengert & Pelfrey, 1997; Austin et al., 2002) have shown that perception is often more important than objective reality in determining people's use of features of the built environments, including transport infrastructure and services. However, approaches derived from the TRA and similar theories have increasingly been criticised for overstating the influence of perceptions and almost completely neglecting of the role of structural and contextual factors in shaping individuals' behaviour. As a result the past decade has seen the growth in perception behaviour models which attempted to encapsulate more contextual and situational factors. For example, the premise of Spears et al.'s (2013) *Perception-Intention-Adaptation* (PIA) model is that both cognitive processes and the physical environment have a direct effect on travel behaviour.

Efforts to measure actual and perceived risks regarding road safety for cyclists can take diverse forms and involve both qualitative and quantitative evidence. Mirroring increasing societal interest in health, diet and fitness metrics, quantitative data that capture cyclists' perceptions and experiences are increasingly in demand (Eisenman et al., 2009). A review of the literature to date indicates that there is an urgent need to collect empirical evidence of cyclists' experiences not only to influence user-applications (health and safety) but also to inform transport and environmental policies (e.g. road conditions, cycling infrastructure provision).

2.2.2 Perceptions of cycling risk

Safety is the primary factor in choosing whether to commute by bicycle (Noland, 1995; Whannell et al., 2012). The major cause of cycling collisions is interaction with motorised vehicles: 82% of cyclist fatalities and 87% of cycling injuries occur in collisions with motorised vehicles. Junctions pose a particular danger to cyclists: 35% of cyclist fatalities take place at junctions, compared to 20% for pedestrians and 17% for car users. The main injuries to cyclists are to the legs, head and arms and the most common types of injury are fractures (34%), bruising (31%) and open wounds (13%). Injured cyclists spend, on average, an extra day in hospital than those injured in car collisions (ERSO, 2012). An uptake in cycling is seen as particularly important from a road safety perspective as the 'Safety in Numbers' theory holds that the likelihood that a cyclist will be in a collision is inversely related to levels of cycling. This may be due to improvements in motorists' awareness (Jacobsen, 2003).

Perception of cycling safety are also influenced by social-structural factors such as attitudes, social norms and habits (Heinen et al., 2010; Ma et al., 2014). Drivers' attitudes to cyclists, for example, are perceived as perhaps the most significant barrier to cycling (Lawson et al., 2013; Wooliscroft & Ganglmair-Wooliscroft, 2015). Cyclists also consider more safety related factors than users of other modes (Fernández-Heredia et al., 2014) and Horton's (2007) 'fear of cycling' goes beyond that of collisions and traffic to include the fear of being on show, of harassment or violence, and of seeming inept or unfit. Many of these fears are culturally embedded and socialised, e.g. parents constrain the travel behaviour of their children based on perceptions of road safety (Timperio et al., 2004; Carver et al, 2010). Perceptions of cycling risk also manifest in social pressure to wear disliked safety clothing, such as high-visibility vests and helmets (Aldred & Woodcock, 2015; Deegan, 2015), which do not increase perception of safety among cyclists (Lawson et al., 2013). However a key gap in research that has been identified is that few studies of perceived cycling risk have included the characteristics of the cyclist (Lawson et al., 2013; Black & Street, 2014; Bill et al., 2015).

The UK Department for Transport considers the perception of cycling risk as a potential barrier to cycling and includes perceived cycling safety in the British Social Attitudes survey (UK DfT, 2014). Surveys indicate that 61% of respondants in the UK consider the roads too dangerous for cycling. This varies significantly with age (47% of 18-24 y/o, 76% of 65+ y/o), gender (69% of women, 53% of men) and cycling experience (48% of those who cycled in the last year, 67% of those who did not) (UK DfT, 2014). Several studies identified age and gender as factors which influence perceptions and which also shape responses to segregated cycling infrastructure (Black & Street, 2014; Ma et al., 2014; Dill et al., 2015). Cycling experience has also been shown to influence risk perceptions and inexperienced cyclists are more likely to perceive road conditions as hazardous (Bill et al., 2015). Sanders (2015) suggests that additional experience and skills gained may make these cyclists more tolerant of risks, although even experienced cyclists are concerned about a variety of possible causes of injury.

Many authors have examined the connection between the built environment and cycling behaviour. The major infrastructural and traffic factors identified as affecting perceived cycling risk include: motorist volume, motorist speed, presence of a cycling facility, lane width, number of junctions, presence of roundabouts, pavement surface, parked cars and traffic mix (Lawson et al., 2013; Bill et al., 2015). Increased perception of cycling crash risk can be found in areas of low density, non-mixed land uses as opposed to compact, mixed-use neighbourhoods. This was even found to be the case when the latter areas experienced greater actual crash risk (Cho et al., 2009). Bicycle-friendly neighbourhoods (connected streets, low-traffic etc.) improve residents' perceptions of the environment and these residents cycle more often due to these positive perceptions (Ma et al., 2014). Major streets with shared lanes are associated with greatest perceived risk while shared-use paved paths are perceived as the safest form of infrastructure (Winters et al., 2012). Parkin et al. (2007a) found that cycling facilities at roundabouts did not reduce the perceived hazard.

Cycling infrastructure on roads with heavy traffic marginally reduced perceived danger, while completely off-road, traffic-free routes significantly reduced perceived danger (Parkin et al., 2007a). Cycle tracks are perceived as the safest form of cycling infrastructure, preferred to raised cycle lanes, cycle lanes, and on-road in traffic in Copenhagen (Jensen et al., 2007). Approximately 45% of respondents felt 'very safe' cycling on cycle tracks, compared to 32% on cycle lanes and 11% on road in traffic. These results are in line with many studies which have shown cyclists' preferences for segregated infrastructure, although there are limits to the additional travel time that cyclists are willing to spend in order to use segregated infrastructure (Sener et al., 2009; Caulfield et al., 2012).

Limitations to the assessment of perceived safety include the under-reporting of cycling collisions, the avoidance of particular routes and the variation in route types and location (Parkin et al., 2007a). There is a need for new qualitative and quantitative methods to determine the factors in perceived cycling risk. The role of segregation, in this regard, is of particular interest.

2.2.3 Mental mapping

Mental maps are defined as "an amalgam of information and interpretation reflecting not only what a person knows about places but also how he or she feels about them" (Johnston et al., 1986). Lynch's (1960) study of images in the city represents an early landmark study in this field. Mental maps have been utilized to explore a range of subjects including perceived desirability of neighbourhoods, orientation and way-finding, perceptions of crime and migration propensities (Fahy & Ó Cinnéide, 2009; Gould & White, 1993). Research into mental maps and travel behaviour is sparse and existing studies focus predominantly on travel route choice (Mondshein et al., 2010; 2013). In one cycling example, Snizek et al. (2013) used a variety of mental mapping to study route experience, whereby an online questionnaire in Google Maps allowed participants to award positive and negative experience points. However, no study has used mental mapping to explore the role of both infrastructural and individual characteristics on perceived cycling risk.

2.2.4 Measures of bicycle suitability

Several measures of cycling level of service (LoS), suitability, friendliness, compatibility give expression to perceived comfort and perceived safety for practical application in traffic engineering and urban design. The empirical background of these measures typically models infrastructural and traffic factors (e.g. road width, traffic volume), associated with perceived risk, although the characteristics of the cyclist are rarely considered. Such measures are useful as road sections can be rated and maps produced to assist cyclists in route choice and to identify those road sections in need of improvement to ensure network safety and coherence. To clarify inconsistent terminology and to classify measures spatially, Lowry et al. (2012) proposes three definitions:

- 'bicycle suitability' (perceived comfort and safety along a *linear section* of road)
- 'bikeability' (comfort, coherence, and convenience of a bicycle *network*)
- 'bicycle friendliness' (laws, policies, education, bikeability of a *community*)

Lowry et al. identified 13 measures of 'bicycle suitability' developed between 1987 and 2011, which vary according to factors considered, points system and weighting.

Seven such measures are the Bicycle Level of Service (BLOS-Sprinkle) (Landis et al., 1997), Cycle Audit and Cycle Review (CACR) (IHT, 1998), Bicycle Compatibility Index (BCI) (Harkey et al., 1998), Bicycle Network Analysis Tool (BNAT) (Klobucar & Fricker, 2006), Risk Rating (Parkin et al, 2007a), Bicycle Level of Service (BLOS-HCM) (TRB, 2011) and, more recently, Lawson et al. (2014) have proposed a Cyclist Safety Index. Parkin et al.'s (2007a) models align with IHT (1998) and are quicker and cheaper to implement (Parkin & Coward, 2009). Factors considered in these measures are: road facility type, outside lane width, number of lanes, lane markings, presence of a cycle facility, type of cycle facility, cycle facility width, motorised traffic volume, motorised traffic speeds, cyclist volume, cyclist speed, percentage of heavy vehicles, presence of on-street car parking, number of junctions/driveways, junction type, pavement condition, presence of a curb. The factors have been weighted as adjustment factors and combined to yield a score for bicycle suitability or perceived comfort or perceived safety.

A Quality of Service measure is included in Ireland's National Cycle Manual (NTA, 2012) and includes pavement condition, width, number of conflicts per 100 m, journey time delay, and percentage of traffic comprised by HGVs. Kang & Lee

(2012) developed a bicycle level of service for traffic-free routes (shared with pedestrians and exclusive for cycling) and found that the level of service is largely determined by route width. Route type, number of lanes and number of encounters (pedestrians and cyclists moving in the opposite direction) were also found to be statistically significant.

The data collection methods for 13 perceived cycling safety studies have been summarised by Lawson et al. (2013) to include: video recordings, video simulations, completion of a test course, interviews and questionnaires, and the novel application of heart rate monitors in the assessment of perceived risk (Doorley et al., 2015). However, only two of the studies reviewed by Lawson et al. (2013) considered the characteristics of the cyclists: Møller & Hels (2008) and Noland (1995). Møller& Hels investigated cyclists' perception of risk at roundabouts, finding that safety perceptions are determined by a combination of the characteristics of the individual cyclist (age and gender), the design of infrastructure (e.g. cycle facility) and traffic volume.

Snizek et al. (2013) used a variety of mental mapping to determine correlations between cycling perceptions of route experience and the built environment, wherein an online questionnaire in Google Maps allowed participants to award positive and negative experience points. Such 'mental mapping' techniques can be used to shed light on this combination of individual and (infra)structural factors and can add to measures and applications of bicycle suitability. This methodcould be used as part of online GIS-based platforms and sensors for crowd-sourcing perceptions of cycling safety and identifying localised risks (Loidl, 2014; Nelson et al., 2015; Zeile et al., 2015).

Building on these methods and results, Chapter 4 of this thesis applies a mental mapping method to unpacking determinants of perceived cycling risk. The method incorporates the individual characteristics of the cyclist (demographics, cycling experience etc.) as well as infrastructural characteristics of road and cycling infrastructure (segregation, traffic volume etc.).

2.3 Designing infrastructure for cycling

To allay perceptions of risk and to improve objective cycling safety, dedicated cycling infrastructure involving segregation between motorised and non-motorised modes, is recommended and sought after regularly. A broad suite of international walking and cycling design guidance has emerged in the last 20 years and the seminal document is *Sign up for the bike* (later *Design manual for bicycle traffic* (CROW, 2007)). Generally this guidance is provided by State transport bodies, e.g. Transport Scotland (2011), NACTO (2011), and NTA (2012). This section first reviews the literature on designing for walking and cycling, followed by a discussion on segregation, vehicular cycling and the hierarchy, and definitions for walking and cycling infrastructure.

2.3.1 Introduction to cycling design

Inadequate design and maintenance of cycling infrastructure are barriers to the uptake of cycling as a mode and contribute to the integrationist argument in the segregation debate. Parkin (2014), for example, plots the development of cycling design guidance, arguing for more comprehensive planning and considering the heterogeneity of cyclists as well as problems with movement and place hierarchies. Bicycles are vehicles capable of speed and highway and traffic engineering principles should guide the design of commuter cycling routes (Parkin & Koorey, 2012). These principles must be complemented by design for the specific characteristics of cycling: movement through physical exertion and a lack of protection (Parkin, 2010). The amount of physical exertion required for cycling can be reduced by route design, e.g. the external power needed by a cyclist to rises considerably with gradient (as well aerodynamic and rolling resistance) (CROW, 2007; Ploeger, 2003).

CROW's (2007) five criteria for cycle infrastructure design remain the industry standard and are summarised in Table 2.2. These criteria relate to many other transport planning guidelines, including, for example Cervero & Kockelman's (1997) 'D's, Density, Destination accessibility, Design, Distance to public transport, and Diversity. Fietsbalans (Bicycle Balance) is the Fietsersbond's (Dutch Cyclists' Union) broader benchmarking tool for the cycling climate and goes beyond attributes in Table 2.2 to include: the competitive position between the bicycle and the car (e.g. journey times and parking costs), cycling modal share, cycling collision risk, urban density, cyclist satisfaction (based on survey), and written policy (i.e. degree to which cycling requirements, infrastructure and budgets for part of policy) (Borgman, 2003; CROW, 2007).

Table 2.2 - Criteria for cycling infrastructure design

Criteria	**Factors**
Attractiveness	Aesthetic, lighting, landscape, connectivity, community
Comfort	Surface quality, gradient, hazards, stop frequency, climate
Coherence	Ease, connectivity, consistency, signage, route choice
Directness	Speed maintenance, delay, detour factor, network density
Safety	Exposure, conflicts, visibility, perception, experience

Sources: ARUP & Sustrans (1997); Nash et al. (2005); CROW (2007); UK DfT (2008); Veith & Eady (2011); NTA (2012)

Deegan & Parkin (2011) note the need to work at the 'highest' level of participation for cycling schemes. Due to the level of exposure of cyclists to the environment, cyclists are a rich source of knowledge for complex urban areas. There should be a bilateral transfer of knowledge between cycle scheme promoters and stakeholders, between well-informed engineers and well-informed cycle users (Deegan & Parkin, 2011). Milakis & Athansopoulos (2014) and Molina (2014) make efforts to include public participative elements in cycling planning using, for example, crowdsourcing. Goodefrooij et al. (2009) and NTA (2012) propose steps in planning a cycle network and these have been aligned in Table 2.3. Further guidance is provided in Gallagher & Parkin (2014).

Table 2.3 - Steps in planning a cycle network

No.	**Godefrooij et al. (2009)**	**NTA (2012)**
1	Define objectives	Urban and Transport Planning
2	Map land use, assess cycling demand	Trip Demand
3	Map routes, facilities, volumes, collisions	Inventory of Existing Cycling
4	Identify priority locations and constraints	Trip Assignment
5	Identify improvements	
6	Predict potential demand	Trip Forecast
7	Prioritise and select schemes	Prioritising Improvements
8	Implement schemes	Programme, Consultation
9	Monitor and assess	Budgets

The number of data sources and mobile applications for cycling is increasing, yet there is a lack of empirical evidence to inform cycle planning (Cope et al., 2007). Cope et al. (2007), for example, call for analytical tools for continuous cycle counts to be used in the planning of cycle networks. Examples of the use of cycle route monitoring data are: Gordon & Parkin (2012) for usage patterns on the UK NCN; Lindsey et al. (2007) for urban trail traffic in Indiana, USA; Deenihan et al. (2013) for monitoring the Great Western Greenway. Other research from a tourism perspective (cf. Lumsdon (2003) for UK NCN) is reviewed in Section 2.6. However it is recognised that significant developments in data collection for cycling are required due to inaccuracies in automatic and other counts (Cope et al., 2007; Deenihan et al., 2013).

Route choice models (e.g. using GPS and GIS) suggest that cyclists prefer: segregation from motorised vehicles (or low traffic speed and volume and traffic-calming), low gradient, low junction frequency, low waiting times at junctions, no on-street parking, traffic signals, smooth surface, dedicated bridge facilities, green areas. These preferences vary on the basis of cyclist demographics (e.g. gender, age, cycling experience) and trip purpose (Dill & Gliebe, 2008; Sener et al., 2009; Broach et al., 2012; Kang & Fricker, 2013; Krenn et al., 2014). These preferences should be considered in tandem with the results of perceived cycling risk studies review in Section 2.2. Other models include a GIS-based model to prioritise cycling infrastructure investments (Larsen et al., 2013) and a bikeway network design model for urban areas (Lin & Yu, 2013). Lin & Liao (2014) later applied this method to recreational cycling routes.

These preferences sometimes come into conflict, e.g. choosing a segregated cycling facility versus a more direct on-road route. In this case, a substantial number of studies have found that the reduction in (perceived) risk offered by segregation is more highly valued than the time savings of cycling with motorised traffic (Hopkinson & Wardman, 1996; Dill & Gliebe, 2008; Tilahun et al., 2007; Caulfield et al., 2012). Off-road cycling facilities are also preferred by motorists (Sanders, 2014), perhaps as this facilitates the free movement of motorised vehicles. Furthermore, junctions between segregated cycling facilities and the highway and the safety challenges they pose are critical.

2.3.2 Segregation, Vehicular Cycling and the Hierarchy

The separation of pedestrians from motorised traffic has long been considered necessary for safety reasons, particularly due to the speed and mass differential between humans and vehicles (Schoon, 2010). Pedestrian infrastructure includes footpaths, pedestrian crossings, pedestrian bridges, pedestrianised streets as well as walking trails. Segregation for cycling, on the other hand, is not as common and is the subject of major debate in the cycling research and advocacy community. *Traffic in Towns* (Buchanan, 1963), also known as the Buchanan Report, has been extremely influential in planning Ireland and the UK (DTTAS & DECLG, 2013).

Buchanan (1963) consolidated existing experience on segregation into a general theory and envisaged a street network which segregated pedestrians and cyclists from motorised traffic (Figure 2.3), a road hierarchy based on land-use (e.g. distributor roads in residential areas), and the consideration of the local environment. The report informed urban flyovers, new roads, one-way streets, pedestrianised areas, and other features. The report has been criticised for treating walking, cycling and public transport as secondary to the car, and for the 'predict and provide' model which induced traffic by releasing latent demand (Vigar, 2002; Buchanan, 2013).

In the Netherlands, Germany, Denmark and elsewhere, segregation of cyclists from motorised traffic is considered a fundamental principle, whereas in the US, and to a lesser extent Ireland and the UK, the integration of cycling with motorised traffic is widespread (Furth, 2012). Segregation may take the form of kerbs, kerbed plinths, bollards, soft margins or verges, or crash barriers. Integration involves cycling on-road, with or without marked cycle lanes (NTA, 2012). CROW (2007), the Dutch design manual for bicycle traffic, outlines the origins of segregation in the Netherlands and argues that a separate network of connections for cycling improves safety and comfort.

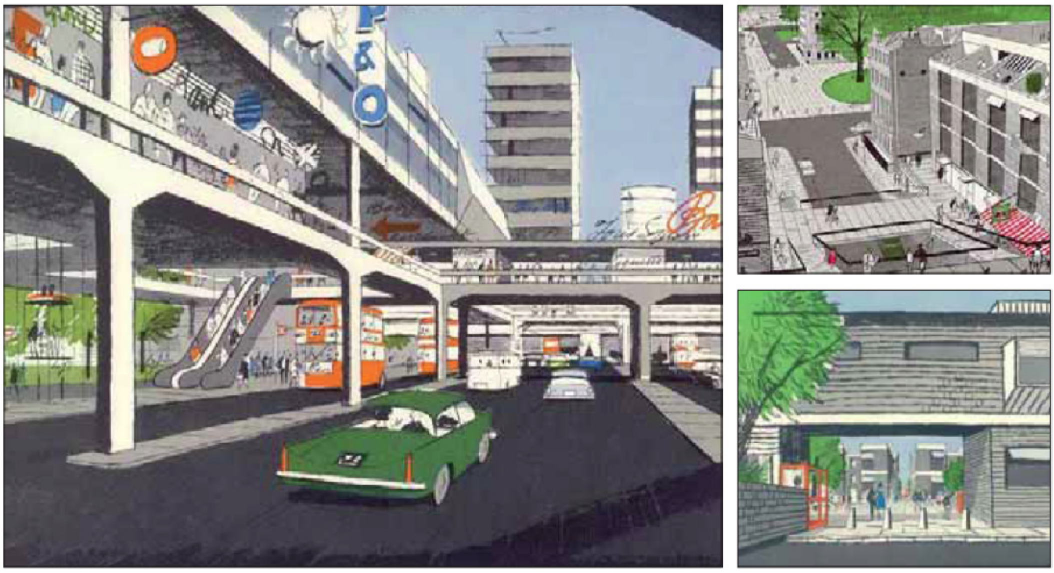

Figure 2.3 - Vertical segregation in'Traffic in Towns' (Buchanan, 1963)

There is extensive evidence to show that the design of the built environment impacts travel behaviour, although other social factors must be considered (Cervero & Kockelman, 1997; Ewing & Cervero, 2010). Goodman et al. (2014) found that those living closer to segregated walking and cycling infrastructure walk and cycle for longer each week. In a longitudinal study of 1796 adults living in proximity to Sustrans Connect2 routes, the authors found that (after two years) residents walk or cycle 15.3 minutes more per week for each km that they live closer to the traffic-free route, i.e. residents living within 1 km walk or cycle for 45 minutes more than those living 4 km away. This increased physical activity was greater for those without a car and was not offset by reductions in physical activity elsewhere in participants' lifestyles.

According to Pucher & Dijkstra (2000), a central reason for lower levels of walking cycling and greater rate of pedestrian and cyclist fatalities in the US, when compared to the Netherlands and Germany, is the lack of facilities for these travellers. The authors call for more and improved segregated facilities, traffic calming and other vehicle restrictions, people-oriented design, and improved education and enforcement. Pucher & Buehler (2007), offering case studies of six cities in the Netherlands, Denmark and Germany, conclude that the most important factor in achieving safe, convenient and attractive cycling is the provision of segregated cycling facilities on roads with large traffic volumes (with complementary traffic-calming in residential areas). Within North America, Pucher et al. (2011) find cities which have been most successful in increasing cycling have implemented segregated infrastructure programmes (as well as other measures).

Segregation is particularly important for children, older people, women, and people with disabilities. In countries with extensive segregated cycling facilities, cycling is more evenly distributed across all age groups and genders. In the Netherlands and

Denmark, the majority of cyclists are women (Garard et al., 2012), while in Ireland, 27% of cyclists are women, down from 35% in 1986 (CSO, 2012a). Garard et al. (2012) show that perceived risk of being hit by a car is the major deterrent to cycling by women and that more segregated infrastructure would encourage more women (to a greater extent than men) to cycle. Children, in particular, require safe dedicated cycling infrastructure (McDonald, 2012). Pucher & Buehler (2009) conclude that the strongest argument for segregation is that a wide spectrum of the population is enabled to cycle – 'cycling for everyone'.

Vehicular cycling (VC) advocates the treatment of cyclists as drivers of vehicles through sharing of road space and is based around the following principles: predictability, visibility, assertiveness, obeying traffic laws, lane and intersection positioning, and communicating with others (Franklin, 2002; Haake, 2009). VC proponents claim that segregated infrastructure is unsafe and marginalises cycling from road space; they argue that investment should not be provided for segregated infrastructure except in isolated circumstances such as inter-urban trails. Key proponents of VC include Forester (2012) and Franklin (2007), who have created cycling training programmes 'effective cycling' in the US and 'bikeability' in the UK, respectively.

Haake (2009), in response to Pucher & Buehler's (2007) case studies on segregation, raises the issues of junctions, bus passenger disembarkation, bike path congestion and the separation of fast and slow cyclists, conflict at left-hand turns (right-hand turns in Ireland and the UK), right-of-way, construction cost, and lack of maintenance. Franklin (2002) discusses whether a cyclist is a vehicle driver or 'some kind of rolling pedestrian', emphasising the need for cyclists to be integrated with motorised traffic. Forester and others successfully convinced AASHTO (1999) to exclude segregation, a move which Furth (2012) claims was adopted to avoid investing in bicycle infrastructure and has therefore stymied cycling in the US. NACTO (2011) has developed its own design guide in response to the lack of treatments offered by AASHTO (1999).

A point in common between the pro- and anti-segregation positions is the need for traffic calming and the use of shared space in certain circumstances, as well as cyclist education (Haake, 2009; Pucher & Buehler, 2009). Moody & Melia (2013), however, have claimed that shared space advocates overstate the evidence underpinning its effectiveness and have called on designers to exercise caution in the development of shared space which includes large traffic volumes. Traffic calming involves the reduction in vehicle speeds to 30 km/h and the reduction of traffic volume. Super-traffic calming of residential areas, known as Woonerf in the Netherlands, Spielstrassen in Germany and Home Zones in Ireland and the UK, involves slowing traffic to approximately 7 km/h (Pucher & Buehler, 2009).

Cycling policy in the UK is situated somewhere between what Aldred (2012) terms ‘segregationist’ and ‘integrationist’ positions. The Hierarchy of Provision prioritises restrictions on motorised traffic before the reallocation of carriageway space or the construction of dedicated cycling infrastructure (Figure 2.4). The Hierarchy first appeared in the 1996 UK Cycle-friendly Infrastructure (UK DfT/CTC/Bicycle Association/IHT, 1996) and was included in the revised UK DfT (2008). The Hierarchy is not a full exposition of Vehicular Cycling, which rejects almost all forms of segregation, instead calling on designers to *consider* integration treatments before segregation. However, Aldred (2012) and the Cycling Embassy of Great Britain (2014) claim that the vehicular cycling approach to be written into UK cycle policy through the Hierarchy, with the latter rejecting the Hierarchy as “ineffective and counter-productive”.

Consider first	Traffic volume reduction
↓	Traffic speed reduction
	Junction treatment, hazard site treatment, traffic management
	Reallocation of carriageway space
	Cycle tracks away from roads
Consider last	Conversion of footways/footpaths to shared use for pedestrians and cyclists

Figure 2.4 - Hierarchy of provision (UK DfT, 2008)

Parkin & Koorey (2012) argue that the Hierarchy “is not helpful in outlining the processes of route and network planning that must precede scheme implementation” and that it leads to adjustments at the individual route level before understanding and providing for demand. Parkin (2010) points to German cycle planning for interconnected, safe, speedy and extensive networks and suggests that a Northern European hierarchy would be “a hierarchy of primary, secondary and leisure routes for cycle traffic as part of a whole network, and which takes account of the speed and connectivity needs of such traffic”.

In Ireland, the Hierarchy was adopted in the NCPF (DTTAS, 2009b) and the National Cycle Manual (NTA, 2012) – it is therefore embedded in Irish policy. However, NTA (2012) also lists benefits of segregation: protection from motorised vehicles, avoiding congestion, and reliable journey times; it recommends segregated facilities where traffic is unsuitable for cycling, where vehicles may park or block an on-road cycle lane, and to prioritise cyclists. The manual notes that detailed design is required for access to and egress from segregated facilities. Segregated facilities are not recommended along routes with frequent junctions, at junctions, and where there is no commitment to maintaining such a facility.

When deciding whether to segregate, designers should consider the separation guidelines displayed in the Guidance Graph (NTA, 2012) – a graph based on the

CROW (2007) separation criteria – see Figure 2.5. This graph has faced criticism as it does not consider road width, percentage of HGV traffic, cyclist composition (school children, fast commuters etc.) and means that most main roads in Irish urban areas would need to be segregated (Foran, 2002).

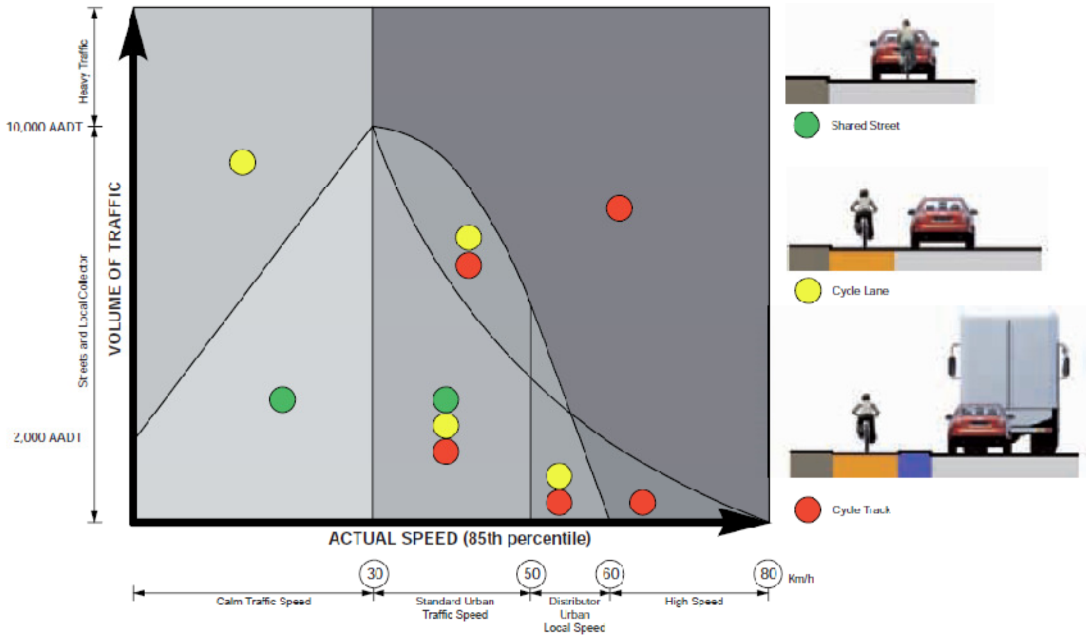

Figure 2.5 - Guidance Graph (NTA, 2012)

In a further complication to the Irish context, a 1997 law known as the 'mandatory use' law was introduced which compelled cyclists to use segregated cycling facilities where provided (Ireland. *Road Traffic (Traffic and Parking) Regulations 1997,* SI 182/1997). Under Irish law, a bicycle is defined as a vehicle (Ireland. *Road Traffic Act 1961*) and cyclists are entitled to use all public roads (other than motorways). The statutory instrument created problems for cyclists as much of the cycle infrastructure constructed was poorly designed and poorly maintained (NTA, 2012). The statutory instrument was removed in 2012 – a stated objective of the NCPF – however, the Dublin Cycling Campaign (2014) has questioned awareness of this removal, with motorists continuing to insist that cyclists move from the road into an adjacent cycle facility if present.

2.3.3 Cycling infrastructuretypology

There is a large variation in terminology used internationally for segregated cycling infrastructure. The brief review is intended to introduce infrastructural options; greater design and construction detail is provided in Section 2.4. Legal definitions of some cycling facilities in Ireland are given to contextualise the case study and to show the framing of the term 'greenway'. Table 2.4 outlines the terminology for infrastructure provision in a selection of countries. Generally, terminology is similar in Ireland and the UK; American terminology has been used as a translation of some continental European terms, while specific German, Dutch and other terms are also commonly used in the English language.

Table 2.4 - Cycling infrastructure terminology

Ireland/UK	Europe / N. America	Description
On-road cycle lane	Designated bike lane	Striped line, no physical barriers
Raised cycle lane	Bike path at sidewalk	Raised from road surface
Cycle track	Protected bike lane	On-road, separated by barriers
Bus lane	Combined bus-bike lane	May include markings; In Ireland, cyclists may use bus lanes, unless specifically excluded
Cycle street	Bicycle street / boulevard	Lightly trafficked road, equal rights to cyclists and motorists; Narrow street, cyclist right of way
30 km/h zones	Traffic-calmed street	Speed limit reduced to 30 km/h, other physical modifications
Home Zones	Woonerf (Netherlands) Spielstrasse (Germany)	Super traffic-calmed residential street; speed reduced to 7 km/h
Shared space	Complete streets (part of)	Road surfaces shared by modes
Bicycle superhighways	Cycle Super Highways (Denmark)	High-speed, low stop frequency routes, often segregated
Greenway / cycle trail	Shared-use path / stand-alone path / multi-use trail	Various non-motorised users, often in parks, abandoned railway etc.
Off-road cycle track / Off-road cycleway	Off-road bike-only paths / separated paths	Parallel to urban road, separate from roadway and footpath

Sources: CROW (2007); UK DfT (2008); Pucher & Buehler (2009); Furth (2012); NTA (2012); DTTAS & DECLG (2013); NRA (2014a)

Table 2.5 - Cycle track and cycle lane typology

Cycle tracks	Description
At grade	Bollards used for 0.3 m segregation; used on collector roads with speeds up to 50 km/h
Raised	Full kerb height (approx. 0.1 m) as segregation, bollards may be added; used on busier roads with speeds up to 80 km/h
Behind verge	Grass or paved verge as segregation (may include trees and furniture);used on distributor and collector roads with speeds over 60 km/h
Cycle lanes	**Description**
Mandatory	Continuous white line; motorised vehicles may only enter for access; no parking allowed
Advisory	Broken white line; motorised vehicles may enter or cross line; set down and loading allowed; used where space insufficient for mandatory lane
Raised	Raised by 25-50mm; remains legally part of carriageway; no parking allowed; used on collector roads with frequent entrances/driveways and adjacent to bus lanes

Sources: NTA (2012); NRA (2014)

Irish law defines a 'cycle track' as: "part of a road, including part of a footway or part of a roadway, which is reserved for the use of pedal cycles and from which all mechanically propelled vehicles, other than mechanically propelled wheelchairs, are prohibited from entering except for the purpose of access" (Ireland. *Road Traffic (Traffic and Parking) Regulations 1997,* SI 182/1997). Where a cycle track is provided on a roadway, without physical segregation, it is known as a 'cycle lane' (NTA, 2012), although 'cycle lane' has no legal definition (Roughan O'Donovan, 2009). See Table 2.5 and Figure 2.6 for descriptions of cycle tracks and cycle lanes in Ireland.

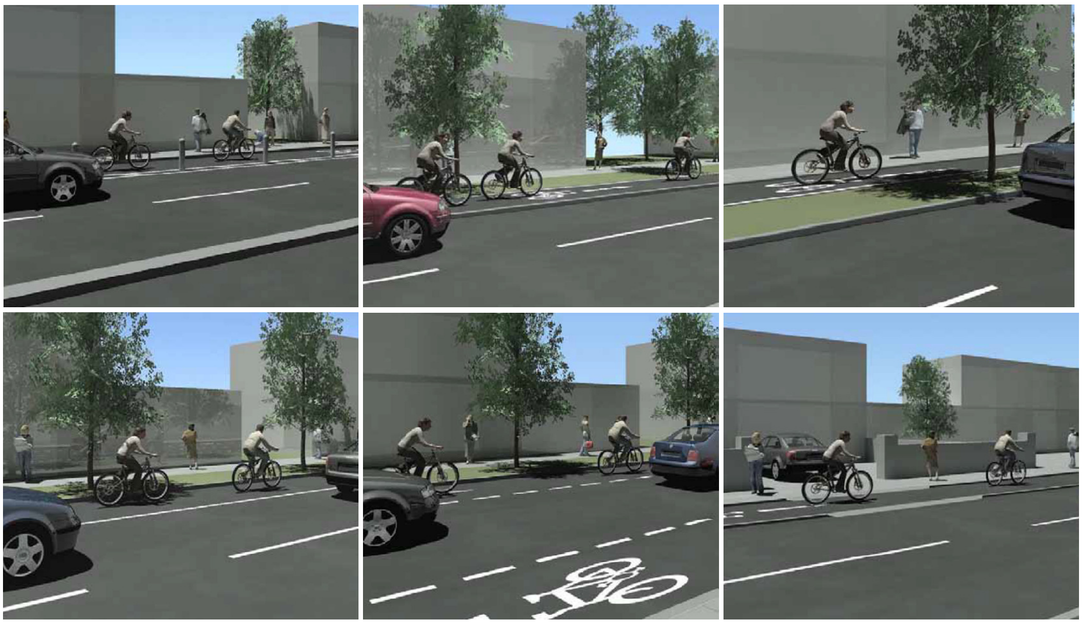

Figure 2.6 - Top (left to right): at grade, raised and behind verge cycle tracks; bottom (left to right): mandatory, advisory and raised cycle lanes (NTA, 2012)

The majority of the infrastructure forms outlined are usually provided in urban and suburban areas and this is the orientation of NTA (2012). In rural or inter-urban areas, cycleways or greenways/cycle trails are used. A 'cycleway' is defined in the Roads Act as:"a public road or proposed public road reserved for the exclusive use of pedal cyclists or pedal cyclists and pedestrians". Road authorities (including LAs) have the power to construct (or otherwise provide) a cycleway and to maintain it. Once built, the road authority must declare whether the cycleway is for the exclusive use of cyclists or for cyclists and pedestrians (Ireland. *Roads Act 1993*). This legal definition of cycleways is highly important due to the statutory obligations placed on road authorities in route selection and design.

Cycleways can take the form of routes through parks or short-cuts. There should be infrequent intersections with roads carrying motorised traffic, employ crossings rather than junctions, provide visibility and lighting, signposting. Raised adjacent footpaths should be considered where there is large pedestrian flow (NTA, 2012). Two distinct cycleway terms (on-road cycleway and off-road cycleway) are defined by NRA (2014a) and are outlined in Chapter 8. In Ireland, the terms ‘cycleway’ and ‘greenway’ have been used interchangeably (e.g. the NCN corridor between Galway and Dublin is regularly referred to as the Galway to Dublin Cycleway and the Galway to Dublin Greenway). This research considers a greenway to be one type of cycleway, set apart by specifications for separation and environmental impact.

2.3.4 Introduction to greenways

‘Greenway’ is a term used in both transport planning and landscape ecology and landscape architecture. Little (1995), in the seminal work on greenways, *Greenways for America*, brings together the multi-purposes of greenways to provide the following elements of a definition:

1. A linear open space established along either a natural corridor, such as a riverfront, stream valley, or ridgeline, or overland along a railroad right-of-way converted to recreational use, a canal, a scenic road, or other route.
2. Any natural or landscaped course for pedestrian or bicycle passage.
3. An open-space connector linking parks, nature reserves, cultural features, or historic sites with each other and with populated areas.
4. Locally, certain strip or linear parks designated as a parkway or greenbelt.

Little (1995) identifies five greenway types and these are described in Table 2.6.

Table 2.6 - Greenway types (Little, 1995)

Type	Description
Urban riverside greenways	Usually created as part of (or instead of) a redevelopment programme along neglected, often run-down city waterfronts
Recreational greenways	Paths and trails of various kinds, often of relatively long distance, based on natural corridors as well as canals, abandoned railbeds and other public rights-of-way
Ecologically significant natural corridors	Usually along rivers and streams and (less often) ridgelines, to provide for wildlife migration and ‘species interchange,’ nature study, and hiking
Scenic and historic routes	Usually along a road or highway (or, less often, a waterway), the most representative of them making an effort to provide pedestrian access along the route or at least places to alight from the car
Comprehensive greenway systems or networks	Usually based on natural landforms such as valleys and ridges but sometimes simply an opportunistic assemblage of greenways and open spaces of various kinds to create an alternative municipal or regional green infrastructure

Fabos (1995; 2004) sees greenways as fulfilling three major roles: (1) nature protection, (2) recreation and tourism opportunities, and (3) protect and restore historical and cultural heritage (see Fabos (2004) and Ahern (2004) for the history of greenway movements in Europe and America). Greenway types, their objectives and use have evolved over hundreds of years; Searns (1995) outlines three generations of greenway:

1. Axes, boulevards and parkways (ancestral greenways)
2. Trail-oriented and recreational greenways (e,g. along rivers)
3. Multi-objective greenways, including recreation, beautification, habitat needs, flood damage reduction, water quality, outdoor education etc.

Pourjafar & Moradi (2015) goes beyond these generations to identify five greenway periods and show how greenway movements and activities have evolved over the last three centuries (Table 2.7).

Table 2.7 - Historical dimensions and trends in the greenway concept (Pourjafar & Moradi, 2015)

Greenway Period	Movements	Activities	Classification
First period (1700-1850)	Bulldozer urban development, park building	Élysée boulevards of Paris, religions ways of Rome, American parkways	Physical, environmental, social
Second period (1850-1900)	Beautiful City	Boston park system	Physical, environmental
Third period (1900-1950)	Open space planning	Green space network in Germany, greenways of England	Environmental
Fourth period (1950-1980)	Environmental movement	Wisconsin ecological network, Design with nature, Greenway projects in Singapore and Malaysia	Physical, environmental
Fifth period (1980-present)	Greenway, sustainable development	European Greenways Association, London green strategy, global activities	Physical, environmental, social

In this research, greenways are viewed primarily as transport and tourism corridors, one form of cycleway, which are motorised traffic-free, and generally well separated from traffic, catering for cyclists, pedestrians and other non-motorised users, such as wheelchair users. This transport and tourism approach must align with the recreational and, to a lesser extent, urban and ecological greenway types in keeping with the concept of the multi-objective greenway. For this research, the separation of motorised and non-motorised traffic is fundamental to the definition of a greenway from both transport, ecological and social perspectives. Key criteria for greenways are therefore judged tobe:

- Linear corridors for the exclusive use of non-motorised travellers with a large degree of separation from motorised traffic

- Link exisiting green resources and are accessible for those of all abilities and from all socio-economic classes
- Multi-purpose routes functioning as resources for transport, recreation and tourism, while protecting the landscape and biodiversity

(EGWA, 2000a; Fabos, 1995; Little, 1995; Palau et al., 2012; Salici, 2013; Sustrans, 2009).

Greenways are receiving increasing attention, particularly in Europe, in recent years as new funding streams (often driven by cycle tourism) bring a new dimension to this fifth period of greenway design. Other than work coordinated by the European Cyclists' Federation (ECF) on EuroVelo, several greenway marketing projects have received EU funding and the European Greenways Association (EGWA) has been to the forefront. In 2011, EGWA was awarded funding for a Greenways4Tour project. The aims of this project are to promote awareness of European greenways for sustainable tourism, and to promote heritage and improved accessibility (EGWA, 2012). Also, in 2013, a consortium of 14 partners from 6 European countries was awarded funding through the EU. Greenways Product aims to stimulate the creation of a new tourism product – Greenways of Europe (EGWA, 2013).

Although greenways have predominantly been envisaged as tourism and recreation routes in rural areas in Ireland, the origin of greenways is in and surrounding urban areas, thus greenways have also been proposed as quality routes for commuting and recreation in sustainable urban areas. Enrique Peñalosa, former mayor of Bogotá, includes in his vision for a sustainable future city a network of hundreds of kilometres of greenways (Peñalosa, 2013). The Mayor of London and Transport for London (2013) proposed a quietway network of sidestreets, greenways and parks.

A number of studies have examined preferences for cycling infrastructure design. Such studies typically use a combination of stated-preference surveys and willingness-to-pay models (based on the value of time) or other route choice models (e.g. GIS-based). The majority of existing literature concerns urban cycling network design and the promotion of commuter cycling. For example, Caulfield et al. (2012)explored cycling infrastructural preferences using a stated preference survey distributed to workplaces in Dublin City. The authors found that segregated infrastructure is preferred by cyclists, regardless of confidence and 74% thought that more off-road cycle tracks would encourage them to cycle to work. For recreational cycling, Parkin et al. (2007b) point to increased development of traffic-free routes on forest trails, restored disused railways and canal towpaths. The authors find that the only significant reduction in perceived cycling risk is linked to traffic-free cycling.

There have been few studies which have examined determinants of greenway use and user preferences. Residential proximity is an important predictor of greenway use (Lu et al., 2013) and minorities and the poor have disproportionate access to greenways (Lindsey et al., 2001). For recreational greenways, scenery and views is usually cited as the most important factor (Mundet & Coenders, 2010; Pettengill et al., 2012). Unpacking the role of scenery and views, Lindsey et al. (2008) correlated urban trail traffic with trail viewshed, neighbourhood and other characteristics, finding that open and green viewsheds, neighbourhood block length and land-use diversity are connected to greater trail use. Similarly, Coutts (2008) showed that simple proximity to populated areas is not sufficient for greater trail use; land-use mixture is an important predictor.

Moving beyond scenery, the most important component of greenways and other recreational cycle routes is separation from motorised traffic and few intersections with roads or rail (Downward & Lumsdon, 2001; Mundet & Coenders, 2010; Williard & Beeton, 2012). Other preferred characteristics are path quality, connectivity to a network, tried and tested routes, refreshment stops and signage/way-finding (Downward & Lumson, 2001; Pettengill et al., 2012). These perceptions vary according to trip type and purpose, e.g. conflict with other users was an issue for 19% walkers, but only 2% cyclists; poor maintenance was a more important issue for cyclists (Mundet & Coenders, 2010).

2.4 Engineering guidance for Greenways

2.4.1 Design Users

Infrastructure must consider, at the design stage, the hetrogeneity of future users, including variations in needs, trip purposes and skill. Greenways are generally targeted at three main user groups: commuters, recreationalists and tourists (EGWA, 2000; Mundet & Coenders, 2010). It should be noted that specific routes can cater for specific design user groups (e.g. school children, commuters) and evolving route funding criteria manifest in route selection (Section 2.8). Other users that should be considered in the design process include people with mobility and visual impairments.

Commuters

Cycle commuters prefer a smooth, direct route with minimal time delays allowing for speed maintenance, they are more prepared than other user groups to interact with traffic. In Ireland, the median cycle commute trip length is 5 km (CSO, 2012a), reaching typical speeds of speeds of 20-30 km/h. For urban commuter cycling in Dublin, Caulfield et al. (2012) found that off-road cycle lanes are the preferred form of infrastructure, followed by a green lane. Other preferences included lower traffic speeds (30 km/h), lower travel time, lower number of junctions, and light traffic volumes. However, many commuters are deterred by distance and time delays and Sager (2002) argues that the cycling culture of a city is more important than a greenway network in influencing commuter cycling levels. Other work has investigated the effects of road markings, lane widths and driver behaviour (Shackel & Parkin, 2014).

Recreationalists

Recreational sport has increased in Ireland in recent years and Lunn & Layte (2011) found that active participation in sport was 33.5% in 2009. Cycling is the sixth most popular sport for adults with 2.8% adults cycling for sport.Between 2009 and 2013, recreational/sport cycling increased from 2.5% to 5.6%. 65% of adults walk at least once per week for recreation. The main motivator for participating in sport is to improve health/fitness and it was found that more women walk and more men cycle (ISC, 2013).

Leisure cyclists are a diverse group including occasional cyclists, experienced cyclists and families, covering short evening cycles and longer day trips. Many of the requirements of leisure cyclists are similar to those of cycle tourists, though often include shorter, looped and family-oriented trips (Downward, 2007; Chen & Chen, 2013). Recreational cyclists look for attractions en-route, toilet and maintenance facilities, information centres and segregated infrastructure (Chen & Chen, 2013). Deenihan (2013) found that 76% of respondents in the catchment area of the proposed Dublin-Mullingar greenway would use the greenway for recreation. Recreational walkers prefer accessible natural-looking trails, well-separated from the noise of traffic (Davies et al., 2012).

Leisure travel is responsible for one third of all distance covered. Of the 7 million domestic trips made by Irish people in 2012, 87% were by car and 11% bus/train (CSO, 2013c). Leisure travel, in particular, is responsible for a large carbon footprint, although much of this is due to aviation. In the UK, recreation/leisure is the single largest source of carbon emissions (ahead of heating); ‘seaside trips’ account for 200 kgCO_2e per person per year (Carbon Trust, 2006).Ownership of a bicycle is associated with likelihood to cycle to work and for all journeys (Driscoll et al., 2013). In 2006, 580,000 households owned one or more bicycles, up from 539,000 in 2003 (CSO, 2007). Although this suggests that at least one million people have access to a bicycle, less than 10% of those use a bicycle for daily journeys and this suggests a large latent demand for cycling. Furthermore, in 2012, bicycle sales outstripped car sales.

Cycle tourists

Cycle tourism is an established industry internationally, with an approximate value of €44bn in Europe, and significant potential to growbased on the EuroVelo network (Weston et al., 2012). Cycle tourism in Ireland has fluctuated over the past ten years, with 100,000-150,000 visitors cycling while on holiday in Ireland (Fáilte Ireland, 2011). High profile greenways, such as the Galway to Dublin Greenway are targeted at attracting thousands of cycle tourists to offset the cost of construction. There are three core factors necessary to attract cycle tourists: (i) safe and continuous route, (ii) pleasant countryside and cyclist friendly villages and cities en route, and (iii) clear and reliable signage and interpretation (Lumsdon et al, 2009). Traffic-free or traffic-calmed routes and networks linking paths, towns and attractions are also important requirements for cycle tourists (Lumsdon, 2000; Faulks et al., 2007).

Cycle tourists value segregated cycling infrastructure highly and are willing to double time spent cycling in order to use a fully segregated facility and to increase cycling time by up to 50% to use a cycle lane (Deenihan & Caulfield, 2015b). This is approximately in line with the findings of Krizek et al. (2007), who showed that cyclists travel 67% further to include a trail facility. 93% of cycle tourists would use a high-quality greenway if it was near to their accommodation and 73% would prefer a cycling facility segregated from traffic (Deenihan, 2013). Roche (2013) found that 92% of Irish respondents agreed that more traffic-free routes are required in Ireland. 90% agreed that Ireland should be promoted as a cycling destination, but 98% agreed that not enough is being done for cycle tourists. Cycle tourism is examined in more detail in Section 2.6.

2.4.2 International design guidance

The following section reviews greenway design guidance with a view towards comparisons with the results of the greenway design preferences survey presented in Chapter 5. Although an extensive range of guidance exists in this area, there are few empirical studies which examine user preferences for design characteristics, specifically highlighting differences in user group needs and desires. Other guidance outlines good practice in greenway design from a political perspective (cf. EGWA (2000) for case studies) and an accessiblity perspective (cf. FFE (2013)); these are not included in this review as detailed engineering guidance is not provided.

Safety

The general approach to designing greenways is to engineer the route for safety. International greenway design guides approach this problem by beginning with the cycling envelope and other specific needs of cyclists (speed maintenance, width requirements, passing distances etc.) and applying traffic engineering criteria for sight distance and visibility etc. This approach was introduced in Section 2.3 and is broadly followed. Firstly, Moore (1994) outlinesthe principles for minimising conflicts on greenways, both infrastructural and informational, and these are summarised in Table 2.8.

Table 2.8 - Principles for minimising conflicts on greenways (Moore, 1994)

Principles	Description
Recognise conflict	Not inherent incompatibility, goal interference
Provide adequate trail opportunities	Length, congestion, user experiences
Minimise number of contact points	Reduce conflicts, identify problem areas
Involve users as early as possible	Identify users, involve in trail planning
Understand user needs	Motivations, experiences, preferences
Identify actual sources of conflict	Specific, tangible causes of conflict

Work with affected users	Reach mutually agreeable solutions
Promote trail etiquette	Educational material for responsible behaviour
Encourage positive interaction	Sponsored 'user swaps,' trail-building projects
Favour 'light-handed management'	Allow freedom of choice and natural setting
Plan and act locally	Sensitivity to local needs, decision-making
Monitor progress	Understand and determine effectiveness

Width

The width of a greenway must cater for the width of the cyclist (or other user), manoeuvring space (i.e. dynamic envelope), clearance from fixed objects and clearance from other users. The typical width of an adult riding a bicycle is 0.75m and an additional 0.25m is allowed for wobble space. A 1m verge is recommended to provide clearance from poles, trees, walls etc. It may be necessary to increase width to accommodate large maintenance vehicles or other users. Additional width is required for edge constraints, such as fences (UK DfT, 2008). Table 2.9 summarises the absolute minimum and preferred minimum widths for various greenway types. Greenways in the Irish NCN will generally be two-way unsegregated shared-use paths for cyclists and pedestrians and, therefore, the preferred width is 3m (AECOM & Roughan O'Donovan, 2013b). Sustrans (2009) prefers unsegregated greenways as this is a more effective use of width, encourages more considerate behaviour, and pedestrians in groups tend to ignore segregation.

Table 2.9 - Preferred minimum and absolute minimum widths of cycling facilities

Facility	Absolute Minimum (m)	Preferred Minimum (m)
One-way cycleway	1.5	2
Two-way cycleway	2	3
Segregated shared use	3 (1.5 m each)	5 (3 m cyclist, 2 m pedestrian)
Unsegregated shared use	2	3

Sources: ARUP & Sustrans (1997); UK Roads Board (2003); DMRB (2005a); UK DfT (2008); Sustrans (2009)

Speed

The design speed of a greenway depends on: (i) function of the greenway, (ii) user profile, (iii) topography, (iv) estimated user speed and, (v) direction of prevailing winds (AASHTO, 1999). Generally, the greenway should accommodate a design speed of 30 km/h and there is broad agreement in the literature. Higher speeds can be expected on commuter or long-distance routes, downhill sections paved surfaces (AASHTO, 1999; UK Roads Board, 2003; DMRB, 2005a; Minnesota DoT, 2007; McRobert et al., 2008; Wisconsin DoT, 2009). Cyclists reach higher speeds on segregated greenways, which may pose danger to pedestrians (Sustrans, 2009). This, again, demonstrates the importance of considering the heterogeneity of greenway users and factoring these requirements (e.g. for fast commuting cyclists) into planning and design.

Gradient

Greenway gradients should be kept to a minimum. Steep inclines are difficult for many cyclists to climb; particularly less skilled cyclists and those with poorly maintained bikes. Steep descents cause some cyclists to exceed the speeds at which they are competent or comfortable. Steep gradients also exclude wheelchair users from using the facility. In general, the lower the longitudinal gradient, the more attractive a cycle route will be. A maximum gradient of 3% is preferred where possible (ARUP & Sustrans, 1997; AASHTO, 1999; UK Roads Board, 2003; DMRB, 2005a; Sustrans, 2009; Veith & Eady, 2011; Transport Scotland, 2011). Gradients of more than 6% will be avoided on the Galway-Dublin Greenway (AECOM/ROD, 2013). There should be a gradient of at least 0.5% to facilitate drainage (i.e. long-fall to prevent water ponding) (NTA, 2012). See Ribeiro et al. (2015) for a review of tools for the evaluation of gradient along poential cycle paths.

Horizontal and vertical alignment

Design of horizontal alignment is required to ensure that the radii of horizontal bends are large enough to provide adequate visibility at bends, i.e. lateral clearance is adequate. The horizontal radius depends on the superelevation of the path, design speed and coefficient of friction. In general, a minimum horizontal radius of 25 m is recommended (AASHTO, 1999; DMRB, 2005a; UK DfT, 2008; Transport Scotland, 2011). Stopping sight distance (SSD) is the distance required to perceive, react and stop safely in adverse conditions. For the average cyclist the reaction time for braking suddenly is generally 2.5 s, therefore SSD is the distance covered in this time plus the distance covered while braking (Transport Scotland, 2011). The minimum SSD is generally between 25 – 35 m (DMRB, 2005a; UK DfT, 2008; Transport Scotland, 2011). Good vertical alignment design should ensure that vertical curves (sag and crest) are not too severe to cause discomfort and that adequate visibility is provided in the vertical direction. However, sharp sag and crest curves are unlikely to occur on greenways given the recommendations for soft gradients. Visibility is calculated based on cyclists' height and minimum vertical curves can then be calculated (AASHTO, 1999).

Crossfall

A crossfall of around 2% is recommended as necessary to provide adequate drainage. A crossfall of much greater than 2% would cause difficulty for wheelchair users and may be hazardous for cyclists and other users in icy and wet weather (AASHTO, 1999; Minnesota DoT, 2007; Wisconsin DoT, 2009; NTA, 2012).

Materials

The choice of pavement surface for greenways will depend on four key factors: (i) smoothness, (ii) skid resistance, (iii) aesthetics and (iv) available resources. A smooth riding surface is often the most important quality in attracting cyclists to the route. Surface types include: asphalt, concrete laid in-situ, unbound (e.g. limestone dust), concrete blocks and clay pavers. For cyclists, asphalt is the preferred form of greenway pavement surface except in special cases (AASHTO, 1999; AECOM & Roughan O'Donovan, 2013b; UK Roads Board, 2003; Sustrans, 2009). Table 2.10 shows various flexible pavement structures recommended by the literature. See NCA (2014) for the evaluation of firmness and stability for 11 trail surface materials and Sustrans (2012) for a variety of other surface options.

Table 2.10 - Flexible pavement structure

Source	ARUP & Sustrans (1997)	DMRB (2001)	UK Roads Board (2003)	DMRB (2005b)	Sustrans (2009)	Transport Scotland (2011)
Surface	20 mm	20 mm	25 mm	25 mm	20 mm	30 mm
	HRA or Dense AC (10 mm nominal aggregate size)[1]					
Base	40 mm	40 mm	40 mm	60 mm	40 mm	40 mm
	Dense AC (20 mm nominal aggregate size)[2]					
Sub-base	150 mm	150 mm	200 mm	150 mm	150 mm	150 mm
	Type A granular material[3]					
Subgrade	CBR > 2.5%	Any	Any	Any	Any	Any

Notes:
HRA = Hot Rolled Asphalt
AC = Asphalt Concrete (formerly known as Bitumen Macadam)
1 – See NRA MCDRW Series 900, Clause 910 and 912 for specification. Defined in BS EN 13108.
2 – See NRA MCDRW Series 900, Clause 906 for specification. Defined in BS EN 13108.
3 – Known as Type 1 in UK. See NRA MCDRW Series 800, Clause 804 for specification. Defined in BS EN 13285.

2.4.3 Importance of maintenance

Cyclists are affected by poor surface quality to a much greater degree than motorists. Bicycles can have thin, highly inflated tyres (up to 800 kPa) and many do not have shock absorbers. Furthermore, cyclists must keep themselves balanced as they pedal and steer. Poor maintenance resulting in surface defects (cracks or potholes) or the accumulation of debris (glass, sand, leaves etc.) can easily result in cyclists falling off. Even if the cyclist manages to stay upright and wobbles, they risk hitting the kerb, pedestrians or other cyclists, or swerving in front of a car (Jensen et al., 2000; Minnesota DoT, 2007; DoT, 2009a; NTA, 2012; Veith & Eady, 2011). 10 - 18% of accidents involving cyclists were caused by debris, and a further 3 - 7% was due to surface defects (Jensen et al., 2000; Schepers & Wolt, 2012). Poor maintenance also affects cyclists' comfort and the general attractiveness of the route. The more uneven the pavement, the less pleasant it is to cycle, and the more energy required to cycle (Jensen et al., 2000; NTA, 2012). If a greenway deteriorates, usage will decline and cyclists may use the road as an alternative or may stop cycling altogether (UK DfT, 2008).

Sweeping

Regular sweeping is the most important regular maintenance activity as cyclists can be destabilised by, or suffer punctures from, broken glass, sand, litter, leaves and grit. Sweeping should be carried out by a mechanical sweeper at least every two months and more frequently in autumn and winter and after storms (Jensen et al., 2000; CERTU, 2008; NTA, 2012).

Surface quality

The main surface defects are cracks, projections and potholes. Cracks can be longitudinal or transverse to the direction of travel and are caused by overloading, relative settlement of the subgrade or by roots. Starting out narrow, cracks allow water into the pavement structure resulting in further damage and widening of the crack.Cracks should be sealed as soon as possible, larger cracking may require an overlay (DMRB, 2001). Projections can be caused by the sinking of part of the pavement, the lifting of a slab by roots or settlement or large potholes (Minnesota DoT, 2007).

Vegetation

Cutting or removal of vegetation from the verges of the path is required to maintain the effective width and visibility of the greenway. Mowing, flailing or strimming may be used. Cutting should be carried out once or twice a year, ideally during growing season and outside nesting season. Relevant habitat management plans should be consulted (Sustrans, 2009; NTA, 2012).

Ponding

Standing water (more than 10 mm) can make the greenway impassable, conceal surface defects increase braking distance and compromise the structural integrity of the pavement. Ponding is a result of drainage failure - drainage channels should be cleared; crossfall and longfall should be also examined (AASHTO, 1999; UK Roads Board, 2003; Minnesota DoT, 2007; CERTU, 2008; UK DfT, 2008; Sustrans, 2009; NTA, 2012).

Ironmongery

Gullies and covers can sink or break or the surface can deteriorate around them, resulting in a hazard for cyclists. Gullies and gratings should be laid out perpendicular to the direction of travel and should have gaps less than 20 mm. Hazardous ironmongery should be replaced and reset flush with the surface (NTA, 2012). Ideally, there should be little or no ironmongery on a greenway.

Lighting
Standards governing the lighting of roads and footpaths are available in BS5489 (BSI, 2003) and guidance for urban cycle lanes is provided in NTA (2012), however, the issue of lighting on greenways (which are often built in lowdensity or rural areas) requires further investigation. In general, leisure and tourist cyclists will travel during daylight hours but commuters will require lighting. User statistics and preferences can inform designers and costs can be estimated with the benefit of additional usage potentially offsetting costs.

Other issues which should form part of a maintenance plan include repainting lines, replacing signs, and repairing furniture and fences.Maintenance should be considered an investment in the greenway and insurance against larger, more expensive repairs or eventual replacement (Minnesota DoT, 2007). Maintenance can be planned (e.g. based on a regular programme) or reactive.

2.5 Great Western Greenway profile

The Great Western Greenway has inspired major interest in greenways in Ireland and internationally. Indeed the route partially inspired this research and is used as a case study for environmental impact in Chapter 6 and economic impact in Chapter 7. The GWG is considered to be the demonstrator for the Irish NCN and its success has been widely reported. Built in three sections between 2009 and 2011, the GWG runs along the Westport-Achill Sound section of the Midlands Great Western Railway, which closed in 1937 (Mayo CoCo, 2014). The route extends for 42 km through Westport, Newport, Mulranny and Achill and officially opened on 29th July 2011. Permissive access agreements were reached with 161 landowners along the route (Connor, 2013). The greenway features a combination of asphalt and gravel surfacing, bridges, viaducts and other structures and includes some sections of off-road cycleway (Figure 2.7).

Funding of €5.6m was provided by Mayo County Council, Fáilte Ireland and DTTAS. Additional support was provided by the local community and landowners have given permissive access for the land-take of the route. There are approximately 80,000 visitors to the greenway per year (34,400 local users, 14,800 domestic (rest of Ireland)) (Fáilte Ireland/Fitzpatrick Associates, 2011). Based on a survey (n=100) between May and September 2010, average daily spends were estimated to be €27.31, €49.85 and €50.71 for local, domestic and overseas users respectively. Including spending from all three groups, Fáilte Ireland/Fitzpatrick Associates (2011) calculated the total annual economic impact to be €7.2 million, i.e. a payback period of less than one year. Deenihan et al. (2013), using automatic counter data, constructed a model to demonstrate the effect of temperature, rainfall and wind speed on GWG usage. The greenway has led to spin-off businesses, including:

Gourmet Greenway, bicycle hire and adventure touring companies, tea rooms and greenway-based merchandise.

Figure 2.7 - GWG surface (left) and Achill section (right) (Connor, 2013)

The greenway has received many awards in the past four years, including: European Commission's Destination of Excellence (EDEN), Exemplary Initiative at European Greenways Award Ceremony, CIWEM Irish Environmental Award, Best Recreational Facility and Best Tourist Attraction at the Local Authority Management Awards and The Irish Times InterTrade Ireland Innovation Award (Connor, 2013). The greenway has featured regularly in the Irish broadcast and print media as well as in the LA Times. Funding has now been allocated to extend the GWG through Co. Mayo and it is envisaged that the GWG will also be extended south through Leenaun/Killary Harbour to Clifden to meet the Connemara Greenway. The greenway has also inspired a water-based trail – the Blueway (Philbin, 2014).

2.6 Economic benefits of Greenways

Greenways are among the most expensive and time-consuming forms of walking and cycling infrastructure to design and construct, yet existing literature has demonstrated that such routes are associated with relatively large benefit-cost ratios due to direct and indirect economic benefits (Downward et al., 2009; Sustrans, 2007). Most greenways opened and planned to date have been pitched as products for the Irish tourism industry and communities must demonstrate the economic potential of greenways before funding is awarded.

2.6.1 Cycle tourism

Cycling and tourism have been connected since the cycle tours of the 1890s (Lamont, 2009) and cycle tourism today is a multi-billion Euro industry. Weston et al. (2012) estimated that 2.3 billion cycle tourism trips are made in Europe each year, with a total value of over €44 billion. This is in the context of the total economic benefit of cycling in the EU, which the ECF has estimated to be €143-155 billion (ECF, 2013a). Estimates for the value of cycle tourism in key European countries are as follows: France (€5.6 billion), Germany (€3.8 billion), Netherlands (€750 million), and Denmark (€400 million). France is the main destination for cycle tourists in Europe, while Germany is the main origin (Weston et al., 2012).

Although EuroVelo is not a major tourism network at present, it has the potential to generate considerable tourism revenue. 60 million EuroVelo trips could generate €7 billion of direct revenue (Weston et al., 2012). In Australia and the South Island of New Zealand, the value of cycle tourism has been estimated to be €154 million and €52 million, respectively (Faulks et al., 2007). In the UK, investment in cycle infrastructure was key to increasing cycle tourism: prior to NCN construction in 1995, the value of cycle tourism in the UK was €718 million; by 2009, this had doubled to €1.43 billion (Sustrans, 2010). Lumsdon et al. (2009) found that, on average, cycle tourists in Europe spend €353 on a cycle-holiday of average length 6.6 days. For day-tripper cyclists, the average spend is €16/day. The average daily spending on the Austrian Danube cycle route is €65.70 for cycle tourists and €37.30 for day-trippers (Meschik, 2012). Table 2.11 presents the economic impact of selected long-distance cycle routes.

Table 2.11 - Economic impact of selected long-distance cycle routes

Route	**Country**	**Length (km)**	**Economic impact (€ m)**	**Economic impact (€ 000 / km)**
Hauraki Trail	NZ	77	10	129.9
C2C	UK	380	12	31.6
Creeper Trail	VA, USA	54	1.2	22.2
Danube Cycle	Austria	460	6.4	14.1

Sources: (AECOM/Roughan O'Donovan, 2013a; Bowker et al., 2007; Weston et al., 2012)

Saelensminde (2004) summarized the benefit-cost ratios of cycle networks in three Norwegian cities, accounting for reduced vehicle collisions, health benefits, travel time improvements and environmental benefits. The author found Benefit to Cost Ratios (BCRs) of between 4 and 5:1, concluding that investment in cycle networks is more beneficial to society than investment in other transport modes. Sustrans (2007) found that sections of four cycle routes in the North East of England attracted 302,000 cycle trips in 2006 and that these users contributed €12 million directly to the local economy, representing a value of almost €17 million to the wider regional economy, thereby supporting 216 jobs. Downward et al. (2009) used travel diaries (n=383) on these routes and found that incomes, group size and trip duration are factors in economic impact. The authors conclude that to maximise economic impact, groups with preferences for longer trips should be targeted and that incomes and group sizes should be considered. Weston et al. (2012) illustrated the potential for a network of greenways to increase the cycle tourism market by identifying four factors necessary to maximise numbers of cycle tourists; (i) safe and continuous routes, (ii) pleasant countryside and (iii) cyclist-friendly villages and cities en route, and (iv) clear and reliable signage and interpretation (Weston et al., 2012).

2.6.2 Journey ambiance and willingness-to-pay

Journey ambiance is the level of enjoyment of the cyclist while on a greenway or other form of infrastructure. Separation from traffic usually results in greater journey ambiance through reduced fear of collision with motorised vehicles and increased comfort. The UK Department for Transport (2010) considers three elements of journey ambiance: traveller care (quality, cleanliness and information of the facility), traveller views (landscape and townscape), and traveller stress (frustration, fear and uncertainty). Hopkinson & Wardman (1996) suggest a value of €10.34/hr for willingness-to-pay for off-road segregated facilities and this is used by various reports (cf. NRA (2011) and UK DfT(2010)), although Walton & Smith (2007) have suggested that this figure should be updated.

Deenihan & Caulfield (2015b) used an intercept stated-preference survey (n=287) to construct a willingness-to-pay model for three cycling infrastructure types: on-road cycle lane, segregated cycling facility and no facility. The nested logit model also considered the impact of weather and route gradient. The authors found that a cycle tourist would be willing to increase journey time by 48% to use a cycle lane rather than a road without cycle facilities and 98% to use a segregated cycling facility rather than a road without cycle facilities. Applying a value of time of €27.81/h (from the Irish National Roads Authority), it was calculated that cycle tourists are willing to pay €13.20/h for an on-road cycle lane and €27/h for a fully segregated facility, if a toll was applied. A limitation of the study is the urban setting (conducted in Dublin City) where there is greater route choice than in rural areas. However, based on these figures the use of time as a proxy for willingness-to-pay is not a true representation of users' actual willingness-to-pay should a tolling facility be installed. Furthermore, the study did not consider a travel cost model to demonstrate the value retained by cycle facility users.

2.6.3 Health benefits

As cycling is a physically active mode of travel, it results in well-cited health benefits for the user and society (Andersen et al., 2000; Cavill et al., 2008; Cope et al., 2003). A large scale study in Copenhagen, reported that cycling three hours per week reduces risk of all-cause mortality to 72% of average (Andersen et al.,2000).Cope et al. (2003) found that 70% of NCN users said that the network had helped to increase their physical activity levels. Kendall & Wright (2015) have undertaken a Health Impact Assessment of multi-use trails in New Mexico, USA. Also, Shafer et al. (2000) discussed the human ecosystem concept and the contribution of greenways to health, fitness and community quality of life.

These benefits can be monetised using tools such as WHO HEAT (WHO, 2011) and Sustrans (2010) estimated the monetized health benefit of cycling trips on the UK NCN to be €328 million. Increased physical activity due to cycling has also been shown to reduce absenteeism, boosting finances of employers (Hendriksen et al., 2010). Deenihan & Caulfield (2015a), using a stated-preference survey (n=845) distributed to local workplaces, applied HEAT to calculate the economic impact of health benefits due to increased cycling along an inter-urban cycle facility. This was found to be between €3.7 million (for a 2.5% modal shift; 1101 additional cyclists) and €19.6 million (10% modal shift; 11735 additional regular cyclists) per year. The benefit-cost ratio of an 80 km segregated cycle facility from Dublin to Mullingar (a large town in the midlands of Ireland) was then found to be between 2.2:1 and 11.8:1. The authors highlight the limitations of HEAT and the data collection method used – cycling levels were overstated by a factor of 15 and without correction this would have led to an unrealistic value for the health economic impact.Health benefits of cycling will accrue due to increased regular cycling and due to population catchment, these will most likely manifest to a greater degree in urban areas, yet greenways constructed in Ireland to date have been limited to rural areas with a tourism orientation (Deenihan & Caulfield, 2015a).

2.6.4 Typical greenway costs

Greenway costs include planning and design, land acquisition, construction (materials, labour, machinery etc.), maintenance and marketing (AECOM/Roughan O'Donovan, 2013a). These costs vary significantly based on greenway type (canal towpath, disused railway etc.), location (urban, rural etc.) and other factors. Guideline construction costs are provided by Fáilte Ireland (2006) and Sustrans (2009) and predicted construction costs for Irish greenways can be found in NCN funding applications. These construction costs have been averaged in Table 2.12. For example, the Great Western Greenway cost €5.6m to construct (€133,000/km). Maintenance costs are approximately €5-10,000 per km per year (Sustrans, 2009) and Deenihan et al. (2013) used a figure of €40,000 per year for the GWG. Land acquisition can account for a significant proportion of greenway costs, however, the use of state-owned land is encouraged to reduce this cost and improve the deliverability of the project (NRA, 2010a). Also, the permissive access model (in which there is no landowner payment) has been used for the GWG. Palau et al. (2012) show that Spanish greenways provide the best cost per use of organised sports facilities: €1.12 per use versus €2.67 for other sports facilities.

Table 2.12 - Greenway construction costs in Ireland and the UK

Route Type	Details	Cost (€/km)
On-Road	Local Road (signed only)	3,000
On-Road	Local Road (some works needed)	10,000
On-Road Cycleway	Regional Road (former National Road)	25,000
Off-Road Cycleway	Shared Use Path	100,000
Greenway	Canal towpath	120,000
Greenway	Old Railway	130,000

Sources: Fáilte Ireland (2006); Sustrans (2009); AECOM/Roughan O'Donovan (2013a)

Greenway projects must demonstrate return on investment to outlay costs typically in excess of €100,000/km. Previous studies have considered a wide range of other economic benefits of greenways ranging from direct benefits forthe user to indirect benefits for society (Krizek, 2007; Litman, 2012), however these studies have been limited to isolated trails or aggregated to a national level. Due to the recreation and tourism orientation of the Irish NCN and greenways, research is required to specifically examine tourist spending and the recreational value of greenways. This will inform the route planning and design criteria which seek to maximise return on investment, as well as government funding selection criteria. As the NCN develops, more opportunities will present for further research on other elements of economic impact of greenways in Ireland.

2.7 'Green' credentials of Greenways

Using the adjective 'green' in the term 'greenway' implies a route which goes through open spaces, parks, gardens and forests and respects the surrounding environment (Medina & Hernández, 2008). Greenways are frequently planned and promoted in the sustainable tourism sector (Meschik, 2012) as well as the landscape and habitat sector (von Haaren & Reich, 2006). Environmental benefits of greenways can include: habitat protection and preservation of biodiversity; water, soil and air quality improvement; flood and stormwater management; environmental awareness and teaching tools; and improving human health and access to green space (CMAP, 2009). A number of studies have examined these environmental benefits in detail (cf. Mason et al. (2007) for suburban greenway habitats for forest-feeding birds). A full assessment of the ecological impact of greenways is beyond the scope of this research, and this section focuses on applying Life Cycle Assessment to greenways, measuring embodied carbon and identifying potential carbon offsets through a modal shift to cycling.

2.7.1 Life Cycle Assessment

To evaluate the environmental impact of construction projects, an environmental life cycle assessment (LCA) is performed. This is a tool used to evaluate the environmental impact associated with a product, process or activity by identifying and quantifying energy and material uses and releases into the environment as embodied carbon or embodied energy. LCA includes four phases according to BSI (2006): (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment, and (4) interpretation.

Phase 1 includes definition of the system boundaries, which determine the range of impacts considered that are directly linked to the product. Ideally the system boundaries are set from the extraction of raw materials until the end of the lifetime of the product lifetime (Cradle-to-Grave), which would include stages such as manufacturing, transportation and decommissioning (or demolition) at the end of its life (BSI, 2006). Due to the uncertainties after product manufacture, it has become common practice to calculate the embodied carbon for materials as all the carbon released as greenhouse gases until the product leaves the factory gate (Cradle-to-Gate) (Hammond & Jones, 2011). The addition of embodied carbon due to maintenance and decommission would be required to achieve a Cradle-to-Grave boundary.The embodied carbon of a material can be used as an indicator for LCA. It is taken as the total carbon released over its life cycle (Hammond & Jones, 2011). By including the embodied carbon due to transport, and the carbon emissions associated with its use on site (e.g. machinery used to place and compact the material), the Cradle-to-Site embodied carbon has been considered in this thesis.

Embodied carbon is measured in carbon dioxide equivalents (CO_2e),which not only includes carbon dioxide (CO_2), but also other greenhouse gases as set out in the Kyoto protocol, such as methane (CH_4), nitrous oxide (N_2O) and PFCs (IPCC, 2007). The CO_2e of a gas is found by multiplying the mass of the gas by the associated global warming potential (GWP) (IPCC, 2007). GWP is based on the relative amount of heat that is trapped in the atmosphere by a greenhouse gas, where CO_2 has a GWP of 1. It should be noted that values for CO_2e are higher than CO_2 values for materials due to the inclusion of other green house gas emissions (CH_4, N_2O, PFCs). For example, CO_2e values are on average 6% higher than CO_2 values for construction materials in the UK (Hammond & Jones, 2011).

2.7.2 Carbon emissions of Irish transport

Irish greenhouse gas emissions in 2013 were 58.29 Mt CO_2e, where 11.07 Mt CO_2e or 19% of these emissions were a result of transport (EPA, 2015; Figure 2.8). Emissions from the transport sector represent the largest proportional increase of any emissions sector since 1990 and today is more than double the 1990 level of 5.1 Mt CO_2e (EPA, 2015; Figure 2.9). Transport emissions are projected to increase by 42% between 2013 and 2035, when this sector will account for 24% of all GHG emissions (With Measures).

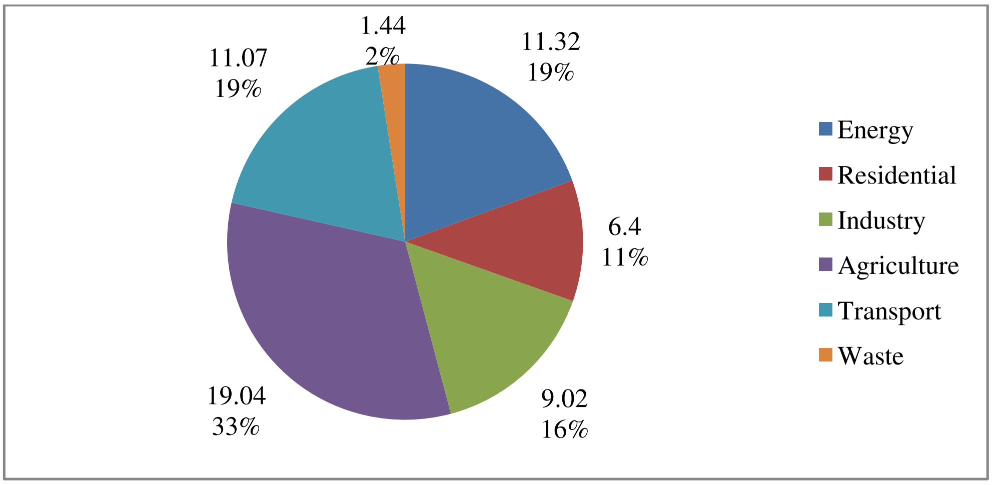

Figure 2.8 - Sectoral GHG emissions in 2013 (EPA, 2015)

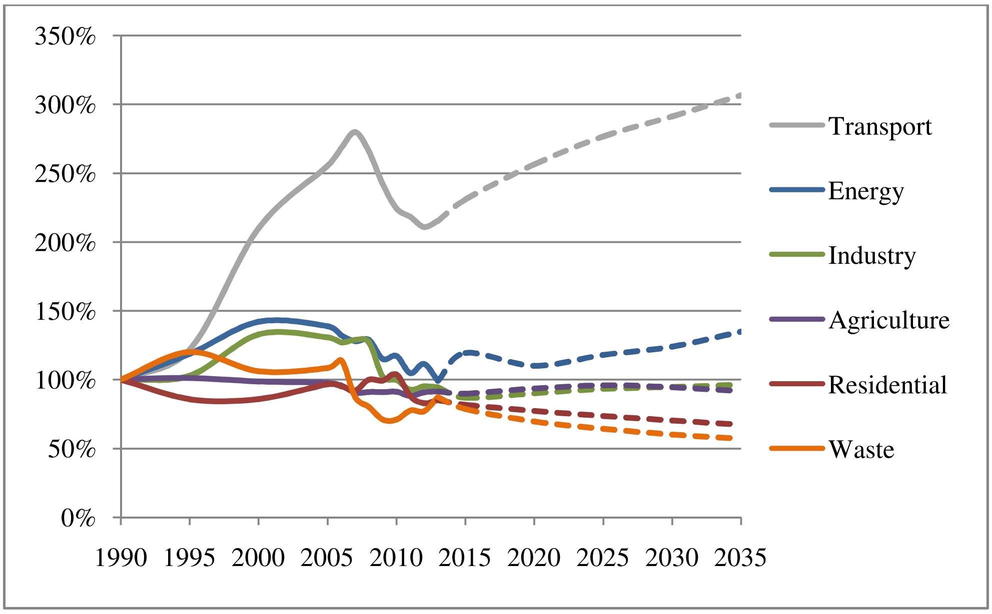

Figure 2.9 - Sectoral GHG emissions indexed to 1990 and projected to 2035 (with measures) [based on EPA,2015]

The average commuting occupancy of Irish cars is 1.1, and the carbon dioxide emissions for an average Irish passenger car are approximately 160 g CO_2e/km (CSO, 2012b; NRA, 2011a; DECC and Defra, 2011). The emissions of CH_4, N_2O and other greenhouse gases emitted by cars are relatively insignificant (DECC and Defra, 2011). Thus an overall figure of 160 gCO_2e/km can be used. Emissions from all Irish passenger cars totalled 5.8 Mt CO_2ein 2009 - a 96% increase on 1990 (Hammond & Jones, 2011; NRA, 2011a). Vehicle emissions can be increased by poor road condition and therefore in rural areas, where road conditions tend to be poorer and greenways may be constructed.

2.7.3 Cycling and carbon

Cycling is not a zero emissions mode of transport and recent research has shown that carbon dioxide emissions as a result of cycling are approximately 11 gCO_2/km. Given that the maximum occupancy of a bicycle is almost always one person (the use of tandems, child seats, trailers being relatively insignificant etc.), the value may be expressed as 11 gCO_2/PKT (Walsh et al., 2008). These emissions include cyclists' exhalation (5 gCO_2/PKT) and the embodied emissions of the manufacture of the bicycle (6 gCO_2/PKT). The emissions of CH_4 and N_2O are negligible in cyclists' exhalation, therefore a figure of 5 gCO_2e/PKT can be used. For the embodied emissions of bicycle manufacture, an aluminium frame has been assumed and emissions have been distributed over the lifespan distance of the bicycle. For aluminium, there is an 11% difference between embodied emissions values in CO_2 and CO_2e (8.24 kg CO_2/kg and 9.16 kg CO_2e/kg) (DECC and Defra, 2011). As the majority of the mass of the bicycle is accounted for by aluminium, a 11% increase has been applied to 6 gCO_2/PKT, yielding a figure of 6.7 gCO_2e/PKT. Summating gives a total of 11.7 gCO_2e/PKT for the embodied emissions of cycling. Other potential components include the embodied carbon of food consumed.

Nonetheless, cycling emits a small fraction of the carbon emitted by driving a car and has great potential as an alternative mode of transport. This is due to the characteristics of cycling, which include: (i) it is a cheap mode of transport, (ii) investment costs for infrastructure are much lower than for other modes, (iii) travel by bicycle can be time effective in congested urban areas, and (iv) the economic impacts and the health benefits of cycling (Massink et al., 2011). Although the potential for modal shift lies predominantly with commuter cyclists, leisure cycling routes may also encourage a modal shift to cycling on commuter routes.Goodman et al. (2014) showed that walking and cycling levels increase according to proximity to traffic-free walking and cycling routes. However, these increased physical activity levels were not associated with sizeable decreases in carbon dioxide emissions as journeys along the routes did not substitute motorised journeys. There is a need for greater active travel promotion and policies to discourage car-use to meet carbon dioxide reduction targets (Brand et al., 2014).

The preferred greenway surfacing is asphalt and the path is generally laid down in three layers, including the surface layer, the base/sub-base layer and the capping layer (Figure 2.10). The capping layer is required in soils of poor bearing capacity (e.g. peatland) and must be of sufficient depth to support construction, maintenance and possibly emergency vehicles. A geotextile, placed between the sub-base and capping layer, may be necessary to separate poor underlying soils such as peat with the base material (Sustrans, 2009). This method has been used in greenways such as the GWG where poor soils were frequently encountered. The carbon footprint of greenways can be divided into: (i) embodied carbon of materials, (ii) transport to site, (iii) machinery: site preparation and construction, and (iv) loss of carbon from carbon sinks, such as peat. These have been modelled for roads using tools such as asPECT and PaLATE (WRAP, 2011; CGDM, 2007).

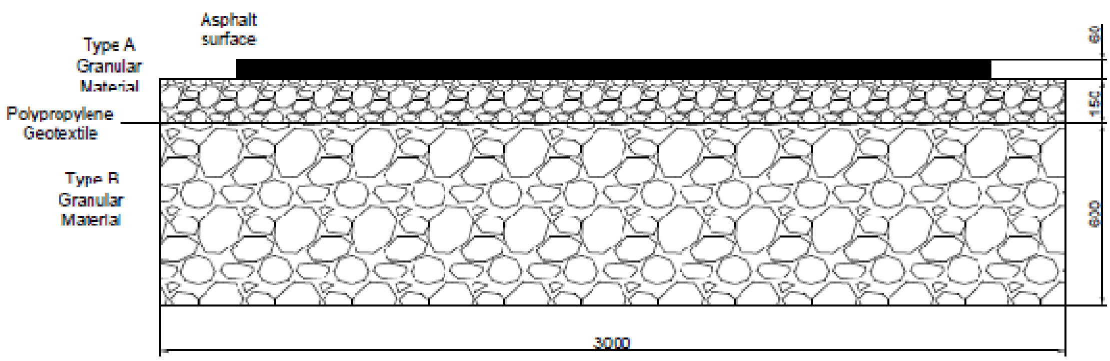

Figure 2.10 - Typical greenway cross-section [based on Sustrans (2009)]

The majority of the NCN in Ireland will be constructed in rural areas. Given the large peatland areas of Ireland (approximately 14% of land surface (Ward et al., 2007)) and given the prioritisation of using state owned lands, the issue of constructing on peat will be important in the Irish context. Peat has a high carbon content ranging from 49% to 62% of its dry weight (SNH, 2003). Near-intact peatlands also slowly take in carbon from the atmosphere and nationally may take in as much as 210,474 tCO_2/yr(57,492 tC/yr) from the atmosphere (Renou-Wilson et al., 2011). Given the low bearing capacity of peat, extraction and replacement may be required. Excavated peat, which has been under anaerobic conditions, starts releasing CO_2 and other gases when exposed to the atmosphere and aerobic conditions (Lindsay, 2010). Other carbon sinks include trees, bushes and organic topsoil.

2.7.4 LCA in transport planning

In recent years, transport engineers have begun to quantify embodied energy and embodied carbon of materials used in transport infrastructure projects. Angelopoulous et al. (2009) and Milachowski et al. (2011) calculated the environmental impact of constructing roads and Chau et al. (2011) examined the embodied energy of sections of a UK rail tunnel. The embodied carbon for construction of asphalt roads using a hot construction method is given as 32.8 $kgCO_2e/m^2$ in Hammond & Jones (2011). Furthermore, Hammond & Jones (2011) present embodied carbon values of 12.3 $kgCO_2e/m^2$ and 54 $kgCO_2e/m^2$ for maintenance and operation of the road respectively; over 40 years. Typical road operation includes street and traffic lights (95% of total energy), road clearing, sweeping, gritting and snow clearing (Stipple, 2001).

Mendoza et al. (2012) applied a LCA methodology to the design and management of pedestrian pavements in urban environments. As a result of these LCA studies, methodologies have been presented for urban pedestrian, road and rail construction that can inform methodologies for cycle infrastructure. However, there are currently no guidelines determining construction-related emissions for use in the planning and design stages of greenways. Evaluating the carbon emissions in the construction of cycle route pavements can be one of the key parameters used in the route selection and design phases of cycle networks.

2.8 Route selection guidance for cycling

Route selection can have a major impact on the future of transport networks and indeed regional development. In the context of the conversion of disused railways into greenways, it is interesting to consider the dynamics of the 19th Century route selection of the Midlands Great Western Railway between Galway and Clifden:

> "The intention had been to improve communications with a developing fishing industry and the [Midland Great Western Railway

> Company] engineers designed a route to follow the coastline, where the population was estimated to be around 60,000. However, a Royal Commission on Public Works thought otherwise and directed that an inland route should be followed via Oughterard. Largely as a result of this decision, freight traffic failed to materialise, and the railway chose instead to develop the tourism potential of the area"(Cox & Donald, 2013)

The coastal route through Spiddal and Carraroe offered opportunities to connect to a larger population and to the fishing industry, however the inland route was selected due to land acquisition and to promote tourism. Due to the low population catchment of the inland route, the Galway-Clifden railway survived just 40 years, closing in 1935. Eighty years later, planning is in place for the line to reopen as the Connemara Greenway, predominantly for recreation and tourism. Greenways, though on a far smaller scale, exhibit the same processes involved in route selection as other transport modes, including being shaped by policy and land acquisition.

2.8.1 Multi-criteria analysis

In policy decision-making, be it for full programmes or individual projects, it is important to consider all relevant factors and not just the economic costs and benefits. For example, expenditure on a public good such as the purchase of a national heritage site may have little or no economic impact (DoF, 2005). Although Cost-Benefit Analysis (CBA) is the most commonly used method of appraisal, Multi-Criteria Analysis (MCA) compares impacts in a method which does not involve assigning criteria explicit monetary values. MCA is not a short-cut or a easier method as it is rarely realistic to monetise all costs and benefits (Dodgson et al., 2009). CBA methods have been criticised for placing a money value on non-marketed impacts, such as numbers of deaths and injuries when appraising a road safety improvement. CBAs of transport infrastructure schemes, in particular, are problematic due to the major environmental effects of such schemes and the lack of valuations of such affects. MCA techniques are more flexible and comprehensive than techniques used in CBA (Dodgson et al., 2009). MCA therefore offers an opportunity to bring together features of greenway planning and design, outlined in previous sections, into one methodology for route selection.

In Ireland there are four stages of infrastructural project appraisal and management: Appraisal (preliminary and detailed), Planning/Approval, Implementation, Post-Project Review (DoF, 2005). A preliminary appraisal states the need for a project and how this will be met. It should include all realistic options, including do-nothing, and a preliminary assessment of costs and benefits. A detailed appraisal should meet nine key elements: define project objectives, list realistic options including do-nothing, list constraints, advise financing, quantify costs, examine costs and benefits including MCA and CBA, identify risks, specify time profile, and recommend a preferred option (DoF, 2005).

Costraints that should be considered in a project appraisal are: financial, technological, legal/regulatory, environmental, physical inputs/ raw material, availability of manpower and skills, time, administrative/managerial ability, distributional, social, spatial policy, land-use planning, co-operation required from other interests, and general policy considerations (DoF, 2005). DoF (2005) calls on 'readily applicable methodologies' for the appraisal of small and routine projects so that these can be applied consistently. For minor projects with an extimated cost below €0.5 million, a simple assessment is required. For projects with an extimated cost between €0.5 million and €5 million, elements of a preliminary and detailed appraisal should be used. For projects with an estimated cost of between €5 million and €50 million, a Multi-criteria analysis (MCA) should be used. For projects with an estaimted cost of over €50 million, a Cost-Benefit Analysis (CBA) should be used (DoF, 2005). In general, CBA is used for larger-scale road programmes, while MCA is used for smaller projects (Browne & Ryan, 2011; Beria et al., 2012).

MCA is used to establish preferences between project options by referencing an explicit set of measurable criteria and objectives. These criteria usually reflect policy and other considerations, such as value for money, costs, social, environmental, equality etc. For example, the DTTAS and NRA method (next section) uses the following high-level objectives for transport schemes: environment, safety, economy, accessibility and integration; these are then broken down into criteria (Dodgson et al., 2009). MCAs use scoring and weighting of criteria to show the relative importance of objectives and should provide enough information on which to decide whether the project should proceed (DoF, 2005).In MCA, a 'performance matrix' (or 'consequence table') is compiled. Each row presents an option and each column a criterion. Performance assessments in the body of the matrix are usually numerical, but can also be colour coded or categorised. The consequences of each option are assigned a numerical score often on a scale of 0 to 100 and numerical weights are assigned to each criterion (Dodgson et al., 2009). See Table 2.13 for the steps involved in MCA.

Table 2.13 - Steps in a multi-criteria analysis (Dodgson et al., 2009)

1	Establish aims, decision makers and stakeholders
2	Identify the options
3	Identify the criteria
4	Describe the performance of each option against the criteria and score each
5	Assign weights to each criteria
6	Combine weights and scores to derive overall value
7	Examine results

Determining the scores and weights of criteria in MCA should yield objective appraisal and consistency in decision-making for projects – the analysis should produce similar results when applied by different decision-makers (DoF, 2005).

Dodgson et al. (2009) advises establishing 0 to 100 scoring based on an interval scale, where 0 represents the worst performance which is likely and 100 the best. A paired-comparison process can be used to assign weights. In such a process, two criteria are compared for their swing, with the criterion of bigger swing retained for comparison to the next criterion. The criterion which emerges from this process with the biggest swing is assigned the weight of 100. The other criteria are then assessed relative to this (Dodgson et al., 2009). MCA is increasingly applied in transport planning, such as sustainable neighbourhood mobility (Beria et al., 2012), public transport preferences (Jain et al., 2014), optimising road investments (Odoki et al., 2013), pavement maintenance management (Cafiso et al., 2002), rail infrastructure (Preston, 1996). There have been some limited applications of MCA in bicycle planning (cf. Rybarczyk & Wu (2010)) and some of these are reviewed.

2.8.2 NRA methodology

The NRA is responsible for the planning, construction supervision, management and maintenance of national roads and cycleways (alongside local authorities). This section reviews NRA road route selection methodology (as outlined in NRA Project Management Guidelines (NRA, 2010b)), noting the areas of which may need to be altered for application to cycling route selection. The phases of project management are listed in Table 2.14.

Table 2.14 - Phases of Project Management (NRA, 2010b)

1	Scheme Concept & Feasibility Studies
2	Route Selection
3	Design
4	EIA/EAR* & The Statutory Processes
5	Advanced Works & Construction Documents Preparation, Tender & Award
6	Construction & Implementation
7	Handover, Review & Closeout

*Environmental Impact Assessment / Environmental Assessment Report

The role of Scheme Concept & Feasibility is to identify the need for a scheme and to examine any particular aspects which may affect feasibility, e.g. safety, reduction in journey time and economic development. A range of greenway feasibility studies have been carried out (cf. River Dodder Greenway (AECOM-ROD, 2013b) and Napa Greenway (Alta, 2009)) and these typically consider the need for the scheme (incl. safety), environmental constraints, and economic impact. If deemed feasible, route selectionthen identifies a suitable Study Area for the examination of alternative routes, identifies key constraints within that Study Area, develops feasible route options and carries out a systematic assessment of these options. The output of the route selection process is a Preferred Route Corridor on which detailed design will be based (NRA, 2010b).

The initial stage in the route selection process is to identify the nature and extent of constraints within a defined Study Area. Constraints are broadly defined as anything of an engineering, environmental, economic or legislative nature that could affect the development of a scheme.These constraints are documented and mapped so that feasible route options can be designed to avoid such constraints, where possible (NRA, 2010b). Such 'constraints' for cycling schemes differ considerably from those for road schemes. In fact, many road scheme constraints act as route opportunities, rather than inhibitors, for cycling – for example, many landscape features and railways. Therefore, it is proposed to rename this phase an 'opportunities study' (as used by AECOM-ROD (2015)). The adaptation of this process, including comments on specific constraints/opportunities, is included in Chapter 9.

Feasible route options are developed based on constraints and typically these number 6 or more and include 'Do-Nothing' and 'Do-Minimum' alternatives. The 'Do-Nothing' alternative involves an investigation into the ability of the existing infrastructure to meet future demand without any upgrade. The 'Do-Minimum' alternative examines the feasibility of an on-line upgrade of the existing route rather than a significant upgrade or the construction of a new route (NRA, 2010b). Following a Preliminary Options Assessment, feasible route options are refined to between 3 and 5 routes. This assessment compares route options under three headings:Engineering, Environment, and Economy. Many of the items included in these headings may not be relevant for NCN routes, e.g. impact on air quality or noise and vibration, and this is discussed in Chapter 9. The performance of each route option is tabulated in a Framework Matrix (Table 2.15) through the attribution of ratings of 'High Preference', 'Medium Preference' and 'Low Preference' and a decision is made on which routes shall progress to stage 2 (NRA, 2010b).

Table 2.15 - Sample Framework Matrix (NRA, 2010b)

Route Options	Economy	Safety	Environment	Progress to Stage 2?
1	High Preference	Medium Preference	Medium Preference	YES
2	Medium Preference	Low Preference	Medium Preference	NO
3	Medium Preference	Medium Preference	Low Preference	NO
4	Low Preference	Medium Preference	Medium Preference	NO
5	Medium Preference	High Preference	Medium Preference	YES
6	Medium Preference	Medium Preference	High Preference	YES

Following this, route selection moves to the Project Appraisal of Route Options stage, where remaining route options are assessed under five headings:Economy, Safety, Environment, Accessibility, and Integration. The performance of each of the route options is summarised in a Project Appraisal Matrix (Table 2.16) through the attribution of ratings of 'Preferred', 'Similar', 'Intermediate' and 'Least Preferred' and a Preferred Route Corridor is selected (NRA, 2010b). Many of the items to be considered in traditional project appraisal are, again, not relevant for cycling routes. Therefore, additional Project Appraisal Guidelines for the appraisal of cycling facilities were compiledas Unit 13 (NRA, 2011a). This unit proposes the evaluation of the main impacts of the scheme in the context of: health benefits, absenteeism benefits, journey ambience benefits, changes in the numbers of accidents, changes in journey time for walkers and cyclists, and other possible impacts. The final stage of route selection is the preparation of a Project Appraisal Balance Sheet under the same headings as the Project Appraisal Matrix. Once a Preferred Route Corridor has been selected, the scheme moves to the design phase where sufficient levels of detail exist to establish land-take requirements and to progress the scheme through the statutory processes and eventually to construction.

Table 2.16 - Sample Project Appraisal Matrix (NRA, 2010b)

Route Options	Economy	Safety	Environment	Accessibility	Integration	Overall
A	Preferred	Intermediate	Intermediate	Similar	Similar	Intermediate
B	Intermediate	Preferred	Preferred	Similar	Similar	Preferred
C	Least Preferred	Least Preferred	Least Preferred	Similar	Similar	Least Preferred

The most high-profile route selection process to take place in Ireland in recent years is the N6 Transport Project in Galway City and County. This scheme is characterised by significant natural constraints, such as Galway Bay to the south, Lough Corrib to the north and the River Corrib. Furthermore, environmental designations both east (limestone pavement) and west (bog cotton) resulted in the rejection of the previous Galway City Outer Bypass scheme (ARUP, 2015).

Figure 2.11 - N6 Transport Project route options (ARUP, 2015)

Demonstrating the phases of route selection: the need for the scheme (Phase 1 – Feasibility & Concept) is to alleviate congestion and reduce journey times, but due to Natura 2000 sites (Phase 2, Stage 1 – Constraints) the original preferred route is not available and preliminary route selection (Phase 2, Stage 2) identified six route options further south, closer to the city centre (Figure 2.11). Following public consultation, the preferred route was selected in May 2015 and is expected to cost up to €750 million.

2.8.3 Existing route selection methods

Although significantly under-developed, there have been some isolated instances of cycling route selection in Ireland and internationally. Three Irish examples of greenway/cycle networks currently under planning in different contexts in Ireland include; (i) the Greater Dublin Area (urban and rural), (ii) Galway City (mostly urban) – on the west coast of Ireland and (iii) County Mayo (mostly rural) (Figure 2.12).

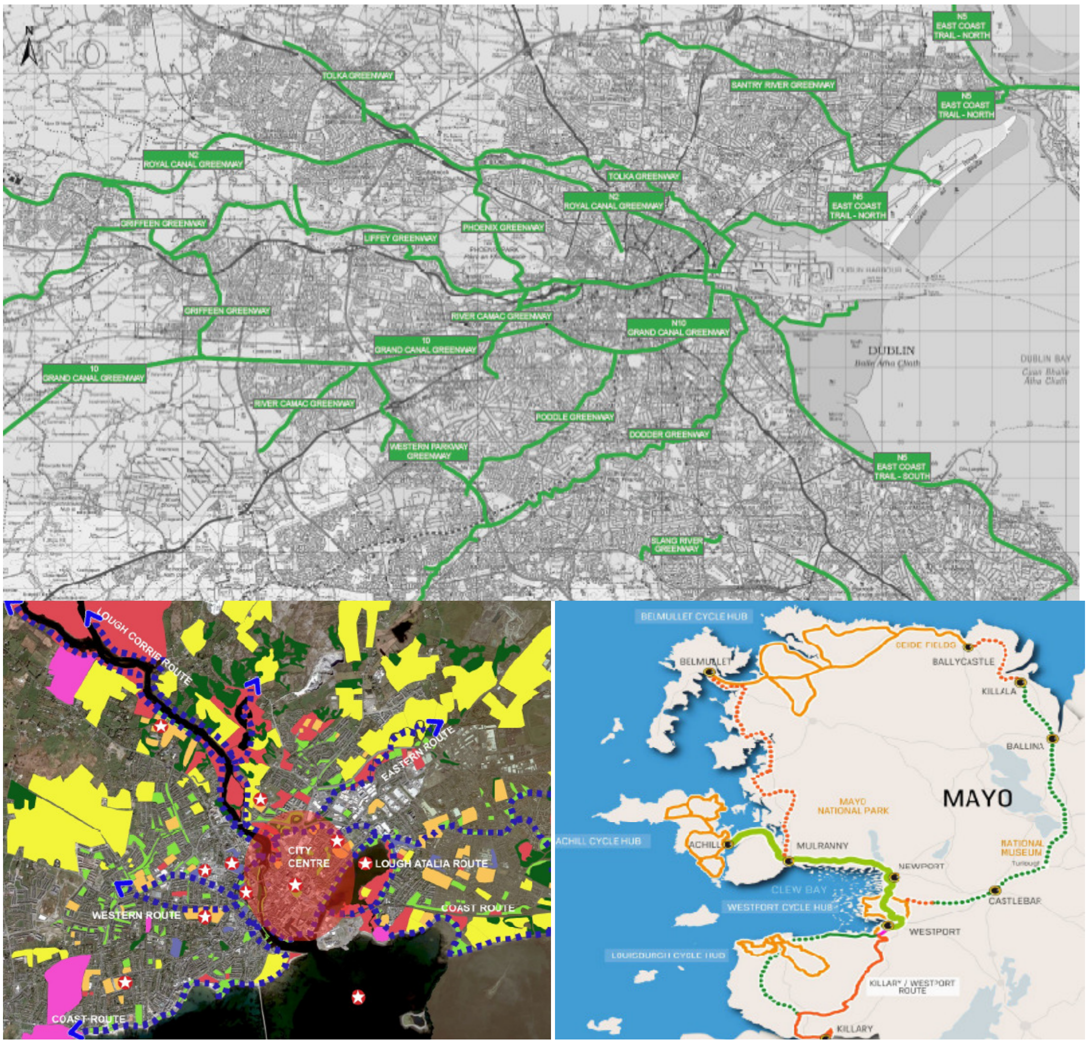

Figure 2.12 - Three proposed greenway networks. Top: GDA (NTA, 2013b); left: Galway City (AECOM, 2010); right: county Mayo (Mayo CoCo, 2013)

The Greater Dublin Area comprises Dublin City and and County and counties Kildare, Meath and Wicklow. NTA (2013b) designed a cycle network for the GDA, including a greenway network throughout the region, connecting to NCN and EuroVelo corridors. The process of identifying routes within this network involved using natural corridors and most of the routes follow the coastline, rivers, and canals (e.g. Irish Sea coastline, River Liffey, River Dodder, River Barrow, Grand Canal, Royal Canal). These routes are mostly planned as tourist recreational amenities in themselves as well as providing access to other tourism and recreation sites (NTA 2013b). The plan also provided for a rural cycle network whereby remote routes would serve recreational cycling on quiet rural roads (in line with the Guidance Graph) and routes within 10 km of main towns would also serve utility cycling trips. Although NTA (2013b) applied a cycle commuting model and Quality of Service to the planning of on-road commuting routes, no comparative route selection procedure was used to plan greenway and rural routes.

AECOM (2010) undertook a similar process for the Galway City greenway network. The planners set out to connect elements of green infrastructure and green space, such as the Galway Bay coastline, River Corrib, Lough Atalia and canals within Galway City. This yielded three recreational greenways and one commuter route, which connect to NCN corridors in the west, north west and east of the city. At the county level, Mayo CoCo (2013) proposes a network of greenways and on-road routes. This network connects exisiting infrastructure (Great Western Greenway and Fáilte Ireland Cycle Hubs) to the main towns and theAtlantic coastline as part of a route around the county.

Based on a review of these three networks, the following route selection guidelines emerge:

- Use natural corridors such as coastlines, rivers, lakes and canals
- Connect to green space and green infrastructure
- Connect to towns and urban cycling infrastructure
- Provideand connect to resources for recreation and tourism

Alta Planning & Design specialises in walking and bicycling infrastructure and has worked on more greenway projects than any other company in North America (Alta, 2015). Alta (2007) developed a multi-criteria method for the route selection of the Central Indian River County Greenways in Florida, USA. The scope of this project was to develop criteria and a methodology that can be used to identify and evaluate greenway alternatives (Alta, 2007). The criteria were required to be quantitative, understandable to the public, and sensitive to the potential differences between greenways elements (bicycling, equestrian, hiking, and multi-use). Alta (2007) developed the greenway selection criteria shown in Table 2.17 and these have been used for several other greenway projects in the USA.

Table 2.17 - Greenway evaluation criteria (Alta, 2007)

Criteria	Description	Weight
Environmental benefits	Provides conservation values, watershed protection and connects people to natural habitats as a 'green' open space corridor	10
System connectivity	Provides transportation and recreational access to activity centres (schools, employment and commercial districts, parks and public lands).	20
Regional benefits	Economic and tourism potential to link into a network that extends throughout the region.	15
Multiple use	Walking, bicycling, in-line skating, equestrians, and other users will share the Central IRC Greenways system. The system needs to address ways to provide for these multiple uses.	10
Agency support	The project is on publicly owned or accessible land and has the potential support of the agency responsible for its use.	20
Enhances safety for non-motorized travel	The Greenways system should be safe for all users, including people travelling along and across roadways, railroads, waterways and other barriers.	10
Constructability	Ease of implementation based on the following factors: intact rights-of-way, probable cost, and design constraints	15

These criteria were used to rank potential greenway projects as part of a process involving an 'Opportunities and Constraints' study, site visits, public consultation and stakeholder involvement. Projects which scored 75+ points based on the evaluation criteria were identified as 'highest potential' greenways to be implemented in 1-5 years; projects scoring 50-75 points are 'moderately challenging' greenways to supplement the network in 6-10 years; projects scoring less than 50 points have long-term (11-20 years) potential (Alta, 2007). The final evaluation matrix for potential greenway projects is given in Table 2.18.

Table 2.18 - Central Indian River County Greenways Evaluation Matrix (Alta, 2007)

Projects	Environmental Benefits (10)	Connectivity (20)	Regional Benefits (15)	Multiple Uses (10)	Agency Support (20)	Safety (10)	Constructability (15)	Total (/100)	Notes
Airport / 43rd Avenue Corridor	5	20	15	10	20	10	10	90	Shared use path
AIA / East Coast Greenway	5	20	10	5	15	10	15	80	On road bike lanes
Barber Bridge / Beachland Blvd	5	20	15	10	15	10	10	85	Extend shared-use path on bridge
17th Street Bridge Corridor	5	20	15	10	15	10	10	85	Extend shared-use path on bridge
IR Boulevard	5	20	15	5	15	10	10	80	On road bike lanes
20th Avenue	5	15	10	10	15	10	15	80	Median shared use path
12th Street Corridor	5	10	10	5	20	10	10	70	Bike lanes and sidewalks
74th Avenue	5	10	10	5	20	10	10	70	Bike lanes and sidewalks
82nd Avenue	5	10	10	5	20	10	10	70	Pending Realignment - Convert Old Road to Shared Use Path
Main Relief Canal	10	20	15	10	0	10	10	75	IR Farms approval required
North Relief Canal	10	15	15	10	0	10	10	70	IR Farms approval required
South Relief Canal	10	15	15	10	0	10	10	70	IR Farms approval required
FEC Railroad Corridor	10	20	15	10	0	10	5	70	Requires FEC approval
Beachway	10	5	15	10	20	0	15	75	Walking/Running/ Recreation
IR Water Trail	10	0	15	5	20	5	15	70	Canoe / Kayak use

There are currently two long-distance greenways in Ireland, the Great Southern Trail (Co. Limerick) and the Great Western Greenway (Co. Mayo). Both of these routes were developed in isolation, section-by-section and did not involve a route selection process. However, the Irish National Cycle Network envisages a full 2,000 km network in which greenway-standard routes are maximised (NRA, 2010a). The background, policy, funding and formation criteria of the NCN are discussed in detail in Chapter 8.

A further long distance greenway (joining the urban centres of Dublin to Galway – a distance of about 220 km) has undergone various route selection processes.This proposed greenway is considered the flagship of the NCN and will be the first greenway in Ireland to extend for more than 50 km and to undergo a formal route selection process. Table 2.19 lists the sequence of route selection reports relating to the Galway to Dublin Greenway (case study of this thesis, Chapter 9). In 2011, Manton & Clifford (2013) were tasked with high-level route selection of the western section of the greenway, while Deenihan et al. researched the eastern section.

Table 2.19 - Sequence of Galway to Dublin Greenway route selection reports

Report	**Reference**
Dublin-Mullingar Route Selection	Deenihan et al. (2011)
Mullingar-Oranmore Route Selection	**Manton & Clifford (2013)**
Galway-Dublin Greenway Business Case	AECOM & Roughan O'Donovan (2013a)
Athlone Town Route Selection	AECOM & Roughan O'Donovan (2013b)
Oranmore-Ballinasloe Route Selection	AECOM & Roughan O'Donovan (2015a)
Ballinasloe-Athlone Route Selection	AECOM & Roughan O'Donovan (2015b)

Deenihan et al. (2011) selected a route in a narrow corridor between Dublin and Mullingar, based on a hybrid of the Royal Canal towpath and a downgraded national road (R148). For this task, the authors developed an evaluation matrix,as part of an MCA proces. McCarthy (2011) and McCarthy et al. (2015) used a desk study of CROW (2007) and other international literature to determine matrix headings: safety, coherence, directness, comfort, deliverability, and cost. Criteria were developed for each heading and an expert survey (n=113) was administered to determine weights for each criterion, (Table 2.20). Scoring these criteria (Good = 3, Medium = 2, Poor = 1) yielded ratings for each of the three route options (canal towpath, national road, hybrid). This route has subsequently been progressed, although without undergoing a full statutory route selection process (including public consultation etc.).

Table 2.20 - TCD evaluation matrix (McCarthy, 2011)

Rating	Good	Medium	Poor	Weight Commuter	Weight Leisure
		Safety		**1**	**1**
Segregation	Segregated	Visual seg	Shared space		
Traffic vol.	< 3 veh/min	3–8 veh/min	8+ veh/min		
Junctions	< 1 jn/6 min	1 jn every 3.75-6 min	1+ jn every 3.75 min		
Speed limits	30 km/h	< 60 km/h	60+ km/h		
Width	3 – 5 m	2 – 3 m	2 m		
		Directness		**0.833**	**0.351**
Detour	0 – 20%	20 – 40%	40%+		
Delay	0 – 20%	20 – 40%	40%+		
		Perceived security		**0.662**	**0.749**
Visual inspection: Overlooked, Shared Use, Planting					
Comfort				**0.667**	**0.745**
Surface	Asphalt / concrete	Paving slabs / grit	Grass / soil / stone		
Gradient	< 3%	3 – 5%	5%+		
		Attractiveness		**0.433**	**0.780**
Amenities: towns	< 30 min	30-45 min	45+ min		
Amenities: rest places	< 8 km	8-12 km	12+ km		
Desirability[a]	70%+	40-70%	< 40%		
		Coherence[b]		**0.622**	**0.596**

[a]Desirability attributes included: public transport, warning signs, quiet/peaceful, two-way cycling, information signs, shared use, rural design, amenities and picturesque.
[b]As there were no other NCN routes for connections, coherence was not included

The route selection of the Mullingar-Oranmore section of the Galway to Dublin Greenway is more complex for a variety of reasons, including: distance, size of the study area, multiplicity of route options, natural constraints and land-use types (Chapter 9). Manton & Clifford (2013) planned a study area, identified the constraints and opportunities and mapped out route options. A preliminary evaluation matrix was developed following a review of international literature, including work by Deenihan et al. (2011), and is based on the NRA methdology previously outlined. The matrix scores preliminary route options on a scale of 1 to 5 for route type, directness, maximum gradient and integration (Table 2.21). Further analysis of economic and environmental impact, as well as specific design features, yielded a preferred route for three sections of the greenway: Oranmore-Ballinasloe, Ballinasloe-Athlone and Athlone-Mullingar. This route selection report represented the initial phase of this PhD thesis and established the basis for route selection of three sections of the Galway to Dublin Greenway (see Chapter 9).

Table 2.21 - Preliminary route selection matrix (Manton & Clifford, 2013)

Rating	5	4	3	2	1
Route Type	Greenway	On-Road (L)	Off-Road Cycleway	On-Road Cycleway	On-Road (R/N)
Directness	100-110%	111-120%	121-130%	131-140%	>140%
Max Gradient	0-2%	2.1-4%	4.1-6%	6.1-8%	8.1-10%
Integration	All headings	4 headings	3 headings	2 headings	1 heading

Following this report, engineering consultants, AECOM & Roughan O'Donovan, were commissioned by the NRA to carry out the statutory route selection process for the Mullingar to Oranmore sections of the Greenway (including public consultation). Firstly, it was decided that a dedicated walking and cycling bridge would be required to cross the major natural constraint of the route in Athlone. AECOM & Roughan O'Donovan (2013a) developed criteria (Table 2.22) and scored 5 route options, yielding a preferred route and independent bridge south of the existing railway bridge (although this route was subsequently changed). These criteria included safety and economy, however, due to the urban setting, environmental considerations regard changes to the traffic and road space environment. Also at this time, AECOM & Roughan O'Donovan (2013b) prepared a business case for the Galway to Dublin Greenway and Westmeath CoCo (2013) submitted a Part 8 planning application for the Athlone to Mullingar section along the disused railway.

Table 2.22 - Athlone Town route selection matrix (AECOM & Roughan O'Donovan, 2013a)

Rating	5	4	3	2	1
Route Type	Greenway/ Cycleway	Separation by verge	Separation by marking	On-Road Cycle Lane	Mixed/Shared Street
Conflicts per 100m	0	1 – 2	3 – 5	6 – 10	> 10
Alteration to traffic flow	Lanes unchanged	Lanes reduced in width	Reduced to single lane	Reduced to one-way	Road closed to motorised vehicles
Reduction in parking	0	1 – 3	4 – 6	7 – 9	> 9
Estimated construction cost (€/km)	0 – 50,000	50,000 – 75,000	75,000 – 100,000	100,000 – 200,00	> 200,000

The other two significant route selection processes were carried out on the Oranmore-Ballinasloe and Ballinasloe-Athlone sections of the Galway to Dublin Greenway, again by AECOM & Roughan O'Donovan (2015a; 2015b). These sections of the greenway, as mentioned previously, present acute challenges for the cycle route design process as no long-distance 'opportunity' infrastructure, such as a disused railway or canal towpath, exists in this area west of the River

Shannon.Therefore, green-field development and consequent land acquisition were incorporated in the route selection process. Figure 2.13 shows the selected route for the Galway to Dublin Greenway, including Dublin to Mullingar (blue, mostly along the Royal Canal towpath), Mullingar to Athlone (green, disused railway) and Athlone to Galway City via Ballinasloe, Loughrea and Oranmore (red, green-field development).

Figure 2.13 - Selected route for the Galway to Dublin Greenway

The consultants emplyed criteria based on the NRA methodology and NRA EIA guidance and were informed by Fáilte Ireland research, the Greenway Business Case (AECOM & Roughan O'Donovan, 2013b) and EuroVelo guidance (Table 2.23). The performance of route options was scored on a subjective seven-pont scale from -3 (highly negative) to +3 (highly positive), where a score of 0 is neutral.A landscape assessment was also commissioned from a landscape specialist to rate scenic and 'wow factor' views. Other minor route selection processes were carried out for the Monasteries of the Moy, Passage West – Carrigaline, Boyne Valley – Lakelands routes.

Table 2.23 - Route selection criteria for Athlone to Oranmore (AECOM & Roughan O'Donovan, 2015a; 2015b)

Criteria	**Description**
Landscape and Visual	Scenic, 'wow factor' view and interests
Flora & Fauna	Adverse impacts, attractions
Cultural Heritage and Visitor Attractions	Tourist attractions, points of interest
Connectivity and Accessibility	Distances to towns/villages, amenities
User Safety	Number of conflicts with roads
Economy	Cost per km (excluding land costs)
Physical Constraints	Topography and flooding
Material Assets, Human Beings	Number land parcels, infrastructure

This section has reviewed the initial route selection methods applied to the Irish NCN. These methods have all applied a multi-criteria analysis approach, moving beyond a narrow focus on economic costs and benefits;other criteria have centerd onsafety, environment and specific cycling design requirements (such as those given by CROW (2007)). Criteria have been aggregated in a route option evaluation matrix form aligned with NRA (2010b), generally using subjective scoringwith some elements of empirical research. These projects demonstrate the challenges of a highly quantitative approach to route selection; many of the desirable attributes of a greenway are difficult to quantify, complicating the development of criteria. Therefore, further research is required to identify greenway user route selection and design preferences, the role of safety (objective and perceived), potential environmental impact and economic costs and benefits, as well as other empirically-informed criteria.

2.9 Summary

Across the world, we face major challenges in improving sustainability in transport, with implications for the environment (GHG emissions, ecological impact), the economy (infrastructure cost, individual costs), road user safety and other social impacts. The most pressing barrier to increasing cycling is the danger posed by motorised vehicles; the proliferation of cars on many roads, and the design of the built environment around them, has led to a significant decline in active travel. Perceptions of cycling risk are linked to the individual characteristics of the cyclist (whereby women, children and inexperienced cyclists are more susceptible to risk) as well as infrastructural characteristics (traffic volume, road lane width, HGVs etc.). This review recognises that there is an infrastructural deficit for cycling in many countries (Ireland being a notable example) and that further research is necessary to fully understand cycling risk perceptions and the role of segregation from motorised traffic.

A review of the segregation debate, vehicular cycling and the Hierarchy demonstrates ongoing differences in policy regarding the provision of cycling infrastructure and this often reflects the design user. Regardless, greenways are gaining traction internationally and networks have been constructed across Europe, the USA and many other countries. However this review demonstrates a lack of empirical studies regarding greenway user preferences and guidance to date is generally drawn from an engineering safety perspective.

Greenways offer the potential for substantial economic impact, despite high costs per kilometre relative to other types of cycling infrastructure. The scope of existing economic impact studies has generally been limited to individual greenways/trails, small survey sample sizes and direct spending. The recreational value of greenways, based on cost of access, has not yet been modelled and would provide insight into the orientation of routes and benefits to various user groups. Furthermore, embodied carbon analysis of cycling infrastructure has the potential to offer more sustainable route design but has not yet been modelled.

Greenways, as cycleways developed by statutory roads authorities, should undergo a robust route selection process. Financial investment (usually from central and local government) demands evidence to determine those routes which have the greatest potential for return on investment, yet many of the benefits of greenways are not easily monetised. A route selection process for greenways should move beyond a narrow focus on economic impact, to incorporate multi-criteria analysis in a method which yields the most effective route under a variety of headings.

This review establishes that further research is needed to develop route selection criteria for greenway user preferences, the role of safety and economic and environmental impact. As current preliminary greenway route selection methods show that there are challenges to an entirely quantitative method and any new approach must blend such quantitative criteria with a flexible and easy to apply method for engineers and planners. There is significant potential in this area to inform high-level network formation and funding prioritisation, as well as a route-specific Level-of-Service, in the delivery of safe, environmentally-friendly, cost-efficient and, most importanly, used and enjoyed greenways.

3 Research Objectives and Method

The review of existing literature demonstrated the paucity of research on the planning and design of greenways. While the cycling research field has grown considerably in recent years, the development of greenways for cycling represents a significant gap in this literature. This chapter outlines the objectives and overall method of this research, acting as a guide to the chapters that follow.

3.1 Objectives

The over-arching objective of this thesis was to develop novel methods for the planning and design of greenways for cycling and to generate findings which will assist future engineers, planners and policy-makers. As this study sits in the broader cycling research field, it was deemed necessary to begin with the most pressing issue facing the promotion of cycling: safety and perceptions of risk. Once a better understanding of cycling safety concerns, it was decided to concentrate on developing planning and design guidance based on user preferences as well as elements of greenway appraisal, specifically environmental and economic impact. Finally, a case study was used to apply the findings of the research and to discover other issues which arise in greenway development in practice.

These elements of research can be viewed as serving five key objectives:

1. **Cycling safety**. To better understand the safety barriers to cycling, focusing on the determinants of perceived risk (at both the user and infrastructural levels) and the potential role to be played by segregation from motorised traffic.
2. **Greenway user preferences**. To engage a large and diverse sample of international greenway users on high-level priorities for greenway planning as well as specific geometric and other design characteristics; furthermore, to channel these findings into planning and design guidance.
3. **Environmental impact**. To calculate the embodied carbon of greenways (as one form of environmental impact) and to examine how this can be offset by a modal shift to cycling.
4. **Economic impact**. To measure and categorise typical user spending on greenways, place this in the context of construction costs, and to evaluate recreational value and willingness-to-pay for access.
5. **Application**. To apply the lessons learned in previous chapters by reviewing a burgeoning national greenway and cycle network and to test the novel methods against the planning and design of one case study route.

3.2 Method

This research comprised two broad phases. The first phase, lasting approximately 18 months, started with a review of a wide range of the academic literature as well as national and international policy, legislation and design guidance. A secondment was then undertaken at Roscommon National Road Design Office, under the supervision of one of the authors of the National Cycle Network Scoping Study (NRA, 2010). Thework completed in this period focussed on adapting NRA road route selection procedures for cycling (including the reclassification of 'constraints' and 'opportunities'), analysing national datasets and the carrying out the initial route selection of the case study greenway corridor, including the collection of mapping resources. This preliminary work was subsequently cited in the formal route selection process completed by a team of engineering consultants (see Figure 3.1).

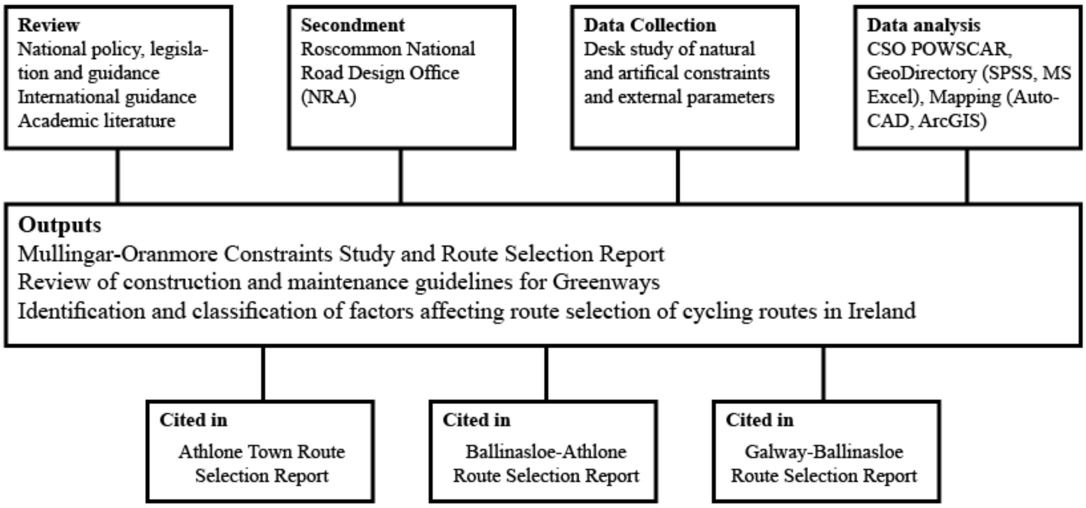

Figure 3.1- Flowchart of preliminary phase of PhD research

In the second and main phase, a more detailed review of the literature was completed, concentrating on the development of a set of novel greenway planning and design methods. Secondments were then completed at two Irish local authorities (Galway City and County Councils), which enabled the further development of experience in greenway and broader walking and cycling planning and design in practice. A semester-long research visit was then undertaken at the Safe Transportation Research and Education Center (SafeTREC), UC Berkeley, adding an international dimension to the research as well as offering the opportunity to audit postgraduate transportation planning classes not currently available in Ireland.

During this time, the four core research areas were identified (safety, design preferences, environment and economy). A novel method was developed for each, tested and findings and recommendations concluded. In total, six co-authored publications were prepared based on this research, two of which were literature review or desk study based while a further four were derived from the four novel empirical methods. Also, an initial constraints study and route selection report and more detailed case study were produced on the Mullingar-Oranmore corridor of the Galway to Dublin Greenway. Ultimately, these outputs, combined with the review of the Irish NCN represent new guidance for the planning and design of greenways (see Figure 3.2).

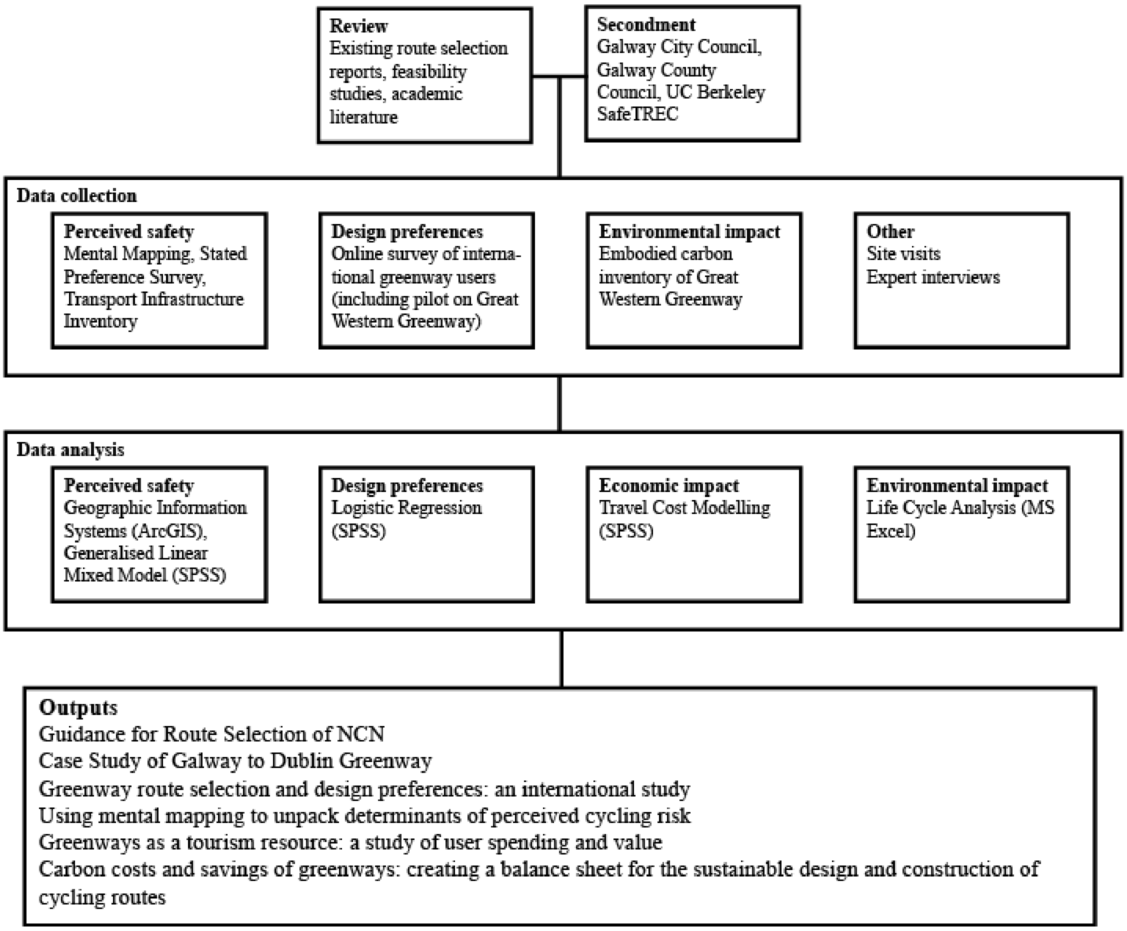

Figure 3.2 - Flowchart of main phase of PhD research

As the research progressed, it became clear that greenway planning and design is a complex and contested field. For example, international survey responses indicated that greenway preferences and priorities are quite diverse (e.g. varying with location and design user) and consequently planning and design guidance must be more nuanced. Also, the official route selection of the case study greenway (Galway to Dublin Greenway) proved to be quite contentious, raising issues regarding the engagement of landowners and broader character of the route selection process.

Thus a core objective of Chapter 5 was to create a framework for the planning and design of greenways, based on multi-criteria analysis, into which novel methods could feed. This framework was developed based on the literature review (including adapting existing national and international route selection criteria) and by condensing qualitative and quantitative greenway user survey results. The final elements of the framework (see Section 5.6) transcended those highlighted in the literature review by introducing two new elements: accessibility and user experience. However, these two new elements proved very challenging to quantify and the remainder of the thesis focuses on the four main empirical elements: safety, design preferences, environment and economy. Each chapter contains a novel method representing one element of the framework and each chapter includes a full methodology section. Figure 3.3 shows the layout and contributions of Chapters 4-7. Chapter 8 then reviews the evolution of the Irish NCN, drawing on these novel methods and results and contextualising the case study which follows in Chapter 9. Finally, the overall contributions of the thesis are summarised in Chapter 10, Conclusions.

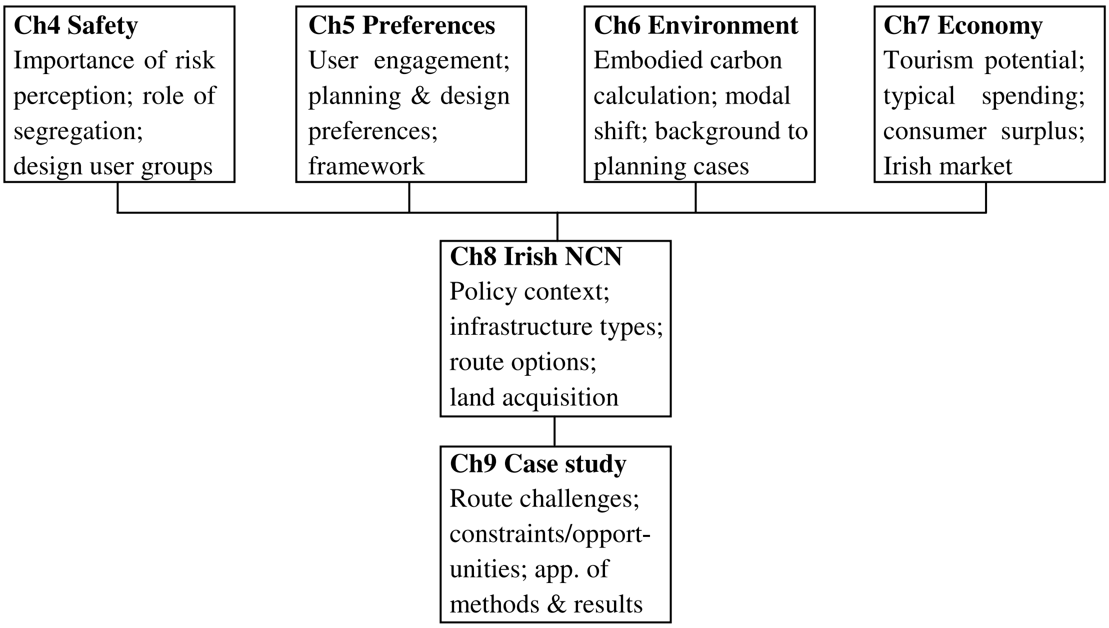

Figure 3.3 - Layout and contributions of thesis chapters

4 Understanding perceptions of cycling risk[1]

4.1 Introduction

Extensive cycling research has highlighted negative perceptions of safety as a major barrier to the growth of cycling (see Section 2.2). However, measuring road safety perceptions among cyclists is complex and requires a combination of methods of data collection and analysis that can handle both quantity and quality. Complementing surveys with unstructured or semi-structured interviews open up some fruitful avenues and the successful application of videos, computer simulations, interactive maps and other visual aids points towards the key role of visualisation in road safety research (Prendergast & Rybaczuk, 2005). Mental mapping, a creative process that seeks to draw out and subsequently visualise people's experiences of their physical and social surroundings, deserves particular attention, yet has not been fully utilised to explore cyclists' perceptions.

The innovative methodology used in this chapter, as subsequently outlined, proposes an alternative means of planning infrastructure that is both safe but also perceived to be safe. The results will be relevant to engineers, planners, policymakers and cycling advocates as part of an interdisciplinary response to improving actual and perceived safety and increasing sustainability in transport. At the end of the chapter, conclusions are drawn for international cycling policy, including greenways, as well as for the Irish NCN.

4.2 Methodology

This study combines mental mapping, a stated-preference survey and a transport infrastructure inventory as part of a mixed-method to unpack perceptions of cycling risk and to make visible both overlaps and discrepancies between perceived and actual safety risks. The results of mental mapping and the stated-preference survey captured perceptions of the cycling environment, while a transport infrastructure inventory collected characteristics of the objective cycling environment. The resulting qualitative and quantitative data were matched using Geographic Information Systems and exported to statistical analysis software to construct a model of the individual and infrastructural determinants of perceived cycling risk. This was developed using as a case study, survey data from Galway City, a university city in the West of Ireland.

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[1] An article based on this chapter was published in Accident Analysis & Prevention.

4.2.1 Study Area

Ireland has established a national cycling target of 10% modal share by 2020, yet safety concerns remain a major impediment to increasing cycling uptake (DTTAS, 2009a; 2009b). There has been a significant rise in cyclist fatalities and injuries in Ireland in recent years. Between 2013 and 2014, cyclist fatalities more than doubled from 5 to 12; between 2011 and 2012, the number of cyclists injured rose 59% to 630 (most recent figures available). To achieve the national cycling target, small, compact urban areas with a young population are deemed to harbour significant potential for modal shift away from the car and towards active travel modes. The present study was conducted in Galway, a university city of 75,000 people on the west coast of Ireland. The study area is affected by a number of issues that might impede uptake of cycling and a recent qualitative study that investigated modal shift among the workforce of a large employer found perceived safety risks in the city to be an important barrier to walking and cycling (Heisserer, 2013). Galway experiences mean annual rainfall of 1193 mm and the mean annual temperature is 10°C (Met Éireann, 2015). The city has a cycling modal share of 5%, while 57% residents travel to work by car, either as a driver or passenger (CSO, 2012a). Recent cycling-related developments include the installation of raised cycle lanes, a series of greenways and a bike-share scheme.

4.2.2 Survey Sampling

In this study, people in Galway City who cycle to work, school or college make up the study population. Convenience sampling was utilised by presenting the paper-based survey to potential participants at large events in 2013; random sampling techniques (e.g. simple random, cluster or stratified sampling) could not be generated due to the lack of a sampling frame (i.e. a selection mechanism such as a register); an intercept survey was also deemed unfeasible due to the time required to complete the survey.It is possible that this sampling process may have biased the results. The National University of Ireland, Galway campus was chosen for its central location (1 km from Galway City centre) and relatively large cycling population (cycling modal share 12% and a campus population of 17,000 students and 2,000 staff (Manton & Clifford, 2012)). As the sample was not randomly selected, it was not possible to make statistical inferences about all cyclists or indeed the population of this study (Smith, 1983).

4.2.3 Mental Mapping

While traditional mental mapping studies asked participants to draw a freehand sketch (Lynch, 1960),this study utilised a base-map of Galway City roads and streets as an assist (see Appendix 1). Participants were provided with one map each (which included a brief written introduction, outlining the task) and coloured pens. They were asked to draw their regularly used (at least weekly) cycling routes and to colour each route section according to their perception of the safety of that section of their route: *Green* for safe, *Amber* for unsafe, and *Red* for very dangerous. The use of this traffic-light sequence allowed for easy expression of risk, compared to more complex rating scales. Participants found their origin and destination on the base map and translated their mental map into coloured ratings of risk along the route. The mapping task was undertaken independently of any interaction with the researcher and there were no time restrictions placed on any of the participants. Participating in this mental mapping exercise offered respondents a chance to reflect on their everyday cycling practices and to offer some practical local improvements.

4.2.4 Stated-Preference Survey

Following the mental mapping exercise, participants were asked to complete a stated-preference survey of 28 questions that reflected the findings of the reviewed literature. Questions on participants' general cycling experience and preferences (e.g. cycling frequency, trip purpose, self-ascribed cycling skill, typical infrastructure used, preferred infrastructure) preceded a series of questions on cycling safety, including involvement in road collisions. The order of questions was designed to invoke the memory of any previous cycling collision before the participant answered specific questions on factors affecting cycling safety, including the volume of cars passing, volume of trucks passing, roundabouts, adjacent car parking, speed limits, road lane width, cycle lane width, and number of junctions. Due to the level of detail involved in these questions, participants were asked to carefully consider each factor before ranking them in order of importance. Finally, participants were asked to provide demographic details including: age, gender, years spent living in Galway, employment status, household composition, and car availability.

4.2.5 Transport Infrastructure Inventory

Data on infrastructural and traffic-based factors affecting safety were collected using a transport infrastructure inventory of Galway City. These included traffic volumes (cars and the proportion of HGVs), on-street car parking, cycling facilities, road width, and junctions. The roads in the study area were divided into sections of similar length (generally between junctions and using named roads where possible) and data on each road section were collected through desk studies and site visits. The volumes of light vehicles (predominantly cars), heavy vehicles (predominantly trucks) were retrieved from Galway City Council (2013), based on annual traffic counts conducted between 7am and 7pm on a standard day in November (the traffic volume on NUI Galway campus roads was estimated from student traffic counts). The locations of adjacent car parking were identified on site and by using Google Streetview. The speed limit on all roads was 50 km/h, with the exception of the NUI Galway campus, which has a speed limit of 20 km/h. The locations of segregated cycling infrastructure were identified from Galway City Council. The widths of road and cycle lanes were measured on site. The number of junctions in each road section was counted from mapping. A shapefile of the road network was imported to ArcGIS and the polylines were split according to road section and inventory data were then added as attributes to each road section.

4.2.6 Data analysis

A model of perceived cycling risk was constructed by matching the perceived environment (mental map) to characteristics of the physical environment (inventory data). Mental maps were uploaded to ArcGIS by attributing the colour-coded ratings of each participant (along with demographic information) to road sections (cf. Boschmann & Cubben (2014) for sketch maps and qualitative GIS, and Snizek et al. (2013) for map matching). This yielded a dataset in which each row represents one observation (the rating given by one participant to one road section); this dataset was then imported into the statistical software package SPSS (version 21) for analysis. The perceived risk rating is the response of interest and is a qualitative variable with values *Green, Amber, Red* in order of increasing perceived risk. Factors (qualitative/categorical input variables) and covariates (quantitative input variables) include the physical characteristics of the road section and the demographics of the individual participant. A statistical model was then developed to identify the significant factors and covariates in perceived cycling risk.

A number of features associated with the study design posed challenges for the model. Firstly, the response data are qualitative and ordinal. Secondly, observations for any given participant may be correlated (i.e. as each participant rated several roads, these may be more likely to receive a similar rating). Thirdly, interactions between several of the variables can (as in any study) also arise. Of particular interest here are the interactions between individual-level and infrastructural variables. The presence of a significant interaction would imply that the effect of one independent variable (e.g. an infrastructural characteristic) on perceived risk (perceived risk being a dependent variable), differs according to a second independent variable (e.g. a characteristic of the cyclist). Also some variables can mask the impact of others and it was considered appropriate to exclude certain variables (e.g. fitness) from the analysis (e.g. when present, multicollinearity may have a masking or other adverse effect). Bearing in mind the design and goals of the study, it was decided to employ logistic regression and to adjust the technique for the previously mentioned possibility of correlations between participants' ratings and allow interactions between input variables. A Generalised Linear Mixed Model was applied to investigate multi-category responses that could accommodate the within-subject correlation through random effects (McCullogh et al., 2008).

The Generalised Linear Mixed Model 'generalises' linear regression by using a link function to relate the response variable to a linear model. Firstly, the linear predictor is shown in Eq. 4.1.

$$\eta_i = \sum \mathrm{X}_\mathrm{i}'\beta$$

Eq. 4.1

Where η_i is the linear predictor of the model, X_i is the factor or covariate (individual and infrastructural variables) and β is the coefficient of the factor or covariate. Secondly, a logit link function is used in the form given in Eq. 4.2.

$$\eta_i = ln\left(\frac{p}{1-p}\right)$$

Eq. 4.2

This is interpreted as log-odds, an alternate way of expressing probabilities (p), for a change in the response variable. For this study, *Red* (dangerous) was chosen, arbitrarily, as the reference category for the response variable (results are not sensitive to the selection of the reference category). Based on Eq. 4.2, the log-odds of a change in the response variable is therefore given in Eq. 4.3.

$$\eta_i = ln\left(\frac{probability\ that\ a\ random\ person\ will\ respond\ Green\ or\ Amber}{probability\ that\ the\ person\ will\ respond\ Red}\right)$$

Eq. 4.3

Equating Eq. 4.1 and Eq. 4.3, the coefficient, β, of a covariate, X, (such as *age* and *road width*) is interpreted as the change in the log-odds for a unit increase in that variable. For a binary input variable (such as *gender* or *segregation*) the coefficient of that variable represents the expected change in the log-odds between the reference category of that variable and the other category. For the only input variable which has three categories, *cycling experience*, there were two parameters involved to represent changes from the reference to each of the two other categories (i.e. from *inexperienced* to *competent* and from *inexperienced* to *highly skilled*).

For most input variables, of interest is whether a change in levels of this variable increases the log-odds (rather than changes the log-odds). Thus this tests whether the alternative/research hypothesis is one-sided, e.g. are women *more* likely than men to perceive cycling risk (as suggested by the literature) rather than simply whether there is any difference between men and women in perceiving cycling risk. For other input variables (such as *age*), a two-sided hypothesis test is applied (the p-value for a one-sided hypothesis test is half that of a two-sided test). In practice, it may be easier for interpretation purposes to exponentiate the log-odds ratios, so that then the linear function described previously is replaced by an exponentiated version and one can carefully interpret the corresponding coefficients as pertaining to changes in odds rather than changes in log-odds.

4.3 Results and discussion

4.3.1 Sample Characteristics

The number of survey participants was 104 and the total number of observations (i.e. perceived risk ratings) was 484, an average of 4.65 observations per participant. The characteristics of the sample are given in Table 4.1. Participants' ages ranged from 17 to 58 years (mean = 30.8 years; standard deviation = 10.7 years). It should be noted that throughout this thesis only adults were sampled. The majority of participants were maleand this reflects the national cycling gender gap – in Ireland 73% cyclists are male (CSO, 2012a). The sample included a majority of students, undergraduate and postgraduate. While approximately one third of survey participants had lived in Galway for less than five years, another third resided in the city for 15 years or more.

Table 4.1 - Sample characteristics (n=104)

Age	%	**Gender**	%
Under 25 years old	36.5	Female	39.4
25 – 44 years old	48.1	Male	60.6
45 – 64 years old	15.4		
Occupation	%	**Time spent living in Galway**	%
At work	35.6	Less than 5 years	33.7
Undergraduate student	35.6	5 – 9 years	19.2
Postgraduate student	21.3	10 – 14 years	12.5
Other / not stated	5.8	15 years or more	34.6

More than half of the respondents cycled everyday (51%), a further 29% cycled several times per week and the remaining 20% cycled less often. In terms of their self-rated cycling experience: 29% of cyclists in the study classified themselves as *highly skilled*, 64% as *competent* and 7% as *inexperienced*. 14% of the sample classified themselves as *very fit*, 51% as *fit*, 29% as of *average fitness* and 6% as *unfit*. The majority of participants (61%) had not been involved in a collision as a cyclist; however it is of note that 39% of respondents had been involved in a collision. Table 4.2 summarises the frequency and purpose of cycling trips made by respondents.

Table 4.2 - Cycling trip purpose by frequency

	Always (%)	**Sometimes (%)**	**Never (%)**
Commuting	*67.4*	*28.4*	*4.2*
Means to other transport	*26.9*	*47.8*	*25.4*
Health/Fitness	*20.5*	*67.5*	*12.0*
Shopping	*19.5*	*59.7*	*20.8*
Leisure	*17.3*	*76.5*	*6.2*

4.3.2 Perceived Environment

A total of 38 road sections in Galway City received a rating. To ensure robustness, only road sections with a minimum number of ten ratings were included, leaving 27 road sections in the final analysis. The River Corrib divides Galway City approximately in half, east and west. As the NUI Galway campus and the majority of residences are located west of the river, road sections at that side of the city received the majority of ratings. The most frequently rated roads were in the immediate vicinity of the university. Figure 4.1 shows a sample mental mapping response across a route from Salthill, a seaside suburb, to the university at the banks of the River Corrib. The start (residential roads) and end (canal towpath and university roads) are rated as *Green* (safe), while one road section is coloured *Amber* and another *Red*.

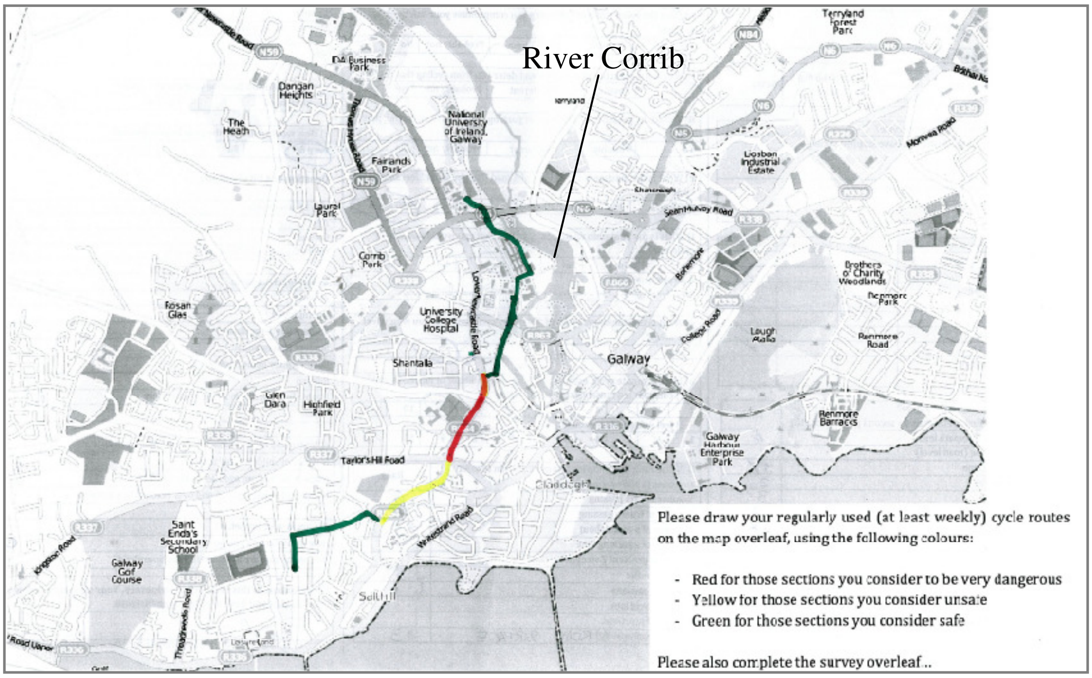


Figure 4.1 - Sample mental mapping response (Male, 31 years old)

Of the 484 road section ratings, almost half (48.6%) were *Green*, 29% were *Amber* and 22% were *Red*. This suggests that the majority of roads are perceived to be unsafe or very dangerous, and route choice, whereby cyclists avoid dangerous roads, is likely to mask the true extent of this perceived risk (Snizek et al., 2013). Of interest here is the relative influence of individual and infrastructural factors in determining this ordinal rating. For illustrative purposes in Figure 4.2, the three response colours have been weighted with values 1, 5 and 10 in order of increasing perceived risk. Averaging these values and forming three equally-sized categories allows a rough comparison of perceived risk across the road network.

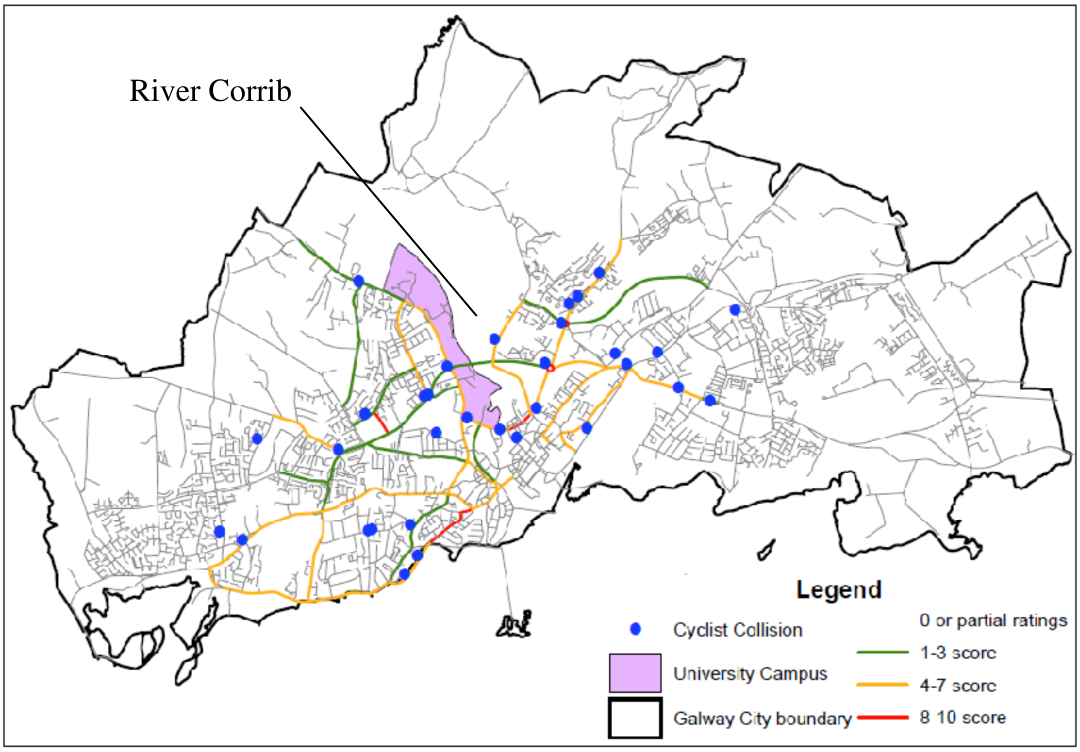


Figure 4.2 - Galway City road network, indicative perceived safety ratings and locations of cycling collisions (a high score indicates a road perceived as dangerous).

Also shown in Figure 4.2 are the locations of the 32 reported collisions involving cyclists in Galway City in 2005, 2006, 2007, 2008 and 2010 (RSA, 2014; most current data). There were no cyclist fatalities in Galway in this period. It should be noted that that cycling collisions, resulting in injury, are believed to be subject to major under-reporting (Short & Caulfield, 2014). In the absence of more reliable measures (e.g. collision intensity, collisions per passenger km or passenger hour), this source of cycling collisions was judged to be an acceptable but basic representation of actual cycling risk. Of the 32 collisions, 23 occurred on road sections included in this study. Four collisions align with the safe category, 15 with the unsafe category and four with the very dangerous category (all at roundabouts). Roundabouts were rated as very dangerous by all participants. Within the limitations of the arbitrary weighting of response colours and the under-reporting of cycling collisions, this suggests that some perceptions of risk align with location of actual collisions.

Finally, a note is provided on the impact of participants' route choice which must be considered for the perceived risk model. Cyclists may avoid roads that they identify as dangerous, e.g. those with heavy traffic. This would lead to a disparity between stated preference results and mental mapping results, as cyclists may not use the roads they perceive to be most dangerous. However, this was not determined to be a significant factor in this survey as the mental mapping results show that the vast majority of participants chose the most direct route between origin and destination, most likely due to the lack of route choice in Galway City which does not have a grid pattern. Many cyclists will also temper safety concerns with time and distance delays caused by alternative routing.

4.3.3 Physical Environment

The engineering and traffic characteristics of the 27 road sections covered by mental mapping were compiled in the transport infrastructure inventory. Traffic volumes ranged between 0 (canal towpath) and 14,791 vehicles per day, the proportion of HGVs between 0 and 4%, road lane width between 2 and 4 m. There were two types of segregated cycling infrastructure: raised cycle lanes and the canal towpath. On-street car parking was a factor in some areas and the number of junctions ranged encountered in routes mapped by respondents ranged from two to nine. Images of typical types of road and cycling infrastructure in Galway City are shown in Figure 4.3.

Figure 4.3 - Clockwise from top left: new raised cycle lane on main road, canal towpath, typical roundabout, and a road without cycle facilities (Google, 2015)

4.3.4 Stated Preferences

Participants were asked to rank nine physical factors (one being the factor perceived as most impacting on safety) according to their impact on cycling safety. Responses were categorised as follows; a ranking of between 1 and 3 was considered high risk, 4 – 6 was considered medium risk and 7 – 9 considered low risk. Table 4.3 and Figure 4.4 present a summary of the number of responses that fall under each category. The key factors seen as causing safety concerns included the number of trucks passing, speed of traffic and number of cars passing and the presence of a roundabout. Other factors expressed in qualitative responses (‘other, please specify’) included road condition and driver behaviour.

Table 4.3 - Physical factors ranked by concern for safety (% respondents)

	High (%)	Medium (%)	Low (%)
Speed of traffic	64.0	29.2	6.7
Number of trucks passing	62.9	28.1	9.0
Number of cars passing	49.4	41.4	9.2
Presence of a roundabout	58.2	26.4	15.4
Width of road lane	41.5	36.6	22.0
Number of junctions passed through	21.1	42.1	36.8
Presence of a car parking lane	27.7	30.1	42.2
Width of cycle lane	19.0	27.8	53.2
Maximum gradient	15.3	26.4	58.3

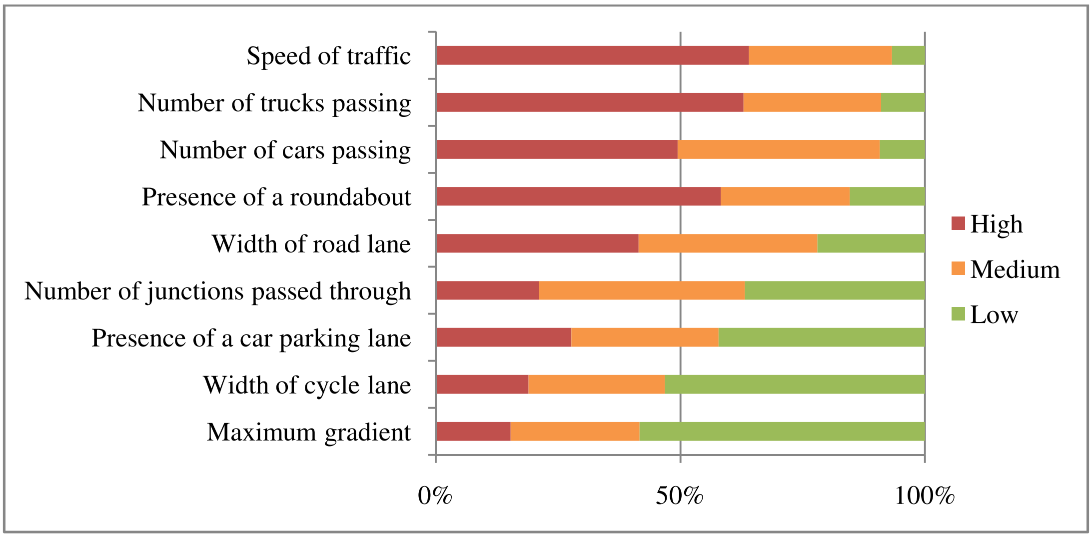


Figure 4.4 - Stacked bar chart of ranked safety concerns

Participants were asked a series of follow-up questions on the degree to which some of the previously mentioned factors compromised their safety while cycling. 59% agreed that the number of trucks passing compromised safety, 55% agreed for the number of cars and 43% for the presence of a roundabout. Adjacent car parking, which can result in ‘dooring’ (cyclists being hit by car doors) deterred just 15% of participants. The maximum speed limit of a road that most participants (57%) would feel comfortable sharing with motorised traffic is less than 50 km/h, 26% said 50-60 km/h and 17% said 60-80 km/h. Also, the average number of junctions that it feels safe to pass though in 30 minutes was reported to be 4.7 (although safety perceptions of junctions vary according to layout and roundabouts were considered particularly dangerous).

Table 4.4 - The degree to which cyclists feel each factor affects safety (% respondents)

	Yes	Possibly	Indifferent	Probably Not	No
Number of trucks passing	59.2	27.2	5.8	5.8	1.9
Number of cars passing	54.5	30.7	4.0	7.9	3.0
Presence of a roundabout	42.6	33.7	7.9	5.0	10.9
Presence of adjacent car parking lane	14.9	26.7	16.8	23.8	17.8

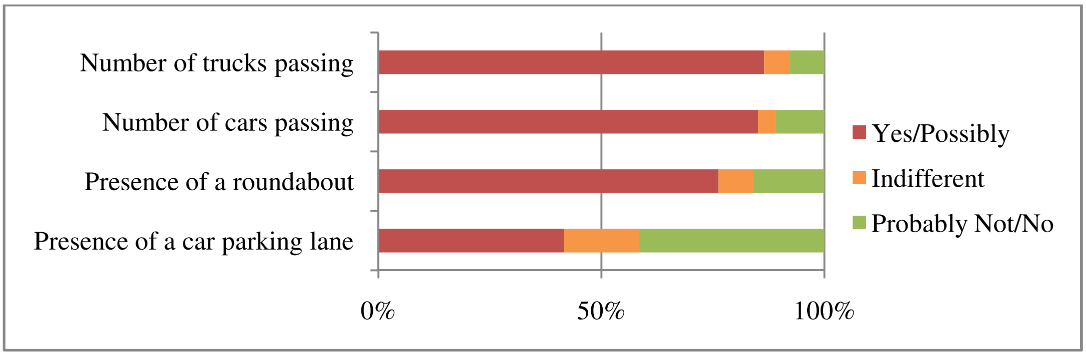


Figure 4.5 - Stacked bar chart of degree of perceived impact on cycling safety

Participants were also asked to rank their frequency of use and preferred type of cycling infrastructure or on-road cycling positions. Figure 4.6shows the results of the participants' actual riding locations and shows that reasonable numbers always cycle on-road, mostly in the secondary riding position (closer to the kerb, rather than 'taking the lane'). Some participants stated that they always cycle on the footpath, potentially indicating significant fear of interaction with traffic. Figure 4.6also shows the participants' preferred cycling locations with raised cycle lanes (footpath level), road-level cycle lanes and greenways receiving the highest rankings. The disparity between this clear preference for segregated cycling infrastructure and actual levels of on-road cycling suggests a deficit of dedicated cycling infrastructure, a finding in line with Caulfield et al. (2012).

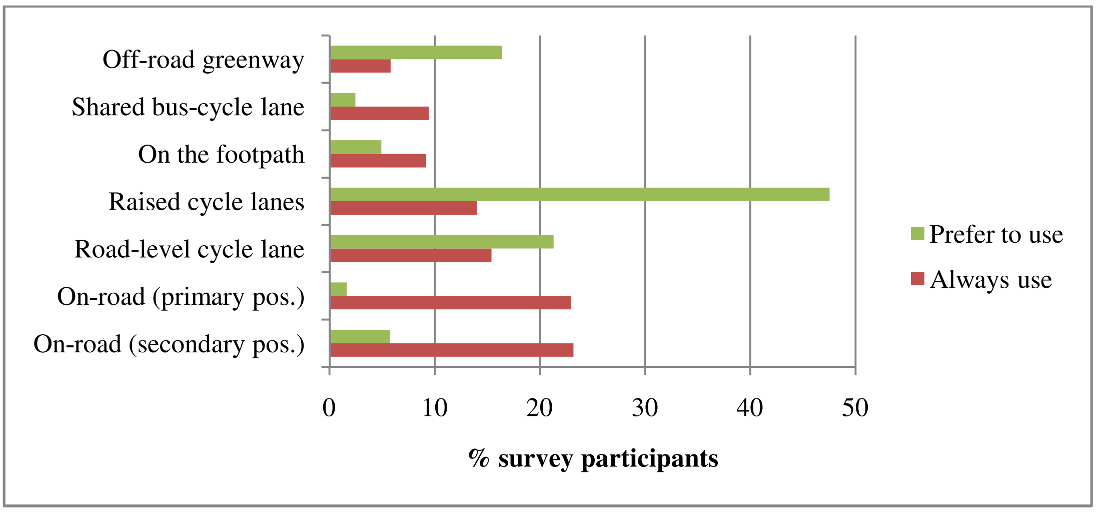


Figure 4.6 - Actual and preferred cycling infrastructure usage

4.3.5 Modelling Perception of Cycling Risk

The information derived the mental mapping survey and the transport infrastructure inventory is summarised in Table 4.5. The naming scheme used in the table does not precisely correspond to the actual road names as it was necessary to combine certain roads (which are often arbitrarily named) to yield sections of similar length. The road sections are included for reference and to enable future research.

Table 4.5 - Summary of mental mapping and transport infrastructure inventory results

Road Section	Green	Amber	Red	n	LV	HV	W	Seg	Park	Coll	Jn
Bishop O'Donnell Rd (1)	4	14	2	*20*	8614	288	3	Y	N	1	2
Bishop O'Donnell Rd (2)	4	10	0	*14*	5436	204	3	Y	N	0	3
Bishop O'Donnell Rd (3)	5	6	1	*12*	5999	149	3	Y	N	0	2
Canal Towpath	0	12	1	*13*	0	0	1.6	Y	N	0	4
Fr. Griffin Road (1)	4	3	7	*14*	7680	184	2.8	N	N	0	3
Fr. Griffin Road (2)	3	5	3	*11*	4912	121	3	N	N	0	3
Fr. Griffin Road (3)	3	5	3	*11*	5157	125	2.8	N	N	0	3
Headford Road (1)	6	2	5	*13*	6902	126	3.3	N	N	0	5
Headford Road (2)	4	6	3	*13*	14183	545	3.3	Y	N	0	4
N6/Seamus Quirke Road	5	6	0	*11*	11392	439	3.5	Y	N	1	2
Newcastle Rd Lower (1)	11	9	4	*24*	5046	94	2.6	N	Y	1	4
Newcastle Rd Lower (2)	13	11	6	*30*	5773	107	2.6	N	Y	0	3
Newcastle Rd Lower (3)	12	4	10	*26*	6021	109	2.6	N	Y	0	4
Newcastle Road Upper	7	9	5	*21*	5105	159	2.3	N	Y	0	8
NUI Galway Roads	7	28	0	*35*	1000	10	2.5	N	N	0	3
Quincentennial Bridge	4	22	7	*33*	14791	464	3.5	Y	N	0	2
Rahoon Road	4	3	3	*10*	6903	230	3.2	N	N	1	5
Salthill Road Lower	4	7	1	*12*	4151	61	2.1	N	Y	0	9
Salthill Road Upper (1)	3	7	4	*14*	6661	127	3	N	Y	0	6
Salthill Road Upper (2)	3	5	2	*10*	6377	111	3	N	Y	0	7
Seamus Quirke Road (1)	3	18	1	*22*	8449	284	3	Y	N	0	3
Seamus Quirke Road (2)	2	19	1	*22*	7958	274	3	Y	N	0	3
Shantalla Road	4	7	1	*12*	2150	40	2.6	N	N	0	8
St. Mary's Road	8	4	5	*17*	4381	64	2.8	N	Y	0	4
St. Vincent's Avenue	5	1	8	*14*	5717	106	2.2	N	Y	0	4
Thomas Hynes Road	3	5	4	*12*	7456	220	3.2	N	N	0	9
University Road	10	8	20	*38*	6799	97	2.1	N	Y	1	6

Notes: Green/Amber/Red = number of green/amber/red safety ratings; n = Number of ratings received
LV = Number of light vehicles, 7am to 7pm; HV = Number of heavy vehicles, 7am to 7pm
W = Width of road lane (m), rounded to nearest 0.1 m
Seg = Segregated cycling infrastructure, Yes/No; Park = Adjacent parking lane, Yes/No
Coll = number of collisions; Jn = number of junctions

A Generalised Linear Mixed Model was built in SPSS, where the Subject was the participant (using a unique participant number to identify repeated measurements) and the Target was the perceived risk rating. The Measurements were the 484 observations, including associated demographic and infrastructural data. The goal was to assess the extent to which the ordinal variable Rating relates to nine main qualitative and qualitative effects (Table 4.6). The qualitative variables are: *gender*, *cycling experience* [inexperienced/competent/highly skilled], *segregation* [of cycling facility; yes/no], *parking* [adjacent car parking; yes/no]. The quantitative variables are: *age*, *LV* [per 1000 light vehicles per day], *%HV* [percentage of heavy goods vehicles], *width*[of road lane in metres], and number of *junctions*.

Table 4.6 - Perceived risk model variable information

	Variable	Category	n	Percent	Minimum	Maximum
Qualitative	*Rating*	*Green*	235	48.6		
		Amber	141	29.1		
		Red	108	22.3		
	Gender	*Female*	189	39.0		
		Male	295	61.0		
	Cycling experience	*Highly Skilled*	160	33.1		
		Competent	298	61.6		
		Inexperienced	26	5.4		
	Segregation	*Not Segregated*	324	66.9		
		Segregated	160	33.1		
	Parking	*No Parking*	230	47.5		
		Parking	254	52.5		
Quantitative	*Age* (years)		484		17	58
	LV (1000 veh)		484		0	15
	%HGV		484		0	3.9
	Width (m)		484		2	4
	Junctions (no.)		484		2	9

Figure 4.7 displays the percentage of participants for each category of gender. These results suggest that female participants perceived more roads as very dangerous and fewer roads as safe (of course, this is not a statistical inference and has not removed the effect of other variables). Figure 4.8 illustrates the corresponding summary for segregation, which appears to have a strong effect: dedicated cycling facilities received a larger proportion of safe ratings than road sections that involve cycling in motorised traffic. Both of these observations were also suggested by the literature and the potential interaction of individual and infrastructural variables is also of interest. For example, female participants rated a greater proportion of segregated infrastructure than their male counterparts – potentially as they are more likely to choose a route on segregated infrastructure – as did older people and inexperienced cyclists.

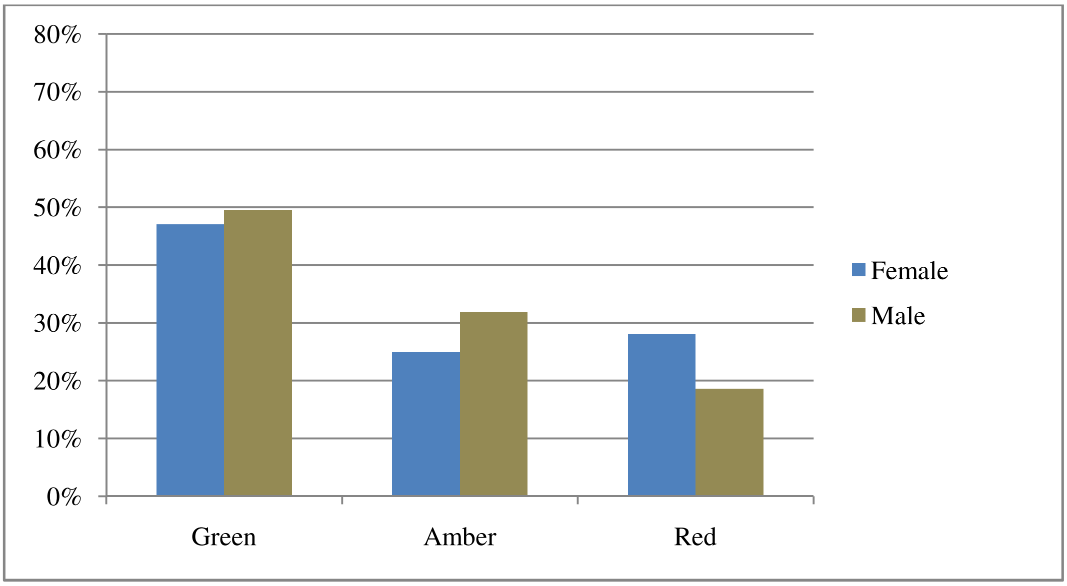


Figure 4.7 - Perceived risk rating plotted against Gender

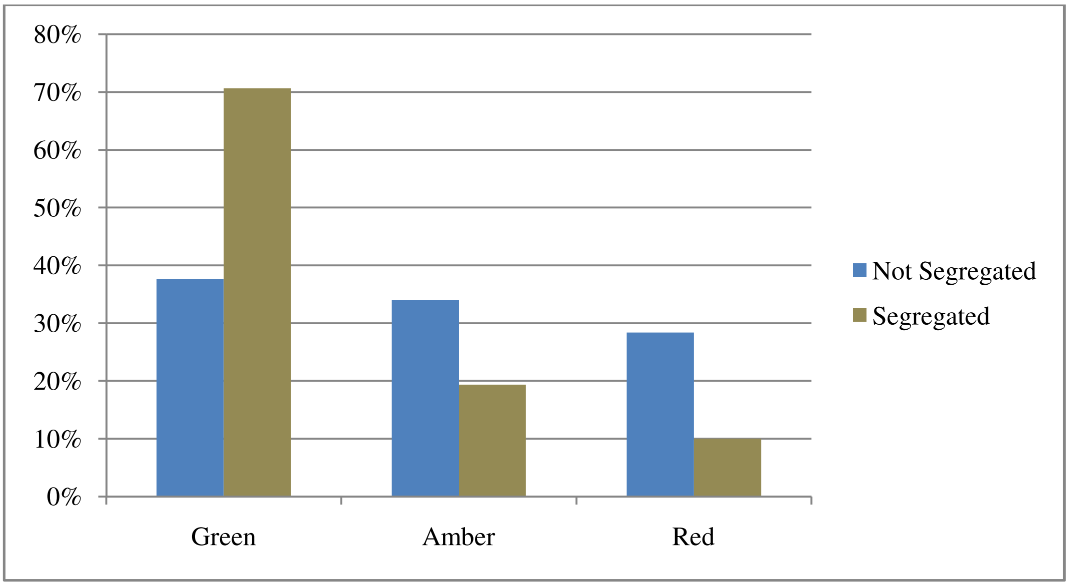


Figure 4.8 - Perceived risk rating plotted against Segregation

To account for interactions between pairs of variables, all two-way interaction terms were initially included in the analysis and then systematically dropped according to their effect on the significance of main effects. Some variables have the potential to mask the effect of others and it was deemed necessary to exclude these. This process was also informed by a thorough analysis of the correlations between each variable. Fitness, for example, was dropped at an early stage of the analysis as it was found to be highly correlated with, and masking the effect of, Cycling Experience; this was also the case with Years Living in Galway and Age. Random Effects were included to account for within-subject correlations. The fitted Generalized Linear Mixed Model components are shown in Table 4.7. In this table, each coefficient, $\widehat{\beta}$, estimates the change in the log-odds of *Green* or *Amber* relative to *Red* for a unit increase in a quantitative variable (units are denoted in parenthesis for quantitative variables) or the change in the log-odds between the reference and the other category (or other categories) for qualitative variables. Theexponentiated log-odds ratio, Exp($\hat{\beta}$), then represents changes in odds; the 95% confidence interval for the true underlying odds, Exp($\hat{\beta}$), is also shown in Table 4.7. Significance is implied by the magnitude of the p-value, displayed in the table.

Table 4.7 - Generalized Linear Mixed Model output

Ref=Red		$\hat{\beta}$	Exp($\hat{\beta}$)	95% CI for Exp(β)		p-value
				Lower	**Upper**	
Age (years)		0.022	1.024	0.984	1.066	0.240
Gender	*Female*	1.526*	4.601	1.336	15.847	0.008
Cycling Experience	*Highly Skilled*	-1.563*	0.210	0.045	0.982	0.024
[ref=Inexperienced]	*Competent*	-1.694*	0.184	0.043	0.787	0.012
LV (1000 veh)		0.176**	1.192	1.076	1.321	0.001
%HV (percent)		0.304	1.355	0.903	2.035	0.142
Width (m)		-0.977*	0.377	0.153	0.929	0.034
Junctions (no.)		0.006	1.006	0.873	1.159	0.932
Parking		-0.521	0.594	0.266	1.325	0.203
Segregation		-2.993**	0.050	0.009	0.269	0.001
Age*[Segregation]		0.070*	1.072	1.029	1.118	0.001
%HV*[Gender = Female]		-0.500*	0.607	0.379	0.971	0.037

*Significant at the 5% level; **Significant at the 1% level

Individual characteristics

The coefficient for *gender* in the fitted model in Table 4.7 is $\hat{\beta}$ = 1.526 and the corresponding exponentiated value is exp ($\hat{\beta}$) = 4.6. This indicates that the estimated log-odds of choosing green or amber rather than red would increase by 1.526 for a female relative to a male (or equivalently, the estimated odds of belonging to Red relative to the reference value Green or Amber is for a female 4.6 times larger than its value for a male), when the other input variables are held constant. This is significant at the 5% level (p-value = 0.008). In other words, female respondents are significantly more likely to rate a road section as dangerous when compared to their male counterparts.

For the covariate *age*, it can be seen from Table 4.7 that exp$(\hat{\beta})$= 1.024, thus for each one-year increase in *age*, the odds of changing from Red to Green or Amber becomes 1.024 times larger. However, this change is not statistically significant (p-value = 0.24). Significant interactions were found between *age* and *segregation* and between *gender* and *%HV*. These interactions confirm the hypothesis that the effect of some infrastructural variables differs with individual characteristics, but complicate the interpretation of the main effects. Turning to cycling experience, being a highly skilled or competent cyclist decreased the odds of perceiving risk by a factor of 0.18 (p-value = 0.024) and 0.21 (p-value = 0.012), respectively, compared to inexperienced cyclists. These results regarding gender and cycling experience confirm the findings of several other studies (Lawson et al., 2013; Black & Street, 2014; Ma et al., 2014; Bill et al., 2015; Dill et al., 2015). Future transport policymakers and planners should thus consider the roles of gender and the lack of cycling experience in the promotion of cycling.

Infrastructural characteristics

Of the six infrastructural variables, the number of cars (*LV*), *width*of the road lane, and cycling *segregation*were significant. The odds of rating a road section as safe (i.e. a change from Red) increased with *width* by a factor of 0.48 (p-value=0.01) for each metre. The number of cars passing increased the odds of perceptions risk by a factor of 1.2 (p-value = 0.001) for each 1000 vehicles. There was no evidence to show that on-street car *parking*, the number of *junctions*or the percentage of heavy vehicle traffic had an effect, (p-values = 0.203, 0.932, 0.142, respectively). Segregation had a strong effect (Exp($\hat{\beta}$) = 19.9, p-value = 0.001) as the presence of a segregated cycling facility significantly increased perceptions of safety. These findings confirm the earlier stated preference results (e.g. for traffic volume) and existing research on cyclists' preferences for segregated infrastructure (Caulfield et al., 2012; Lawson et al., 2013) as well as policy and advocacy for reduced motorised traffic volumes and increased road space for cycling.

Choice of model

The Generalized Linear Mixed Model correctly predicted 92% of Green (safe) responses and the overall percentage correctly predicted was 67%. Two other models were developed, namely multinomial logistic and ordinal logistic. Both of these models gave the same results in terms of significance of the various factors and covariates but differed from the mixed model multinomial logistic analysis in that *segregation* and the interaction between *%HV* and *gender*each became non-significant. It is interesting to note that the mixed model employed, a multinomial logistic, has allowed for possible correlation between observations on the same person, whereas the (non-mixed) multinomial and ordinal logistic models assume independence of all response observations. Future research could explore which model is more appropriate for the analysis of data from this study design.

4.3.6 Recommendations based on model findings

The findings are, firstly, very relevant for the promotion of cycling through traffic engineering and transport planning. Regarding cycling in traffic, concerns about traffic speeds and volumes suggest that these should be reduced (see discussion on Hierarchy of Measures in Section 2.3). Also, concerns about narrow road widths could be improved by increasing the minimum overtaking clearance distance(a distance of 1.5 m is enshrined in law in France, Belgium and Portugal and is the aim of the 'Stayin' Alive at 1.5' campaign in Ireland (Safe Cycling Ireland, 2015)). These findings also contribute to the integration-segregation debate by demonstrating the importance of segregation for reduction in perceived risk (see

Parkin et al., 2007a; 2007b; Section 2.3). Cyclists are a heterogeneous group, however, and characteristics such as gender and cycling experience influence risk perceptions and infrastructure preferences. Segregated infrastructure may well bring safety benefits for large sections of the population, but space restrictions, indirect routes and junction requirements mean that sharing the road with motorised traffic remains cyclists' primary means of negotiating urban areas. A combination of carefully-designed dedicated-space for cycling and making roads safer for cycling, for example by reducing traffic speeds and volumes, is therefore recommended for improving safety perceptions among current and future cyclists.

The findings also have significant implications for wider cycling and transport policy. Ambitious cycling targets (such as in Ireland), require a serious commitment to changing current attitudes and improving interactions between motorists and cyclists (particularly in urban areas).National policy initiatives could be designed to both dispel prevailing perceptions of risks and raise awareness of the vulnerability of non-motorised road users. Furthermore, 'soft' interventions (e.g. cycle training) and 'hard' interventions (e.g. segregated infrastructure) could be designed and targeted at those user groups, for example women and inexperienced cyclists, which are particularly sensitive to perceptions of cycling risk (cf. Garard et al. (2012)) as part of broader policy of dismantling the 'fear of cycling'. For example, the gaps between participants' stated preferences and actual cycling behaviour suggest a segregated cycling infrastructural deficit in Galway City, whereby most would prefer to cycle in cycle lanes, yet in practice cycle on road in traffic.

4.4 Conclusions

Perceived cycling risk has the potential to overshadow objective cycling risk as the major barrier to increasing uptake of cycling. Cycling perceptions have received substantial academic attention over recent years; however, this work has focused on infrastructural determinants of perceived risk and rarely considers the characteristics of the cyclist. The contribution of this chapter has been to use a novel methodology comprising mental mapping, a stated-preference survey, a transport infrastructure inventory and a Generalized Linear Mixed Model to unpack perceptions of cycling risk.

The conclusions of this analysis and relevance for the remainder of the thesis are as follows:

1. Both participants' stated concerns and the determinants revealed by the model show the impact of factors such as traffic volume and road width on perceptions of cycling risk. In particular, there was a clear preference for segregated infrastructure throughout the findings. In this context, the remainder of the thesis examines the case of greenways as one particular form of segregated infrastructure for cycling.

2. It was evident that not all cyclists perceive the cycling environment in the same way – cyclists are not a homogenous group. For example, women and inexperienced cyclists are more likely to perceive risk. This is important to bear in mind for the planning and design of greenways (and cycle routes in general), as different user groups (e.g. commuters v. tourists; age; gender) will have different sets of requirements and preferences (e.g. surface materials, routing). This finding influenced the design of the greenway survey and analysis outlined in the next chapter.
3. Participants responded well to the mental mapping exercise, which delivered rich perceived safety data and has the potential to be a powerful research tool. The overall method in this chapter represents a novel development in cycle planning and introduces an end-user-engagement perspective that is pursued in the next chapter in the context of greenways.

Regarding future research, this method could be further developed using sophisticated online mapping tools, linked to bicycle suitability measures (see Section 2.3). Engaging cyclists and the general public through GPS-based mobile applications and the crowd-sourcing of data, including elements of mental mapping, can further unpack perceptions of cycling risk (for some recent attempts, see Loidl (2014), Nelson et al. (2015) and Zeile et al. (2015)). Furthermore, these tools could inform mechanisms for greater public participation in transport planning.

5 User preferences for Greenway design[2]

5.1 Introduction

While the previous chapter examined the role of perceived risk in urban cycling, this chapter of the thesis explicitly focuses on the design of greenways (as introduced in Section 2.3.4). This specific type of segregated cycling infrastructure is fast becoming a feature of the landscape not only to facilitate non-motorised travel, but also because it offers a wide range of other environmental benefits. While the literature review provided a background to the engineering of greenways, there is a lack of information on greenways from those who use them. The review broadly demonstrated the importance for route selection of scenery, proximity to urban areas and separation from motorised traffic, but also suggested the differing requirements of user groups. Similarly to the approach in Chapter 4, where users were asked to engage with topics regarding cycle route design, this chapter presents survey data from greenway users on conceptualisations of these routes, their functions and design – from high-level priorities to specific infrastructural characteristics. Although the methods may not be as innovate as mental mapping, a combination of qualitative, quantitative and ranking questions yields a rich set of data on a hitherto under-researched form of infrastructure.

Building on the findings of Chapter 4, this chapter firstly responds to the segregated cycling infrastructural deficit, outlining the potential role of greenways (including the degree of separation from motorised traffic). Secondly, as perceptions of risk were found to vary according to cyclists' characteristics (e.g. gender, cycling experience), the role of these same characteristics are studied in the formation of greenway users' design preferences. This informs infrastructural provision which should move beyond a 'one size fits all' approach to consider a broad range of users and settings. Finally, this chapter draws on two existing sets of design criteria (CROW (2007) and NRA (2011)), to channelsurvey results into a new framework for the route selection and design of greenways which will be operationalised in further chapters of the thesis.

5.2 Methodology

The aim of this chapter is to determine user preferences for greenway design, centred on four research questions:

1. **Purpose**: what do users consider greenways to be?
2. **Planning**: which greenway characteristics should be prioritised?

[2] An article based on this chapter will be submitted for peer review to Landscape & Urban Planning.

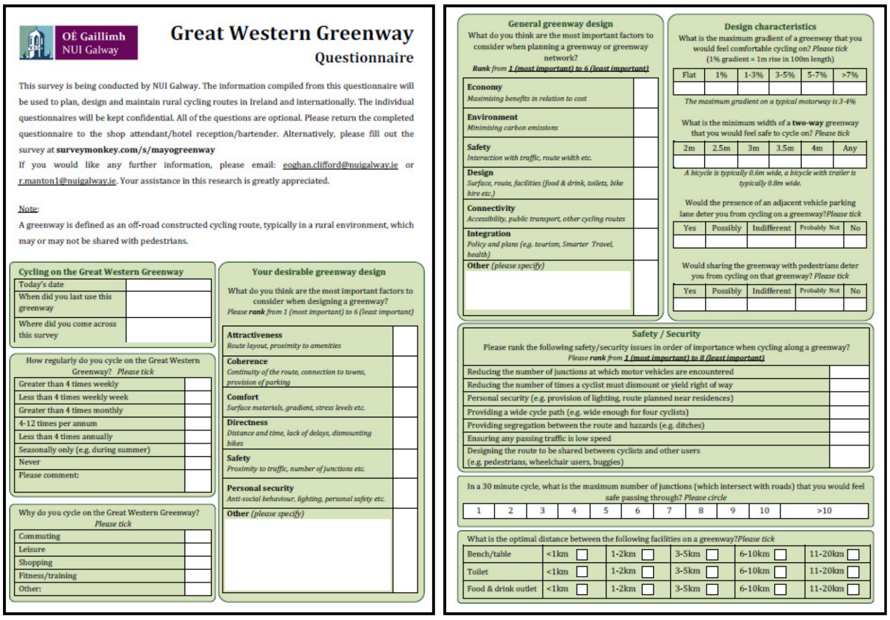
3. **Design**: how should greenways be engineered?
4. **Users**: how do these preferences vary according to user characteristics and how do they influence planning and design?

To answer these questions, a research methodology comprising a pilot study, an international greenway survey and statistical modelling was designed and rolled-out.

5.2.1 Pilot study

Due to the limited number of greenway studies carried out to date, a pilot study was deemed necessary to identify any potential challenges and to hone research questions. A questionnaire was designed based on a review of the literature and in consultation with greenway practitioners. It was decided to focus on one greenway and given its success (in terms of usage and publicity), the Great Western Greenway (GWG) in County Mayorepresented the obvious choice. One key question facing the progression of the research was whether to collect survey responses using hard-copy questionnaires or an online survey. This survey was aimed at a wider group of greenway users and one centralised location was not identifiable.To this end, a hard-copy questionnaire was designed and an online survey (containing identical questions) was programmed in Survey Monkey.

The pilot was conducted during the summer months (June and August 2013) due to higher usage rates of the greenway. Approximately twenty accommodation providers (hotels, B&Bs etc.), shops and bicycle hire companies in Westport, Newport and Mulranny were contacted and visited to display the hard-copy survey. The online survey was promoted through press releases and interviews in local newspapers and on local radio stations. Figure 5.1 shows the first two pages of the GWG questionnaire. The survey is included in Appendix 2.


OÉ Gaillimh NUI Galway

Great Western Greenway Questionnaire

This survey is being conducted by NUI Galway. The information compiled from this questionnaire will be used to plan, design and maintain rural cycling routes in Ireland and internationally. The individual questionnaires will be kept confidential. All of the questions are optional. Please return the completed questionnaire to the shop attendant/hotel reception/bartender. Alternatively, please fill out the survey at **surveymonkey.com/s/mayogreenway**

If you would like any further information, please email: eoghan.clifford@nuigalway.ie or r.manton1@nuigalway.ie. Your assistance in this research is greatly appreciated.

Note:
A greenway is defined as an off-road constructed cycling route, typically in a rural environment, which may or may not be shared with pedestrians.

Cycling on the Great Western Greenway

Today's date	
When did you last use this greenway	
Where did you come across this survey	

How regularly do you cycle on the Great Western Greenway? *Please tick*

Greater than 4 times weekly	
Less than 4 times weekly week	
Greater than 4 times monthly	
4-12 times per annum	
Less than 4 times annually	
Seasonally only (e.g. during summer)	
Never	
Please comment:	

Why do you cycle on the Great Western Greenway? *Please tick*

Commuting	
Leisure	
Shopping	
Fitness/training	
Other:	

Your desirable greenway design

What do you think are the most important factors to consider when designing a greenway?
Please rank from 1 (most important) to 6 (least important)

Attractiveness *Route layout, proximity to amenities*	
Coherence *Continuity of the route, connection to towns, provision of parking*	
Comfort *Surface materials, gradient, stress levels etc.*	
Directness *Distance and time, lack of delays, dismounting bikes*	
Safety *Proximity to traffic, number of junctions etc.*	
Personal security *Anti-social behaviour, lighting, personal safety etc.*	
Other *(please specify)*	

General greenway design

What do you think are the most important factors to consider when planning a greenway or greenway network?
Rank from 1 (most important) to 6 (least important)

Economy *Maximising benefits in relation to cost*	
Environment *Minimising carbon emissions*	
Safety *Interaction with traffic, route width etc.*	
Design *Surface, route, facilities (food & drink, toilets, bike hire etc.)*	
Connectivity *Accessibility, public transport, other cycling routes*	
Integration *Policy and plans (e.g. tourism, Smarter Travel, health)*	
Other *(please specify)*	

Design characteristics

What is the maximum gradient of a greenway that you would feel comfortable cycling on? *Please tick*
(1% gradient = 1m rise in 100m length)

Flat	1%	1-3%	3-5%	5-7%	>7%

The maximum gradient on a typical motorway is 3-4%

What is the minimum width of a **two-way** greenway that you would feel safe to cycle on? *Please tick*

2m	2.5m	3m	3.5m	4m	Any

A bicycle is typically 0.6m wide, a bicycle with trailer is typically 0.8m wide.

Would the presence of an adjacent vehicle parking lane deter you from cycling on a greenway? *Please tick*

Yes	Possibly	Indifferent	Probably Not	No

Would sharing the greenway with pedestrians deter you from cycling on that greenway? *Please tick*

Yes	Possibly	Indifferent	Probably Not	No

Safety / Security

Please rank the following safety/security issues in order of importance when cycling along a greenway?
Please rank from 1 (most important) to 8 (least important)

Reducing the number of junctions at which motor vehicles are encountered	
Reducing the number of times a cyclist must dismount or yield right of way	
Personal security (e.g. provision of lighting, route planned near residences)	
Providing a wide cycle path (e.g. wide enough for four cyclists)	
Providing segregation between the route and hazards (e.g. ditches)	
Ensuring any passing traffic is low speed	
Designing the route to be shared between cyclists and other users (e.g. pedestrians, wheelchair users, buggies)	

In a 30 minute cycle, what is the maximum number of junctions (which intersect with roads) that you would feel safe passing through? *Please circle*

1	2	3	4	5	6	7	8	9	10	>10

What is the optimal distance between the following facilities on a greenway? *Please tick*

Bench/table	<1km	1-2km	3-5km	6-10km	11-20km
Toilet	<1km	1-2km	3-5km	6-10km	11-20km
Food & drink outlet	<1km	1-2km	3-5km	6-10km	11-20km

Figure 5.1 - Great Western Greenway questionnaire

In August 2013, the online survey was closed and the businesses along the GWG were revisited to collect completed questionnaires. A low number of hard-copy questionnaires were received(approximately 20), however the completion rate varied substantially. Business owners reported that while some greenway users were interested, many respondents did not take the time to complete the survey. Other business owners had forgotten to display the survey or had lost the questionnaires. Meanwhile, the online survey received 196 responses and a summary of these results is provided in Section 5.3. A preliminary analysis did not show any significant difference between these results and the limited results of the hard-copy survey.

There were a number of lessons from the pilot study for further research:

- The online distribution method was considered preferable due to the higher response rate and the lower time and financial burden.
- The capacity of an online survey (and the question designs included) to reach greenway users was deemed appropriate based on the size of the response received. For example, the widely cited Fáilte Ireland / Fitzpatrick Associates (2011) carried out economic modelling based on a sample size of 100 greenway users.
- The pilot survey focused on cyclists and based on responses from walkers (who used the 'other' category) it was decided to broaden the research to include other greenway users and indeed to analyse the effect of user type on design preferences.
- Rich information derived from several qualitative questions showed the benefits of this question type (particularly for an emerging area of research and practice), though potential response burden suggested the need for one clear question.

In general, the positive response and interesting results achieved in the pilot study encouraged the progression to an international greenway survey. Minor alternations were made to the survey as indicated previouslyand in Section 5.3.

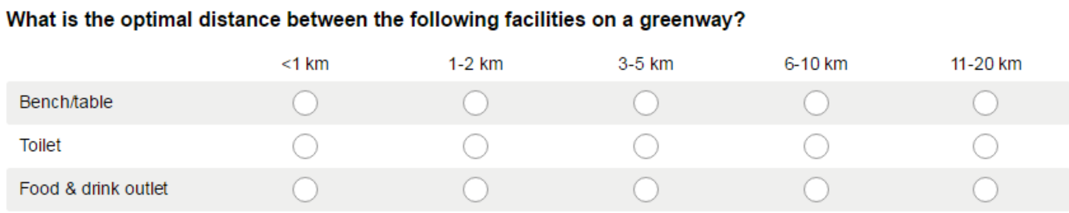
5.2.2 International greenway survey

Following the analysis of the results of the pilot study and further review of the literature, an international greenway survey was designed (see Appendix 3 for the survey).The spring/summer timeframe was chosen for distribution and the survey was opened on Survey Monkey between March and August 2014, hosted on SurveyMonkey (see Figure 5.2 for the survey cover image). Online distribution was selected in line with the conclusions of the pilot and to ensure a wide international sample for data collection. The survey was circulated using social media, blogs, and emails to cycling organizations, greenway mailing lists and tourist groups. This is a convenience sampling method which entails both advantages (e.g. ease and extent of distribution, economy, accessibility) and disadvantages (e.g. attaining a representative sample of the entire population). However, due to the lack of a sampling frame for international greenway users (e.g. a register or census) and indeed the diversity of this population, this method was considered appropriate. The characteristics and limitations of the sample are discussed in Section 5.4.

Figure 5.2 - Cover image for international greenway survey, clockwise from top left: GWG, GST, C2C (UK), Vías Verdes (Spain)

The following greenway definition was supplied at the outset of the survey: “a greenway is an off-road, traffic-free, constructed walking and cycling route, typically in a rural environment”. It was necessary to provide such a definition due to terminology complications and to introduce the survey. To provide further background for respondents, the following greenway examples were provided: Great Western Greenway and Great Southern Trail in Ireland, Vías Verdes in Spain and traffic-free sections of the C2C in the UK. These examples offer a variety of greenway characteristics (e.g. surface materials, width, setting and user profiles) as shown in Figure 5.2. The main body of survey questions then comprised three sections: (i) qualitative understanding of greenways, (ii) ranking greenway priorities, and (iii) geometric design preferences.

Before completing detailed, quantitative questions on greenway design characteristics, respondents were first asked one qualitative question to gauge greenway conceptualisations and priorities. This question read: ‘what do you think is the most important factor to consider when designing a greenway?’ Each response was‘coded’into a word or short phrase that captured the essence of the response (Saldaña, 2012). These codes were subsequently combined to identify priority themes. It was envisaged that this array of information would be useful for greenway designers to, firstly, gain an understanding into how users conceptualise greenways and, secondly, to gain an appreciation of the variety of user preferences and priorities. These qualitative responses complemented the quantitative questions which followed in the survey (see Figure 5.3 for a typical survey question layout).



What is the optimal distance between the following facilities on a greenway?

	<1 km	1-2 km	3-5 km	6-10 km	11-20 km
Bench/table	○	○	○	○	○
Toilet	○	○	○	○	○
Food & drink outlet	○	○	○	○	○

Figure 5.3 - Typical question layout in SurveyMonkey

In the literature review, a set of route selection criteria were developed. These criteria were predominantly based on NRA (2010b) route selection process for roads. Within this process, road design engineers assign route options preference rankings (e.g. preferred, intermediate and least preferred) based on experience in road design projects combined with the engineer's personal judgement and some quantitative tools. However, as stated before, this process must be adapted for greenways (as these routes possess very different characteristics and priorities to roads), yet few data or tools exist to this end. Therefore, these route selection criteria were presented to respondents in a ranking question to ascertain which criteria greenway users would prioritise. One addition was made – design – on the basis that while road schemes are regulated by engineering standards, greenways are not (yet). To aid respondents, a description of each criterion was provided based on the NRA process, the literature and the author's personal judgement (Table 5.1). The qualitative question enabled the degree to which these descriptions match respondents' perceptions of greenway priorities to be analysed (i.e. keywords used and how the responses are coded).

Table 5.1 - Route selection criteria

Criteria	Descriptions
Safety	Interaction with traffic, route width
Connectivity	Accessibility, public transport, other cycling routes
Design	Surface, route, food & drink, toilets, bike hire
Environment	Minimising carbon emissions
Integration	With policy and plans: tourism, Smarter Travel, health
Economy	Maximising benefits in relation to cost

A second ranking question immediately followed the ranking of the aforementioned route selection criteria. This question used CROW's (2007) cycling design requirements as adapted by McCarthy (2011) (who added 'personal security') (Table 5.2). Although these are intended as design requirements, it was informative to ask respondents to undertake the same ranking procedure, particularly as this facilitated a comparison with the results of McCarthy (2011). It was also illustrative to compare these results with the previous ranking question and to garner lessons for the route selection methodology on, for example, categorisation and terminology for criteria.

Table 5.2 - CROW cycling design requirements

Criteria	Descriptions
Attractiveness	Route layout, proximity to amenities
Coherence	Continuity of the route, connection to towns, parking
Comfort	Surface materials, gradient, stress levels
Directness	Distance and time, lack of delays, dismounting bikes
Safety	Proximity to traffic, number of junctions
Personal security	Anti-social behaviour, lighting, personal safety

The next and most detailed section of the survey concerned greenway users' preferences for specific design characteristics. A range of important characteristics was selected from literature, including surface materials, gradient, width, mixed-use versus segregation, number of junctions, andacceptable distance between suggested facilities. The options and formats for these questions are outlined in Section 5.7. This section of the survey also included questions on spending on greenways the results of which are used for the economic modelling in Chapter 7. The final section of the survey recorded the demographic and other characteristics of the sample, including: age, gender, country of birth, country of residence, marital status, employment status, usual mode of travel, self-reported fitness, and cycling experience

5.2.3 Statistical analysis

In the vast majority of these cases, the major preference of the sample was clear and it was not deemed necessary to explore the data in any further detail. However, in two cases (whether to segregate between pedestrians and cyclists, and the choice of surface material), it was of particular interest to observe the effect of the individual characteristics of the greenway user on these preference and statistical models to measure the effect of each variable of the response were developed. To this end, it was decided to build a logistic regression model for one of the design preferences – the choice surface material. For reasons outlined in Section 5.7.3, it was necessary to reduce this choice to 'asphalt' and 'not asphalt'; this was deemed appropriate as asphalt is recommended by the literature and was the majority preference in the survey results. It was therefore of interest to see which variables (demographic and greenway/travel characteristics of the individual greenway users, e.g. age, greenway mode, fitness) have a significant impact on the choice of surface materials.The response is a categorical dependent variable with two nominal categories of response and therefore a (binomial) logistic regression model was selected.

Although the Generalised Linear Mixed Model constructed in Chapter 4 is a much more complicated construction (e.g. an ordinal response variable with more than two categories as well as correlated observations), the fundamentals regarding the format of the parameter estimates and the interpretation of the results are the same and therefore are not repeated here. The dataset was cleaned (no missing values) and imported to SPSS (v21) to build the model. The outputs were a table of descriptive statistics and the parameter estimates of the model and these are discussed in Section 5.7.3.

5.3 Pilot study results

The Great Western Greenway survey received 196 responses and the key results are summarised here. In general, the online distribution method was considered successful and this was the main finding of the pilot study. While the majority of responses to the question 'how regularly do you cycle on the GWG' related to annual or monthly use, 19 people chose the option 'never' and several others wrote 'walk' in the 'other – please specify' section. As walking was also specified in responses to further questions (and may have therefore influenced results), it was decided to rephrase questions and add a walking option for the international survey.

The sample was mainly composed of leisure users who had taken a trip on the greenway in the last year. Design preferences included a maximum gradient of 3-5%, 2.5-3m width and asphalt surfacing (77% of first preferences). The specified optimal distances between greenway facilities were 3-5 km (bench/table), 6-10 km (toilet) and 11-20 km (food & drink stops). In the ranking questions, the first preferences were safety (NRA criteria) and attractiveness (CROW criteria). There were mixed views on the effect of adjacent parking, while shared use with pedestrians and cyclists was not considered a deterrent. Just 4% were previously involved in a collision on a greenway and causes included collisions with other cyclists, gates, groups of pedestrians and loose gravel. None of these results was particularly surprising and only minor changes were subsequently made to these questions.

The GWG pilot survey included several qualitative questions which were included to source ideas for further research as well as future specific questions and options.

- The main suggestions for additions to the GWG were: improved signage (18 responses), rain shelters (12), repair stations (12), water facilities (10), toilets (8), camping/picnic areas (5), food & drink vendors (4) and bike parking (4).
- Suggestions for general greenway design included: more greenways nationally / extension of GWG to Achill Sound (15), removal of sections with traffic (13), asphalt surface for full length (12), removal of cattle grids/kissing gates/dismounts (7), improved signage (6), food/drink/water stops (5), removal of steep gradients (5).
- The 'biggest issues' that respondents stated which would, if addressed, encourage them to cycle more often were: more greenways/separation from

traffic/safety (54), better weather (13), improved fitness/health (9), motorist awareness / reduced speed (8), and more free time (5).

While it was not possible to incorporate all of these issues into the international greenway survey, these responses nevertheless informed the overall research approach including, for example, the importance placed on separation from traffic.

5.4 International survey sample characteristics

There were 1,002 responses to the online greenway survey from greenway users in 26 countries. Table 5.3 shows the breakdown of responses by country of residence and country of nationality. Due to the use of the English language, the sample is skewed towards countries where the majority of the population speaks English (Australia, Canada, Ireland, New Zealand, UK and USA account for over 90% of the sample). This skew may have an effect on user preferences as cycling conditions vary by country and English-speaking countries generally have lower cycling modal shares (Pucher & Buehler, 2012). The sample was two-thirds male and mostly middle-aged (albeit with a large age range: the youngest survey participant was 17 years old and the oldest was 80). These demographics are very similar to Lumsdon et al.'s (2004) findings on the North Sea Cycle Route. The majority of the sample was married (61%) and employed (81%) and the average number of children was 1.2. The average income was quite high (more €10,000 larger than the average Irish and US incomes), although the response rate for this question was far lower than the rest of the survey. Furthermore, many studies have shown that cycle tourists (as an example of one greenway user group) tend to be higher income earners and that this income is connected to higher spending (Lumsdon et al., 2004; Weston et al., 2012).

Table 5.3 - Demographic characteristics of the sample

Demographic characteristics			
Age	***years***	***Income***	***€***
Average	44.7	Average	56589
Standard deviation	12.9	Standard deviation	41626
Gender	***%***	***Marital status***	***%***
Female	35	Single	34.8
Male	65	Married	60.8
		Divorced/Separated	3.9
Country of residence	***%***	Widow/widower	0.5
Ireland	38.8		
UK	13.3	***Employment status***	***%***
Rest of Europe	4.2	Employed	81.1
North America	38.2	Retired	9.7
Australia & New Zealand	3.3	Unemployed	5.8
Rest of World	2.3	Student	3.4

The travel characteristics of the sample are given in Table 5.4. These statistics are difficult to validate or compare with other studies as few have consider the impact of these characteristics on greenway use (see Section 5.7.3). Although Deenihan's (2013) cycle tourist survey found a similar modal share pattern, demographic characteristics were quite different. If the sample was intended to be representative of the wider commuting population, there would be a clear over-sampling of bicycle commuters (31%) which represent 1-2.5% of all commuters in Ireland, UK and USA (CSO, 2012a; Pucher & Buehler, 2012). However, it is reasonable to assume that bicycle commuters are more likely to be greenway users and indeed some greenway use represents commuting to work, school or college. The average commuting distance is broadly in line with the average Irish and American commute (10-20 km; CSO, 2012b; Pucher & Buehler, 2012).

Table 5.4 - Travel characteristics of the sample

Travel characteristics			
Usual mode of transport	***%***	***Commute distance***	***%***
Car (driver)	50.4	< 1 km	11.4
Car (passenger)	1.4	1 – 2 km	7.3
Bicycle	30.6	2 – 5 km	17.6
On foot	9.8	5 – 10 km	20.1
Public transport	6.8	10 – 20 km	22.8
Motorcycle/scooter	1/1	20 – 50 km	14.5
		> 50 km	6.2
Fitness	***%***		
Very fit	17.6	***Cycling experience***	***%***
Fit	46.2	Highly skilled	34.3
Average	32.3	Competent	57.6
Unfit	3.9	Inexperienced	8.1

5.5 Qualitative results

Based on the initial qualitative question, the greenway conceptualisations and design priorities of respondents were outlined. Of the 1,002 responses to the survey, it was possible to code 937 responses under one of 20 titles - this broad range of coding was generated based on existing literature and the content of responses received. Where the intentions of the respondent were clear, every effort was made to create a code for this response. Descriptions of each code were also derived from responses and are included along with the number of responses in Table 5.5. There was an average of 11 words per response, though one-sixth of responses contained one word only. Of these, 'access' or 'accessibility' and 'safety' were the most common terms used, which itself is indicative of the priorities of greenway users.

Table 5.5 - Greenway priorities - qualitative response coding

Code	Description	n
Accessibility	Ease of access; for all abilities; landowner access	134
Safety	Interaction with motorised traffic; junctions; surface; security	121
Scenery	Views; landscape; changing landscape	99
Separation	Entirely traffic-free; buffer from traffic; quiet	98
Connectivity	To public transport, urban areas, facilities, points of interest	84
User experience	Overall experience; design user; comfort	83
Environment	Natural feel; improves biodiversity; low-carbon materials	70
Surface	Flat; smooth; materials; well-maintained	56
Location	Setting; Place-based character of the route	50
Economy	Maximum usage and benefit-cost ratio; vendor opportunities	27
Interest	Points of interest along the route; heritage; architecture	25
Community	Public consultation; community support; landowner consent	23
Width	For all user types, including overtaking	18
Gradient	Not too steep; accessible for all abilities	11
Signage	Adequate and informative signage	10
Continuity	Continuous separation and surface; free from obstacles	9
Length	Covers the maximum length possible	7
Infrastructure	Uses existing paths; preserves disused railway corridor	6
Drainage	No ponding; maintain surface integrity	4
Loops	Route is a loop; route connects to loops	2

5.5.1 Conceptualisations of greenway functions

The variety of priorities outlined in Table 5.5 shows that users conceptualise greenways as serving various functions. Considering high-level functions, the most common perception was that greenways serve as corridors for human use, rather than, for example, the conservation and greenbelt function identified in the landscape literature (see Little (1995) and Ahern (2004)). From Table 5.5, the five codes which received the highest number of responses (*accessibility, safety, scenery, separation* and *connectivity*) reflect this perception by placing an emphasis on human use (and in particular the ease and enjoyment of use). This finding is unsurprising given the definition of greenways provided to responses and the growing belief in greenways as corridors for walking and cycling. Nevertheless, greenways are multi-functional corridors and their environmental function was mentioned by several respondents.

Beyond this, a second interesting conceptualisation was the conflict between leisure/tourism use and commuting/utilitarian trips. The priority given to scenery, separation etc, rather than directness, for example, suggests a recreational orientation, however, the emphasis placed on connectivity appears to demonstrate utility travel potential. Many responses outlined this conflict:

> "Greenways need to link people and activity centres (towns, cities, villages). They need to be part of the community not just random routes through remote areas"

> “[A greenway] cannot be a road to nowhere, it shouldn't be just a ‘destination place’ but a place that gets you to your destination"

Finally, a general theme of the responses was that greenways should be open and accessible for all, rather than for highly skilled cyclists or specialist users. This theme is also clearly seen in the willingness-to-pay results as well as in the approach of the *Vías Verdes* network in Spain. This is discussed in more detail in the ‘access’ design priority.

5.5.2 Greenway design priorities

There are clear links between several of the main emerging themes (in particular between *accessibility* and *connectivity*, between *safety* and *separation*) and the coding and descriptions in Table 5.5 were composed to make visible the terminology used by respondents. The codes were subsequently combined (see Table 5.6) to identify five main greenway priorities for further analysis. These were: (i) access, (ii) safety, (iii) user experience, (iv) design characteristics, and (v) sustainability.

(i) Accessibility

Ease of access or connectivity was perhaps the clearest expression of users' greenway priorities. This included the accessibility of trail heads, connections to other greenways, connections to public transport and local population areas (thereby maximising usage) and generally ensuring a lack of barriers. Many respondents noted that greenways should be accessible “for all abilities and ages”, including wheelchair users, and this should be considered in determining gradients and other physical design characteristics. Although separation, isolation and scenery were emphasised, this must be balanced with good accessibility – as two respondents noted:

> “Good connectivity to transport, roads and points of interest along the route. It's a matter of balancing the joy of isolation, with the need to enter or exit at reasonable intervals, and in the right places”

> “Either something accessible from cities/easy to get to, or something very scenic, or both!”

Generally, the priority given to accessibility seems to indicate that many existing greenways are inaccessible and/or unconnected. Some of these greenways are planned opportunistically using any available ‘route facilitators’, such as natural features, which may not connect to trip destinations. This was summarised by one respondent as:

> "A creekside trail is pleasant, but one that gets people where they want to go is better."

There was also a sub-theme of access for and cooperation with landowners, which has emerged as a significant issue for the development of greenways in Ireland, particularly for the route selection of the Galway to Dublin Greenway.

(ii) Safety

Safety was regarded as the second priority for greenway development and the vast majority of responses related to the minimisation of interaction with motorised traffic. As the characteristic 'traffic-free' was included in the greenway definition provided to respondents, it is possible that without this descriptor, 'safety' would have received even greater priority (as expanded upon in Chapter 4, safety is ranked as the primary concern in the vast majority of cycling-based studies). In this survey, respondents continuously noted the need for *separation* from motorised vehicles. Many of these responses could relate to user experience as described in (iii), however, this information has been included here as it primarily relates to safety. For example, respondents prioritised greenway designs which are "entirely traffic-free with buffer", where there is "peace and quiet, away from traffic" and mitigate anti-social behaviour. Two responses received were:

> "That people feel safe on and around it. Users need to feel safe and also local residents and stakeholders need to feel that it won't attract unsocial behaviour."

> "Safety would be of paramount importance, if the greenway is going to extend over a long distance you require first aid points at regular intervals."

Many aspects of safety highlighted also related to the engineering characteristics of the route, e.g. paved surfaces without potholes, safe junction design, width (especially in the context of sharing with pedestrians) and geometric layout, including sight lines. For example, the greenway design priority for one respondent was:

> "Engineering it to be safe at cycling speeds. That is, no sharp or blind curves. Generously wide enough for two-way traffic. "

Most of these safety-related priorities have been suggested by the broader cycling literature (and have been included in the stated-preference questions), however, greenway design presents some unique challenges for engineers. For example, there is a need to balance a safe design with the minimisation of incursion into the landscape as well as a balance between separation and accessibility.

(iii) User experience

A constituency of responses related to the broad category of 'user experience', including scenery, route location or setting and including points of interest. In fact, many respondents simply cited the "experience" or "location". More detailed responses unpacked this experience by generally placing a large emphasis on scenery – including a 'natural feel' and a changing landscape. The importance of landscape is to be expected given the role of greenways in landscape planning and the priority of this experience was thus summarised:

> "That it passes through a beautiful or interesting landscape - from my perspective, this is not about just being out in the air, but being able to pass through such a landscape."

> "User experience from a sensory perspective: sight/views, smells, feel of the tread of the path, etc."

Many other respondents noted the need for a variety of built environment points of interest, including cultural and heritage aspects (e.g. an old railway or canal). A key element of the user experience was also related to the complete separation from motorised traffic. As outlined previously, this is related to noise, air quality and safety as part of a more comfortable experience. One Irish greenway user urged against the use of the hard-shoulder (i.e. on-road cycleway) for this reason:

> "Completely separated from traffic, i.e. not on hard shoulder"

There are significant challenges in quantifying or otherwise designing for some of these characteristics such as landscape (although work in this area includes Lindsey et al. (2008) and AECOM & Roughan O'Donovan (2015a; 2015b)). For other elements of the user experience, such as complete separation from motorised traffic to yield a tranquil environment, high priority should be given. However these pose challenges including for land acquisition, accessibility and cost.

(iv) Design characteristics

A variety of specific physical route design characteristics were prioritised by respondents. These included: surface, continuity, width, gradient, drainage, signage, water points, length, infrastructure and looped routes; descriptions for each of these are provided in Table 5.5. The most important design characteristic according to these respondents is surface, including maintenance. In this section, a clear conflict was present between a desire for a smooth, usually asphalt, surface (generally by cyclists) and a natural, environmentally-friendly surface (generally from a conservation approach). This is illustrated in the two responses:

> "From a cyclist's point of view: surface quality. Needs to be well-laid and smooth, not a mess of mud or potholes or huge chunks of stone that requires mountain bike tyres and is barely passable in winter."

> "Maintain a rural feel (no tarmac)"

This issue of surfacing material is discussed in more detail in the stated-preference results, where it is interesting to observe the effects of greenway mode choice on design preferences. For the characteristics width and gradient, a strong emphasis was placed on design for the comfortable, accessible and safe use by variety of users, for example a "wide path with gentle slopes so that it is easy to use by all".

(v) Sustainability

The final emerging theme focused on the broader societal impact of greenways. These codes conveniently corresponded to the three pillars of sustainability (environment, economy and society) and are described here as the environmental, economic and community impacts of greenways. The environmental function of greenways was the most reported of these and related to conservation, improving biodiversity and educating users about nature. This also includes the 'natural feel' as expanded upon in 'user experience' and many of these users were distinctly opposed to the use of asphalt or concrete surfacing and the over-use of signage, picnic benches etc. This theme is summarised in the following two responses.

> "As well as it being a route without cars, it should also be a refuge for native wildlife, functioning as an ecological corridor, which can be very important for biodiversity."

> "A greenway must be green that implies that it is sustainable and doesn't damage the habitats it passes through. The greenway if possible should enhance surrounding

biodiversity. Native species of local stock should be planted along the greenway to enhance biodiversity."

Economic impact, although reported as a priority for a smaller number of respondents, represents a vital component for securing funding and informing policy. Respondents' views on this area centred on ensuring the economic viability of the greenway by establishing the need for the route, generating demand and otherwise maximising usage, for example:

> "The most important factor is that the facility will be used"

> "No point having a Greenway from nowhere to nowhere as it will not see sufficient traffic to justify the expenditure."

Finally, the need to consider the impact on the local community was clearly stated in several responses. This feature of greenway planning is well established in the literature (cf. Little (1995)) and respondents emphasised community consultation, involvement and buy-in. One greenway user's phrased his priority as follows:

> "Support of the various communities along the length of the greenway and their feedback"

Other responses discussed the importance of the privacy and security of local residents as well as landowner consultation and access. Although this sustainability priority is challenging for the engineer, it is an emerging component of an ever-broadening toolbox, which now includes environmental impact assessment, cost-benefit analysis and extensive public consultation. Each of these areas is discussed in further detail through this thesis.

5.5.3 Summary

The 937 responses to the qualitative questions were classified into 20 codes and further analysed to form five main greenway priority themes, which were then summarised, including quotes from 20 different respondents to add depth to the discussion. Table 5.6 shows how the 20 codes were combined to form priority themes.

Table 5.6 - Combining codes to form greenway priority themes

Category	**Codes**	**n**
User experience	User experience; Scenery; Location; Interest	257
Safety	Safety; Separation	219
Accessibility	Connectivity; Accessibility	218
Design characteristics	Surface; Continuity; Width; Gradient; Drainage; Signage; Length; Infrastructure; Loops	123
Sustainability	Environment; Economy; Community	120

Although there was significant overlap between several codes and themes, it is envisaged that this combination will shed some light on the conceptualisations and priorities of greenways, as considered by their users. As the results are qualitative, the number of responses received by each theme serves only as a basic indication of their priority. Significantly more quantitative detail is added in the stated-preference discussion and conclusions are considered together in Section 5.6.3.

5.6 Matrix results

5.6.1 Route selection criteria ranking

The first ranking question related to the NRA (2011) project appraisal criteria for route selection as outlined in Section 2.8.2. To the five criteria (economy, safety, environment, accessibility and integration), 'design' was added to capture the specific design requirements for cycling. Respondents were asked to rank these six criteria in order of importance for the "planning of a greenway or greenway network" and the descriptions provided are outlined in Section 5.2.2. Figure 5.4shows the clear priority is safety (35% first preferences), followed by connectivity and design, while the remaining three criteria received less emphasis.

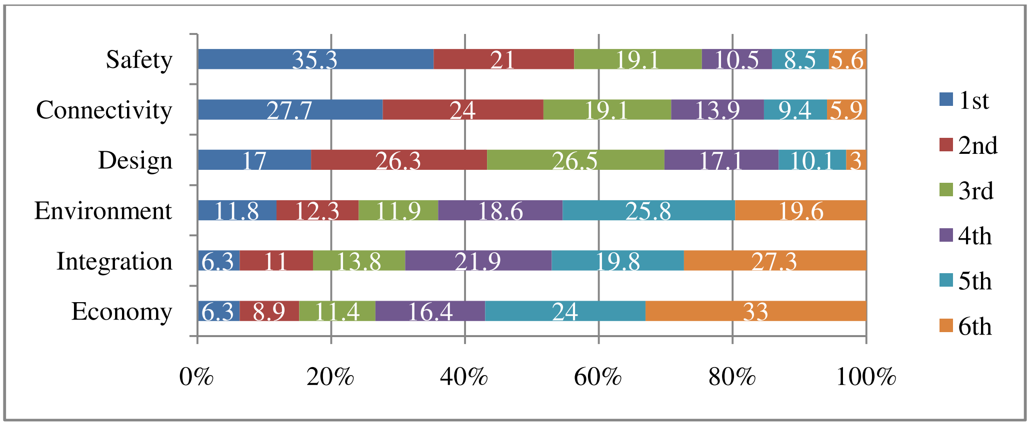


Figure 5.4 - Stacked bar chart of ranked NRA route selection criteria

These results and the priority themes developed in the previous section show a good degree of alignment – safety and accessibility/connectivity are the top two preferences, while sustainability (incl. environment and economy) were ranked lower. Unlike planners and engineers, end-users may not be aware of the challenges in and importance of: (i) complying with legislation (particularly environmental), (ii) complementing existing policies and plans, or (iii) remaining within budget or delivering the best value for money. Nevertheless, some of these elements may be incorporated in more highly-ranked criteria. For example, connectivity or accessibility is regarded as highly important and (as Chapter 7 shows) this can be translated into economic significance using a travel cost model (based on greenway access and usage). Furthermore, while integration may not be highly regarded, many of these policies or legislation may enshrine a quality user experience (e.g. tourism development, air quality) or safety (compliance with standards).

While these ranking results are data-rich in terms of users' preference, for the reasons outlined previouslythey also show the limitations of quantifying route selection criteria based on a user survey. When these criteria are utilised by the NRA for road route selection, they not weighted (as with AECOM/Roughan O'Donovan's (2015) applications to the Galway-Dublin Greenway), rather they are all seen as vital elements and the engineer uses his/her experience and judgement to select a preferred route based on a range of outputs. In that sense, the purpose of this section was to identify a set of core criteria which can be used for greenway route selection and about which some quantitative indications can be developed to inform engineers and planners.

5.6.2 Design criteria ranking

The second set of criteria to be ranked was that advocated by CROW (2007) for cycling design, presented to respondents as "design considerations". These criteria were adapted by McCarthy (2011) to include personal security (i.e. whether the route is overlooked, in line with the 'eyes on the street' principle) and are described in Section 5.2.2. The results are displayed in Figure 5.5. This information shows that there were similar levels of importance attached to attractiveness, coherence and safety: 24-29% first preference, 43-48% first and second preferences. The main differences between NRA and CROW criteria (other than their respective emphasis on route selection and design) was the inclusion and prominence of attractiveness. This is indicative of the more user-centric nature of the CROW criteria. Coherence (which is related to connectivity) and safety were also highly-ranked.

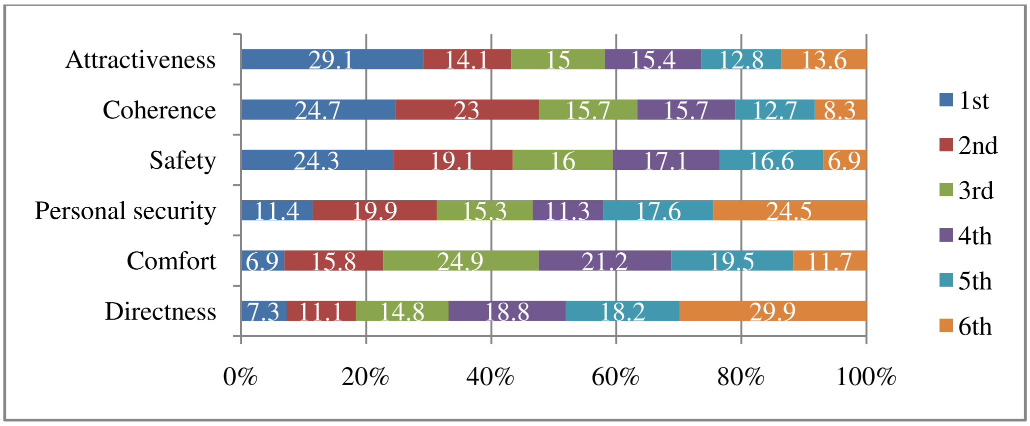


Figure 5.5 - Stacked bar chart of ranked CROW criteria

Meanwhile, McCarthy (2011) found the following order of importance for leisure cyclists: safety, attractiveness, personal security, comfort, coherence, directness. It should be noted that McCarthy's (2011) results were based on an expert survey, drawn from stakeholders in the Irish NCN, rather than from end-users, and this is likely to have affected the rankings. Furthermore, that route selection included on-road elements and this could explain strong priority given to safety. An evaluation matrix was then developed by McCarthy (2011) to apply these (weighted) criteria (see Table 2.21) to the route selection of the Mullingar-Dublin inter-urban cycleway (see Deenihan et al. (2011)). While this approach for the broader route selection of greenways will not be followed completely, the user- and design-oriented criteria advocated by CROW (2007) and the quantified checklist or QoS approach supplemented by McCarthy (2011) has nonetheless informed the formation of planning and design criteria in this thesis.

5.6.3 Developing a greenway planning and design framework

Comparing the results of the qualitative questions to those from the two matrix-based questions, a framework for the planning and design of greenways was developed. The three sets of criteria are listed, including the limitations of each:

- NRA route selection criteria (adapted here to include design) are limited for greenways due to their intention for roads(e.g. they do not include any element of the greenway user's experience)
- CROW cycling design criteria (adapted by McCarthy (2011) to include personal security) are limited by their main intention for commuter and urban cycling (e.g. inclusion of directness) and the lack of planning necessities (e.g. economy and environment)
- Priority themes from survey results (developed here) are limited by their derivation from coded qualitative response (rather than metrics or engineering experience)

The three sets of criteria were initially combined subjectively, although assigning a score of 6 to 1 for each criterion gives the same result. In Table 5.7 each element is tracked by colour to show its contribution to the end result. This final framework includes 5/6 criteria from NRA (2011), 4/6 from CROW (2007) and 5/5 from greenway users' priority themes. Two criteria have been omitted: integration (which is considered to be a precursor to any greenway scheme) and directness (which has been disregarded for greenways by survey respondents and the literature).

Table 5.7 - Formation of final framework for route selection and design

NRA (adapted)	CROW (adapted)	Results themes	Final framework
Safety	Attractiveness	Accessibility	Accessibility
Access	Coherence	Safety	Safety
Design	Safety	User experience	User experience
Environment	Personal security	Design	Design
Integration	Directness	Sustainability	Environment
Economy	Comfort		Economy

This framework leaves space for planning and engineering experience, judgement which can account for local conditions. To inform these decisions, some data and metrics are required and these are developed in this thesis for safety on cycling route sections with interaction with traffic (Chapter 4), for environment (Chapter 6) and for economy (Chapter 7). The framework is later operationalised in the review of the Irish NCN (Chapter 8) and the case study (Chapter 9).

5.7 Geometric design results and discussion

Survey respondents were asked to provide their preferences on the following greenway characteristics: surface materials, maximum gradient, minimum width, mixed-use between pedestrians and cyclists, maximum number of junctions and the optimal distance between a range of facilities along the route. The most important of these, surface materials, has been cross-tabulated with demographic and other characteristics also collected (e.g. age, gender, mode, residence, marital status, usual mode, fitness, cycling experience). To statistically state the significance of the effect of this preference, the potential effects of other characteristics must be accounted for and this is outlined in the multinomial logistic regression model.

5.7.1 General design preferences

Table 5.8 shows respondents' preferences for greenway surface materials, 60% opting for asphalt while 17% and 16% chose earth and gravel respectively (in line with the literature reviewed in Section 2.4.2). The qualitative results indicate that comfort, safety and continuity underpin this preference for asphalt. Nevertheless, questions remain about the suitability and expense of asphalt surfacing in many environments (including embodied carbon – see Chapter 6) and there is a variety of other materials available (cf. NCA (2014) and Sustrans (2012)). Finally, both the literature and qualitative responses emphasised the importance of maintenance, regardless of materials used. As surfacing is a particular area of interest, this will be examined in further detail through cross-tabulation with mode of travel on greenways and further in the surface model.

Table 5.8 - Surface material preferences

Surface	Asphalt	Gravel	Concrete	Earth	Total
No. respondents	465	123	54	134	776
%	59.9	15.9	7.0	17.3	100

Preferences for maximum gradient are tabulated in Table 5.9 and show a median preference for a maximum gradient of 5%. Meanwhile, 28% and 15% of respondents selected maximum gradients of 10% and 20% respectively. It should be noted that the typical maximum gradient for a motorway (5%) was provided to inform respondents. The design manual literature (cf. Transport Scotland (2011)) recommends a 'preferred' maximum of 3%, although an 'absolute' maximum of 5% is also included. Steep gradients (such as 10-20%) present major accessibility challenges for inexperienced cyclists and for those with mobility impairments, including wheelchair users, and this was raised in the qualitative responses.

Table 5.9 - Maximum gradient preferences

Max. gradient	Flat	1%	3%	5%	10%	20%	Total
No. respondents	5	39	167	257	225	122	815
%	0.6	4.8	20.5	31.5	27.6	15.0	100

The results achieved for width preferences (Table 5.10) show close alignment with the literature. Overall, 55% of survey participants selected 2.5 m or 3 m, while the literature recommends a value of 3 m. One possible issue here (as with gradient) is that respondents may simply have selected the middle option and this is a limitation of stated-preference surveys – although this does not appear to be case with the rest of the design characteristics. The provision for width is connected to whether the route is segregated or mixed-use, for which Sustrans (2009) recommends widths of 3 m and 5 m, respectively.

Table 5.10 - Width preferences

Width	2 m	2.5 m	3 m	3.5 m	4 m	Any	Total
No. respondents	107	192	257	99	90	75	820
%	13.0	23.4	31.3	12.1	11.0	9.1	100

Respondents were posed the question "would mixed-use (e.g. walking, cycling, wheelchair users, skaters) deter you from using a greenway' and the results are tabulated in Table 5.11. The results give a clear indication that users would not be deterred on this basis (as is best-practice): three-quarters responded 'no' or 'probably not'. Nevertheless, as some respondents expressed a clear preference for segregation on the basis of safety in the qualitative results, this design feature is examined in more detail in the cross-tabulation with mode of travel in the following section.

Table 5.11 - Segregation (between pedestrians and cyclists) preferences

Segregation	Yes	Possibly	Indifferent	Probably not	No	Total
No. respondents	28	127	55	223	392	825
%	3.4	15.4	6.7	27.0	47.5	100

Regarding car parking, the survey included a question: 'would the presence of an adjacent vehicle parking lane deter you from using a greenway' (see Table 5.12). While a large majority (70%) responded 'no' or 'probably not', this represented a greater deterrent to greenway use than sharing the route between pedestrians and cyclists. As greenways are (or should be) generally well separated from motorised traffic, the issue of 'dooring' may not be considered as much of a risk as with on-road cycle lanes: for example, in the perceived safety survey conducted in an urban area (Chapter 4), 15% were deterred from using cycling infrastructure by the presence of an adjacent car parking lane. Meanwhile, some qualitative responses highlighted the importance of car parks at trail heads for accessibility purposes.

Table 5.12 - Adjacent parking preferences

Parking	Yes	Possibly	Indifferent	Probably not	No	Total
No. respondents	61	243	108	238	171	821
%	7.4	29.6	13.2	29.0	30.8	100

Respondents were also asked the number of junctions that they would feel safe passing through in the course of 30 minutes on a greenway (see Table 5.13 for results). The median number of junctions was 5, while the mean was 4.34 with a standard deviation of 2.15. These results confirm the findings of McCarthy (2011), who (using the same question design) judged passing through 5 junctions in 30 minutesto bea good to medium standard. This said, it must be considered that junctions are not homogenous: some pose more danger than others (based on visibility, traffic volume etc.) and while it is best to minimise interactions with traffic, this must be balanced with accessibility. Also, Chapter 4 found that while the number of junctions was not significantly related to perceptions of safety, some junctions such as roundabout are perceived to be very dangerous.

Table 5.13 - Junction preferences

Junctions	1	2	3	4	5	6	7	8	9	10	Total
No. respondents	51	83	153	125	138	97	14	24	5	37	727
%	7.0	11.4	21.0	17.2	19.0	13.3	1.9	3.3	0.7	5.1	100.0

The final design characteristic question in the survey related to preferences for distances between occurrences of three facilities: benches / rest stops, toilets and food & drink stops (see Table 5.14). The median optimal distances reported were: 3-5 km for benches, 6-10 km for toilets and 11-20 km for food & drink services (see cross-tabulation by mode). McCarthy (2011) found an optimal distance of 8 km between general rest stops and in the qualitative responses, there was a strong preference for regular water facilities.

Table 5.14 - Facility distance preferences

	Facility	<1 km	1-2 km	3-5 km	6-10 km	11-20 km	Total
Bench	No. respondents	84	219	277	130	85	795
	%	*10.6*	*27.5*	*34.8*	*16.4*	*10.7*	*100*
Toilet	No. respondents	19	53	249	309	169	799
	%	*2.4*	*6.6*	*31.2*	*38.7*	*21.2*	*100*
Food & drink stop	No. respondents	8	29	102	297	362	798
	%	*1.0*	*3.6*	*12.8*	*37.2*	*45.4*	*100*

The literature review also outlined a range of recommendations regarding other elements of the engineering of greenways (e.g. horizontal and vertical alignment, crossfall, design speeds) and although these were not examined in the survey, readers are directed to Section 2.4 for references to existing best practice. The key greenway design preferences found in this research are summarised in Table 5.15.

Table 5.15- Greenway design preferences

Design characteristic	User preference
Surface material	Asphalt
Maximum Gradient	5%
Maximum Width	3 metres
Route segregation	Shared-use
Adjacent car parking	Not a deterrent
Junctions	Max. 5 in 30 minutes
Facility distances	3-5 km (benches) 6-10 km (toilets) 11-20 km (food & drink)

5.7.2 Cross-tabulation with mode of travel

For the majority of design characteristics, there was no substantial difference between greenway users of various modes (or other individual characteristics). One exception is the distance between facilities, which understandably varies according to modes of travel which move at different speeds and travel different distances. For example, walkers prefer rest stops every 1-2 km, while cyclists prefer 3-5 km; 3-5 km v. 6-10 km for toilets; and 6-10 km v. 11-20 km for food & drink services.

Two particular areas of conflict between greenway users over design characteristics, as highlighted in qualitative responses, are surface material and segregation. One would expect that cyclists would prefer an asphalt surface (smoothness and comfort), while walkers may prefer a non-asphalt surface for a more 'natural' feel. Similarly for segregation, some walkers may want to be separated from fast cyclists for comfort and safety reasons while cyclists may want an uninterrupted route for speed maintenance. To gain an indication of the effects of greenway mode use on surface and segregation preferences, cross-tabulations have been plotted in Table 5.16 and Table 5.17.

Table 5.16 - Cross-tabulation of surface material preferences and mode of travel on greenways

			Surface				Total
			Asphalt	***Gravel***	***Concrete***	***Earth***	
Mode	***Cycle***	n	354	70	43	60	527
		%	*67.2*	*13.3*	*8.2*	*11.4*	*100*
	Run / Jog	n	18	13	4	11	46
		%	*39.1*	*28.3*	*8.7*	*23.9*	*100*
	Walk	n	47	28	6	55	136
		%	*34.6*	*20.6*	*4.4*	*40.4*	*100*
Total		n	419	111	53	126	709
		%	*59.1*	*15.7*	*7.5*	*17.8*	*100*

There appears to be a substantial difference in the surfacing preferences for the various greenway user types. While the majority (61%) of cyclists prefer asphalt, the preferred mode for walkers is compacted earth (40%). Turning to segregation, there does not appear to be any substantial difference between the users: all three modes indicated that mixed-use would not deter them from using a greenway, i.e. that segregation is not necessary (46-56%).

Table 5.17 - Cross-tabulation of segregation preferences and mode of travel on greenways

			Segregation					**Total**
			Yes	Possibly	Indifferent	Probably Not	No	
Mode	Cycle	n	20	93	31	150	255	549
		%	*3.6*	*16.9*	*5.6*	*27.3*	*46.4*	*100*
	Run / Jog	n	1	6	4	12	29	52
		%	*1.9*	*11.5*	*7.7*	*23.1*	*55.8*	*100*
	Walk	n	2	15	13	43	68	141
		%	*1.4*	*10.6*	*9.2*	*30.5*	*48.2*	*100*
Total		n	23	114	48	205	352	742
		%	*3.1*	*15.4*	*6.5*	*27.6*	*47.4*	*100*

5.7.3 Logistic Regression model

To build the logistic regression model, it was necessary to completely clean the dataset (all responses with at least one missing value were removed, rather than attempt to incorporate these missing values in the model). This reduced the size of the sample to 472, although a preliminary check of the data showed that this reduced sample did not significantly vary from the larger sample used for the descriptive statistics for the design characteristics outlined in previous sections. It was also necessary to recode several of the qualitative variables due to small sample sizes when cross-tabulated with surface preference (e.g. residence) and to code the quantitative variable age into four categories. As some of the alternative surfaces received few responses, it was also necessary to combine these surfaces as ‘not asphalt’ (i.e. concrete, gravel or earth).

The approach taken is to consider ‘surface material’ as the response variable and to use ‘not asphalt’ as the reference category of the response. In that way, it will be possible to observe which variables result in a significant deviation from the best practice surface – asphalt. Descriptive statistics for the total sample and the two surface categories are presented in Table 5.18.Ten variables were initially considered: greenway mode, greenway frequency, greenway purpose, usual mode, cycling skill, fitness, residence, gender, marital status, and age. The most accurate model was achieved by including five of these and the parameter estimates (exported from SPSS v21) for the model are given in Table 5.19.

Table 5.18 - Descriptive statistics for surface model

Variable	***Category***	**Asphalt**		**Not Asphalt***		**Total**	
		N	%	N	%	N	%
Greenway Mode	*Cycle*	249	*84*	107	*61*	356	*75*
	Run/Jog	15	*5*	23	*13*	38	*8*
	Walk	31	*11*	47	*27*	78	*17*
Greenway Purpose	*Commuting*	64	*22*	21	*12*	85	*18*
	Fitness	56	*19*	40	*23*	96	*20*
	Leisure	175	*59*	116	*66*	291	*62*
Cycling Skill	*Competent*	160	*54*	96	*54*	256	*54*
	Highly Skilled	114	*39*	61	*35*	175	*37*
	Inexperienced	21	*7*	20	*11*	41	*9*
Residence	*Ireland*	114	*39*	70	*40*	184	*39*
	UK	46	*16*	16	*9*	62	*13*
	US/Canada	109	*37*	75	*42*	184	*39*
	ROW	26	*9*	16	*9*	42	*9*
Age (years)	*<35*	80	*27*	52	*29*	132	*28*
	36-45	76	*26*	57	*32*	133	*28*
	46-55	64	*22*	34	*19*	98	*21*
	56+	75	*25*	34	*19*	109	*23*

*Not asphalt = gravel, concrete or earth

Table 5.19 - Parameter estimates for surface model

Variable[a]	***Category***	$\hat{\beta}$	**p-value**	**Std. Error**	**Exp($\hat{\beta}$)**	**95% CI for Exp(β)**	
						Lower	*Upper*
Intercept		-0.234	0.672	0.553			
Greenway Mode	*Cycle*	1.389**	0.000	0.308	4.012	2.192	7.345
	Run/Jog	0.275	0.551	0.462	1.317	0.533	3.257
	Walk	Ref					
Greenway Purpose	*Commuting*	0.748*	0.019	0.318	2.113	1.133	3.939
	Fitness	0.277	0.326	0.283	1.320	0.758	2.297
	Leisure	Ref					
Cycling Skill	*Competent*	-0.096	0.808	0.395	0.908	0.419	1.971
	Highly Skilled	-0.318	0.464	0.434	0.728	0.311	1.704
	Inexperienced	Ref					
Residence	*Ireland*	0.328	0.400	0.390	1.388	0.646	2.982
	UK	0.747	0.109	0.466	2.110	0.846	5.262
	US/Canada	-0.231	0.545	0.382	0.793	0.375	1.678
	ROW	Ref					
Age (years)	*<35*	-0.417	0.184	0.313	0.659	0.357	1.219
	36-45	-0.804*	0.010	0.311	0.448	0.243	0.824
	46-55	-0.441	0.170	0.321	0.644	0.343	1.208
	56+	Ref					

[a]The reference category is 'Not Asphalt'; *Significant at the 5% level; **Significant at the 1% level

The pseudo R-squared for the model was 0.137, i.e. the model explained 13.7% of the variance in surface preferenceandthe model correctly classified 63% of cases. As the reference category of the response is 'not asphalt', coefficients (β) for each category of each variable in Table 5.19 represent the increase in log odds of choosing 'asphalt' for the category in question relative to the reference category of that variable. The equivalent odds (i.e. exponentiated log-odds) are then given by Exp(β). The p-value indicates the significance of the variable and the standard error and the 95% confidence interval for the exponentiated log-odds are also included.

The model yielded three significant results:

1. Cyclists are four times as likely as walkers to prefer an asphalt surface (β = 1.389, Exp(β) = 4.012, p-value = 0.000)
2. Commuters are twice likely as leisure users to prefer an asphalt surface (β = 0.748, Exp(β) = 2.113, p-value = 0.019)
3. Younger people (36-45 years old) are approximately half as likely as older people (over 56 years old) to prefer an asphalt surface(β = -0.804, Exp(β) = 0.448, p-value = 0.010)

The model was re-run with all four categories of the surface response variable and it suggested that younger people and walkers prefer earth surfacing.These results show how the characteristics of the design user must be considered at the planning stage. Furthermore, if, for example, a greenway route is oriented to cyclists (as the Irish NCN is intended to be) and asphalt is chosen as the surface material along a route of significant length, this can have major economic and environmental implications, as the next two chapters will show.

There are two main assumptions in this model: independence of the variables (e.g. greenway mode is independent of greenway purpose) and independence of observations (respondents' preferences are independent of one another). It would be possible to discuss these results in much greater detail, to present more statistics and indeed to run alternative models.However, as the descriptive statistics, backed-up by the qualitative responses, as well as evidence from the literature, clearly demonstrate the preferences of the majority of users, this has not been carried out at the present time. Further research could construct models taking other design preferences as dependent variables to observe the effect of each greenway use, travel, health, and demographic variable, as well as comparing the goodness-of-fit for a variety of models.

5.8 Conclusion

There were three main components to this chapter: (i) qualitative analysis to explore greenway priorities, (ii) criteria ranking questions to form a framework, and (iii) specific design preferences.

Firstly, the qualitative analysis of ‘the most important factors to consider when designing greenways’ yielded four main conclusions:

1. Greenways serve a broad variety of functions, although an emphasis is placed on leisure and tourism travel.
2. There are five broad priority themes for greenway design: accessibility, safety, user experience, design characteristics and sustainability.
3. It is challenging to quantify many characteristics such as ‘user experience’.
4. It is also challenging to balance the priorities of different users, e.g. between separation and connectivity, between a smooth cycling surface and potential environmental impact.

Secondly, the framework for greenway planning and design combined greenway users’ rankings of existing national/international criteria with results derived from the qualitative responses. This framework will be used as a lens through which to analyse the development of the Irish NCN in Chapter 8 and operationalised in more detail in the analysis of route options for the case study greenway in Chapter 9.

Thirdly, a series of specific design preferences were established to inform future greenway design. Some of these preferences vary according to user type, for example preferred distances between facilities are understandably lower for walkers than cyclists. For a more detailed analysis of one fundamental design characteristic – surface material – a logistic regression model was built. This model showed that cyclists, commuters and older people prefer asphalt surfacing and points to future research to further unpack the influence of greenway user characteristics on design preference (particularly for routes oriented to specific design users).

6 Embodied carbon of Greenways[3]

6.1 Introduction

Greenways offer such a variety of environmental benefits that this is recognised in the likely origin of the term as a portmanteau of 'greenbelt' and 'parkway'. These environmental benefits include (but are not limited to): habitat protection and preservation of biodiversity; water, soil and air quality improvement; flood and stormwater management; environmental awareness and teaching tools; and improving human health and access to green space. It was not possible to explore this important feature of greenway planning in great detail in Section 2.7 of the literature review; the reader is encouraged to examine the greenway literature in the landscape architecture and landscape ecology fields (cf. Ahern (1995; 2004), Fabos (1996), Hellmund & Smith (2013), Little (1995)). The recent proliferation of motorised traffic-free routes for walking and cycling in Ireland, which partially inspired this thesis, has adopted this term 'greenway', yet has paid scant attention to the environmental benefits of these routes or indeed a wide range of environmental impact, e.g. embodied carbon.

In general, the considered environmental impact of the routes has been restricted to compliance with environmental legislation in the planning process, usually the demonstration of the lack of negative impact on protected sites, by following the road scheme approach (and not recognising the fundamental difference between greenways and roads) (e.g. the route selection reports for the Galway-Dublin Greenway (AECOM & Roughan O'Donovan (2015a)). Typically, the Environmental Impact Statement (EIS) of a road scheme will primarily focus on designated sites, but will also pose the total embodied carbon of the development in the context of the Irish climate targets (which is important given the scale of recent motorway construction). One greenway EIS (RPS, 2012) directly transposed this approach to the Connemara Greenway by broadly estimating the embodied carbon of the route and placing this figure in the context of Irish Kyoto Protocol commitment:

> The total estimated greenhouse gas emissions associated with the proposed Greenway is calculated at approximately 1500 tonnes of CO_{2eq} compared to the National Kyoto Target of 63 million tonnes of CO_{2eq}. This increase is considered to be negligible (0.002%) in the context of the National Kyoto Target.

Although positive that embodied carbon was considered, it is clear that a more detailed approach is required for these figures to be useful in greenway planning.

[3] An article based on this chapter was published in the International Journal of Environment and Sustainable Development.

The underpinning idea of this chapter is that while a modal shift to cycling has the potential to reduce carbon emissions in the transport sector, the carbon footprint of constructing new cycling routes, particularly greenways, has not been previously considered and has the potential to negate carbon savings of the modal shift of many commuters. This will be particularly relevant in rural areas where a greenway has been constructed, yet usage is relatively low. Goodman et al. (2014) in the iConnect project touched on this issue by attempting to associate increased physical activity levels on traffic-free routes in the UK with reductions in carbon emissions (at the aggregate level), though they did not find a significant relationship. Others such as Sustrans have investigated the potential for greenways as 'corridors for wildlife' and Wann (2013) studied the biodiversity of the Creeslough-Burtonport abandoned railway in the context of potential conversion to a greenway. However, to date there has been no attempt to systematically measure the embodied carbon of a greenway.

This chapter describes a methodology for calculating the carbon footprint due to the construction of greenways (carbon costs) and the modal shift to cycling (carbon savings) necessary to 'balance' or offset these costs. As throughout the thesis, this chapter approaches the problem from a civil engineering perspective (rather than say landscape ecology), but introduces new methods. In this instance, Life Cycle Assessment (LCA) is used to calculate embodied carbon (in carbon dioxide equivalents), counter-posing this with the carbon savings of shifting Passenger Kilometres Travelled (PKT) from driving a car to cycling, using an Irish case study (GWG). Conclusions on the minimisation of embodied carbon and lessons for the Irish NCN are provided at the end of the chapter.

6.2 Methodology

The 'goal' of the LCA in this chapter is to evaluate the carbon footprint of a greenway. This methodology identifies, based on a case-study, the emissions associated with various stages of the construction of the route. This can allow better design and construction to reduce the emissions associated with various route options. This methodology includes a LCA approach as outlined in BSI (2006) and has been applied to the 42 km GWG (see Section 2.5 for a profile).

While information on cross-sections and the materials used for international greenways is often available, it is more difficult to gather data on the sourcing of materials and local soil conditions. Given that the actual profile of the case study greenway changed frequently due to on-site conditions, all equations are presented in a general manner and then applied to a greenway cross section. Once a life cycle inventory of embodied carbon for materials, transport of materials and operation of construction machinery has been set up, the embodied carbon of a greenway can be calculated for a Cradle-to-Site boundary (Figure 5.1).

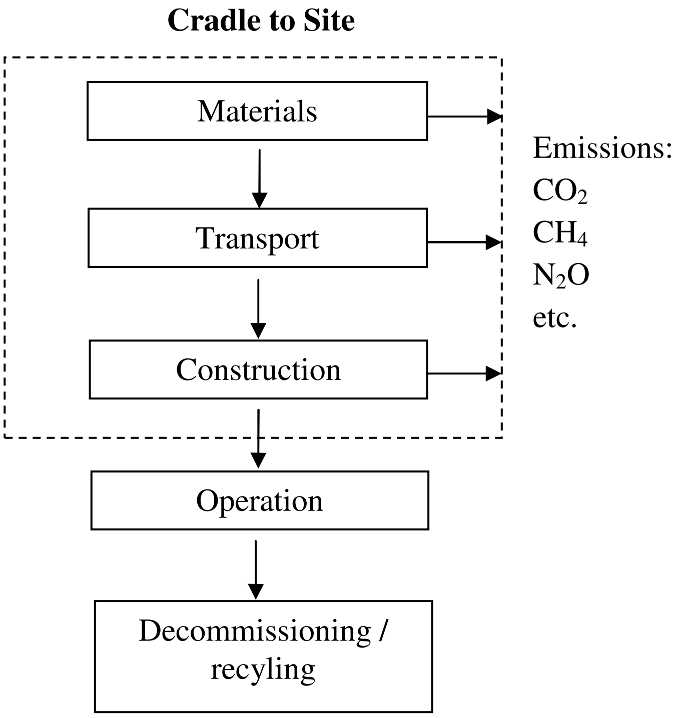


Figure 6.1 - LCA system boundary

6.2.1 Embodied carbon of materials

As described in Section 2.4, a typical greenway comprises three layers: (i) asphalt surface, (ii) asphalt base, and (iii) Type A granular material sub-base. Type A granular material (known as Type 1 in the UK) comprises gravel, crushed rock or recycled crushed mixed concrete aggregates (NRA, 2011b; BSI, 2010). A polypropylene geotextile is generally used to prevent mixing with the subgrade and regrowth of vegetation. The embodied carbon of each layer was calculated as follows (Eq.6.1).

$$EC_{layer} = Vol_{layer} \times \rho \times \frac{EC_{material}}{1000} \qquad \textbf{Eq. 6.1}$$

Where EC_{layer} is the total embodied carbon for the material in the layer in tonnes (tCO_2e), Vol_{layer} is the volume of the layer (m^3), ρ is the density of the material (kg/m^3) and $EC_{material}$ is the embodied carbon of the material ($kgCO_2e$/kg material). The volume of the layer (m^3) over a given section of route being considered was taken as in Eq.6.2.

$$Vol_{layer} = L_{layer} \times d_{layer} \times B_{layer} \qquad \textbf{Eq. 6.2}$$

Whered_{layer} (m) and B_{layer} (m) are the average depth and breadth of the layer over a particular section of length, L_{layer}, (m).

6.2.2 Embodied carbon due to transport of materials

The carbon emissions associated with transporting construction materials can be significant; particularly so in the case of heavy materials, such as stone. Eq.6.3 expresses the embodied carbon due to transport of construction materials:

$$EC_{transport} = \frac{Dist}{1000} \times \left(\left(W \times EC_{full} \right) + \left(n \times EC_{empty} \right) \right) \qquad \textbf{Eq. 6.3}$$

where the embodied carbon for transport, $EC_{transport}$ (tCO_2e) was calculated from the embodied carbon of the truck for the transport of construction material to site, EC_{full} (kg CO_2e/t-km), multiplied by the distance from Gate-to-Site, Dist (km), and the mass of the material transported, W (t). This is then added to the embodied carbon for the empty return journey for the truck, EC_{empty} (kg CO_2e/km), multiplied by the number of trips, n, and Dist (km). The number of trips, n, is calculated by dividing the mass of the material by the capacity of the truck.

6.2.3 Embodied carbon due to machinery operation

A wide variety of machinery can be used to build a greenway (though some trails are built almost exclusively by hand). For the purposes of this thesis, the carbon emissions of excavators, dump trucks and rollers were analysed. Only the consumption of fuel by these machines is considered and the embodied carbon associated with the manufacture of the machines is omitted. In the initial stage of construction, it may also be necessary to cut and to fill sections to ensure gradients remain within tolerances. The amount of excavation will depend on the strength of the soil, the profile of the route, verge and drainage requirements, and the potential of the soil to support the weight of the structure. Embodied carbon from the use of excavators to clear soil and vegetation, $EC_{excavator}$ (tCO_2e) was based on the volume of soil excavated, $Vol_{material}$ (m^3), the working rate of the excavator, Rate ($m^3{}_{material}$/h), the fuel consumption of the excavator, FC (l/h) and the embodied carbon of the fuel (in this case diesel was assumed), $EC_{diesel\text{-}e}$ ($kgCO_2e$/l) (Eq. 6.4).

$$EC_{excavator} = \left(\frac{Vol_{soil}}{Rate} \right) \times FC \times \frac{EC_{diesel-e}}{1000} \qquad \textbf{Eq. 6.4}$$

Dump trucks are included in EC calculations as they place the materials in the excavations for the capping layer and sub-base layer. The carbon cost of this vehicle, $EC_{dumptruck}$, (tCO_2e) is a function of the pavement length, L (km), the mass of materials, W (t) and the embodied carbon for the dump truck per tonne kilometre, $EC_{vehicle}$ ($kgCO_2e$/t-km) (Eq. 6.5).

$$EC_{dumptruck} = L \times W \times \frac{EC_{vehicle}}{1000} \qquad \textbf{Eq. 6.5}$$

For the top layer, a paver lays the asphalt which is sometimes fed by a dump truck. A vibrating roller is then used to compact the layer. The carbon cost of a vibrating roller EC_{roller} (tCO_2e) was calculated from the drum width, D_{width} (m), the pavement width, P_{width}, (m) the pavement length, L (km), the number of times of compaction, $Comp_{number}$ and the embodied carbon of diesel for a vehicle between 1.74 and 3.5 tonnes in weight, $EC_{diesel-r}$ ($kgCO_2e$/km) (Eq.6.6).

$$EC_{roller} = \left(Roundup\left(\frac{P_{width}}{D_{width}} \right) \right) \times L \times Comp_{number} \times \frac{EC_{diesel-r}}{1000} \qquad \textbf{Eq. 6.6}$$

where the term ‘roundup’ indicates P_{width}/D_{width} rounded up to the nearest whole number.

6.2.4 Additional sources of emissions

Two additional sources of emissions are now considered: travel to greenways and peat extraction. These sources of emissions are outside the system boundary and the data derived from the case study greenway may not be representative of international greenways. Therefore, these two sources have not been included in the overall balance sheet for this case study, yet represent potentially substantial contributions to the total environmental impact of the route.

Firstly, it was observed from the international greenway survey (as outlined in Chapter 5) that a large proportion of users arrive at greenways by car and that this could represent a major carbon footprint, particularly as many of these trips are exclusively to use the greenway. Respondents were asked which mode of travel they used, and how far they travelled, to their most recently used greenway and the results for the GWG were isolated. The carbon footprint of each mode of travel was then multiplied by the corresponding proportion of the 14,800 non-local domestic users who are estimated to travel to the GWG each year to calculate the total carbon footprint of travel to the GWG.

Secondly, as the embodied carbon of peat is particularly large and since much of the Irish NCN is planned near peatlands, this will be given additional focus. Excavated peat can be dried for agricultural purposes or dried and burnt as a fuel where it will lose 100% of its carbon. However, peat placed in peat disposal areas or in restoration of a peatland will likely retain a high proportion of its carbon (Nayak et al., 2008). Loss of carbon from excavated peat, EC_{peat} (tCO_2e) is calculated using the carbon content of the peat $pC_{drypeat}$ (%), the dry soil bulk density $\gamma_{drypeat}$ (g/cm^3), the volume of excavated peat, Vol_{peat} (m^3) and the percentage of carbon lost from the peat – pC_{lost} (%). A factor of 3.67 (44/12) is used to convert the molecular mass of carbon to CO_2 and is expressed in tCO_2.

The short term release of methane as peat is excavated can be difficult to estimate and can vary significantly between sites and construction practice. It is likely to be relatively limited compared to the overall carbon dioxide emissions. Excavated peat left on the surface will likely be exposed to aerobic conditions, therefore long term methane emissions, as a result of excavation, may be limited as anaerobic conditions are required for CH_4 production (Sundh et al., 2000; Roulet et al., 1993). Martikainen et al. (1993) has also shown that N_2O emissions are negligible from nutrient-poor peatlands. Eq.6.7 is adapted from Nayak et al. (2008).

$$EC_{peat} = \frac{44}{12} \times \frac{pC_{drypeat}}{100} \times \gamma_{drypeat} \times Vol_{peat} \times \frac{pC_{lost}}{100}$$ **Eq. 6.7**

6.3 Results and discussion

6.3.1 Carbon savings

For each commuting trip shifted from a car of average occupancy (in Ireland) to bicycle, the carbon avoided was calculated to be 134 gCO_2e/km (Table 6.1). This figure will be used in Section 6.3.7 to determine the modal shift required to balance the embodied carbon of greenway construction. Major potential for modal shift exists amongst commuters with daily journeys of 5 km or less. To meet the Irish government's sustainable transport target, 150,000 people will be required to shift from driving a car to cycling by 2020 (DoT, 2009). This amounts to approximately 2,200 km per commuter (10 km per day for 220 working days/year), and a total of 330 million PKT per year. The avoided greenhouse gases in the form CO_2e in such a scenario is quantified in Table 6.1.This avoided carbon accounts for just under 0.8% of current Irish passenger car emissions. Although this calculation does not consider other carbon emissions relating to car-based transport (e.g. road construction), it nevertheless shows the need to shift longer-distance commutes to public transport (integrated with cycling) and for urban planning to reduce commuting distances.

Table 6.1 - Avoided carbon due to a modal shift from a car trip to a bicycle trip

Mode of Transport	Embodied Carbon of trip (gCO_2e/km)	Average Occupancy	Carbon emissions of trip (gCO_2e/PKT)
Car	160[1]	1.1[2]	145
Bicycle	11[3]	1	11
Avoided carbon (gCO_2e/km)			134
Avoided carbon (tCO_2e/million PKT)			134
Avoided carbon (tCO_2e) if Irishtargets are met			44220

[1]NRA (2011); [2]CSO (2012b); [3]Walsh et al. (2008)

6.3.2 Materials

Turning to the carbon costs of greenway construction, it was anticipated that the largest impact would be associated with the embodied carbon of the construction materials. For the GWG, the case study greenway, a disused railway track-bed was cleared of vegetation and excavated; Figure 6.2 shows the GWG before and during construction. Although for most of its length the greenway uses a gravel surface, the embodied carbon of the asphalt sections is presented here to maximise relevance for international research which recommends asphalt surfacing (see Section 2.7).

Figure 6.2 - Railway trackbed (left) and GWG construction (right) (Connor, 2013)

The cross-section of the 3 m-wide greenway is given in Table 6.2. The depth of the asphalt layer (surface and base courses) was in line with literature at 60 mm. A 150 mm sub-base of Type A (known as Type 1 in UK) was also recommended by the majority of the guidelines reviewed in Section 2.4. However, due to the weakness of the subgrade along parts of the route, a 600 mm capping layer was provided between the sub-base and the subgrade. This capping layer used Type B granular material (known as Type 2 in UK), a fill of cheaper crushed rock to protect the sub-base and strengthen the subgrade (NRA, 2011b; BSI, 2010). As Table 6.2 shows, this added substantially to the total mass of the material required, which had implications for embodied carbon due to transport.

Table 6.2 - Mass of materials required for a 1 km of 3 m-wide section of the GWG

Material	**Depth of layer (m)**	**Volume (m^3)**	**Density (kg/m^3)**	**Mass required(t)**
Asphalt	0.06	180	2243	404
Type A granular material	0.15	450	1600	720
Type B granular material	0.6	1800	1600	2880
Geotextile	/	3000 (m^2)	120 (g/m^2)	0.36

After determining the mass of material required, the embodied carbon (Cradle-to-Gate) for was calculated to be 46.36 tCO_2e/km (Table 6.3). Values for the embodied carbon of Type A and Type B granular materials were acquired in $kgCO_2/t$ and converted to $kgCO_2e/t$ by increasing the value by 6%, as recommended by Hammond & Jones (2011) and MPA (2009). Although substantially more Type B material than asphalt was used, such is the embodied carbon of asphalt that the embodied carbon of this layer was more than double that of the capping layer (Figure

6.3). The embodied carbon of the surface layer can be significantly reduced by incorporating recycled materials (or indeed choosing an alternative surface) and this is discussed in Section 6.3.8.

Table 6.3 - Embodied carbon of materials used in a 1 km long, 3 m-wide section of the GWG

Material	Mass required(t)	Embodied Carbon ($kgCO_2e/t$)	Embodied Carbon(tCO_2e)
Asphalt	403.74	71[1]	28.67
Type A granular material	720	4.54[2]	3.27
Type B granular material	2880	4.58[2]	13.19
Geotextile	0.36	3430[1]	1.23
Total			46.36

[1]Hammond & Jones (2011); [2]MPA (2009)

Figure 6.3 - Embodied carbon of GWG materials

6.3.3 Transport of materials

The embodied carbon of the greenway due to transportation of the materials was estimated to be 19.78 tCO_2e(Table 6.4). The vehicles used are assumed to be Heavy Goods Vehicles (HGVs) in excess of 17 tonnes and are assumed to be full on the outward journey and empty on the return journey. 100% full HGVs have an embodied carbon of 0.1205 $kgCO_2e$per tonne-kilometre and an average payload of 9.42 tonnes (DECC and Defra, 2011). Empty HGVs have an embodied carbon of 0.7925 $kgCO_2e$per kilometre over n empty return journeys (DECC and Defra, 2011). In Table 6.4, ‘EC out’ refers to the embodied carbon of the journey out from the quarry, while ‘EC in’ refers to the journey back in. The distance travelled was estimated based on the locations of quarries in relation to the GWG; such information should be available at the route planning stage. Gravel and crushed rock are often available locally in Ireland and excavated rock may also be used.

Table 6.4 - Embodied carbon due to transport of materials for the GWG

Material	Mass required (t)	Distance (km)	n	EC out ($kgCO_2e$/t-km)	EC in ($kgCO_2e$/km)	EC (tCO_2e)
Asphalt	403.74	60	43	0.1205	0.7925	4.96
Type A	720	20	77	0.1205	0.7925	2.96
Type B	2880	20	307	0.1205	0.7925	11.81
Geotextile	0.36	60	1	0.1205	0.7925	0.05
Total						19.78

6.3.4 Machinery operation

The types of construction machinery considered to contribute to the embodied carbon of the greenway are listed in Table 6.5 in $kgCO_2e$per litre, per tonne-kilometre or per kilometre. The embodied carbon of diesel is 2.668 $kgCO_2e$/l, while dump trucks used are assumed to be average laden HGVs, which have an embodied carbon of 0.1292 $kgCO_2e$per tonne-kilometre (DECC and Defra, 2011).The vibrating roller is in the category of vehicles whose weight lies between 1.74 and 3.5 tonnes and, therefore, has an embodied carbon figure of 0.27 $kgCO_2e$/km (DECC and Defra, 2011).

Table 6.5 - Embodied carbon of each machine (DECC and Defra, 2011)

Vehicle	Embodied Carbon
Excavator	2.668 ($kgCO_2e$/l)
Dump truck	0.1292 ($kgCO_2e$/t-km)
Roller	0.27 ($kgCO_2e$/km)

Excavation to a depth of 600 mm for a 3 m wide by 1000 m long section requires the excavation of 1800 m^3 of material. A 21 tonne excavator has a fuel consumption of 16 l/h and a working rate of about 84.7 m^3/h (Langdon, 2010; Landpro, 2012). The roller used was assumed to be a 2.75 tonne Wacker hydrostatic vibratory roller with a drum width of 1.2m. It was estimated, on average, to pass over the 3 m by 1000 m section twice. Using Equations 5.3, 5.4 and 5.5 the embodied carbon of the greenway due to the operation of construction machinery has been estimated as 1.46 tCO_2e/km and is shown in Table 6.6.

Table 6.6 - Embodied carbon estimated due to machinery

Operation	Vehicle	Embodied Carbon (tCO_2e/km)
Clearance and excavation	Excavator	0.907[2,3]
Placement of surface/base	Dump truck, Roller	0.057[1]
Placement of sub-base and geotextile	Dump Truck, Roller	0.098[1]
Placement of capping	Dump Truck	0.372[1]
Total		1.43

[1]DECC and Defra, 2011; [2]Langdon (2010); [3]Landpro (2012)

6.3.5 Total embodied carbon

The total embodied carbon of constructing the GWG was calculated to be 67.6 tCO_2e/km (Table 6.7). This figure excludes the release of any carbon dioxide and other greenhouse gases that may have been stored in organics due to carbon sequestration, but subsequently released back into the atmosphere due to its removal or disturbance during construction. The embodied carbon due to construction materials is the main contributing factor, accounting for 73.3% of the total. The second largest contributor is that due to the transport of materials, account for 24.4%. Machinery operation during the construction of the greenway, meanwhile, accounts for just 2.3%. It should be noted that the capping layer included in this case study will not be necessary for all greenways. Omitting the embodied carbon of this layer gives a total of 42.2 tCO_2e/km (a reduction of approximately one-third).

Table 6.7 - Total embodied carbon of the GWG

	Embodied Carbon (tCO_2e/km)	%
Materials	46.36	68.6
Transport of materials	19.78	29.3
Machinery operation	1.43	2.1
Total	67.6	

Comparing Table 6.7 to the embodied carbon of other forms of transport infrastructure, it was found that the embodied carbon of a greenway is approximately 30% that of a single lane rural road (225 tCO_2 per lane km) and 13.5% of a railway line (500 tCO_2 per single track km) (Transport Scotland, 2009; Hammond & Jones, 2011). It should be noted that these values for the single lane rural road and railway line only include carbon dioxide (accounting for other greenhouse gases would increase these values by approximately 6% on average (Hammond & Jones, 2011)). Furthermore, roads require greater width, verges, sight-lines etc. and therefore the overall embodied carbon of a road corridor is many times greater than that of a greenway.

6.3.6 User travel

The carbon footprint of travel (by non-local domestic users) to the GWG is tabulated in Table 6.8. The majority of users arrived at the greenway by car (whether as a driver or passenger), while 29% arrived by bicycle. Most train users travelled from Dublin, hence the large average distance of 244 km. However, the average cycling distance of 63 km appears unusual (though plausible) and may be due to some confusion by respondents (who may have thought that this question corresponded to travel *on* rather than *to* the greenway). Therefore, the cycling contribution has been excluded from the total. The total carbon footprint of annual travel to the GWG was calculated to be 236.8 tCO_2e, 87% of which relates to car driving.

Table 6.8 - Carbon footprint of travel to the GWG

Mode of travel	%	Annual users	Averagedistance (km)	Carbon footprint (gCO_2e/km)	Carbon footprint per mode (tCO_2e)
On foot	7	1036	13	0	0.0
Bicycle	29	4292	63	11	6.0*
Bus	3	444	142	31	3.9
Train	8	1184	244	29	16.8
Car (driver)	46	6808	101	149	204.9
Car (passenger)	8	1184	63	75	11.2
Total					236.8

*Excluded from total

If the GWG was entirely of asphalt surfacing, the embodied carbon of the route would be 2839 tCO_2e (42 km x 67.6 tCO_2e/km), therefore the annual carbon footprint of user travel to the GWG would account for 8% of the embodied carbon of the route. This points to the need to make greenways accessible by public transport and to encourage uses to avail of sustainable modes of travel (although one of the towns on the GWG, Westport, is connected to Dublin, Galway and other towns by train and bus routes, services are infrequent).

6.3.7 Peat removal

A further consideration for the embodied carbon of greenways is carbon loss of the material removed, particularly if this material is peat. If peat is burnt or dried, 100% of the carbon content of the peat is released. For example, if the 3 m wide by 1000 m long section of the GWG was constructed on peat and the full 1800 m^3 of peat was excavated and burnt or dried, assuming a dry density of 0.1g/cm^3 (100 kg/m^3) (Nayak et al., 2008) and 50% carbon content (Müller et al., 2010), the carbon emissions alone (i.e. excluding CH_4 and N_2O) would be approximately 330 tCO_2/km; approximately five times the embodied carbon due to construction materials, transport and machinery. The size of this potential impact illustrates the importance of the use of peat disposal areas, peatland restoration and good construction techniques. Further research is required to resolve the design issues presented by peat with a view to minimising the requirement for peat excavation.

6.3.8 Balance sheet

By equating the carbon costs and savings in a basic balance sheet, the 'offset' of commuters required to shift from driving a car to cycling can be calculated. Eq.6.8 demonstrates this, where $EC_{Greenway}$ ($kgCO_2e/km$) is the embodied carbon of the greenway, $L_{Greenway}$ is the length of the greenway, $Dist_{commute}$ is the average commuting distance, $Commutes_{annually}$ is the number of commutes completed per year (around two per day for 220 days), and $LC_{Greenway}$ is the life cycle of the greenway. The number of 5 km commuters required to shift from the car to the bicycle based on the embodied carbon of a 10 km asphalt greenway with a life cycle of 20 years is 115 per year, as shown in Table 6.9. Excluding the contribution of the capping layer, 72 people would be required to shift their 5 km commute.

$$Commuters_{required} = \frac{EC_{Greenway} \times L_{Greenway}}{CO_{2,avoided} \times Dist_{commute} \times Commutes_{annually} \times LC_{Greenway}} \qquad \textbf{Eq. 6.8}$$

Table 6.9 - Sample calculation of commuter shift required for offset

Embodied Carbon ($kgCO_2e/km$)	67600
Length of greenway (km)	10
Total 10 km greenway embodied carbon ($kgCO_2e$)	676000
CO_2e avoided ($kgCO_2e/km$)	0.134
Commute distance (km)	5
Commutes (/year)	440
Life cycle of greenway (years)	20
Total carbon offset per 5 km commuter ($kgCO_2e$)	5896
Commuters required to shift from car to bicycle per year	**115**

From the results, the following actions could significantly reduce or offset the carbon footprint of greenways:

1. Use of recycled asphalt and demolition waste along with the investigation of the use of novel materials in the surface layer of greenways.
2. Use of locally-recycled materials and local crushed rock and gravel in the sub-base and capping layers, thereby minimising transport of materials.
3. The use of novel materials in the base/sub-base layer and the capping layers could offer a more sustainable solution. Given the reduced loads on cycle lane foundations solutions such as tyre bales offer potential.
4. Novel designs could be used to minimise the volumes of peat removed – these may include the development of floating cycle lanes. This technique is commonly used for forestry and wind farm access roads in Ireland.

5. Use of existing road infrastructure, (e.g. local roads or other assets) where possible, to reduce the length of greenway constructed.
6. Promotion of greenways once constructed to ensure large usage and modal shift.
7. Encouraging modal shift from high carbon transport, e.g. single occupancy driving, SUVs etc., to cycling, walking and public transport.
8. Access to these greenways by public transport (and provision of bicycle hire) can further improve their carbon efficiency by reducing trips by car to the facility. This is particularly relevant for Ireland, where greenways developed to date are located in rural areas with relatively poor public transport availability.

When considering this carbon offset, it should be noted that using a greenway (e.g. for leisure) may encourage people to cycle more often or indeed to shift journeys from driving a car to cycling in their everyday lives away from the greenway. Gardner (1998) investigated this idea in a study of over 500 cyclists finding that leisure cycling is perceived to be very different to utilitarian cycling: an image of peacefulness versus one of danger and stress. The report recommends bringing the characteristics of leisure cycling into utilitarian cycling, though Parkin (2007b) cautions the assumption of any link between the two types of cycling. In this context, the international greenway survey in this thesis included a question ‘has cycling the greenway encouraged you to cycle more often?’ to which 33% of GWG users replied ‘yes’ for commuting and 76% for other leisure trips. This issue was also evident in the more recent iConnect study (cf. Goodman et al. (2014) and Sahlqvist et al. (2015)), though more research is require to fully understand the relationship between greenways and utilitarian cycling and the promotion of pro-environmental behaviour.

6.4 Conclusions

While a modal shift to cycling has clear potential to reduce carbon emissions in the transport sector,the carbon cost of constructing new cycling infrastructure should be considered at the planning and design stages. This is particularly important for asphalt-surfaced greenways, which can embody significant levels of carbon. This chapter has described a methodology, based on a LCA approach, of assessing the potential carbon cost associated with the construction of greenway routes.

The main conclusions of this method are:

1. The embodied carbon of asphalt-surfaced sections of the GWG is 67.6 tCO_2e/km or 22.5 $kgCO_2e/m^2$. Excluding the large capping layer used in the GWG, the embodied carbon of a more typical greenway is 42.2 tCO_2e/km (assuming similar access to quarries and machinery used).

2. Construction materials represent the largest contribution (69%) to greenway embodied carbon. Low-carbon, recycled materials and novel cross-section designs could minimise this impact.
3. Transport of construction materials comprises 29% of the embodied carbon in a greenway. This contribution could be minimised by using locally sourced and lighter materials.
4. Policy-makers could target a modal shift of 115 commuters annually to cycling for each 10 km greenway to offset embodied carbon. Operational carbon could also be minimised by ensuring users can access the route without a car.

Environmental issues have been sorely lacking in greenway developments in Ireland to date, despite the strong and varied environmental benefits of what are more than just routes for walking and cycling. This chapter is one contribution in the promotion of a more environmental view of greenways for cycling. For example, the figures for embodied carbon, the LCA methodology and the proposal for a link with utilitarian cycling offsets can be used in the planning of greenway and cycle networks. In Chapters 8 and 9, this information will be applied to the Irish NCN and used in prioritising route options for the Galway-Dublin Greenway. This process involves many challenges, e.g. balancing cyclists' desire for asphalt surfaces with the need to minimise embodied carbon and promote a 'natural feel', and this demonstrates the need for an integrated, holistic approach in planning and design.

7 Greenway user spending and recreational value[4]

7.1 Introduction

While previous chapters have demonstrated many of the benefits attached to greenways, these routes are expensive to construct (often €100,000 per kilometre) and national and local government budgetary constraints demand that infrastructural investment must demonstrate return on investment. Greenways are receiving significant investment in Ireland, Europe and internationally, however, there is a lack of information on the economic impact of these investments. In the broader field of cycle tourism research (cf. Weston et al. (2012)), economic impact has received considerable attention, yet studies have often relied on expert interviews and small samples of user spending diaries or have been confined to individual cycle routes (see Section 2.6). There has been limited research conducted on user spending andeconomic impact of greenway routes specifically.

Greenways offer opportunities for recreation and exercise that produce fitness and health benefits, alternate transportation routes, conservation of habitats and biodiversity, economic development, and aesthetic, visual, and psychological amenities (Lindsey et al., 2004). While some facets of this impact have been examined, such as health benefits and journey ambience, the value retained by the greenway user has not been examined. Leisure economics points to the fact that people who engage in recreational activities, such as cycling, gain value from the active use of greenways. These are commonly measured using travel cost recreation demand modelling techniques (Loomis & Walsh, 1997; Hynes & Hanley, 2006). Recreation demand modelling estimates the number and value of trips to outdoor recreation sites, as well as the impact of changes in site attributes or quality, and the most common approach is the travel cost method. Though this method offers major potential to explore the recreational value of greenways, it has never been applied to this area.

This chapter builds on the international greenway survey results from Chapter 5, examining user spending responses and uses this information to build a travel cost model to estimate the recreational value attached to greenways. Due to the scale of the investment proposed in Irish greenways, particular attention is paid to providing economic information to inform policy and planning in Ireland. The spending on the GWG is profiled and further insights are provided on users' willingness to pay for greenway access as well as perceptions of the Irish cycle tourism product.

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[4]An article based on this chapter was published in Tourism Planning & Development. Travel cost modelling was carried out by Dr. Stephen Hynes.

7.2 Methodology

Building on the gaps identified in the existing literature, the aims of this chapter are:

1. Explore and categorise international greenway user spending
2. Estimate the recreational value of greenways
3. Assess willingness to make a financial contribution for greenway use
4. Profile the spending on the Great Western Greenway
5. Outline international perspectives on the Irish cycle tourism product

7.2.1 International greenway survey

The data analysed in this chapter are derived from the international greenway survey used in Chapter 5; a series of economic questions followed those on design preferences. For greenway spending, respondents were asked to consider their most recently used greenway and were provided with seven categories: 'Food & Drink', 'Accommodation', 'Bike Rental', 'Retail', 'Public Transport', 'Petrol (Gasoline)/ Diesel', and 'Other'. To profile spending on the GWG, responses citing this greenway as their most recently used were isolated and spending figures were averaged for each category. Respondents were also asked their willingness to make a direct financial contribution, in terms of Euro (€) per hour, for greenway use and offered the opportunity to comment on their motivations. A series of questions on the Irish cycle tourism product followed and was used to build an overview of international perceptions. As the spending-related questions received a lower response rate than the main, design-related section of the survey, the sample used in this chapter is reduced and has different characteristics than that of Chapter 5.

7.2.2 Travel Cost Model

A Travel Cost Model (TCM) is used to simulate the demand for the services of a recreation site. One of the main goals of this model is to measure the willingness to pay for access to recreation sites in order to compare the recreational value of land with the value of competing uses (Haab and McConnell, 2002). Greenway recreation is well suited for the use of the travel cost model as it is conducted at distinct, identifiable sites, and most trips are taken for the sole purpose of recreation at the site (English and Bowker, 1996; Hynes and Hanley, 2006). The price faced by recreationists is the cost of access to the recreation site (mainly the time and money costs of travel from home (or accommodation the previous night for international visitors) to the site), and the quantity demanded per year is the number of recreation trips they make to the greenway per year.

Following Hynes and Hanley (2006), it is assumed that a model of greenway recreation demand can be estimated assuming either a Poisson or a negative binomial distribution for the dependent variable. The Poisson model has been criticised because of its implicit assumption that the conditional mean of the expected number of trips, T_i, is equal to the variance. This mean-variance equality rarely holds since real data frequently exhibits '*overdispersion'*, where the conditional variance is greater than the conditional mean.The Poisson distribution is generalised to take into account this problem of over dispersion using the negative binomial probability distribution (Englin and Shonkwiler, 1995) where an individual, unobserved effect is introduced into the conditional mean. This probability distribution, used to develop the current travel cost model can be written as:

$$\Pr(T_i) = f(T_i) = \frac{\Gamma(T_i + 1/\alpha)}{\Gamma(T_i + 1)\Gamma(1/\alpha)}(\alpha\lambda_i)^{y_i}(1 + \alpha\lambda_i)^{-(T_i + 1/\alpha)} \qquad \textbf{Eq. 7.1}$$

where there are i = 1, 2, …, n observations, T_i is the number of trips to the greenway for individual i and λ_I is some underlying rate at which the number of trips occur, such that some number of trips in a particular year is expected, i.e. the mean of the random variable T_i ($E(T_i | X_i)$) is given by λ_i and $\lambda_i = \exp(X'_i\beta)$. The variance of y_i ($\mathrm{var}(T_i | X_i)$) is given by $\lambda_i(1 + \alpha\lambda_i)$. The vector X_i represents the set of explanatory variables reported for each individual *i*. It is a 1 by k vector of observed covariates and β is a k by 1 vector of unknown parameters to be estimated. The scalar α and the vector β are parameters to be estimated from the observed sample. Γ in Eq. 7.1 indicates the gamma function that distributes λ_i as a gamma random variable. Finally α is an overdispersion parameter to be estimated along with β. This parameter is a measure of the ratio of the mean to the variance of the number of trips taken. Larger values of αindicate greater amounts of overdispersion. The model reduces to the Poisson when α = 0.

Hellerstein and Mendelsohn (1993) show that the expected value of consumer surplus, *E*(*CS*), derived from count models can be calculated as in Eq. 7.2.

$$E(CS) = E(T_i | x_i)/\beta_p = \hat{\lambda}_i /(\beta_p) \qquad \textbf{Eq. 7.2}$$

Where $\hat{\lambda}_i$ is the expected number of trips, and β_p is the price (*i.e.*, travel cost) coefficient. Therefore the consumer surplus per trip is simply $1/-\beta_p$.

In thisanalysis, travel cost to the greenway is a key parameter for welfare estimation and is calculated using the Automobile Association (AA) of Ireland's calculations for the marginal costs of motoring for a car of average size of €0.28/km (AA, 2014). To this is added any costs associated with bike rental at the site. Only travel within the country is included as it is assumed thatany international visitors will be spending time away from the greenway while on their trip and have other interests to pursue. Therefore only their travel costs from their accommodation to the greenway are included. This is a common approach to take with international visitors to a site in recreation demand modela to avoid overestimating the willingness-to-pay of users.

7.3 Results and discussion

7.3.1 Sample characteristics

There were 1,002 initial respondents to the international greenway survey, however not all respondents provided sufficient data for the travel cost model or full greenway spending information (this question was optional and received one of the lowest response rates). For the travel cost model, the vital data are the number of trips made on greenways in the last year and the travel cost to the greenway. For this sample, the average number of greenway trips taken by respondents in the last 12 months was 37.8, with a standard deviation of 90. This large standard deviation is a reflection of the frequent use of greenways by some users (e.g. commuters).

As the travel cost model is designed for recreational use, it was necessary to further reduce the sample based on the number of trips taken. The sample was restricted to those taking 80 trips or fewer per year, which resulted in a sample with an average of 10 trips per year. It is envisaged that this cut-off, although arbitrary, excludescommuting or other utilitarian trips. This yielded a sample of 654 respondents for the travel cost model and the sample characteristics are given in Table 7.1.

Table 7.1 - Demographic and other characteristics of the sample

		%			%
Years of age	0-24	4.6	**Fitness**	Very fit	17.8
	25-34	21.5		Fit	44.9
	35-44	26.6		Average	33.1
	45-54	24.6		Unfit	4.2
	55-64	16.9	**Usual mode of travel**	Bicycle	30.4
	65+	5.8		Bus	4.2
Marital status	Single	35.1		Car (driver)	50.6
	Married	60.7		Car (passenger)	1.3
	Divorced	3.2		Motorcycle	1.2
	Separated	0.5		On foot	9.6
	Widow/widower	0.5		Train / tram	2.8
Employment status	Employed	80.9	**Cycling skill**	Highly skilled	32.8
	Student	6.2		Competent	58.5
	Unemployed	3.4		Inexperienced	8.7
	Retired	8.8	**Greenway mode of travel**	Cycle	73.6
	Homemaker	0.8		Run / Jog	6.9
Country of residence	Ireland	47.9		Walk	19.4
	UK	12.4		Wheelchair	0.1
	Rest of Europe	3.4	**Greenway journey purpose**	Commuting	18.0
	North America	31.8		Fitness/training	19.8
	Australia &NZ	2.6		Leisure/tourism	61.1
	Rest of World	1.9		Shopping	1.1

37% of respondents were female, potentially reflecting the gender gap in cycling.The average age of the sample was 44 years with a standard deviation of 12.7 years.The majority of respondents were between 35 and 54 years old, were married, and were employed. The average earnings of respondents was €53,000, although the response rate for this question was lower than for other questions (the optional nature of this question was emphasized) and this may have resulted in an inflated figure. This figure is significantly above the €34,000 average earnings for OECD countries (OECD, 2014).

The sample includeda large proportion of regular cyclists at 30%, considerably higher than commuting modal share in Ireland, USAor the UK (where cycling modal shares are 1-2%).The survey sample comprises predominantly competent and highly skilled cyclists of average to moderate fitness. A large majority of these greenway users cycle along the routes, though walking and jogging were prevalent also. The majority of respondents used greenways for leisure or tourism purposes, followed by fitness or training, and finally commuting. As outlined in Chapter 5, the vast majority of responses were received from countries where the majority of the population speaks English (90% respondents lived in Ireland, UK or North America).

7.3.2 Spending on greenways

A smaller sample of 458 respondents provided information on full greenway spending and these results (day trips and overnight stays) are categorized and presented in Table 7.2. The table shows that the average spending for day trippers is €18.01, which is 12.5% more than the €16 estimated by Lumsdon et al. (2009) for cycle tourist day trippers. Over 70% of this spending was directed towards *food & drink* and *petrol / diesel*. For users who stayed overnight to use a greenway, the total spend per night was €63. The average number of nights users stayed in the location while using the greenwaywas 3.2.Lumsdon et al. (2009) estimated average overnight spending to be €53.48 per night (€353 over 6.6 nights; 19% less than these findings), which may have been affected by the definition of the study (cycle tourists in Europe) and the longer typical trip length.

Table 7.2 - Spending on greenways for day trips and overnight stays

Spending category	**Day trip**	*%*	**Overnight (per night)**	*%*
Food & drink	7.01	*38.9*	16.88	*26.6*
Accommodation	0.00	*0.0*	25.60	*40.4*
Bike rental	2.25	*12.5*	2.59	*4.1*
Retail	1.34	*7.4*	4.68	*7.4*
Public transport	0.77	*4.3*	5.64	*8.9*
Petrol / diesel (gasoline)	5.90	*32.8*	6.49	*10.2*
Other	0.75	*4.2*	1.54	*2.4*
	18.01	*100*	63.42	*100*

The largest categories of spending were *food & drink* and *accommodation*. Interestingly, the amount spent per night on *petrol / diesel* for overnight users was similar to that of day trippers, however, spending on public transport was eight times larger. This appears logical as day trippers are more likely to be domestic recreationalists who drive to a greenway, while overnight users are more likely to be tourists. Furthermore, a lack of public transport frequency may encourage users to stay overnight.

Table 7.3 classifies spending by greenway users according to spending category and country of residence. Some of these statistics should be considered as descriptive of the survey sample rather than extending to each of the national cycle tourism markets due to the small sample sizes. The average total spend of all greenway user groups was €169.12 with an average group size of 2.33staying over 1.56 nights – thereby giving a spending of €47 per person per night.It should be noted that this table includes both daytrippers and those who stayed overnight.

The largest category of spending for all countries of residence isaccommodation, which accounted for between 34.2% and 38.6% of total spend (an average of €18 per person per night). This is followed by food and drink, and the cost of travel to the greenway, whether the cost of public transport or vehicle fuel. There are several differences in spending according to user residence and this is partly attributable to variation in group size (2.11-2.44) and number of nights stayed (0.57-1.80). Irish groups were found to spend the largest amount (€187). Once the group size and number of nights stayed is taken into account, the largest spend was by users from Australia / New Zealand who spent an average of €96 per person per night – however, as mentioned previously this is based on a small sample size.

Comparing the categorized spending of users from various countries suggests some interesting features of greenway use in each country and comparison between Ireland and the UK is particularly interesting due to similarities in climate, cycling modal share and many other factors. It can been seen inTable 7.3that Irish greenway users could spend more than twice the proportion of spending of UK users on *petrol / diesel* (14.3% v. 7.1%), while UK users spend four times as much on public transport. This may be an indication of the more connected nature of UK greenways, which, through the UK National Cycle Network, tend to be closer to urban areas. In Ireland, for example the Great Western Greenway is located 80 km from the nearest city (Galway) and 250 km from Dublin. Irish users also spend substantially more than UK users on bike rental – again potentially a consequence of distance travelled to the greenway or bicycle ownership rates which may increase bicycle hiring rates. In these figures for travel spending to greenways and for bike rental, Ireland seems to much more closely resemble spending by North American users than those from the UK or the Rest of Europe.

Table 7.3 - Spending on greenways by category and country of user residence

Spending category	All users	Ireland	UK	Rest of Europe	North America	Aus / NZ
n	*458*	*217*	*50*	*15*	*112*	*8*
Total group spending (€)						
Food & drink	46.21	52.26	53.00	35.68	50.73	38.38
Accommodation	64.34	72.21	66.20	56.13	63.33	45.00
Bike rental	7.73	10.14	1.50	3.52	7.33	1.88
Retail	12.49	11.58	9.64	19.85	1.33	0.00
Public transport	14.57	9.12	35.44	12.40	8.00	18.75
Petrol / diesel (gasoline)	19.50	26.85	12.80	9.02	21.33	10.00
Other	4.27	5.03	1.80	3.18	13.33	17.50
Total spend	169.12	187.18	180.38	139.77	165.40	131.50
Average group size	2.33	2.40	2.11	2.44	2.37	2.40
Average no. of nights	1.56	1.80	1.46	1.64	1.21	0.57
Spending per person per night (€)						
Food & drink	12.76	12.06	17.26	8.94	17.64	27.98
Accommodation	17.76	16.67	21.56	14.06	22.02	32.81
Bike rental	2.13	2.34	0.49	0.88	2.55	1.37
Retail	3.45	2.67	3.14	4.97	0.46	0.00
Public transport	4.02	2.10	11.54	3.11	2.78	13.67
Petrol / diesel (gasoline)	5.38	6.20	4.17	2.26	7.42	7.29
Other	1.18	1.16	0.59	0.80	4.64	12.76
	46.69	43.21	58.75	35.00	57.51	95.89
Percentage breakdown of spending						
Food & drink	*27.3*	*27.9*	*29.4*	*25.5*	*30.7*	*29.2*
Accommodation	*38.0*	*38.6*	*36.7*	*40.2*	*38.3*	*34.2*
Bike rental	*4.6*	*5.4*	*0.8*	*2.5*	*4.4*	*1.4*
Retail	*7.4*	*6.2*	*5.3*	*14.2*	*0.8*	*0.0*
Public transport	*8.6*	*4.9*	*19.6*	*8.9*	*4.8*	*14.3*
Petrol / diesel (gasoline)	*11.5*	*14.3*	*7.1*	*6.5*	*12.9*	*7.6*
Other	*2.5*	*2.7*	*1.0*	*2.3*	*8.1*	*13.3*
	100	100	100	100	100	100

A limitation to this comparison is, firstly, the lack of representative data and, secondly, the lack of more detailed analysis on the locations of the greenways used. It was not possible to compare spending across a range of specific international greenways (as was intended at the outset of the research) due to the sample sizes and wide international variation – it was instead necessary to assume that greenway use occurred in the respondent's country of residence. Neither was it possible to build a user spending model which could include as variables the country of user residence and the categorised spend. Further research should consider conducting surveys on a range of similar greenways internationally with a view to using statistical models to identify the statistically significant factors in greenway spending – see Section 7.3.

7.3.3 Willingness-to-pay, consumer surplus and recreational value

Willingness-to-pay in this context represents the total on average a person would be willing to pay to make a trip to the greenway. This approach involves modelling the effect of travel cost on the number of trips taken by greenway users. The consumer surplus element of WTP can be thought of as the access fee users would have been willing to pay on top of travel expenses to enter the greenway, but which is retained by the user. Parameter estimates for the greenway travel cost model are listed in Table 7.4. The negative binomial model was the preferred choice, as this was found to best fit the data in terms of the log likelihood value (a higher value implies a better fit).

The negative sign for the coefficient for travel cost implies that as travel cost increases, the probability of the number of greenway trips decreases, which is to be expected, and this is significant at the 1% level. Being of Irish nationality also reduces the probability of making a higher frequency of trips to greenway sites. Meanwhile, being a skilled cyclist or employed all significantly increase the probability of making more trips. Although being married, having children, being a student or retired all increase the probability of making a higher frequency of trips to greenway sites in the Poisson model, these parameters were not found to be significant in the Negative Binomial model (although still with positive signs).

Table 7.4 - Parameter estimates for the different specifications

Parameter	Poisson		Negative Binomial	
	$\hat{\beta}$	SE	$\hat{\beta}$	SE
Travel Cost	-0.014**	0.001	-0.013**	0.002
Age	-0.001	0.001	0.002	0.005
Married	0.219**	0.036	0.178	0.124
Student	0.605**	0.091	0.454	0.282
Retired	0.242**	0.084	0.255	0.277
Employed	0.340**	0.061	0.362*	0.178
Irish	-0.579**	0.037	-0.626**	0.108
Has children	0.060**	0.013	0.068	0.049
Fit or very fit	-0.017	0.032	0.079	0.106
Unskilled cyclist	-0.415**	0.075	-0.360*	0.197
Constant	1.896**	0.086	1.721**	0.267
Dispersion Parameter	-		0.358**	0.057
Log Likelihood	-4651		-1859	
Likelihood Ratio Chi^2	1107		108	

*Significant at the 5% level; **Significant at the 1% level

From Table 7.4, the travel cost coefficientwas found to be -0.013 and the consumers' surplus per trip was calculated to be €76.92 (i.e. $E(CS)$ =1/- β_p from Section 7.2.2). Given an average travel cost of €16.16 in our sample, this implies that the average total willingness-to-pay for a recreational trip to a greenway is €93.08. The fact that 82.6% of total willingness-to-pay is in the form of consumer surplus would indicate that a high proportion of the recreational value of visiting a greenway is retained by the user.

7.3.4 Willingness to make a direct financial contribution

Respondents were asked their willingness to make a direct financial contribution for greenway use. This stated preference is unlike the willingness-to-pay model above, which modelled number of greenway trips on travel cost, and is unlikeDeenihan& Caulfield (2015b), which used additional time spent cycling. The question was included to examine public perceptions of direct payment for greenway use and to get an insight into public conceptualisations of greenways, particularly against a backdrop of greenways as tourism 'products'. 72% of users were not willing to make a direct financial contribution (Table 7.5).

Table 7.5 - Willingness to make a direct financial contribution for greenway use

	All users	Ireland	International
Willing to pay (%)	28	25	31
Not willing to pay (%)	72	75	69
Willing to pay per hour	€2.18	€1.56	€2.71

Of those willing to pay, the average was found to be €2.18 per hour, with international respondents (€2.71) willing to pay more than those in Ireland (€1.56). Taking the example of the GWG, for which the average time taken to complete the 42 km length is 3.5 hours, 28% of Irish users may consider a charge of €5.46 to use the greenway for one full trip.Some respondents suggested a contribution for an annual pass or other form of payment. Others indicated a willingness to make a contribution for other facilities such as car parking and bike rental, or to pay more in taxes to enable further greenway construction.

However, there was a large majority in opposition to direct payment for greenway use (72% not willing to pay) and this has not been proposed in Ireland. The results of an open-ended question illustrate some of the reasons behind respondents' unwillingness to pay a charge:

- the deterrent to greenway use posed by charging
- the benefits to the local economy through spending elsewhere
- savings to the health service through health benefits
- the fact that greenways are often built using public funds
- conceptualisations of open public space

Two particularly illustrative responses received were:

> "I think these should not be taxed, they should be open to all, because they encourage people to get active. Putting a tax would deter many to use them. The indirect money made from using them would be: hotel, B&B, camping, bike shops, local stores. They would all make money out of the people using the infrastructure"

> "I would not pay anything to use it. However, I would pay more money in taxes to have more greenways built"

The opposition to paying for greenways at the point of use is an indication of the ownership of recreational public space and bodes well for the use of greenways. Greenway users are willing to spend significant sums on travel costs to greenways, to add substantial time to their cycling journeys to use greenways and to pay more in taxes to fund greenway construction, however, direct payment for greenway use is not advisable and is likely to deter usage.

7.3.5 Spending on the Great Western Greenway

As the GWG has been widely cited as an economic success story, and a demonstrator greenway for the Irish NCN, this route is analysed in more detail. Importantly (and perhaps as a consequence of this success) a larger survey sample (n=170) provided spending information (Table 7.6) allowing a level of detail which was not possible for a range of international greenways. The average group size of GWG users was 2.18 and the average number of nights stayed was 1.58. The average spend per user per night was found to be €50.87 – approximately 8% more than the average international greenway user and 18% more than the average Irish user.

Table 7.6 - Breakdown of spending on the Great Western Greenway

Spending category	Group spend (€)	Spend per person per night (€)	%
Food & drink	51.46	14.99	*29.5*
Accommodation	62.61	18.24	*35.9*
Bike rental	13.53	3.94	*7.7*
Retail	10.89	3.17	*6.2*
Public transport	7.72	2.25	*4.4*
Petrol / diesel (gasoline)	26.74	7.79	*15.3*
Other	1.69	0.49	*1.0*
Average total spend	174.64	50.87	*100*

Comparison of results with Fáilte Ireland / Fitzpatrick Associates (2011) is judged to be of major importance as these are the only other economic impact results available for greenways in Ireland and due to the weight which this widely-cited report carries in the appraisal of greenways in Ireland. This analysis uses a larger sample than that of Fáilte Ireland/Fitzpatrick Associates (2011) and, unlike that study, includes a breakdown of expenditure. These results confirm the findings of the report for the overall spend per person per night: Fáilte Ireland / Fitzpatrick Associates (2011) found this to be €50.71 (for users from overseas), while a figure of €50.87 (for all users) was found in this study – a difference of just 0.3%.

Categorized spending on the route was broadly in line with that of all greenway users – a notable exception was the spending on *petrol / diesel*, which accounted for 15.3% for the GWG, but 11.4% for all greenway users; this is mirrored in a lower spend on public transport, reflecting the rural location of this greenway. Based on these results, the relative accessibility of greenways linked to travel spending (fuel, public transport and to a lesser extent bicycle hire) appears to be a significant factor in variations in user spending and therefore economic impact.

It was envisaged that spending profiles would be compiled for a range of other greenways in Ireland and internationally which could serve as comparisons for the GWG. However, as outlined in Section 7.3.2, due to the small samples received (potentially due to response burden and question formats) and the wide variety of responses received, this was not possible. For example, 15 respondents provided detailed spending information on the Great Southern Trail (Co. Limerick), 12 for other named Irish greenways, 4 for the C2C, 6 for the North Sea Cycle Route (both UK) and 8 for the Camino in Spain. These limitations are discussed in the conclusion of the chapter.

7.3.6 Cycle tourism in Ireland

Of the respondents not resident in Ireland, 36% had previously visited Ireland and of these, 43% said that cycling accounted for a significant part of their trip. Satisfaction with walking and cycling facilities in Ireland was measured and is presented in Table 7.7. These results show that although a large majority was satisfied with walking facilities, the majority of respondents considered cycling facilities in Ireland to be inadequate or very inadequate.

Table 7.7 - Satisfaction with active travel facilities (%)

	Walking facilities	Cycling facilities
Excellent	10.9	5.5
Satisfactory	71.3	42.2
Inadequate	14.7	37.6
Very inadequate	3.1	14.7

In the open-ended questions that followed, the need for segregation from traffic and optimisation of user safety were recommended to improve satisfaction with facilities. Asked whether the construction of more greenways would encourage them to visit Ireland, 36% replied ‘yes’ and 41% chose ‘possibly’. A majority also noted that they would be willing to travel more than 10 km from their accommodation to use a greenway. The tourism potential of Irish greenways is discussed in Chapter 8.

7.3.7 Limitations

Reflecting on the methodology of this section of the research, there were some challenges which limited the results and discussion. Primarily, it was difficult to gather sufficient responses for a variety of international greenways on which to build categorised spending models; attaining representative samples is a further challenge. Beyond this, the response rate of the survey fell approaching the spending questions and it was necessary to use reduced samples (in comparison with Chapter 5). This declining response rate may be due to response burden (the spending section was located near the end of the survey) or question format (optional v. mandatory, number of categories etc.) or simply that it was challenging for respondents to recall. Therefore, further research could consider shorter, more precise and targeted survey instruments, including a roll-out of identical intercept surveys on a variety of international greenways. Despite these sample limitations, the findings on greenway spending were relatively consistent with international literature (15% margin of error against Lumsdon et al. (2009)) and route-specific literature (0.3% against Fáilte Ireland / Fitzpatrick Associates (2011)).

7.4 Conclusion

Handy et al. (2014) note the need for improvements in the assessment of costs and benefits of cycling to better inform policy-makers. In this regard, this chapter contributes to a number of key areas of greenway and cycling research:

1. Average greenway user spending was found to be €63 per night for overnight visitors and €18 for day-trippers. The largest categories of spending are accommodation, food and drink, and petrol / diesel. This information can be used as part of economic forecasting to predict the economic impact of routes at the planning stage.These findings are linked to those of Chapter 5, which noted the need for access to food and drink services every 11-20 km and highlighted the importance of other services such as opportunities for vendors along the route and connections to towns.
2. The recreation demand method (travel cost model) shows that the significant predictors of the frequency of greenway trips are: travel cost, employment, country of residence and cycling skill. Although travel cost is a deterrent to increased greenway use, such is the ‘willingness-to-pay’ to get to a greenway, that 83% (or €77 per trip) of this amount is retained by the user as consumer surplus. Broadly speaking, this illustrates the large recreational value that greenway users place on these resources. More specifically, this value can be compared with that for competing recreational or other uses.
3. Most users are opposed to paying directly for greenway access and therefore any return on exchequer investment is likely to be indirect, i.e. via the local economy, health benefits etc.
4. Spending on the Great Western Greenway, an Irish demonstrator greenway, was found to be €50.87per person per night and categorised spending was

similar to international greenways, although petrol / diesel spend was found to be higher than average.

5. A majority of respondents consider cycling facilities in Ireland to be inadequate and suggestions for improvements included improved safety and segregation from traffic.

This chapter holds some key lessons for the Irish NCN. Specifically, these results confirm and categorise the spending patterns of greenway users on the GWG and provide some detail on the potential for increased cycle tourism based on the construction of further greenways around the county. More generally, the willingness of greenway users to travel extensively for greenway access is important in Ireland given the currently isolated and disconnected nature of the NCN and this finding is unsurprising given the success of the GWG. Yet a tourism-oriented greenway network in scenic rural locations is not a panacea as low population catchments mean that other economic benefits, such as those due to modal shift and improved public health, are not realised (Deenihan et al., 2015b). Furthermore, car-dependence in travel to greenways (in part due to a lack of public transport integration) has negative implications for the environment (Chapter 6) and therefore economy. Route selection also raises concerns for equity; the communities which receive greenway investment will not only have a recreational resource for personal use, but will also be given the opportunity to benefit directly and indirectly from economic impact. These intersecting issues highlight the importance of the holistic approach advocated by the framework developed in Chapter 5, which will be used in the next chapter plot the development of the NCN.

8 Planning and design of the Irish NCN

In 2009, there was minimal policy or infrastructural provision for cycling in Ireland. By 2015, a series of sustainable transport policies were adopted, design guidance for active travel infrastructure was improved, and significant amounts of funding were awarded for the construction of a National Cycle Network. Despite this significant progress and future potential, the Irish NCN has not (to the best of the author's knowledge) been studied by any academic publication. This chapter plots the development of the NCN and greenways in Ireland to date, applying the framework created in Chapter 5and the methods and results of Chapters 4-7. Figure 7.1 shows the contributions of each previous chapter to this study and the contribution of this chapter to the case study which follows. The chapter is divided into general planning (route and network criteria and land acquisition) and more detailed design (cycling facilities and examples). It concludes with the relevance of this thesis to the NCN.

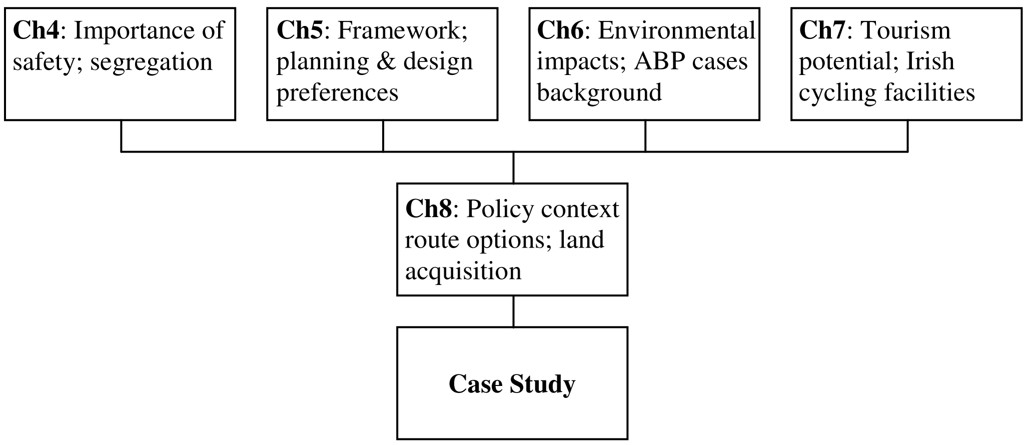

Figure 8.1- Contributions to and by this chapter

8.1 Background

8.1.1 Policy

A cycle network for Ireland was first mooted at national level by Fáilte Ireland (tourism development board) around 2006. In 2005, Fáilte Ireland carried out research on the Irish cycle tourism product in the context of relatively low cycle tourist visitor numbers and levels of satisfaction (Fáilte Ireland, 2007). During the 2000s, there was a decline in visitor satisfaction with cycling in Ireland; in 2000, 76% said that they were 'very satisfied' and by 2009 this declined to 38%. This decline was attributed to:

- Perceived safety of on-road cycling
- Lack of traffic-free routes
- Lack of integration with other modes of transport
- Lack of bicycle hire facilities

A key recommendation of Fáilte Ireland’s research was the development of a national designated cycle network, emphasising safety and including themed routes, improved surfaces and signage. Sustrans was commissioned by Fáilte Ireland to design a cycle tourism network (Figure 8.2) and proposed a series of strategic greenways (Fáilte Ireland, 2007).

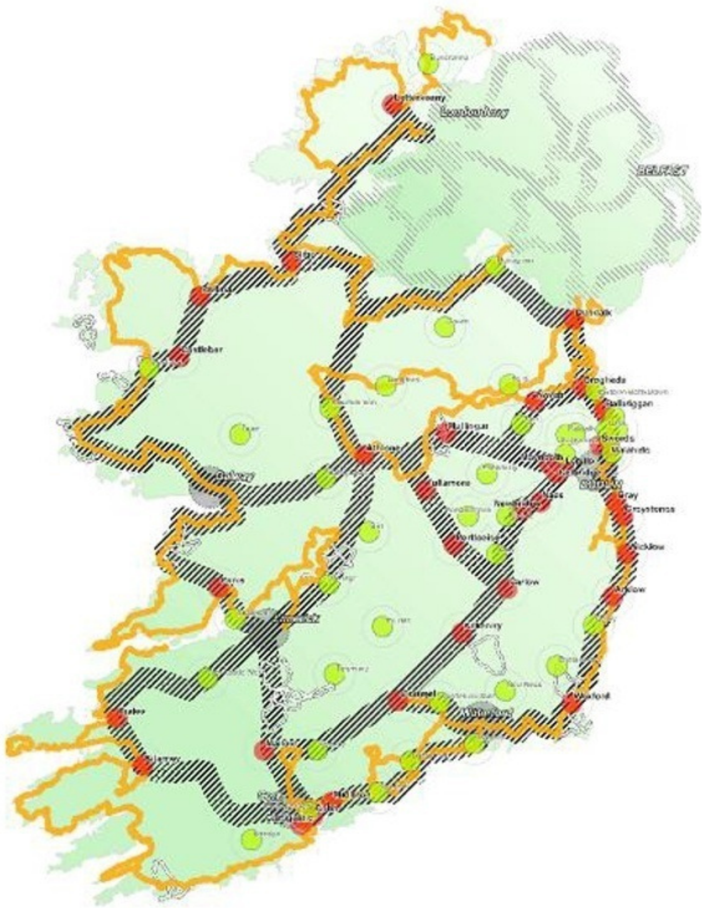

Figure 8.2 - National Cycle Network as proposed by Fáilte Ireland (orange) and NRA (black), towns over 10,000 population (green), towns over 5,000 population (red) (NRA, 2010a)

The adoption of *Smarter Travel* (DTTAS, 2009a) and the *National Cycle Policy Framework* (DTTAS, 2009b) represented a change in Irish transport policy, importantly placing priority on improving sustainability in the sector. DTTAS (2009a) emphasised the promotion of cycling for everyday purposes, particularly commuting, and recognised the need for safe, direct and coherent walking and cycling networks. The policy called for:

- the creation of traffic-free urban centres to facilitate cycling
- investment in a national cycle network with urban networks given priority

Although the policy includes the promotion of walking and cycling for rural recreation and cycle tourism, there is no reference to the Fáilte Ireland network. Furthermore, there is no reference to the Hierarchy of Provision. The emphasis in

DTTAS (2009a) is markedly different to Fáilte Ireland (2007): priority is placed on urban cycle networks as these are seen to deliver greatest potential for modal shift – the primary focus of the policy.

DTTAS (2009b) employed a different approach. This policy, which adopted the Hierarchy, emphasised the poor quality of previously constructed dedicated cycling infrastructure stating that the provision of this infrastructure has not, generally, increased cycling levels. The policy emphasised the reduction of traffic volumes (especially in urban areas and around schools), traffic calming in urban areas, and improving cycling safety at junctions. Objective 3 supports the provision of "dedicated signed rural networks" based on Fáilte Ireland (2007), noting that the promotion of recreational cycling in an important feature of creating a cycling culture. The policy envisaged recreational routes in and around urban centres, linking to rural areas.

The National Roads Authority was then commissioned to undertake a scoping study of the NCN and proposed a new network (NRA, 2010a). The criteria for forming corridors of the network included:

- connect each urban centre of population greater than 10,000
- facilitate commuter, leisure and tourism usage
- utilise or connect to existing road cycling infrastructure

This yielded a 2,000 km network of thirteen corridors of a different character to the tourism-based Fáilte Ireland proposal, though the two proposals overlap for 1,600 km – see Figure 8.2. The map was intended to provide a framework for the delivery of an NCN with broad corridors (rather than specific routes) selected, acting as a skeleton off which local authorities could develop further routes, and a basis on which to facilitate the funding of projects.

8.1.2 EuroVelo

A driving factor in the development of the Irish NCN has been a desire to link into the European cycle tourism market, including through integration with EuroVelo. EuroVelo (EV) is a Europe-wide cycle network managed by the European Cyclists Federation (ECF) (Figure 8.3). The network comprisesfourteen long distance routes covering a total of 70,000 km, including both on-road and off-road routes. Significant advances on this infrastructure have been made with 45,000 km of bike paths completed to date (ECF, 2014; Weston et al., 2012). The approach taken by the ECF involves upgrading existing cycling or road routes and re-branding the EV route through signage and interpretation. Some routes are well advanced, but others are just lines on a map (Lumsdon et al, 2009). While the ECF provides some route development guidelines, priority is given to national standards. By 2020, it is expected that all EV routes will be delivered on low-traffic roads or on traffic-free infrastructure with an asphalt or other good quality consolidated surface (ECF, 2011).

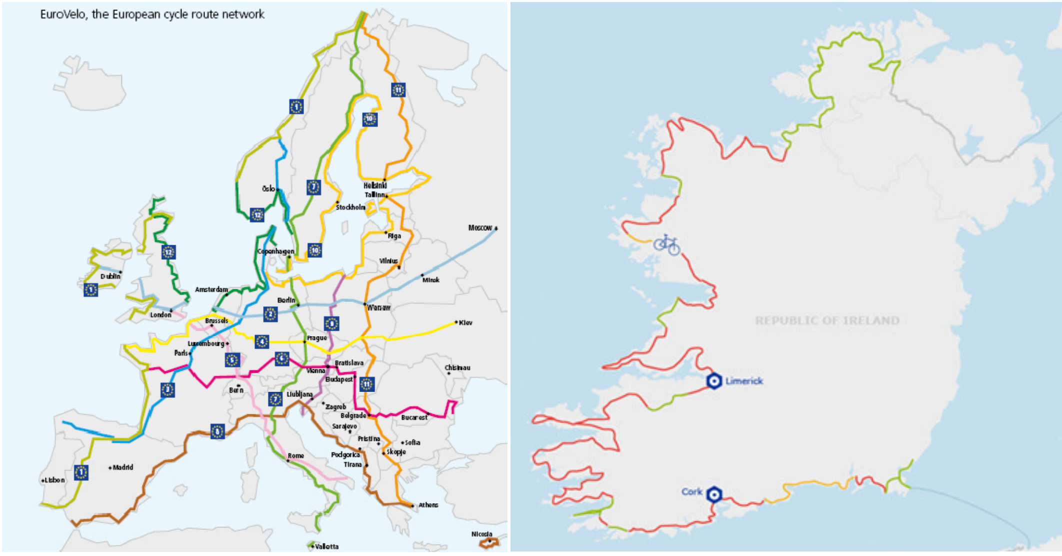

Figure 8.3 - Left: EuroVelo; right: EV1 in Ireland showing realised (green), not realised (orange) and planned (red) routes (ECF, 2014)

Two EV routes pass through Ireland:

- EV 1, 'The Atlantic Route' from Northern Norway to Southern Portugal, enters Ireland at Larne, passes through Northern Ireland and enters the Republic via the Kingfisher Trail. The route continues along the west coast, the south coast and ends in the south east of the country. The route comprises existing greenways and signed cycle routes.
- EV 2, 'The Capitals Route' begins in Moscow and travels through Minsk, Warsaw, Berlin, Amsterdam, London and Dublin and ends in Galway. Therefore, the route will be facilitated by the Galway to Dublin Greenway.

8.1.3 Funding 2009-16

In 2009 and 2010, NCN funding was provided by DTTAS (2010), along with Fáilte Ireland and Mayo County Council, to construct the first phase of the GWG. Although the NCN map as proposed by NRA (2010a) has not formally been adopted in policy, it was used as the basis for local government funding programmes in 2012, 2013 and 2014. In 2012, the National Cycle Network Funding Scheme awarded €7 million across 16 projects of varying infrastructure covering 334 km, including some short-distance greenways, but also for the adding of on-road cycleways to down-graded national roads (DTTAS, 2012a) (see Appendix 6). This followed an NRA-backed approach for on-road and off-road cycleways (see Section 8.3.1) rather than greenways.

The success of the GWG, following official opening in 2011 and through 2012, bolstered support for greenways amongst policy-makers, local authorities and the public. In 2012, citing the success of the GWG, the Minister for Transport, Tourism and Sport called on the Galway to Dublin corridor of the NCN to be "a cross-country, off-road cycle route, and this would have significant potential to be marketed internationally and attract new tourists who may want to walk or cycle across Ireland" (DTTAS, 2012b). Due to the lack of policy on NCN design, this ministerial statement informed planning for the Galway to Dublin Greenway and the wider NCN. The statement signalled a shift in focus to greenways and an orientation to tourism (cycling holidays etc.), and this is borne out in subsequent funding programmes. The emphasis on direct return on investment, particularly to local business, is an indication of the tourism orientation – as opposed to, for example, a greater emphasis on commuting or local recreation which could deliver health and other indirect economic benefits.

In 2013, the National Cycle Network Seed Funding scheme awarded €400,000 seed funding to 12 projects to enable local authorities to develop detailed greenway proposals (DTTAS, 2013). This seed funding scheme recognised the time and financial resources required by local authorities to plan and design NCN routes. The 2014-2016 funding programme called for "routes that are predominantly off-road" and "which will offer the best return in investment in terms of meeting demand and generating economic activity" (DTTAS, 2014a). €7 million was awarded across four greenways. A further €10 million was awarded to routes in nine counties as part of a national infrastructural stimulus programme. However, as Figure 8.4 shows, the routes completed do not form a coherent network at present.

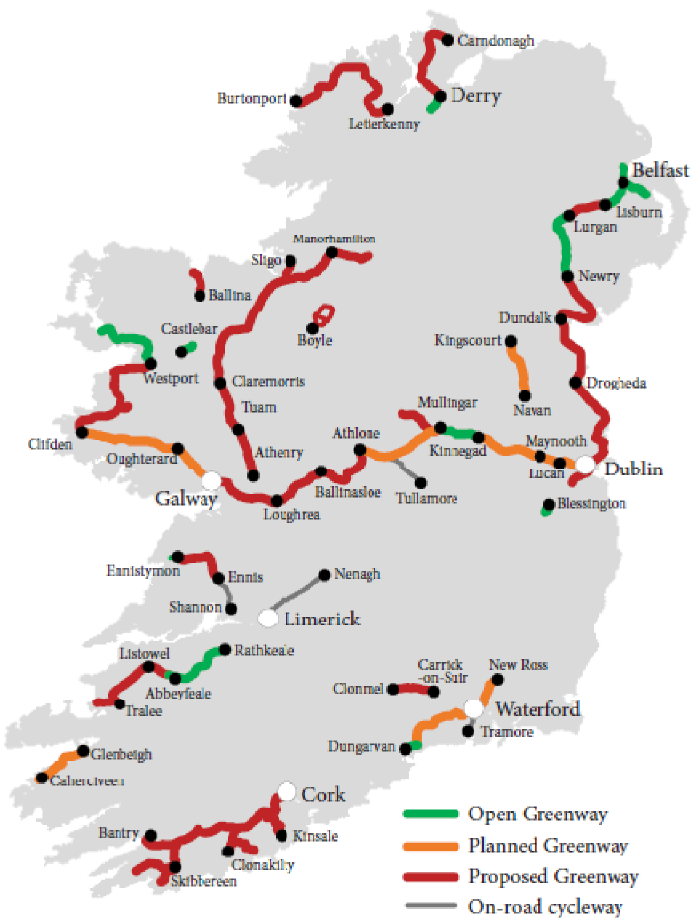

Figure 8.4 - Open, planned and proposed greenways over 10km in length

Between 2009 and 2016, €29.7 million has been invested in NCN projects; Table 8.1 presents the breakdown of funding by source and year. Other sustainable transport funding was awarded through the Active Travel Towns funding scheme (€6 million in 2012-13 and €6.5m in 2014) and the Smarter Travel Areas competition (€21.7 million for 2012-16). Routes within the Greater Dublin Area (GDA) are managed by the NTA, which invested €17.5 million and €13.4 million in walking and cycling projects in 2013 and 2012 respectively, including the Grand Canal Cycle Route as part of the Galway to Dublin Greenway (Aherne, 2014). Other routes which link to the NCN have been developed by local authorities.

Table 8.1 - Funding for NCN projects 2009-2014 (excluding GDA)

Year	Funding (€ m)	Funding programme	Funding body
2009-11	5.6	GWG funding	DTTAS, FI, DCRGA*
2012	7	NCN funding scheme 2012	DTTAS
2013	0.4	NCN seed funding	DTTAS
2014	0.4	Wild Atlantic Way funding	DTTAS
2014	6.3	NCN funding scheme 2014-16	DTTAS
2014	10	Infrastructure stimulus	DTTAS
Total	**29.7**		

*Department of Community, Rural and Gaeltacht Affairs – abolished in 2011 with remits subsumed into DECLG, DAHG and others

8.1.4 Future of the NCN

Recent policy announcements in three different sectors point to a bright future for greenways in Ireland:

1. **Tourism**. The new national tourism policy, Growing Tourism to 2025, recognises the importance of public funding for capital investment in tourism infrastructure, including greenways, and praises the innovation of the GWG. For future investment, DTTAS (2014b) proposes that all future investment must be evidence-based and within a framework for destination development.
2. **Rural development**. CEDRA (2014) and the €30 million Town and Village Renewal Scheme, cite the potential for greenways as vehicles of rural development and call on the use of state-owned lands for these routes.
3. **Transport**. The Capital Investment Plan (DPER, 2015) set aside €100million for Smarter Travel, including greenways. DTTAS (2014c) notes the environmental, economic, health and congestion benefits of walking and cycling calls for greater investment in sustainable modes to cater for future transport demand. It also calls for more effective spatial planning policies to cater for growing travel demand in an environmentally and economically sustainable way.

The Irish government has also identified the potential to leverage European funding for greenways (Kelly, 2014a), e.g. Rural Development Fund, Cohesion Policy (Regional Development Fund, Social Fund, Cohesion Fund), and funds directly from EU institutions (Ten-T, FP7, Life etc.) (Ensink, 2014). Funding for Irish NCN routes could take the form of sections of EuroVelo routes through the Ten-T programme, cross-border routes with Northern Ireland, or international routes through collaboration with Wales or elsewhere (Corrigan, 2014).

8.2 Planning

It is worth recalling at this point the planning framework developed in Chapter 5 which would be key to both the planning and funding of greenways:

- Accessibility – connectivity, land, population centres, facilities
- Safety – segregation, design (e.g. junctions)
- User experience – separation, scenery, attractions
- Design – see list of user preferences
- Environment – low-carbon, 'natural feel'
- Economy – maximising benefit:cost, facilitating cycle tourism

8.2.1 Network foundation criteria

Approaching the NCN from a tourism perspective, Fáilte Ireland (2007) cited the following planning requirements for cycle tourists: safe places to cycle, attractive routes with good scenery, well-connected and signposted routes and destinations avoiding long detours, opportunities to visit local attractions and specific places of interest, food, accommodation and refreshments available at comfortable intervals, and easy access to alternative cycle-friendly modes of transport. These criteria generally align with those formed in this research and led the organisation to propose the following for the NCN between urban areas:

- Utilise the network of country lanes and roads,
- Consider regional roads with low traffic volumes and speeds,
- Consider national roads with wide, well-surfaced hard shoulders,
- Consider providing cycle tracks beside busy roads,
- Investigate providing greenways along disused railway lines, canal towpaths and river-side paths.

A departure from this research is the proposal to use the hard shoulders of regional and national roads. Respondents to the international greenway survey clearly stated their desire to be well-separated from traffic and many qualitative responses mentioned that hard shoulders are inadequate for an attractive cycle tourism product.

Smarter Travel (DTTAS, 2009a) stated that walking and cycling facilities should:be a safe and pleasant experience, form a coherent network, place an emphasis on safety, directly serve the main areas where people wish to travel, provide priority over vehicular traffic at junctions, be free from obstructions, and have adequate public lighting. Furthermore, the policy notes that significant housing development should be fitted with safe walking and cycling routes, particularly routes to schools and access for people with disabilities. In general, DTTAS (2009a) emphasises the need for traffic-free or traffic-calmed urban centres and safe routes for walking and cycling for everyday journeys. With regard to the NCN, the policy recommends:

- the creation of traffic-free urban centres to facilitate cycling, and
- investment in a national cycle network with urban networks given priority.

The policy calls for the use of state-owned lands for walking and cycling trails, including canal tow-paths, disused railways and Coillte (forestry) land. This policy concentrated on improving sustainability in transport and therefore placed greater emphasis on urban networks, which show far greater potential for modal shift.

In the *National Cycle Policy Framework*, DTTAS (2009b) adopted the Hierarchy, prioritising traffic volume and speed reduction, and building cycle networks that are composed not only of cycle lanes and cycle tracks, but of cycle-friendly roads and junctions – designed to provide a safe passing distance of 1.5 metres. The policy defines 'cycle-friendly' routes as those that are safe, direct, coherent, attractive and comfortable (following CROW (2007)). The policy supports rural cycling networks,primarily for cycle tourists and also for recreationalistsin and around urban areas, by:

- using a mix of minor roads and some greenways
- using greenways for typically the first 10 km from busy urban centres
- considering disused railways and canal tow-paths
- considering hard-shoulders and the contiguous space of roads

The policy tends towards the integrationist position in the segregation debate, yet recognises the importance of tourist-oriented off-road infrastructure in some places.

For the *National Cycle Network Scoping Study*, the most influential document guiding the NCN, NRA (2010a) chose the following route corridor criteria:

- Connect the major cities and settlements of greater than 10,000 population
- Facilitate commuter, leisure and tourism usage
- Utilise or connect to existing road cycling infrastructure
- Use or connect to the proposed Fáilte Ireland network
- Link to ports and major airports
- Achieve good coverage countrywide
- Connect to the NCN in Northern Ireland

There is a strong emphasis on connectivity and accessibility in these criteria, which is not seen to the same degree in the preceding recommendations. Although this emphasis manifested in greater priority given to on-road and off-road cycleways, rather than greenways. This could be indicative of the NRA approaching the NCN from a traditional road planning perspective, rather than considering the different requirements for cyclists (e.g. cycle tourists and separation from traffic). Although, NRA (2010a) was the most influential for the initial funding for NCN routes in 2012, the experience of the GWG shifted the priority to greenway provision and this is evident in the funding criteria and design guidance.

While the four main contributions to NCN formation have been outlined previously, it should be noted that a wide range of other national policies and strategies are also relevant. For example, the recreation policies of several semi-state boards, particularly those with significant land holdings, are important (bodies are detailed in Appendix 8). Also, below national level, the formation of the NCN is informed by regional planning guidelines, city and county development plans, local area plans and walking and cycling strategies. A National Trails Advisory Committee has been assembled to account for the wide range of stakeholders and policy areas. Generally, these stakeholders are supportive of the concept of greenways, promoting rural recreation and development,but have not provided specific criteria for the formation of the network.

8.2.2 Route funding criteria

There have been three NCN funding programmes to date, as outlined in Section 8.1.3. The progress of these programmes display three connected trends: (i) towards greenways, (ii) towards a tourism orientation, and (iii) towards the need to demonstrate return on investment. Firstly, DTTAS (2012a) called for routes that would facilitate both local transport demand, recreation and tourism. Emphasis was placed on safety and the suitability of routes for all users. Specifically, routes had to consider existing cycle routes, potential to link to routes in other area and future plans for development of routes. Secondly, DTTAS (2013), offered seed funding for off-road greenways with potential to be world-class trip attractors, generating recreational, tourism and economic activity. Finally, DTTAS (2014a) called for routes that are *predominantly* off-road offering return on investment by generating economic activity. Table 8.2 presents the NCN funding criteria for the three funding programmes.

Table 8.2 - NCN route funding scheme criteria (DTTAS, 2012a; 2013; 2014a)

2012	2013	2014-16
Alignment with concept (e.g. safety)	Off-road, world-class route (e.g. length)	Off-road, world-class route
Potential demand (transport & tourism/day-trip)and economic impact	Tourism attraction in own right	Tourism / day trip attraction, local transport where feasible
Deliverability in time (no land ownership issues)	Potential for local and functional cycling	Destination attributes (scenery, traffic-free, safety)
Alignment with other transport, tourism, sport locations/priorities	Connectivity and future development plans	Family cycles (shorter distances between rest stops, junction warning signs)
Cost and potential co-funding	Geographic spread	

Thesecriteriaillustrate a shift of emphasis from the role of linking towns and general function as a transport corridor to a tourism and recreation role. In the 2014-16 scheme, the role as a transport corridor should only be considered *where feasible* and generally funded rural, unconnected greenways. Although it is positive that greenways have started to receive more attention (rather than say on-road cycleways), it is of concern that these cycling schemes could further marginalise cycling as a tourism or leisure mode of travel, rather than a serious option for everyday, utilitarian trips; this is discussed in the conclusion of the chapter.

8.2.3 Land acquisition: opportunities and constraints

The acquisition of land has proven to be a major factor influencing the planning of the NCN. The NRA route selection process was outlined in Section 2.8.2 and the first stage of this process is the identification of contraints – anything of an environmental, economic or legislative nature that could affect the development of a scheme. This framework is not fully applicable for cycling (see Section 2.8.2) and a reclassification is proposed here to reflect 'opportunities' and 'constraints' for routing and land acquisition. These factors can also determine the design characteristics of greenways, e.g. some land-use types (such as bogland) pose distinct design challenges. Some of the natural and artificial opportunities and constraints have been adapted from the NRA Project Management Guidelines in Table 8.3. As an example of how some factors can represent both opportunities and constraints: rivers provide scenic views and often have accompanying paths, but require a bridging point; busy population centres may be positive for commuters, but negative for some leisure cyclists. External parameters such as legislative frameworks, including access agreements and compulsory purchase, policy, plans, engineering standards etc should also be considered. Six examples, focusing on route opportunities, follow the table and will be referenced in the case study in Chapter 9.

Table 8.3 - Some natural and artificial opportunities and constraints

Natural		**Artificial**	
Opportunities	*Constraints*	*Opportunities*	*Constraints*
Woodland	Designated sites	Railways	RMPs
Bogs	Steep hills	Quiet roads	Traffic
Rivers	Rivers	Canals	Motorways
Lakes	Lakes	State infrastructure	Landfills
Parks		Population centres	Population centres
Landscape		Points of interest	

Bogland

Bogland can be suitable for cycleway construction due to the relatively reduced structural requirements when compared to roads. Bord na Móna (peat board) holds approximately 77,000 ha (770 km^2; 1% total Irish land area) over 130 bogs, mainly in the midlands, and has constructed cycling routes in the past, e.g. Lough Boora, Co. Offaly. Bord naMóna has constructed 700km of permanent railway track, 140km of temporary railway track and several railway bridges to transport peat, which may be suitable for routes (BnaM, 2015). Specific design challenges include the minimisation of environmental impact (see Chapter 6) and the use of light-weight materials and structures (cf. Abbeyleix Bog Project (2015) for boardwalks over bogs).

Woodland, National Parks & Nature Reserves

Forests can provide scenic cycle routes and many forest roads can act as route facilitators. Coillte (forestry service) owns over 445,000 ha (4,450 km^2) in Ireland – about 6% of total land cover. Coillte owns the longest walking trail network in Ireland and have, to date, developed over 2,000km of walking and cycling trails, 150 recreation sites and 10 forest parks (Coillte, 2015). There are also six national parks in Ireland, managed by the National Parks and Wildlife Service. Nature Reserves are areas of importance to wildlife and are protected by ministerial order (NPWS, 2015), there are 72 in Ireland. These parks and nature reserves include a range of walking and cycling routes. As many of these areas form environmentally designated areas (SAC, SPA, NHA), careful planning and design are required to minimise environmental impact and to negotiate the planning process.

Railways

Railways are seen as particularly desirable for greenway development as the alignment are usually state-owned, flat, straight, connected to town centres and can offer scenic views. A rail-with-trail is a greenway located adjacent to (or on) an active railway (Birk et al., 2002). Thousands of kilometres of these routes have been successfully built and are in regular use, particularly in Spain, UK, USA, Canada, Australia and New Zealand (Birk et al., 2002; Aycart Luengo, 2012). Railways in Ireland went into decline during the proliferation of the motor car and there are hundreds of kilometres of abandoned and disused lines across the island of Ireland (Figure 8.5) (see Hennessy (2012) for an animated railway timeline). Several of these routes have already been converted to greenways, including the GWG and Great Southern Trail (Co. Limerick) and others are planned. Where the ownership of the alignment has not remained in State ownership, access agreements or land purchase are required. In the development of greenways on closed railways, conflict has emerged between greenway campaigns and campaigns to reopen railway lines, e.g. between the Sligo-Mayo Greenway and the Western Rail Corridor. Specific design challenges include the assessment and renovation of bridge and other structures.

Canals and navigations

Figure 8.5 shows the major canals and navigations on the island of Ireland, numbered 1 to 7: Barrow navigation, Erne system, Grand Canal, Lower Bann navigation, Royal Canal, Shannon Erne waterway, and Shannon navigation (Waterways Ireland, 2015). There are also many shorter urban canals in Irish cities, e.g. Galway and Limerick. The Royal Canal connects Dublin to the River Shannon (at Cloondara, Co. Longford) (145 km) and currently includes sections of the Galway to Dublin Greenway. The Grand Canal connects Dublin to the River Shannon (at Shannonbridge) via Tullamore (132 km) and has the potential to be a further cross-country route, however there are fewer population centres and would require 20 km spurs. Butler (2009) outlines the contemporary role of canal towpaths and points to measures necessary for recreational use. Safety measures and restrictions on the use bituminous materials constitute key design challenges (cf. McCool (2013)).

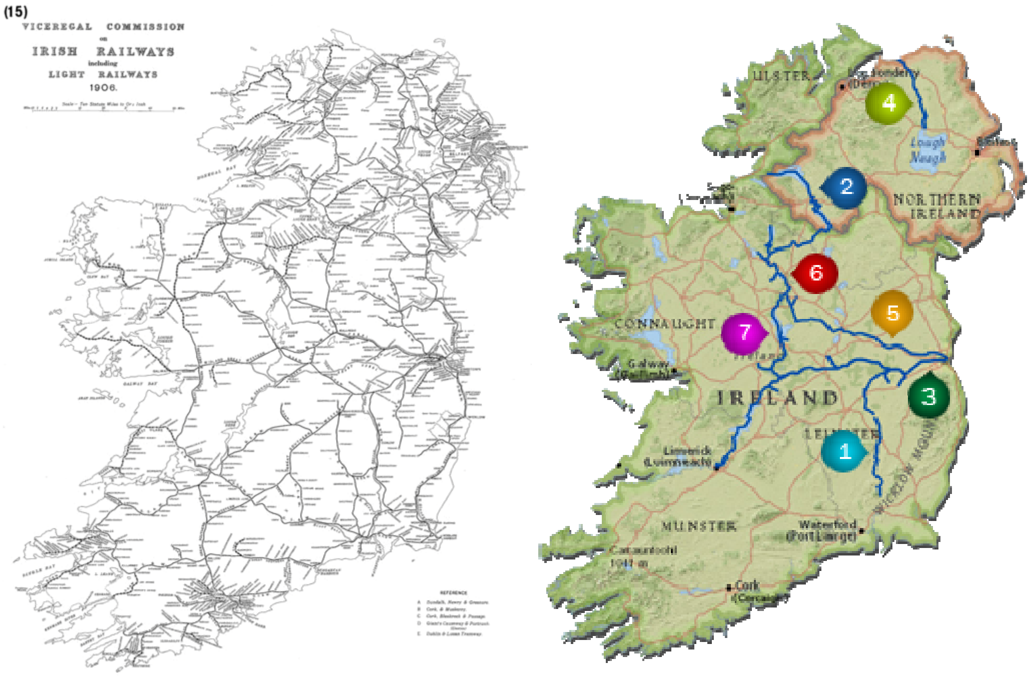

Figure 8.5 - Left: Irish railways in 1906 (Winchester, 2014); right:canals and navigations (Waterways Ireland, 2015)

Access agreements

Where State lands are not available for greenway development, access agreements or land purchase must be considered, e.g. in the case of green-field development. Permissive access has emerged as the preferred model (Kelly, 2014b) and has been implemented on the GWG (Connor, 2013). In this arrangement, a local authority negotiates agreements with individual landowners to secure land for the greenway without direct payment (other than accommodating works – fencing, drainage etc.). The agreement stipulates that the route close for one day per year to prevent the establishment of a right of way and any one landowner can withdraw from the agreement at any time. Disadvantages of the permissive access model are its precarity (GWG has closed due to disputes between the local authority and landowners) and the resource intensity of negotiation (Kelly, 2014b). Other land access options for greenways include recreational access schemes, such as the Mountain Access Scheme and Walks Scheme. Now discontinued, these schemes provided landowners with payments for the development and maintenance of national walking trails. Buckley et al. (2009) found that 21% of Irish landowners are willing to provide access free of charge for recreational walking routes. 28% are willing to provide access if compensation is provided and the mean willingness-to-accept for these landowners was found to be €270/km per year. However, 51% of landowners are not willing to provide access.

Compulsory purchase

Compulsory purchase for transport infrastructure development is common and has its origins in the Wide Streets Commission as well as in land acquisition for canals and railways. In Ireland local authorities have the power to use CPO “for the purposes of performing any of its functions” (Donoghoe, 2015). Compulsory purchase has only recently been suggested for greenways, precipitated by the route selection of the Galway to Dublin Greenway. The justification of this method is the percarity of permissive access for a scheme of this length and investment and the lack of available State lands (AECOM/Roughan O’Donovan, 2013a; Donoghoe, 2015). However, opposition by landowners to the use of CPOs has resulted in the shelving of the Ballinasloe-Galway section of the Galway-Dublin Greenway (Figure 8.6) and has delayed the Glenbeigh to Caherciveen/Renard route (Co. Kerry) (O’Sullivan, 2015; Tierney, 2015). Further information on land acquisition is provided in the case study in Chapter 9.

Figure 8.6 - Opposition to greenway development in east Co. Galway (N65 outside Loughrea) and west Co. Galway (Moycullen/Oughterard) (Galway Bay FM, 2015)

8.3 Design

This section describes the facility options for NCN routes in rural, inter-urban areas, building on Section 2.3 of the literature review, which broadly outlined the types of cycling infrastructure. The analysis considers four types of infrastructure: on-road cycleways, off-road cycleways, greenways and quiet local roads. As cycleways are defined as public roads, appeal to different users and are shaped by policy, funding, legal and design guidance developments, careful consideration is required in route selection – as shown in the An Bord Pleanála cases which follow. The choice of prevailing route type will characterise the NCN.

8.3.1 Facility options

On-road cycleways

On-road cycleways are separated from motorised traffic by delineation markings at least 0.5m wide and can cater for cyclists and pedestrians (NRA, 2010a) – see Figure 8.7. Hard shoulders (after surface treatment / enabling works) may be considered for NCN routes, thereby avoiding land acquisition. The road classification and posted speed limit are vital considerations for on-road cycleways. In Ireland road classifications (and typical speed limits) are as follows: Motorways (120 km/h), National (100 km/h), Regional (80 km/h), Local (varies). Inside built-up areas, the speed limit is 50 km/h; a special speed limit of 30 km/h, can be used in the vicinity of some schools and in some built-up areas to promote road safety and cycling (RSA, 2012). Following motorway construction in recent decades, many national roads have been downgraded to regional status and are considerably less trafficked. These roads generally offer sufficient width for the construction of on-road cycleways (Roscommon CoCo, 2012).

Figure 8.7 - On-road cycleways R445 Limerick to Nenagh (Limerick Cycling Club, 2013) (left) and R292 Sligo to Strandhill (ROD, 2013) (right)

On-road cycleways have been aligned on a number of downgraded national roads. However, the ambiance and comfort (and therefore usage and value-for-money) of these routes was called into question (Limerick Post, 2012; NRA, 2014a).This criticism mirrors the findings in Chapter 5 for user experience and a preference for separation from motorised traffic. Although on-road cycleways are cost-effective and quick to develop and embody little to no carbon, this form of infrastructure exposes users to vehicular emissions and is less likely to attract cycle tourists and recreational users, particularly families.

Off-road cycleways

In rural areas, cyclists have traditionally used the hard-shoulders of national roads and these hard-shoulders can be improved for cycling. However, new road types (Type 3) without hard-shoulders have been introduced by the NRA and accommodation for pedestrians and cyclists on these roads is therefore required (Roughan O'Donovan, 2009). Off-road cycleways are segregated from the road surface using a grass verge or a related form of physical separation (NRA, 2010a; NRA, 2014a) – see Figure 8.8. These routes use roadside verge space for construction and therefore may or may not require land acquisition. The advantages and disadvantages of off-road cycleways are discussed in the context of the ABP cases.

Figure 8.8 - Off-road cycleways on the N56 Cloghboile to Boyoughter (left) (ROD, 2014a) and N59 at Derrylea (right) (ROD, 2014b)

Greenways

A review of greenway theory and development was provided in Section 2.3 and Chapter 5 detailed user preferences. While NRA (2014a), in the context of rural cycle schemes, defines a greenway as any cycleway in a recreational environment, this thesis places a greater emphasis on separation from motorised traffic, closer to that of a trail. These routes are known by a wide variety of terminology, including: shared-use paths, stand-alone paths, multi-use trails, and rail-trails. Considering trails, the Irish Trails Strategy (ISC, 2007) defines a recreational trail as a corridor, route or pathway for recreational walking, hiking, cycling, canoeing and horse-riding. There are 44 National Waymarked Trails, which are classified and managed by the NTO. Focusing on greenways for cycling, routes have been developed in non-vehicular environments such as in parks, next to waterways and shorelines, and more recently as part of the NCN. Long-distance tourism and recreation routes have been built in Co. Mayo and Co. Limerick and dozens of similar greenways are planned or have been proposed in most counties (see Appendix 7). Urban greenways have been built in the Tolka River Valley and along the Grand Canal in Dublin City, and are planned across the GDA, Galway City and other urban areas.

Quiet local roads

Ireland has a dense local road network of quiet, low-trafficked, rural roads which offer a significant opportunity for cycling routes (Laird et al., 2013; Fáilte Ireland, 2007; van den Dool & Murphy, 2014). Several of these roads are located in less densely-populated, scenic west coast region with significant cycle tourism potential. The main issues with these roads relate to safety, particularly due to motorised traffic speed and volume (as highlighted in Chapter 4 for urban roads). EuroVelo guidelines (ECF, 2013b) state that routes on roads with speed limits in excess of 30 km/h should carry no more than 2,000 vehicles per day (or preferably less than 500) as may be the case for many rural Irish roads. However, nearly all rural roads are designated speed limits far in excess of 30 km/h – generally 80 km/h. (A new rural speed limit (and road sign) was introduced in March 2015 and means that motorists should use their own judgement, though 80 km/h technically remains the speed limit). In these scenarios, the Guidance Graph (Figure 2.7, Section 2.3) and NRA (2014a) call for off-road infrastructure.

Figure 8.9 - Advisory cycle lanes on EV2: D-Netz 3, Saxony-Anhalt, Germany (left) (Anhalt-Dessau-Wittenberg, 2015) and LF4, South Holland, Netherlands (right) (ECF, 2015)

A potential compromise is the use of advisory cycle lanes - marked by broken white lines and motorised vehicles may enter the cycle lane for overtaking (described in Section 2.3.3). These lanes have been used in Germany and the Netherlands (also known as ‘auxiliary lanes’).Advisory cycle lanes have been developed in a small number of locations in Ireland since their inclusion in the National Cycle Manual (such as Cemetery Road in Sligo Town), but been met by criticism (usually based on poor application by LAs and a lack of understanding by motorists). If this route type is to be used, it is vital that only genuinely low traffic roads (e.g. below 2,000 veh/day) are considered. Other potential safety issues include excessive speed, poor sight lines, surface quality, dangerous junctions.

8.3.2 Evolution of design guidance

The design guidance and legal context of the NCN is of far-reaching importance for route layout within the network, strongly influencing the choice between designing for on-road cycleways, off-road cycleways and greenways. The NRA has played a formative role in the NCN and, given its role in national road design and responsibility for delivering the Galway-Dublin Greenway, also plays a specific design role. It is therefore worth briefly examining the evolution of NRA guidance on rural cycle scheme design and later the planning and legal context of this design.

On-road cycleways and the general use of hard-shoulders of national (and down-graded national to regional) roads were judged by the NRA to meet the statutory obligation (under the Roads Act) to accommodate all road users, including pedestrians and cyclists. This also aligned with the NRA (2010a) concept of linking urban centres as part of the NCN. Over 100 km of on-road cycleways were constructed, however, the attractiveness and usage of these routes were called into question. The introduction of new road types (e.g. Type 3) for improvements to national roads in rural areas with relatively low traffic volumes required a new provision for pedestrian and cycle facilities as no hard-shoulder would be provided. In this provision, it was considered that the locations applicable for this road type coincided with locations popular with cycle tourism and intended for the inclusion in the NCN. A review of the Type 3 single carriageway cross section was completed to include provisions for cyclists and pedestrians on national roads in rural areas (NRA & ROD, 2009) and this was followed by an NRA Interim Advice Note on provisions for cyclists and pedestrians on Type 2 and Type 3 carriageway national roads in rural areas in 2012 (NRA, 2012a). These road types were piloted in short sections in Connemara (N59) and the Dingle Peninsula (N86). Finally, a full Rural Cycle Scheme Design standard was published as part of the DMRB in 2014 (NRA, 2014a).

The Type 3 road section comprises lane widths of 3m, narrower than the Type 1 and Type 2 lane widths of 3.65m and 3.5m, respectively – see Figure 8.10 and Figure 8.11. This narrower width, designed to mitigate impact on the landscape, was expected to impact on the perceived comfort and safety in sharing the road lane with motorised vehicles and, therefore, separate cycleways were provided. A full rural cycle scheme design standard, TD300 (NRA, 2014a), was developed, reflecting the increased priority given to cycling infrastructure design. Regarding facility selection, TD300 states that off-road facilities must be provided for roads with a 85^{th} percentile speed of 50 km/h and/or an AADT of over 1000 motorised veh/d. It notes, however, that off-road cycleways require more land (potentially involving CPO) and that interface with the road requires significant consideration. Now standardised, rural cycle facility choice is summarised in Table 8.4. The major question left open by this standard is the choice between off-road cycleway and greenway (both potentially cycle tracks); this question arose in two ABP cases.

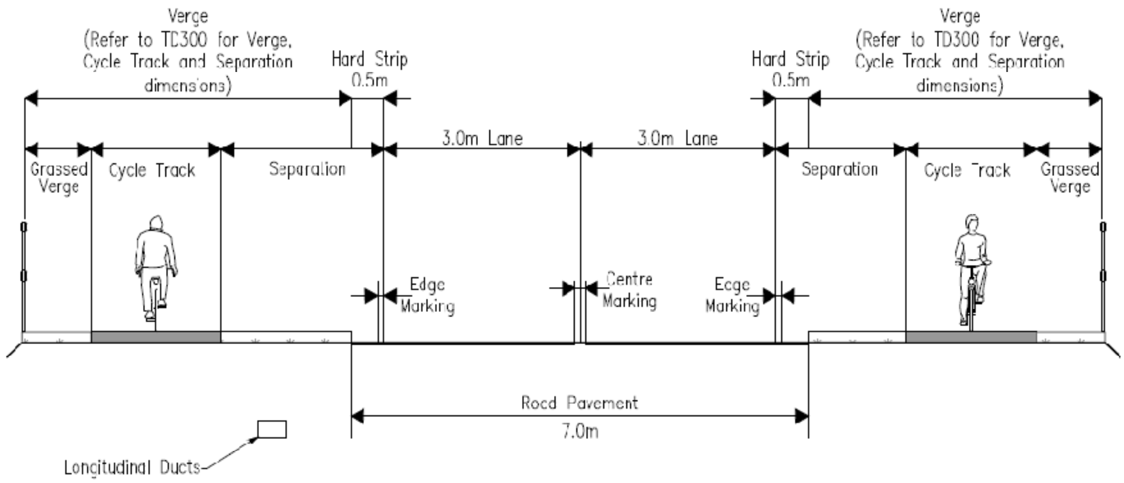

Figure 8.10 - Type 3 single carriageway cross-section (NRA, 2014a)

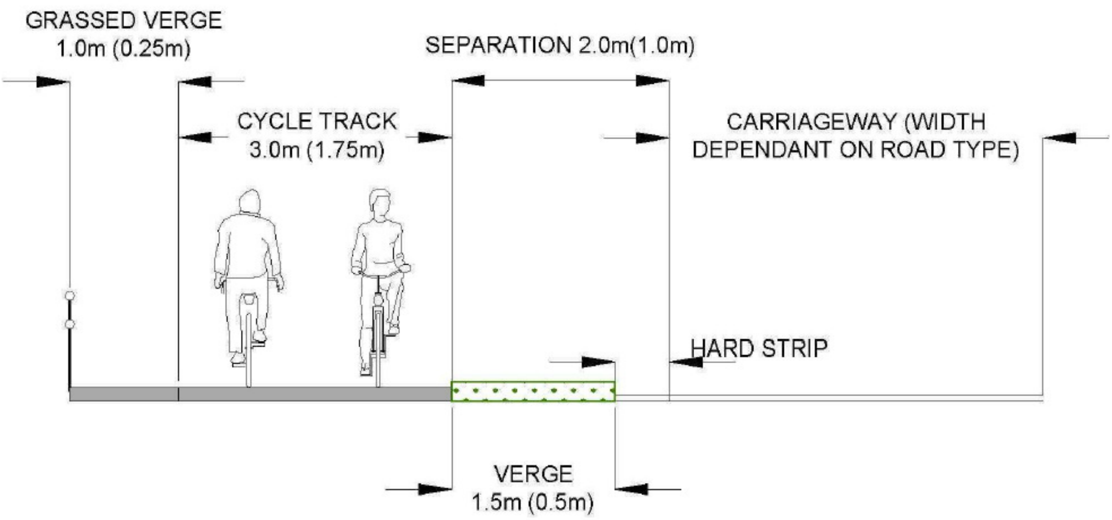

Figure 8.11 - Off-road cycleway cross-section (NRA, 2014a)

Table 8.4 - Rural cycle facility choice (NRA, 2014)

85th Percentile Speed / Traffic Volume	< 50 km/h	50-60 km/h	60-80 km/h	> 80 km/h
< 1000 AADT	Shared Road Space	Cycle Lane / Off Road Cycle Track	Off Road Cycle Track	Off Road Cycle Track
1000-6000 AADT	Cycle Lane / Off Road Cycle Track	Cycle Lane / Off Road Cycle Track	Off Road Cycle Track	Off Road Cycle Track
> 6000 AADT	Off Road Cycle Track	Off Road Cycle Track	Off Road Cycle Track	Off Road Cycle Track

8.3.3 An Bord Pleanála cases

An Bord Pleanála (Planning Board) is responsible for appeals of local authority planning decisions and strategic infrastructure development (including roads) under the Planning and Development Acts (ABP, 2013a). National Cycle Network routes have featured in two significant cases, which have an important bearing on corridor design. Both cases relate to secondary national roads in rural, high-tourism and Gaeltacht (Irish language speaking) areas (consult Figure 8.2 and Appendix 7 for context mapping).

N59: Oughterard to Clifden

In 2012, Galway CoCo sought permission to build the Connemara Greenway between Oughterard and Clifden (52.4 km). The greenway is planned to follow the abandoned railway line for all save 11.7 km (22%) of total length, where railway sections were incorporated into the N59 alignment. For this section, Galway CoCo intended to provide an off-road cycleway adjacent to the N59. However, there was opposition (including from Galway Cycling Campaign) to this form of infrastructure on the basis that this design is sub-optimum for a tourism-orientated greenway and that a suitable traffic-free alternative exists in the forms of unused railway trackbed and quiet local roads (which were presented to ABP at an oral hearing - Figure 8.12)

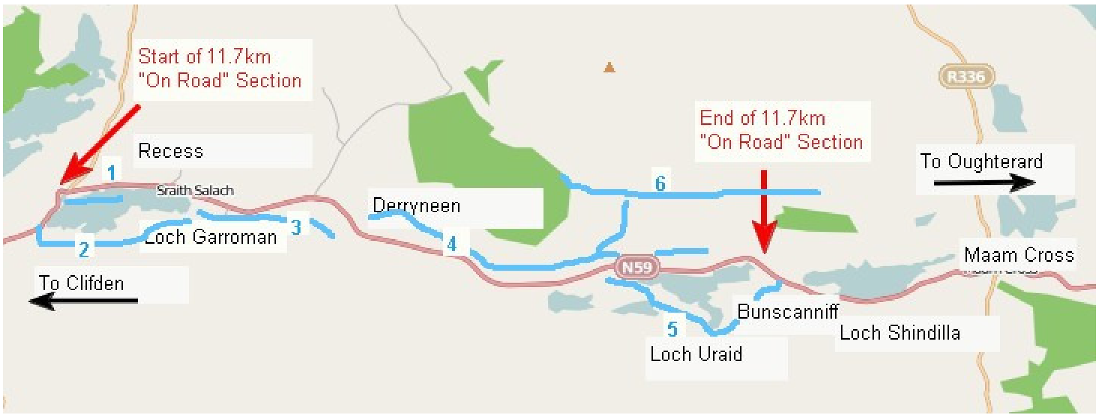

Figure 8.12 - Alternative quiet local roads (blue) presented to ABP for Connemara Greenway

Galway CoCo accepted some of these alternatives and halved the length of off-road cycleway to 5.2 km. The council also agreed to provide a 2.5 m separation (0.5 m hard-shoulder and 2 m verge) between the off-road cycleway section and the carriageway edge. Other objections were lodged based on landownership and environmental impact. ABP (2012) granted permission for the greenway on the conditions that separation between users and motorised vehicles is maximised as well as other environmental-based conditions. The case shows that the local authority originally sought the option of an off-road cycleway where there were alternatives; however, the local authority was prepared to provide further separation for this section to maximise greenway-quality sections, emphasising separation. At the time of writing, Galway CoCo is in consultation with landowners, but has not been granted any substantial funding. The route between Oughterard and Galway City is also at the landowner consultation phase, but has faced some opposition (Figure 8.6).

N86: Dingle to Camp

The second case, which also began in 2012, saw Kerry County Council request planning permission for the N86 Dingle to Annascaul and Gortbreagoge to Camp road improvement scheme, worth €65 million. The aims of the scheme were to improve road safety along 28 km of the main route through the Dingle Peninsula and to facilitate the economic development of the area, particularly in the context of the Wild Atlantic Way (tourism driving route). The scheme included an off-road cycleway in a Type 3 layout (Figure 8.13). The Dingle Peninsula is regularly visited by cycle tourists and the N86 forms part of the EuroVelo EV1, the Atlantic Route.

Kerry CoCo submitted an Environmental Impact Statement (EIS) to ABP, arguing that the road upgrade was necessary and that the cycleway would improve conditions for cycle tourists in the area, citing Fáilte Ireland (2007). The Irish Cycling Advocacy Network, Cyclist.ie, opposed the scheme at the oral hearing, referring to it as a 'fake greenway'. It was argued that recreational cyclists are not looking for just any traffic-free facility, but one that is away from noise, smell and other disturbances due to high-speed vehicular traffic. The campaigners pointed to the success of the GWG and pointed out that the abandoned Tralee-Dingle railway and quiet country roads exist as off-line alternatives (Cyclist.ie, 2013).

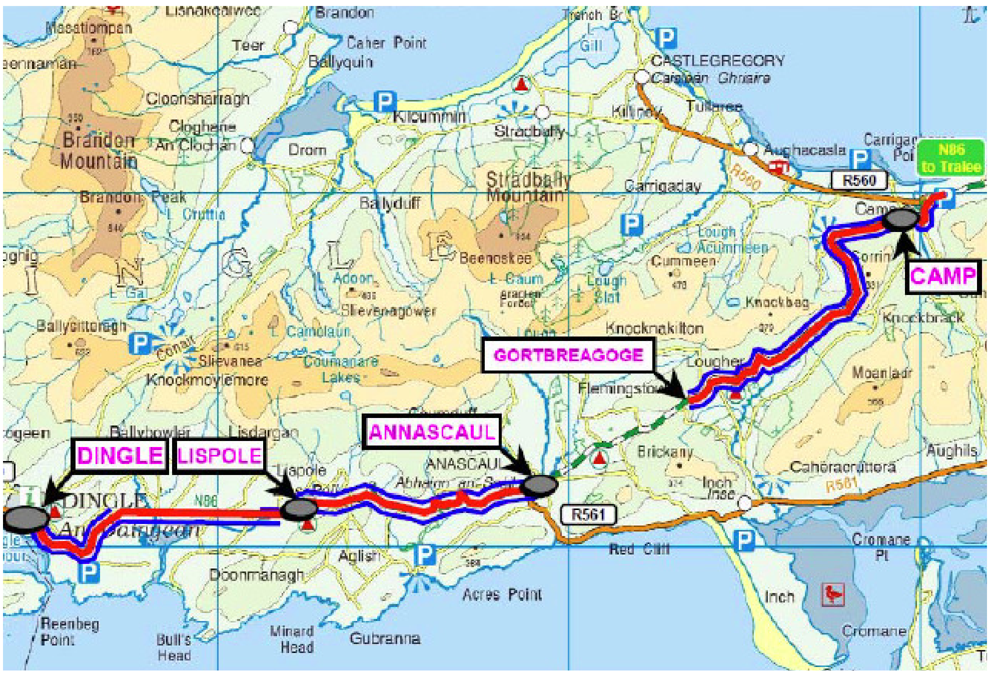

Figure 8.13 - N86 improvement scheme: road (red) and cycleways (blue) (RPS, 2011)

Although ABP (2013b) accepted the need to upgrade the road, the Board refused to approve the EIS of the scheme on the basis that the 28 m width of the construction corridor was excessive, resulting in excessive loss of natural habitats. ABP considered the inclusion of proposed cycleway to significantly contribute to the width of the corridor and that the route might not be attractive for pedestrians and cyclists due to the proximity to a busy secondary national route, resulting in underutilisation of the cycleway. An Bord Pleanála instructed Kerry CoCo to omit the cycleway from the width of the road alignment and to consider alternatives for the cycling route.

However, in 2014, the ABP (2013b) ruling was overturned in a judicial review in the Commercial Court by Judge Peter Charleton (2014). Charleton ruled that ABP does not have the power to decide which roads are necessary and how they should be built –this is the duty of the local authority. Furthermore, since ABP is a road authority, subject to the Roads Act 1993-2007, it must consider the needs of all roads users. ABP, by excluding the cycleway, failed to consider the needs of pedestrians and cyclists in the road scheme. Without off-road cycleways, Charleton judged that cyclists would be expected to share the roads with vehicular traffic. Although there was a proposal to provide for cyclists on an alternative dedicated trail, Charleton ruled that ABP has no power to refuse permission on the basis that an alternative route for pedestrians and cyclists be constructed. Charelton also noted that the alternative route has a steeper gradient and that greenways take years to deliver – if they ever are in fact delivered. The ABP (2013b) decision to refuse permission was therefore quashed and Kerry CoCo was invited to resubmit the EIS. In November 2014, ABP reversed their position and approved the cycleway as part of the full scheme.

In 2015, An Taisce was granted leave to review ABP's November 2014 decision based on environmental impacts of the scheme, including on the visual landscape, stating that an EIS should have been completed across the full length of the scheme rather than sections (known as 'project splitting'). The local population responded to An Taisce's objection by organising a protest of 700 people in Dingle in February 2015, arguing that the road improvement scheme should proceed on the basis of economic development and road safety. As of November 2015, the scheme is in the Court of Appeal. This case illustrates the complex set of actors and legal framework which are sometimes in play in cycling infrastructure developments.

8.4 Conclusions

A shift in Irish policy has increased the emphasis on promoting walking and cycling for sustainability in transport. Furthermore, work by Fáilte Ireland has highlighted the potential for increased cycle tourism in Ireland, including the facilitation of EuroVelo, but only on the basis of improved safety and infrastructural provision for cycling. The National Cycle Network has emerged from this background as a vehicle to promote cycling for transport, tourism and recreation. The success of the Great Western Greenway inspired investment in the NCN and encouraged a tourism and greenway orientation for routes. Government schemes now prioritise the economic impact of cycle investment schemes and require demonstration of value for money.

Despite these developments, there has been little research on the NCN planning and design or indeed the impacts on user safety, economy and environment. This chapter pioneers a critical analysis of the Irish NCN, identifying route selection criteria, policy requirements, funding mechanisms, infrastructure options and research required (this information will be used in the case study chapter which follows). Moreover, the methods and results throughout this thesis are highly relevant for international greenway and cycle networks. There are four main conclusions:

1. **Public engagement and user preferences**. Disputes arising from land acquisition and the ABP cases highlight the importance of meaningful public engagement with landowners, local communities, cycling advocacy groups, government bodies and other stakeholders. The needs and preferences of these stakeholders should be factored in at the planning and design stages of cycling infrastructure (as highlighted by Deegan & Parkin (2011)). Chapter 5 has made a contribution to this process by engaging over one thousand international greenway users, but local consultation is vital in this regard.

2. **Facility choice and design guidance**. In his ruling on the N86, the central problem for Charleton was the exclusion of consideration for cyclists and pedestrians, which he stated was unequivocal government policy – the needs of all road users must be included in road plans. The adoption of the rural cycle scheme design standard TD300 (NRA, 2014a) recognises that facilities must be provided for non-motorised users in all road developments (excluding motorways and Type 1 roads), although: *"There may be occasions where a facility for non-motorised users […] is not justified, due to the existence of a suitable alternative off line route or where there is minimal demand for such a facility anticipated. In such exceptional circumstances, the omission of a facility for non-motorised users shall only be accepted under an approved Departure from standards"* (NRA, 2014a). This context raises the question of whether greenway-standard routes will be provided if an off-road cycleway has been developed nearby or if there is an upgrade planned to a nearby road or if there is the potential to provide a more cost-effective off-road cycleway in a nearby location. While other options, such as on-road cycleways and quiet local roads, are most cost-effective, Chapter 4 showed the perceived risk associated with interactions with motorised traffic (particularly for women and older people). Furthermore, Chapter 7 highlighted the value that users place on greenways and a move away from this model could reduce potential economic impact.

3. **User experience and separation**. The key difference between on-road / off-road cycleways and greenways is proximity to motorised traffic. Separation was strongly emphasised in Chapter 5 as relating to exposure to vehicular emissions, noise and visual impact. Considering exposure to particulate matter: due to longer travel times and higher activity rates, pedestrians and cyclists may intake more pollutants than motorists – even up to 14 metres away from the centreline (Grange et al., 2014), although this depends on activity and dispersion conditions. Buffers, such as a 3 metre wide parking lane, reduce cyclists' intake of ultra-fine particulate matter (Kendrick et al., 2011). Although usually located in rural areas, adjacent to relatively low-trafficked roads, the choice of an off-road cycleway facility above a greenway (where an alternative exists) will nevertheless lead to a greater intake of particulate matter by the facility users and negatively impact the user experience of the route.

4. **Environmental impact**. Following from point 3, it must be acknowledged that greenways (and to a lesser extent off-road cycleways) have the potential for significant environmental impact (as calculated in Chapter 6). This impact must be balanced with design users, preferences (e.g. surfacing) and the environmental context of the scheme (e.g. designated sites, visual amenity). Failure to adequately consider environmental impact can lead to refusal by ABP to approve the EIS or in extreme cases a protracted legal battle extending three years or more.

The following chapter will apply these conclusions to a case study of the route selection of the Mullingar to Oranmore section of the Galway to Dublin Greenway. This case study will also draw on many of the sections of this chapter including the policy context, route options and challenges facing land acquisition.

9 Case study: Oranmore-Mullingar NCN corridor

This chapter describes a case study of the planning and design of a greenway in the Oranmore to Mullingar corridor, the largest part of the Galway to Dublin Greenway, flagship of the Irish NCN. This corridor was identified at the earliest stages of this research as representing an ideal test case for the novel methods developed in this thesis. Indeed, the actual planning of Oranmore-Mullingar corridor by engineering consultants encountered fundamental challenges and the route has recently been ‘paused’ until a solution can be found. To this end, the case study draws on the principles, methods and findings from each of the other chapters of this thesis, including the route selection methods and design guidance from the literature review, empirical findings on safety, design preferences, environment and economy in the chapters which followed. The review of the Irish NCN also provides context and highlights many of the key challenges faced in planning and designing this important corridor.

9.1 Introduction

9.1.1 Galway to Dublin Greenway

The NCN scoping study identified the Dublin to Clifden corridor as the flagship of the network (NRA, 2010a). This coast-to-coast route would connect the capital and most populous city of Ireland, Dublin on the east coast, with Galway City and Clifden, popular tourist centres in the west. The route would facilitate EV2 ‘The Capitals Route’, from Moscow through to Galway. The corridor comprises the Connemara Greenway (starting in Clifden) and the Galway to Dublin Greenway. As the Connemara Greenway is currently in planning as a separate route, this case study focuses on the Galway to Dublin Greenway, which has been divided into six sections (Table 9.1) and involves eight local authorities (of the 31 in Ireland). Before honing in on the Mullingar-Oranmore section for this case study, it is necessary to provide some background on the Galway to Dublin Greenway and the challenges faced in route selection.

Table 9.1 - Galway to Dublin Greenway sections

Section	Dist (km)*	Local Authorities
Dublin – Maynooth	29	Dublin City, Fingal, Kildare
Maynooth – Mullingar	61	Kildare, Meath, Westmeath
Mullingar – Athlone	51	Westmeath
Athlone – Ballinasloe	26	Westmeath, Roscommon, Galway County
Ballinasloe – Oranmore	56	Galway County
Oranmore – Galway City	11	Galway County, Galway City

*By current roads (excluding motorways), serving main towns. The shaded area of the table marks the sections in the Mullingar to Oranmore corridor.

Although piecemeal route developments were funded through the 2012 and 2014-16 NCN funding rounds, a more coordinated approach was adopted for the Galway to Dublin Greenway. Following the Minister for Transport, Tourism and Sport's statement in late 2012 (DTTAS, 2012b), a greenway-standard route gained impetus and significant emphasis was placed on demonstrating return on investment. Fáilte Ireland (2013) was commissioned to undertake market research on the cycle tourism potential of the region and based on this information, a joint venture between two engineering consultancy firms, AECOM & Roughan O'Donovan (2014), prepared a business case for the greenway. In 2015, these firms were then hired to plan and design the greenway. Their work built on the initial phase of this research, which was consulted for the preparation of route selection.

There were three main findings of the market research phase of Fáilte Ireland's and AECOM/Roughan O'Donovan's work:

1. **Greenway preference**. There was a strong preference for traffic-free cycle routes with flat gradients, (varied) scenery, access to historical and cultural attractions, frequent facilities, and attractive urban areas. These results confirm those of Chapters 4 and 5 of this thesis and sit in the development of a greenway orientation for the NCN, as described in the previous chapter.
2. **Long-distance preference**. There is a need for routes of sufficient length to attract long-distance cycle tourists and therefore directness is not a priority (as found in Chapter 5). Given average cycling distances of 60-80 km per day, to allow for a 10-day cycling holiday (including rest days), routes should extend for more than 200 km with an ideal length of 300 km (i.e. confirming the results of Downward et al. (2009)).
3. **Economic potential**. There is the potential to attract 35,600 overseas visitors from Britain, Germany, France and the Netherlands each year. Based on overseas spending on the GWG (see Chapter 7), the economic benefits of these users was estimated to be €13.4 million per year. Using a 30 year appraisal period and a discounted construction cost of €82.6 million, the benefit-cost ratio was found to be 2.6. The break-even point for the greenway was established at 14,000 visitors per year. Domestic users were not included in the economic impact as this spending does not represent a net gain to the national economy.

Based on these findings, AECOM & Roughan O'Donovan (2015a) set the following vision for the Galway to Dublin Greenway:

> *Develop a segregated cycle and walking trail of international standard, extending from Dublin City to Galway which is of a scale that will allow Ireland to harness the potential of an identified growing tourism market for cycling. This corridor will form part of an interconnected national cycle network of high quality, traffic free, inter urban corridors, which will establish Ireland as a quality international tourism destination for a broad range of associated recreational activities and pursuits.*

Developing such a segregated trail, or greenway, would not prove majorly challenging for the eastern section of the route due to the presence of the Royal Canal towpath from Dublin to Mullingar and a disused railway from Mullingar to Athlone; these options were identified from an early stage of the NCN. West of the River Shannon (at Athlone), on the other hand, no such suitable corridor exists and AECOM/Roughan O'Donovan (2013a) acknowledged the need for a "green-field route" to provide an off-road experience.

9.1.2 Greenway planning 'paused'

The consultants undertook a route selection process (in line with NRA methodology), formed custom criteria and yielded a preferred route corridor (see Figure 2.14 and Table 2.24 in Section 2.8). The team considered it vital "that there is a secure 'right of way' along the extent of the route that is not jeopardised at any point in the future" and this position led the NRA to approach DTTAS for support in the use of CPOs, rather than permissive access, for land acquisition west of Athlone (see Section 8.2.3). Following the completion of the route selection phase and the approval to proceed with CPOs, many landowners contacted their local representatives and the Minister for Transport, Tourism and Sport to oppose the route and what they perceived as the 'threat' of CPO. In response, the Minister instructed the project team to consult with individual landowners.

The team duly visited 194 of the approximately 1000 landowners who own land within or adjacent to the preferred route corridor in Co. Galway (between Galway City and Ballinasloe) to ascertain opinions on the route. This process found mass opposition to the current preferred route: 63% opposed, 27% in favour, 10% undecided or unresolved (TII, 2015). In Co. Roscommon (between Ballinasloe and Athlone), there was much greater support for the route, although this section is substantially shorter. Of the 86 landowners along the route, 74% accepted the route, 1.2% objected (1 landowner) and 24% were undecided or were not contacted. Upon receipt of the report, the Minister decided to 'pause' the planning of the greenway between Galway and Athlone to "allow time for all to reflect on the issues raised and to give consideration to the possibility of developing a new route that works locally and has the support of key landowners" (DTTAS, 2015).

These issues were raised in the Transport Infrastructure Ireland (TII) report and expressed in media interviews. The two main farming organisations, the Irish Farmers' Association (IFA) and the Irish Cattle and Sheep Farmers' Association (ICSA) both opposed the greenway, citing a lack of consultation and a top-down approached based on "maps and theory [with] little regard for local communities"(Healy, 2015). Some of the specific issues raised by individual landowners were: farm division and hassle of crossing the greenway, reduction of holding value, reductions in single farm payment, ability to secureplanning permission in the future, security/trespassing/privacy, danger posed by animals to greenway users (timber fences inadequate), and the effects of crop spraying and silage cutting on greenway users. Based on this opposition, landowners, farming representative organisations and public representatives proposed a variety of alternative routes and some of these are listed in Table 9.2.

Table 9.2 - Alternative routes as proposed by a variety of stakeholders

Route	Proposers
Coillte / BnaM lands	TD1, TD2, councillors
Greenway on active rail	Selected route landowners
Cycle lanes on R446 (old N6)	TD2, TD3, Senators, councillors, IFA
Quiet local roads	Galway Cycling Campaign

Sources: Hutton & Rodgers (2015), Whelan (2015); TD = Teachta Dála (Member of Parliament)

There was almost universal support by public representatives for the use of state-owned land and many representatives cited the disused railways and canals as used in the eastern sections of the greenway; others suggested Coillte forestry land and Bord na Móna bogland. However, no detailed discussion took place on whether these disused infrastructures or landbanks have the potential to cover the distance between Athlone and Galway City. There are two existing corridors which cover the distance – one road and one active railway. Many (including farmers' organisations) strongly favoured the use of the old N6 (R446) road, while a number of affected landowners raised the active railway – far to the north of their holdings. Also, the Galway Cycling Campaign suggested the use of quiet local roads, citing similar routes as part of EuroVelo.

9.2 Methodology

9.2.1 Route option scoring

This case study examines a set of route options, using a similar route selection approach as the NRA and AECOM/Roughan O'Donovan, but incorporating lessons from other chapters of the thesis. This was completed as a desk study and it was not possible to undertake a detailed analysis of the various route options (e.g. site visits, user surveys, structural surveys, biodiversity surveys, economic modelling). Therefore, it was not possible to fully apply some of the empirical results found in this thesis (e.g. user spending and embodied carbon).

The main output of the case study is therefore the application of the principles derived from other chapters as well as the overall method. The structure of the route selection process is as follows:

1. The study area is defined and route opportunities and constraints are outlined.
2. Sets of route options are identified for each section, then scored and eliminated based on the scoring mechanism shown in Table 9.3.
3. A preferred route corridor is highlighted and analysed.

While it was not possible to apply detailed empirical results from previous chapters to this high-level route selection, a set of key points has been attributed to each of the criteria.

Table 9.3 - Case study scoring mechanism

Criteria \ Score	5	4	3	2	1	0
Accessibility	Frequent connections to towns, services, roads and PT	Connected by many roads to several towns, some services	Connects to main towns, facilities or roads	Served by few local roads and connects to few villages	Isolated route, few road connections or villages	Completely isolated route
Safety	Fully separated greenway with safe junctions	Fully separated, proximity to roads or rail	Some separation and few junctions	On quiet local roads, but with few junctions, adequate width	On quiet local roads, many unsafe junctions, narrow	On National or Regional roads, too narrow for cycleways
User experience	Traffic-free, many points of interest, views or route theme	Traffic-free, lower comfort or less scenic	Low traffic, several points of interest, landscape	Low traffic, though lower comfort levels	Medium-traffic, poor comfort, e.g. exposure to emissions	On-road, heavy traffic, no points of interest
Design	Excellent: separated, wide, flat route, good facilities	Excellent, but with some specific design challenges, e.g. bridges	Good potential for on-road or off-road cycleway	On-road route with some potential for sepation or calming	Sign-posted on-road route, no potential for separation or calming	Acceptable cycle design not possible, e.g. very steep gradient or motorway
Environment	No negative impact on environment incl. designated sites	Low EC and low impact on designated sites	Low EC, potential for flooding or impact on designated sites	Asphalt surface (large EC), low impact on designated sites	Asphalt surface (large EC), vegetation clearance, impacts designated sites	Prohibitive impact on designated sites
Economy	Low cost, state lands, high tourism potential and local recreation potential	Low cost, medium tourism and recreation potential	Low cost, low tourism and recreation potential	Medium cost, low tourism and recreation potential	High cost, low tourism and recreation potential	Prohibitive cost

A description of each route option and the the application of Table 9.3 is provided in Appendix 4, while brief summaries are included in the following sections. Throughout the case study, drawing numbers relate to those in Appendix 5. The pdfs have been layered so that when viewing the maps digitally in Adobe Reader it is possible to turn on and off each layer (as shown in the legend) for clarity.

9.2.2 Study Area

The Study Area was generated by implementing the following basic criteria (derived from the NCN Scoping Study, Fáilte Ireland market research and Chapter 5 findings):

(i) Link Mullingar to Athlone, Athlone to Ballinasloe, Ballinasloe to Oranmore via Loughrea and/or Athenry

(ii) Inclusion of viable existing infrastructure, e.g. roads, rail

(iii) Inclusion of points of interest, e.g. historical, cultural

(iv) Inclusion of major natural features, e.g. rivers, lakes, hills

Figure 9.1 shows the chosen study area (in red), the Dublin-Clifden NCN corridor (5 km buffer in black) and the major towns along the route. Also see Drawing 1 for a larger context map of the study area.

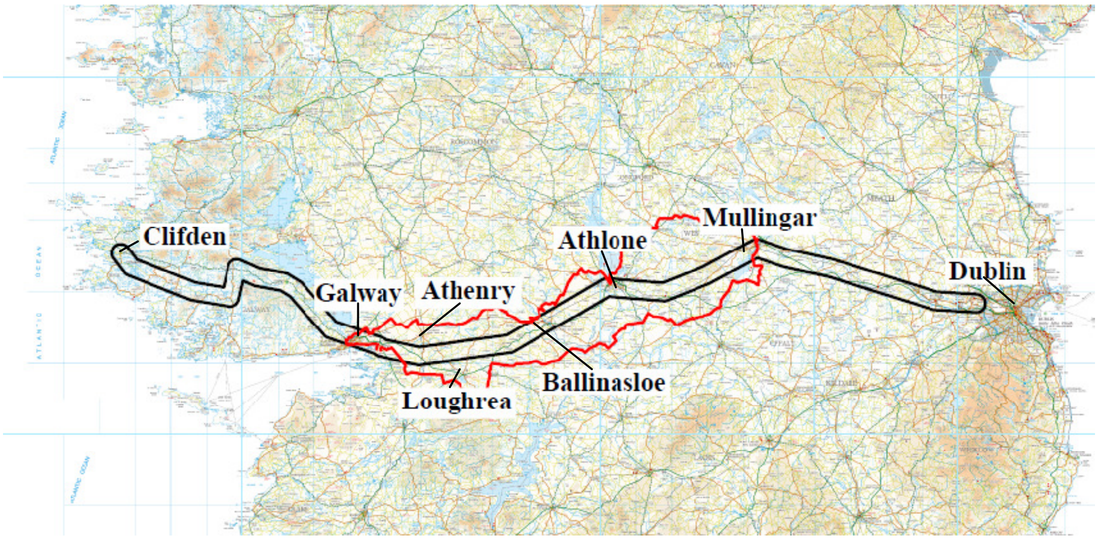

Figure 9.1 - Dublin to Clifden NCN corridor and case study area

The northern and southern boundaries of each section were defined primarily by reference to the major natural and artificial constraints (see Section 9.3). The northern boundary stretches from the banks of Lough Owel outside Mullingar to the Lough Rea near Athlone (where it crosses the River Shannon) and remains north of the active railway to Galway City, incorporating Athenry. The southern boundary starts at the banks of Lough Ennell, encompassing Clara Bog through Co. Offaly, crosses the River Shannon at Shannonbridge to include BnaM railways and the River Suck, remaining sufficiently south to incorporate Loughrea town and Lough Rea before reaching Galway Bay. The total size of the study area is 1988 km^2. The area has been subdivided into three sections to simplify analysis of the route options (Table 5.1) and maps of the three sections can be found in Drawings 2-4. While the study area is centred on NCN02 (Dublin to Clifden), it is intersected by three other NCN corridors: NCN08 (Galway to Tralee) in Oranmore, NCN11 (Limerick to Carrick-on-Shannon) in Athlone and NCN12 (Athlone to Carlow) in Moate - see Drawing 5.

Table 9.4 - Study area sections

Section	Length (km)*	Area (km^2)
A. Mullingar-Athlone	41.5	862
B. Athlone-Ballinasloe	21.1	424
C. Ballinasloe-Oranmore	47.9	702
Total	**111.5**	**1988**

*Straight line distance

9.3 Route Selection

9.3.1 Section A: Mullingar-Athlone

Section A is the largest of the three sections and stretches from Mullingar to Athlone in Co. Westmeath to the border with Co. Roscommon, a straight-line distance of 41.6 km and an area of 862 km^2. The majority of Section A is located in Co. Westmeath. The section also includes parts of Co. Longford (to Ballymahon) and Co. Offaly (to Clara). The section begins at Oliver Plunkett St. in Mullingar, passes through Moate (to connect to NCN12) and ends at Athlone Castle, allowing for connections to NCN11.

Opportunities and constraints

Natural

Natural opportunities and constraints have been plotted in Drawing 6. The main bog is 6 km east of Ballymahon (Co. Longford) and the largest woodland is Ballymahon forest (1698 ha). There are two nature reserves: Clara Bog (460 ha) and Scragh Bog (16 ha). Designated sites which include water bodies, such as lakes Owel, Ennell, Ree, the River Shannon and the Royal Canal. The topography is relatively flat other than some small hills outside Mullingar. These factors do not present any major constraints for route selection. The major SACs in the area (Lough Owel, Lough Ennell, Lough Rea and Clara Bog) may provide an opportunity for route ambience, while Ballymahon Forest may be suitable for a traversing route.

Artificial

Artificial opportunities and constraints are shown in Drawing 7. There are two main towns in the section, Mullingar (19,770 population – see Drawing 8) and Athlone (17,544 – see Drawing 9) with some smaller villages, such as Clara (3,001) and Moate (1,888), between. The key points of interest are Belvedere House (158,500 annual visitors), Locke's Distillery (39,500) and Mullingar Pewter (10,500). The M6 motorway runs at the southern end of the study area, representing a significant constraint, and there are many local roads. There is a dense collection of Recorded Monuments and Places (RMPs), including hundreds of historic monuments. There is some cycling infrastructure, including the Táin Trail, Mullingar cycle loops and the recently developed greenway on the towpath of the Royal Canal. The closed Mullingar-Athlone Railway runs along the southern end of the section and is the major opportunity for route development. The railway is 45 km long, opened in 1851 and closed in 1987, with stations in Mullingar, Moate and Athlone. As the track has been closed for a relatively short period (25 years), most structures may remain in good condition. An abandoned railway exists between Clara and Horseleap.

External Parameters
Westmeath County Council has been to the fore of developing cycling infrastructure and local and regional plans include several pro-cycling policies, including investigating the use of the disused Mullingar-Athlone railway as a cycleway. The promotion of cycling forms part of the Midlands Regional Planning Guidelines and the Offaly, Roscommon and Westmeath County Development Plans. The towns of Mullingar, Athlone and Tullamore are defined as a linked gateway in the National Spatial Strategy (DoEHLG, 2001), working in partnership to promote economic and social development. Westmeath CoCo was previously granted funding for upgrades of the Royal Canal towpath and Offaly CoCo was awarded funding for an on-road cycleway on the R420 (old N80) from Tullamore to Moate. Other national policies, laws and standards also apply.

Route options
Based on the opportunities and constraints, six route options (Table 9.5) were identified, analysed and plotted in Drawings 10-15. The framework for greenway planning and design, developed in this thesis, was then applied to score each route option and to yield a preferred route. Each of the six options and scores received are discussed in more detail in Appendix 4.

Table 9.5 - Section A route options

Route option	Description	Drawing
A1	Disused Mullingar-Athlone Railway	10
A2	Local Roads (Táin Trail)	11
A3	Regional Road (R390)	12
A4	Regional & National Roads (R392/N55)	13
A5	Local Roads (close to railway)	14
A6	Local Roads (north of railway)	15

Preferred route
The scores for each route option have been tabulated in
Table 9.6. Route A1 (disused Mullingar-Athlone railway) has been selected as the clear preferred route and a series of photos are provided in Drawing 16. This route would comply with international greenway users' preferences for a traffic-free, well-separated route. Two potential disadvantages are construction cost and environmental impact. At a construction cost of €130,000 per kilometre (see Section 2.6.4), this 45.4 km section has an estimated price tag of €5.9 million. Using the average spend per greenway user from Chapter 7, and a ten year pay-back period, the

break-even point for the route is 12,826 overnight users per year or 42,143 day-trippers. Applying the results of Chapter 6, the total carbon footprint of the greenway is estimated to be 2724 tCO_2e, requiring 941people to shift a 5 km commutefor 10 years from driving a car to cycling to offset this level of carbon.

Table 9.6 – Section A summary

Category	A1	A2	A3	A4	A5	A6
Accessibility	4	4	2	3	3	2
Safety	5	1	0	0	2	1
User experience	5	1	1	0	2	1
Design	4	2	1	1	2	2
Environment	2	4	4	4	4	4
Economy	4	3	3	2	3	3
Total	**24**	**15**	**11**	**10**	**16**	**13**

9.3.2 Section B: Athlone-Ballinasloe

Section B is the smallest of the three sections of the study area, yet has perhaps the most diverse range of opportunities, constraints and route options. This section covers the area between Athlone (Co. Westmeath) and Ballinasloe (Co. Galway), with the majority of the area in Co. Roscommon. Section B covers a distance of 21.1 km and an area of 424 km^2. The section begins at Athlone Castle and finishes at Main St. in Ballinasloe

Opportunities and constraints

Natural

Natural opportunities and constraints are plotted in Drawing 17. The topography in the section is relatively flat and there are two rivers, the Shannon and the Suck. There is extensive bogland in this area, which represents the major constraint and specific design challenges for cycling routes. Alternative methods of construction such as floating roads and boardwalks could be investigated for construction on this bogland (as well as BnaM railways). There are some small forests, including in Larkfield Bog outside Athlone. There is one nature reserve, Mongan Bog (119 ha) and designated sites comprise several of the bogs and the callows of both rivers – which may be suitable opportunities for adjacent routes.

Artificial

Artificial opportunities and constraints are shown in Drawing 18. The two main towns in the area are Athlone (17,544 population) and Ballinasloe (6,449 – Drawing 19). Clonmacnoise, a 6th Century monastery, is the largest tourist attraction in the midlands (144,500 annual visitors), located between Athlone and Shannonbridge. Other points of interest include Derryglad Folk Museum near Athlone (5,000). There are fewer RMPs in this section, though they still number in the hundreds, clustered around Clonmacnoise and Athlone. The main artificial constraint is the M6 motorway. Opportunities exist in the active railway, Bord na Móna industrial railways (Figure 9.2) and local roads. Existing cycling infrastructure includes the Táin Trail and a planned greenway in Ballinasloe along the banks of the River Suck from Main Street to Station Road, parallel to Society Street and Sarsfield Road.

Figure 9.2 - Bord na Móna industrial railways (Raby, 2010)

External Parameters

At present, Galway County Council, Roscommon County Council and Athlone Town Council are involved in the design of various cycling routes. This includes investigating the use of the hard-shoulders of the R446 as a cycling route, as well as improving cycling infrastructure in Ballinasloe. The promotion of cycling forms part of the Midlands and Western Regional Planning Guidelines and the Galway, Roscommon and Westmeath County Development Plans. Other national policies, laws and standards also apply.

Route options

Based on the opportunities and constraints, seven route options (Table 9.7) were identified, analysed and plotted in Drawings 20-26. As for Section A, the planning and design framework was applied to score each route option.

Table 9.7 - Section B route options

Route option	Description	Drawing
B1	Active railway	20
B2	Local Roads (Táin Trail North)	21
B3	Local Roads (Táin Trail South)	22
B4	Old N6 (R446)	23
B5	Regional Roads (R446, R444, R357)	24
B6	Local Roads & BnaM Railway	25
B7	Local Roads & R357	26

Preferred route

The scores for each route option have been tabulated in Table 9.8. Route B1 (active railway) has been selected as the preferred route and a series of photos are provided in Drawing 27.The selection of the route was not as clear-cut as in Section A – three points, rather than eight, separated the route options. There are many challenges facing the active rail-based route (rail-with-trail), including the impact of passing trains on the user experience, design and investment required to ensure safety, design and potential alternative routing required at bridges, isolation of the route in sections and, most importantly, consultation with Iarnród Éireann (Irish Rail) to secure land adjacent to the corridor. These challenges are discussed in the conclusion. Following a more detailed planning and consultation process, it may become evident that route options on quiet local roads close to the River Shannon (potentially involving BnaM railways, e.g. route option B6) are preferable. As with Section A, two other disadvantages of a greenway-standard route are cost and carbon footprint. Using the same method as the previous section, the cost is estimated to be €2.9 million with a break-even point of 5,652 overnight users per year or 20,714 daytrippers. The carbon footprint is estimated to be 1356 tCO_2e, requiring a modal shift of 460 drivers to cycling.

Table 9.8 - Section B summary

Category	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
Accessibility	3	3	3	3	4	4	3
Safety	4	2	2	1	0	2	2
User experience	4	2	3	1	1	3	1
Design	4	2	2	2	2	2	2
Environment	2	4	2	4	3	2	4
Economy	3	3	4	2	3	4	3
Total	**20**	**16**	**16**	**13**	**13**	**17**	**15**

9.3.3 Section C: Ballinasloe-Oranmore

This is the second largest section of the study area, though there is the smallest variety of opportunities and constraints. Section C is entirely contained in east County Galway, covers a distance of 47.9 km and an area of 702 km^2. The section starts at Main St. in Ballinasloe and finishes at Main St. in Oranmore.

Opportunities and constraints

Natural

Natural opportunities and constraints are plotted in Drawing 28. There are no major natural constraints and the topography is reasonably flat. The Dunkellin River is the only river of any significant length and Lough Rea (366 ha) and Rahasane Turlough are the only large designated sites. There are many small forests and small areas of bogland in the east of the study area. There are no nature reserves or national parks. Lough Rea could represent an opportunity for a leisure route near Loughrea town.

Artificial

Artificial opportunities and constraints are given in Drawing 29. There are four main towns in the study area: Ballinasloe (6,449 population), Loughrea (4,532), Oranmore (3,513) and Athenry (3,205). The key decision to be made is the inclusion of

Loughrea and/or Athenry. Each town is popular with recreational visitors from Galway City and the surrounding area and tourist attractions such as Athenry Castle (9,000 annual visitors) and Lough Rea are also present. Aughrim battle site is also an important point of interest located and is located just outside Ballinasloe. There are hundreds of RMPs in the area, clustered around Loughrea and Athenry. The main constraint in this section is the M6 motorway. The R446 (former N6) runs from Ballinasloe, through Loughrea, to Oranmore. The active Galway-Dublin railway runs along the northern boundary of the study area, while there is a closed railway between Athenry and Tuam and an abandoned railway between Loughrea and Attymon – all three representing opportunities for cycle route development.

External

Galway County Council is involved in the design a number of cycling routes. These include investigating the use of the hard-shoulders of the R446 as a cycling route, as well as cycling infrastructure in Ballinasloe, Loughrea and Athenry. The promotion of cycling forms part of the Western Regional Planning Guidelines and the Galway County Development Plan. Other national policies, laws and standards also apply.

Route options

Based on the opportunities and constraints, six route options (Table 9.9) were identified, analysed and plotted in Drawings 30-35. As in previous sections, the planning and design framework was applied to score each route option.

Table 9.9 - Section C route options

Route option	Description	Drawing
C1	Active Railway	30
C2	Old N6 (R446)	31
C3	Local Roads (Loughrea & Athenry)	32
C4	Regional Roads (R446, R349, R348)	33
C5	Local Roads (Loughrea)	34
C6	Local Roads (Athenry)	35

Preferred route

The scores for each route option have been tabulated in Table 9.10. Route C1 (active railway) has been selected as the preferred route and a series of photos are provided in Drawing 36. The route options other than C1 are very similar. The main issues related to a connection to Loughrea and/or Athenry, and the use of local or regional roads. Unlike Section B, there was no major tourist attraction or river to influence the route selection. As outlined for Section B, the active railway appears to be the only viable corridor on which to provide an off-road route (without land acquisition) and this entails a number of challenges – which are discussed in the next section. As stated in Section A and B, this level of construction can entail large financial and carbon costs. The cost of this section is estimated to be €6.6 million with a break-even point of 14,348 overnight users per year or 47,143 daytrippers. The carbon footprint is estimated to be 3042 tCO_2e, requiring a modal shift of 1032 drivers to cycling.

Table 9.10 - Section C summary

Category	C1	C2	C3	C4	C5	C6
Accessibility	3	4	4	4	3	3
Safety	4	2	2	2	2	2
User experience	4	1	1	1	1	1
Design	4	2	2	2	2	2
Environment	2	4	4	4	4	4
Economy	3	2	3	3	3	3
Total	**20**	**15**	**16**	**16**	**15**	**15**

9.4 Discussion

9.4.1 Preferred route analysis

The preferred route is analysed under the headings of each of the six criteria, drawing on the findings of previous chapters and AECOM/ROD's reports:

1. **Accessibility**. The full route between Athlone and Oranmore is 119 km long, representing a reasonably direct route due to the use of a disused railway (rail trail) and an active railway (rail-with-trail) (see Drawing 37). The route connects to each of the main corridor towns as identified in the NCN Scoping Study: Mullingar, Athlone, Ballinasloe and Oranmore;it was then necessary to include Athenry rather than Loughrea in order to maintain an off-road route. Although the route is isolated in parts due to the use of railway lines, it is served by many local roads with the potential for off-shoot business and spurs to other locations in the future.

2. **Safety**. The main safety concerns highlighted in Chapter 4 were due to interaction with motorised traffic and this greatly influenced the selection of an off-road route (which is also connected to user experience and design). Such an off-road design has the potential to confer additional perceived safety benefits for women, children and older people. Nevertheless, careful design along the active railway will be required to ensure safety as well as at road junctions. Road-based routes were suggested as alternatives to a green-field greenway, including the R446 and quiet local roads. As discussed in the route options, these alternatives could pose major safety risks, as well as compromising user experience. Furthermore, the vast majority of these road options would not comply with NRA standards, the NCM or EuroVelo guidelines on the basis of traffic volumes, speeds and available widths. In this desk study, it was not possible to go into further detail on this point due to the lack of available data – dedicated traffic monitoring would be required.

3. **Design**. The selection of disused and active rail will, for the most part, allow for the development of a greenway which meets the design preferences outlined in Chapter 5. Although restrictions along the active rail corridor (especially at bridges) remains a challenge, there appears to be sufficient space available at the southern side of the railway for appropriate greenway development. Also, by locating the route adjacent to the railway, issues surrounding farm division can be avoided. AECOM/Roughan O'Donovan highlighted this fact, though the consultants ultimately preferred green-field developed greenways along the southern boundaries of each study area section (banks of River Shannon in Section B and through Loughrea and Clarinbridge in Section C). These routes would be preferable for reasons of design quality and user experience, but are not currently viable due to opposition by landowners and consequent deliverability concerns. Furthermore, costs would be substantially higher due to land acquisition. The use of active rail, though not ideal, represents the only alternative off-road option to green-field development and land acquisition, particularly between Oranmore and Ballinasloe. An on-road route should be considered a 'Do-Nothing' option (except sign-posting, road marking and minimal safety measures), while an on-road cycleway or advisory cycle lanes would constitute 'Do-Minimum' (see Section 2.8.2).

4. **User experience**. The Mullingar to Athlone disused railway has the potential to offer a world class walking and cycling experience, especially if continued east to Dublin and west to Galway. The active rail sections, while delivering an off-road experience, will not be as attractive. There are approximately 8 services on the Galway-Dublin railway in each direction each day. Without private land acquisition, this appears to be the only option to yield a traffic-free, well-separated route. However, there are a number of challenges that would need to be overcome to deliver this route and maximise user experience: consultation with Iarnród Éireann (Irish Rail), particularly regarding availability of land, the condition of bridge structures and possibility of adjoining structures, underpasses or alternative routes. Regarding landscape and scenery, the landscape consultant hired by AECOM/Roughan O'Donovan found better views near the southern boundaries of study area Sections B and C, especially relating to the River Shannon. However, is was necessary to trade-off between landscape (and tourism) and segregation.

5. **Environment**. A key feature of greenway analysis which has been neglected is the environmental impact of these routes. AECOM/Roughan O'Donovanconsidered this impact from the conventional EIS approach by examining the impact on designated sites. A contribution of this research is to add a dimension on embodied carbon and the potential for carbon offset through modal shift. The total embodied carbon of the preferred route was calculated to be 7,122 tCO_2e, requiring 2433 commuters to stop driving and start cycling for at least 10 km each working day over the course of ten years. As discussed in

Chapter 6, this is a major challenge for rural greenways that are orientated towards tourism and recreation rather than utilitarian trips and modal shift. Questions remain on whether using a greenway such as this one could encourage everyday cycling and whether modal shift initiatives should be confined to urban areas.

6. **Economy**. Using the estimated construction cost of €130,000 per kilometre for a railway-based greenway, the total cost of the route is €15.4 million. It is important to note that this excludes many other costs, such as land acquisition, services, maintenance, design etc. The use of existing rail corridors has the potential to substantially reduce cost, e.g. the estimated cost of a mostly green-field greenway between Galway and Dublin was estimated to be €82.6 million, mostly due to land acquisition costs – Section 9.1.1. Drawing on the results of Chapter 7, 32,826 overnight users or 110,000 day-trippers would be required to use the greenway each year to offset these costs over a ten year period. This compares favourably with GWG usage and the Fáilte Ireland (2013) estimate of 35,600 annual visitors from selected countries in Europe, accruing annual economic benefits of €13.4 million.

9.4.2 Proposed alternatives

The proposed alternatives to green-field development (as proposed by a range of stakeholders) were: Coillte woodland, BnaM bogland, active rail, R446 (old N6) and quiet local roads (Section 9.1.2). Road-based options have been discussed in depth through the route selection process (and in each case an off-road route was selected), however, it is worthwhile to further examine whether there are possible routes through Coillte and BnM land as these are state-owned holdings. Figure 9.3 and Figure 9.4 show the natural opportunities and constraints in Sections B and C, respectively. BnaM bogland is shown in hatched brown, Coillte woodland in solid green and designated sites in hatched green (consult Drawings 17 and 28).

For Section B, it would appear possible to weave an off-road route along the eastern bank of the River Shannon (SAC), however, this route would still require private land acquisition between bogs, permission from BnaM (to use land and railways), develop a design solution over the bogland, avoid any actively harvested bog and active railway, cross the River Shannon at Shannonbridge, BnaM railway or a new crossing and then get to Ballinasloe. AECOM/Roughan O'Donovan note that BnaM have concerns about cyclists using long distances of operational bogs (dust pollution in peat harvesting etc.) and deemed these routes not to be practical. Nevertheless, this option deserves further consideration along with the consultants' preferred route on the western bank of the River Shannon, which did not experience the same extent of landowner opposition as Section C.

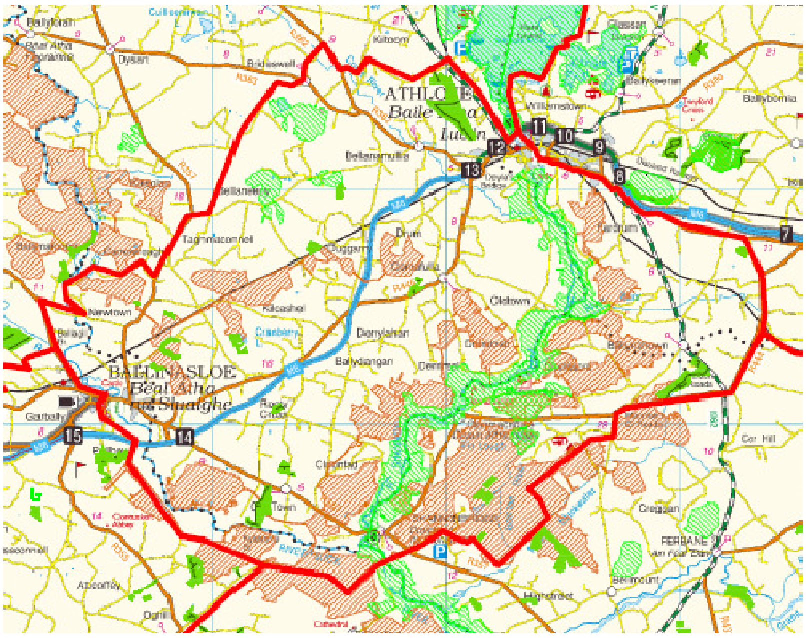

Figure 9.3 - Natural opportunities and constraints in Section B (based on Drawing 17)

Turning to Section C, there is simply insufficient Coillte and BnaM land to develop any corridor from Ballinasloe to Oranmore/Galway City – as clearly shown in Figure 8.4. Coillte land is generally concentrated in the south of County Galway and BnaM land is generally further to the east in Counties Roscommon and Offaly. The only existing corridors in this area are roads or the active railway – any other corridor would require land acquisition and is likely to involve farm division. As stated previously, a well-separated greenway (i.e. away from roads and active rail) would represent a better solution, but is circumscribed by natural constraints and external parameters. It is therefore recommended that authorities continue to engage with stakeholders, such as landowners, while seriously considering a route along the active railway, starting by consulting with Iarnród Éireann and commissioning a survey of the railway structures and potential users.

Figure 9.4 - Natural opportunities and constraints in Section C (based on Drawing 28)

9.4.3 Method review

The method adopted in this case study was necessarily broad for a number of reasons, which constitute limitations of the research:

1. This is a desk study. It was not possible to carry out extensive site visits or surveysto examine local conditions (e.g. structural, biodiversity, usage, economic impact). This lack of local data prevented the full application of empirical findings from other chapters, e.g. specific design preferences, categorised economic impact.
2. The study was limited by space and time. A detailed study of the entire corridor would run to several hundred pages and take several years to complete. This case study set different objectives to a full route selection and design.
3. The conclusion of Chapter 5 cautioned against an overly-quantitative approach, which may fail to consider varying local conditions, the importance of engagement and an allowance for engineering judgement.
4. From point 3, extensive engagement is vital in the development of national cycle routes and greenways in particular. This was demonstrated in the influential opposition posed by landowners who pointed to a lack of consultation as a major grievance. Furthermore, this study indicates the wide range of stakeholders involved, including large state bodies such as Bord na Móna, Coillte and Iarnród Éireann. It was not possible to engage these stakeholders at a route level for the purposes of this study.

Bearing these limitations in mind, the method advocated in this case study appears to have merit and indeed influenced consultants' approach, selected a potential route and provided further analysis. The identification of route options by studying opportunities and constraints in a fundamentally different approach to road route selection was particularly innovative. However, it should be noted that in each section an off-road route option was selected as this characteristic was somewhat subjectively emphasised in the scoring mechanism. A more detailed scoring mechanism, which facilitates the input of local data, could better encorporate the findings of previous empirical chapters. Furthermore, due to a lack of research on two elements of the planning and design framework (accessibility and user experience), these elements of the scoring mechanism were influenced to a greater degree by qualitative responses.

Further research on route selection methods could apply a more quantitative scoring approach by, for example, gathering local data to calculate potential economic and environmental impact, examine safety at junctions, potential usage rates, costs, map access to local services in detail, interview landowners, hold community workshops on route options etc. These data, combined with the methods and results of the empirical chapters of this thesis, could then yield a more nuanced scoring mechanism for route options. Furthermore, there are important lessons to be learned from the 'pausing' of the Galway to Dublin Greenway and an analysis of the actors, institutions and motivations involved (including a comparative study with similar routes) would represent a good start for the future development of greenways, not only as part of the Irish NCN, but internationally.

9.5 Conclusions

The contributions of this case study to the thesis and the broader field are:

1. The application of a general multi-criteria approach to greenway and cycle planning, suggesting alternative criteria and providing empirical data for engineering consultants, local authorities and national planning organisations. Although comparisons between the case study and the AECOM/Roughan O'Donovan reports are limited due to terms of reference, it is envisaged that the incorporation of these findings could add to future route selection schemes, thereby informing the future direction of the Irish NCN and international greenway and cycle networks.
2. The demonstration of specific principles, methods and headline empirical findings of other chapters, in particular: the importance of segregation and separation for safety, user experience and design quality; the importance of access and connections to towns, attractions and services; potential economic impact relating to tourism and recreation; and embodied carbon and potential for carbon offsets through modal shift to cycling.
3. The identification of alternative route options for the Oranmore to Athlone section of the Galway to Dublin Greenway which could be further investigated while the route is'paused'. Progress on this section is vital if the Irish government is serious about delivering a connected network of world-class greenways, starting with this 'flagship'.

10 Conclusions

10.1 Introduction

The promotion of cycling has gained considerable attention in academia, policy and practice as an alternative mode to private car travel at a time of environmental crisis. The distinct characteristics of cycling, including movement by personal effort and exposure to risk, mean that this mode of travel requires dedicated planning and design; provision should not simply be tacked-on to road schemes. In fact, conflict with motorised vehicles and resulting concerns for safety remain the primary impediments to increasing cycling and harnessing its wide-ranging benefits. It is in this context that many authors point to segregated infrastructure for cycling as a solution, drawing on examples from 'high cycling' countries such as the Netherlands, Denmark and Germany. Yet, in the design of dedicated infrastructure, it must be recognised that cyclists represent a diverse group and that a 'one size fits all' approach is insufficient. Furthermore, this allocation of space raises fundamental questions for transport planning, including the curtailment of motorised traffic on existing infrastructure, land acquisition for green-field development and the role of the bicycle in future urban and rural planning.

These are running themes throughout the wider cycling research field and manifest in this thesis in the context of greenways. Greenways are fast becoming features of the landscape across the world as traffic-free corridors for active travel. While greenways have received some academic attention in the fields of landscape architecture and ecology, the study of their use for cycling remains underdeveloped despite major projects in Europe and further afield. Greenway cyclists are themselves a diverse group, encompassing tourists, recreationalists and commuters, with varying requirements and preferences. Greenways also raise complex questions related to space and this is shown in campaigns for the conversion of disused railways and for other route opportunities. The review of the greenway and broader off-road cycling literature highlighted the need for new methods for greenway planning and design to account for these complex design issues and to focus on safety, environment and economy as particular problem areas.

To this end, this thesis employed methods and ideas from a range of disciplines and distilled this information into practical guidance for the transport engineering and planning field. The thesis is structured as four empirical chapters (reflecting focus on safety, design, environment and economy), an in-depth review of a burgeoning greenway/cycle network and a case study of a long-distance greenway. This involved three distinct data collection techniques (mental mapping cycling survey, international greenway survey and a carbon inventory of greenway materials) and applied five forms of analysis (generalised linear mixed modelling, logistic regression, qualitative analysis, life cycle analysis and travel cost modelling).

The research then drew on concrete examples from Ireland for three main reasons:

1. Greenways were given (rapid) priority in Irish cycle policy and provision. Partly inspired by the success of the Great Western Greenway, there have been widespread calls for greenway development by communities, user groups and local authorities. Greenways, in a sense, became the symbol of cycling resurgence, rural development and tourism, and the embryonic National Cycle Network was reorientated to facilitate extensive greenway construction.
2. From above, greenways in Ireland started to receive extensive government investment. Despite low levels of capital spending, significant funds now became available for planning a new form of infrastructure for the country. More than €30 million funding has been provided in the past five years and there is a government commitment for a further €100 million. This investment has been predicated on demonstrating value-for-money centred on the potential for tourism revenue.
3. Greenways in Ireland have encountered many planning and design challenges along the way – which may be related to their rapid popularisation and lack of research to date. Routes have been challenged on environmental, safety and user experience grounds, resulting in prolonged An Bord Pleanála planning cases. More worryingly, the flagship greenway has been 'paused' due to serious opposition by landowners and public representatives.

While some elements of these three points are unique to the Irish case (and required detailed analysis), the broader issues are indicative of those facing international greenways. Indeed, most of the greenways developed in Ireland to date are located within two EuroVelo corridors. In general, it is envisaged that the methods and findings of this research make valuable contributions not only to the direction of Irish greenways, but to the wider greenway, cycle and transport planning fields.

10.2 Contributions to research

Perceived cycling risk

This first empirical chapter established the basis for what followed in the thesis by: (a) applying a novel method to cycle planning, (b) considering dual issues of user characteristics and infrastructure, and (c) concluding on the importance of segregation from motorised traffic. This study involved a highly novel combination of mental mapping, map-matching and logistic regression modelling and was applied to Galway City in Ireland.

- The mental maps of n = 104 cyclists in Galway City (Ireland) yielded n = 484 perceived risk observations and these were matched in ArcGIS to road data extracted from a transport infrastructure inventory.
- Preliminary analysis suggested alignment between perceived risk and the actual locations of cycling collisions.

- Sophisticated statistical modelling was required to unpack the infrastructural and individual determinants of perceived cycling risk and this was achieved using a generalised linear mixed model.
- Significant infrastructural characteristics were segregation, road width and the volume ofmotorised traffic, while the gender and cycling experienceof the cyclist was also significant.
- These findings contribute to the growing literature on cycling safety (which generally focuses on infrastructural issues alone) and encourage further methodological development. Moreover, the results point to the potential importance of segregated cycling infrastructure and the added benefits that these environments can present for women and inexperienced cyclists.

Greenway preferences

Greenways, a particular form of segregated cycling infrastructure, have the potential to capture these safety benefits while also representing effective resources for economy and environment, yet have received a lack of attention beyond the individual route level.

- This section of the research launched an international greenway survey, believed to be the first of its kind, which received 1,002 responses from over 20 countries.
- An initial qualitative analysis of these responses highlighted the variety of functions that greenways serve, the role of user characteristics, and priority themes for planning and design.
- More detailed preferences for design characteristics (surface, gradient, width, junctions), facilities (resting areas, food & drink) and other preferences (segregation, parking) were then quantified and compared with best-practice.
- Continuing a user-oriented design perspective, a logistic regression model determined the impact of user characteristics on design preferences such as surface material, finding that cyclists, commuters and older people prefer asphalt.
- Finally, drawing on two prominent sets of planning/design criteria, CROW (2007) and NRA (2011), survey results were distilled into a new framework for the planning and design of greenways, comprising: accessibility, safety, user experience, design, environment and economy.

Greenway embodied carbon

Greenways have the potential to be corridors for humans and wildlife alike, encompassing a vast array of environmental benefits. Yet, while greenway usage can reduce the alarmingly high carbon emissions of the transport sector, the embodied carbon of greenway construction has never been considered.

- This chapter promotes a unique approach to cycle route planning and design, whereby the 'carbon costs' of construction are balanced by the 'carbon savings' of modal shift from driving to cycling.

- The first step in this approach was to measure the embodied carbon of a case study greenway (GWG) using life cycle assessment.
- Considering embodied carbon due to materials, construction machinery, transport of materials and removal of vegetation and peat, this was calculated to be 67.6 tCO2e/km (or 42.2 tCO2e/km excluding the large capping layer).
- In this case, a cycling modal shift of 115 commutersper year (253,000 PKT, 134 gCO2e per PKT) would required to 'balance' or offset the carbon footprint ofone 10 km asphalt greenway (over20 year life cycle).
- Interestingly, the fact that the asphalt surfacing was responsible for the majority of the embodied carbon shows the trade-off between user preferences and environmental impact.
- A set of recommendations were made for the minimisation of environmental impact of greenways at the planning and design stages.

Greenway spending and value

Greenways are generally framed in the contexts of tourism (bringing spending to an area) and recreation (a resource for communities). However, neither of these contexts has been thoroughly studied which is surprising given the costs of greenways, investment to date and the policy importance of demonstrating value for money.

- Building on the international greenway survey results, the average spend on a greenway was calculated to be €18 for a day-tripper and €63 per night for overnight users; accommodation and food & drink account for the largest proportions of this spend.
- Focusing explicitly on the GWG, average user spend per night was calculated to be €51, confirming earlier findings of economic consultants and justifying the attention given to the GWG as a 'demonstrator' route in Irish government policy.
- A Travel Cost Model (recreational demand method) was then built in SPSS to measure the recreational value of greenways for the first time. Such is the demand for greenway recreation that 83% (or €77) of total 'willingness-to-pay' is retained by the user as consumer surplus.
- However, most users are opposed to paying directly for greenway access and any return on exchequer investment is therefore likely to be indirect, e.g. spending in the local economy.

Irish National Cycle Network and greenway case study

As described in Section 10.1, the Irish NCN and greenways have developed rapidly, yet not one academic publication has reviewed this development.

- This thesis thoroughly examined the evolution of the policy, planning criteria and design guidance underpinning the NCN and a set of recommendations were made regarding user engagement, facility choice, separation and environmental impact.

Following this was a case study of the challenging route selection process of the recently paused Oranmore to Mullingar section of the ‘flagship’ Galway to Dublin Greenway.

- This study drew on the principles, methods and findings from each of the other chapters of the thesis to analyse route constraints/opportunities, develop route options and identify a preferred route.
- This selected route was compared with the output from engineering consultants and the alternatives proposed by a range of stakeholder. It was found that the multi-criteria planning and design framework created in earlier chapters provided a useful mode of analysis, although it was not possible to employ a completely quantitative approach due to the high-level nature of route selection and the need for substantial public engagement.

Overall, the guidance developed in these chapters and throughout the thesis will be a major asset to local authorities, engineering consultancies and community groups, assisting the planning and design of safe, environmentally-friendly, cost-efficient and well-used greenways in Ireland and internationally.

10.3 Further research

Reflecting the findings and limitations of this research, further research is suggested at the greenway planning and design levels.

10.3.1 Greenway planning

This thesis has developed novel methods in the areas of safety, environment, economy and route selection, however, there are many other areas of greenway planning which are deserving of academic attention:

- **User preferences and engagement**. Mixed-methods research can better understand greenway user preferences and, for example, the qualitative analysis in Chapter 5 could be expanded to use interviews, focus groups or online tools to engage users, stakeholders and professionals to flesh out the priorities identified in this thesis. Such an approach should recognise the need for public engagement on greenway planning to extend far beyond statutory obligations and could develop an efficient and rewarding engagement mechanism.
- **Accessibility/connectivity** was identified as one of the most important planning criteria, yet existing transport planning tools in this area do not adequately reflect user preferences for a balance between accessibility and isolation (or the role for access controls etc.). Further research on accessibility and connectivity is therefore needed to inform planning guidelines.
- **Land acquisition**. Particular research attention should be paid to the concerns of land owners and farming organisations, given their importance in greenway land acquisition and the recent challenges faced in Ireland. For example, questions could be added to national farm surveys to quantify land owners’ willingness-to-

accept for cycling access rights, route construction and/or land purchase. This willingness-to-accept could then be related to results from Chapter 7, such as cyclists' willingness-to-pay, recreational value and overall economic impact of greenways.

- **In-depth greenway planning study**. A substantial contribution to the greenway planning field would be to undertake a detailed study of the development of one greenway project from pre-planning stakeholder engagement through construction, maintenance and monitoring. This study could draw on the network and route analyses in Chapters 8 and 9 by further examining the relative roles of engineering challenges, institutional interests and user behaviour. Outputs could include a streamlined planning, design and construction process.

10.3.2 Greenway design

While this thesis delved into several areas of greenway design, it was necessary to neglect many others for reasons of space and scope. Some potential areas of further research include:

- **Engagement tools**. Related to point 1, engagement tools could be developed to yield safe, efficient and attractive design, re-design or maintenance. This work could build on the problem areas highlighted in Chapter 4, identifying preferred current or potential greenway and other cycling routes. Such tools could be facilitated by GPS-based mobile applications and used to crowd-source defects or desired links etc. Although some similar applications are currently available, a dedicated greenway platform could be developed and promoted through international cycle tourism bodies such as EuroVelo.
- **Junction and feeder road design**. Chapters 4 and 5 emphasised the safety concerns of interaction with motorised traffic and suggested particular challenges relating to junction design. Further research could identify the greenway-road junction layouts which are safest for cyclists, paying particular attention to user profiles (e.g. users who may not be accustomed to cycling in traffic). This work could also examine feeder roads (especially urban networks) that connect to greenways.
- **Environmental impact**. To reduce the embodied carbon of greenways and cycling routes shown in Chapter 6, further research could investigate alternative surfacing options (including recycled asphalt and rubber) including by adapting the work done in this area for roads and bearing in mind the specific requirements of cycling routes, e.g. riding comfort, skid resistance, low loading.
- **Detailed design**. Further greenway design studies could focus on one specific design feature at a time and apply a wide range of engineering and scientific methods, including observational studies, interventions/trials and intercept surveys.

References

Abbeyleix Bog Project (2015). Our new boardwalk. Available at: http://www.abbeyleixbog.ie/boardwalk [Accessed 27th May 2015].

AECOM (2010). Galway City and environs walking and cycling strategy. Galway, Ireland.

AECOM/Roughan O'Donovan (ROD) (2013a). *Galway to Dublin Greenway: business case.* Prepared for the National Roads Authority. Dublin, Ireland.

AECOM/Roughan O'Donovan (ROD) (2013b). Route Selection Report Athlone Town. Prepared for the National Roads Authority. Dublin, Ireland.

AECOM/Roughan O'Donovan (ROD) (2015a). Galway-Dublin Greenway Oranmore to Ballinasloe Corridor Selection Report. Dublin, Ireland.

AECOM/Roughan O'Donovan (ROD) (2015b). Galway-Dublin Greenway Ballinasloe to Athlone Corridor Selection Report. Prepared for the National Roads Authority. Dublin, Ireland.

Ahern, J. (1995). Greenways as a planning strategy. *Landscape and Urban Planning*, 33(1), pp.131-155.

Ahern, J. (2004). 'Greenways in the USA: theory, trends and prospects', In R.H. Jongman & G. Pungetti (eds.), *Ecological networks and greenways: concept, design, implementation*. Cambridge University Press, pp.34-55.

Aherne, M. (2014). *VeloCity Dublin 2005: 9 years after.* Presentation to European Cyclists' Federation conference, Dublin, Ireland, 24-25th April.

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Performance and Human Decision Processes*, 50, pp.79–211.

Aldred, R. & Woodcock, J. (2015). Reframing safety: an analysis of perceptions of cycle safety clothing. *Transport Policy*, 42, pp.103-122.

Aldred, R. (2012). *The role of advocacy and activism.* In J. Parkin (ed.) Cycling and Sustainability, Emerald, London, UK, pp.83-110.

Allgemeiner Deutscher Fahrrad Club (ADFC) (2014). *Radnetz Deutschland.* Available at: http://www.adfc.de/tourentipps/d-netz/adfc-qualitaetsradrouten [Accessed 25th August 2014].

Alta (2007). Central Indian River County Greenways Plan. Florida, USA.

Alta (2009). Napa Greenway feasibility study. California, USA.

American Association of State Highway and Transportation Officials (AASHTO) (1999). *Guide for the development of bicycl facilities.* Washington DC, USA.

An Bord Pleanála (2012). *Connemara Greenway Project - Clifden to Oughterard, County Galway: Board Direction PL07.JA0033*. Dublin, Ireland.

An Bord Pleanála (2013a). *Annual report and accounts 2013.* Dublin, Ireland.

An Bord Pleanála (2013b). *N86 Dingle To Annascaul And Gortbreagoge To Camp Road Improvement Scheme: Board Direction 08.HA0035/04.KA0023.*Dublin, Ireland.

Andersen, L. B., Schnohr, P., Schroll, M., & Hein, H. O. (2000). All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. *Archives of Internal Medicine*, 160(11), pp.1621-1628.

Angelopoulous, G.I, Koroneos, C. J. and Loizdous, M. (2009). Environmental impacts from the construction and maintenance of a motorway in Greece. In*Proceedings of the 1st International Exergy Life Cycle Assessment and Sustainabilty Workshop & Symposium* (ELCAS), Nisyros, Greece.

Anhalt-Dessau-Wittenberg (2015). Der Europaradweg R1 in Sachsen-Anhalt. Available at: http://www.anhalt-dessau-wittenberg.de/themen/radtourismus/europaradweg-r1/index.html [Accessed 10th November 2015].

ARUP (2015). N6 Transport Project Route Options. Galway, Ireland.

ARUP & Sustrans (1997). *NCN Guidelines and Practical Details – Issue 2.* London, UK.

Austin, M.A., Furr, A.L. & Spine, M. (2002). The effects of neighbourhood conditions on perceptions of safety. *Journal of Criminal Justice*, 30, pp.417-427.

Automobile Association (AA) (2014). Cost of motoring 2014. Available at: http://www.theaa.ie/AA/Motoring-advice/Cost-of-motoring/Cost-of-Motoring-2014.aspx [Accessed 4th August 2014].

Aycart Luengo, C. (2012). Connection of greenways to new niche markets in Spain. *1st European EuroVelo Greenway and Cycle Tourism Conference.* Nantes, France, 26th September.

Bamberg, S. (2012). Understanding and promoting bicycle use – insights from psychological research. *Cycling and Sustainability*, pp.219-246.

Beria, P., Maltese, I. & Marioti, I. (2012). Multicriteria versus cost benefit analysis: a comparative perspective in the assessment of sustainable mobility. *European Transport Research Review*, 4(3), pp.137-152.

Bill, E., Rowe, D. & Ferguson, N. (2015). Does experience affect perceived risk of cycling hazards? Scottish Transport Applications and Research (STAR) Conference. Glasgow, UK. 20th May.

Birk, M.L., Ferster, A., Jones, M.G., Miller, P.K., Hudson, G.M., Abrams, J. & Lerch, D. (2002). *Rails-with-Trails: Lessons Learned.* U.S. Department of Transport, Washington DC, USA.

Black, P. and Street, E. (2014). The power of perceptions: exploring the role of urban design in cycling behaviours and healthy ageing. *Transportation Research Procedia*, 4, pp.68-79.

Bord na Móna (2015). *Land & Property.* Available at: http://www.bordnamona.ie/our-company/our-businesses/land-property/ [Accessed 9th June 2015].

Borgman, F. (2003). The cycle balance: benchmarking local cycling conditions. In R. Tolley, *Sustainable Transport*, Cambridge: Woodhead, pp.511-524.

Bowker, J.M., Bergstrom, J.C. & Gill, J. (2007). Estimating the economic value and impacts of recreational trails: a case study of the Virginia Creeper Rail Trail. *Tourism Economics*, 13(2), pp.241-260.

Boschmann, E.E. & Cubben, E. (2014). Sketch maps and qualitative GIS: using cartographies of individual spatial narratives in geographic research. *The Professional Geographer*, 66(2), pp.236-248.

Brand, C., Goodman, A. & Ogilvie, D. (2014). Evaluating the impacts of new walking and cycling infrastructure on carbon dioxide emissions from motorized travel: a controlled longitudinal study. *Applied Energy*, 128, pp.284-295.

British Broadcasting Corporation (BBC) (2013). *Why the war between drivers and cyclists?* BBC News Magazine, 22nd May 2013.

British Standards Institution (BSI) (2010) BS EN 13285:2010: Unbound mixtures. Specifications. BSI, London, UK.

British Standards Institution (BSI) (2006) BS EN ISO 14040:2006: LCA Principles and framework. BSI, London, UK.

British Standards Institute (2003). *BS 5489: Code of Practice for the design of road lighting*. Milton Keynes, UK.

Broach, J., Dill, J.& Gliebe, J. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transportation Research Part A: Policy and Practice*, 46(10), pp.1730-1740.

Browne, D, Caulfield, B. and O'Mahoney, M. (2011). *Assessing the barriers to sustainable transport in Ireland.* Environmental Protection Agency, Co. Wexford, Ireland.

Buchanan, C. (1963). *Traffic in towns.* Penguin: London, UK.

Buchanan, P. (2013). Traffic in towns and transport in cities. SKM Colin Buchanan, London, UK.

Buckley, C., Hynes, S., van Rensburg, T.M. & Doherty, E. (2009). Walking in the Irish countryside: landowner preferences and attitudes to improved public access provision. *Journal of Environmental Planning and Management*, 52(8), pp.1053-1070.

Buehler, R. & Pucher, J. (2012). International Overview: Cycling Trends in Western Europe, North America, and Australia. In J. Pucher and R. Buehler (eds) *City Cycling*, Cambridge: MIT, pp.9-30.

Butler, R. (2009). Recreational use of towpaths. For Heritage Council, Ireland.

Cafiso, S., Di Graziano, A., Kerali, H. & Odoki, J. (2002). Multicriteria analysis method for pavement maintenance management. *Transportation Research Record*, 1816, pp.73-84.

Carbon Trust (2006). *The carbon emissions generated in all that we consume.* London, UK.

Carver, A., Timperio, A. and Hesketh, K. and Crawford, D. (2010). Are children and adolescents less active if parents restrict their physical activity and active transport due to perceived risk? *Social Science & Medicine*, 70, pp.1799-1805.

Caulfield, B. & Ahern, A. (2014). The green fields of Ireland: the legacy of Dublin's housing boom and the impact on commuting. *Case studies on Transport Policy*, 2(1), pp. 20-27.

Caulfield, B., Brick, E. & McCarthy, O.T. (2012). *Determining bicycle infrastructure preferences – a case study of Dublin.* Transportation Research Part D, 17, pp.413-417.

Cavill, N., Kahlmeier, S., Rutter, H., Racioppi, F. & Oja, P. (2008). Economic analyses of transport infrastructure and policies including health effect related to cycling and walking: a systematic review. *Transport Policy*, 15, pp.291-304.

Chicago Metropolitan Agency for Planning (CMAP) (2009). Northeastern Illinois Regional Greenways and Trails Plan. Chicago, USA.

Central Statistics Office (CSO) (2000). That was then, this is now: Change in Ireland 1949-1999. Cork, Ireland.

Central Statistics Office (CSO) (2007). *Census 2006, Volume 12.* Cork, Ireland.

Central Statistics Office (CSO) (2009). *Transport 2008.* Cork, Ireland.

Central Statistics Office (CSO) (2011). *National Travel Survey 2009.* Cork, Ireland.

Central Statistics Office (CSO) (2012a). *Census 2011, Profile 10.* Cork, Ireland.

Central Statistics Office (CSO) (2012b). *Place of Work, School or College Census of Annonymised Records (POWSCAR).* Cork, Ireland.

Central Statistics Office (CSO) (2013a). *Road traffic volumes.* Cork, Ireland.

Central Statistics Office (CSO) (2013c). *Household travel survey 2012.* Cork, Ireland.

Central Statistics Office (CSO) (2015). *Vehicles licensed for the first time (number) by taxation class and year.* Cork, Ireland.

Centre for Studies on Networks, Transport, Urban Planning and Public Construction (CERTU) (2008). *Guidelines for Cycle Facilities.* Ministry of Ecology, Sustainable Development and Spatial Planning, Lyon, France.

Cervero, R. & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D*, 2(3), pp.199-219.

Charleton, P. (2014). Kerry County Council v An Bord Pleanála [2014] IEHC 238, High Court Judgement. Dublin, Ireland.

Chau, C., Soga, K., O'Riordan, N. & Nicholson, D. (2012). Embodied energy evaluation for sections of the UK channel Tunnel rail link. *Proceedings of the Institution of Civil Engineering-Geotechnical Engineering*, 165, pp 65-81.

Chen, C-F. & Chen, P-C. (2013). Estimating recreational cyclists' preferences for bicycle routes. *Transport Policy*, 26, pp. 23-30.

Clearingstelle Verkehr (CV) (2012). Deutsches Mobilitätspanel (MOP): Bericht 2011/2012: Alltagsmobilität und Tankbuch. Karlsruhe, Germany.

Commission for the Economic Development of Rural Areas (CEDRA) (2014). *Energising Ireland's rural economy.* Dublin, Ireland.

Connor, A. (2013). Development of recreational trails in County Mayo: an integrated approach. Presentation to *Developing the Socio-Economic Potential of Waterway Corridors conference*, Clonmel, Co. Tipperary, 9-10th October.

Consortium on Green Design and Manufacturing (CGDM) (2007). *Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE).* University of California, Berkeley, USA.

Cope, A., Cairns, S., Fox, K., Lawlor, D.A., Lockie, M., Lumsdon, L., Riddoch, C. & Rosen, P. (2003). The UK National Cycle Network: an assessment of the benefits of a sustainable transport infrastructure. *World Transport Policy & Practice*, 9(1), pp.6-17.

Cope, A.M., Abbess, C.R.& Parkin, J. (2007). Improving the empirical basis for cycle planning. In *4th IMA International Conference on Mathematics in Transport*, pp.139-151.

Corrigan, O. (2014). Department of Transport cycling policy. Presentation to *European Cyclists' Federation conference,* Dublin, Ireland, 24th April.

Coutts, C. (2008). Greenway accessibility and physical-activity behavior. *Environment and Planning B,* 35(3), pp.552– 563

Cox, R. & Donald, P. (2013). *Ireland's Civil Engineering Heritage.* Collins: Cork.

CROW (2007). *Design manual for bicycle traffic*. Ede, Netherlands.

Cycling Embassy of Great Britain (2014). *Hierarchy of Provision*. Available at: http://www.cycling-embassy.org.uk/dictionary/hierarchy-of-provision [Accessed 12th August 2014].

Cyclist.ie (2013). *Cyclists welcome rejection by An Bord Pleanála of controversial Kerry N86 road design.* Available at: http://www.cyclist.ie/2013/09/cyclists-welcome-rejection-by-an-bord-pleanala-of-controversial-kerry-n86-road-design/ [Accessed 19th August 2014].

Dargay, J., Gately, D. & Sommer, M. (2007). *Vehicle ownership and income growth, worldwide: 1960-2030.*

Davies, N.J., Lumsdon, L.M. & Weston, R. (2012). Developing recreational trails: motivations for recreational walking. *Tourism Planning and Development*, 9(1), pp.77-88.

Deegan, B. (2015). Mapping everyday cycling in London. In P. Cox (Ed.), *Cycling Cultures*, Chester: University of Chester, pp.106-129.

Deegan, B. and Parkin, J. (2011). Planning cycling networks: human factors and design processes. *Proceedings of the ICE-Engineering Sustainability*, 164(1), pp.85-93.

Deenihan, G., McCarthy, O., Caulfield, B. and O'Dwyer, D. (2011). Dublin to Mullingar Cycle Route Assessment Report. Trinity College Dublin, Ireland.

Deenihan, G. (2013). *Bike-ology: evaluating inter-urban and rural cycling infrastructure*. PhD thesis, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Ireland.

Deenihan, G. & Caulfield, B. (2015a). Estimating the health economic benefits of cycling. *Journal of Transport & Health*, 1(2), pp.141-149.

Deenihan, G. & Caulfield, B. (2015b). Do tourists value different levels of cycling infrastructure? *Tourism Management*, 46, pp. 92-101.

Deenihan, G., Caulfield, B. and O'Dwyer, D. (2013). Measuring the success of the Great Western Greenway in Ireland. Tourism Management Perspectives, 7, pp. 73-82.

Demers, M. (2006). Walk for your life! Restoring neighborhood walkways to enhance community life, improve street safety and reduce obesity. New York: Vital Health Publishing.

Department of Energy and Climate Change (DECC) and Department for Environment, Food and Rural Affairs (Defra). (2011) *Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting.* London, UK.

Department of Environment, Heritage and Local Government (DoEHLG) (2001). *National Spatial Strategy for Ireland, 2002 – 2020, People, Places and Potential.* Dublin, Ireland.

Department of Environment, Heritage and Local Government (DoEHLG) (2007). *National Climate Change Strategy 2007-2012.* Dublin, Ireland.

Department of Finance (DoF) (2005). Guidelines for the appraisal and management of capital expenditure proposals in the public sector. Dublin, Ireland.

Department of Public Expenditure and Reform (DPER) (2015). Building on Recovery: Infrastructure and Capital Investment 2016-2021. Dublin, Ireland.

Department of Transport (DoT) (2009). Guidelines on a common appraisal framework for transport projects and programmes. Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2009a). *Smarter Travel: a sustainable transport future.* Dublin, Ireland.

Department of Transport, Tourism and Sport (2009b). *Ireland's first national cycle policy framework.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2010). *Ministers Dempsey and Cuffe and Fáilte Ireland announce funding for Mayo to complete Great Western Greenway route.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2012a). *2012 National Cycle Network funding announcement.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2012b). *Dublin-Galway off-road cycle route would have significant tourism potential.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2013). *2013 National Cycle Network funding announcement.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2014a). *2014-2016 National Cycle Network funding announcement.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2014b). *A national tourism policy for Ireland.* Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2015). Galway/Roscommon Greenway paused to allow local issues be resolved while Kildare/Meath section gets green light. Available at: http://www.transport.ie/press-releases/2015/galwayroscommon-greenway-paused-allow-local-issues-be-resolved-while [Accessed 21st November 2015].

Department of Transport, Tourism and Sport (DTTAS) & Department of Environment, Community and Local Government (DoECLG) (2013). *Design Manual for Urban Roads and Streets.* Dublin, Ireland.

Design Manual for Roads and Bridges (DMRB) (2001). Volume 7 – Pavement Design and Maintenance, Section 2 – Pavement Design and Construction, Part 5 – Footway Design, HD 39/01. London, UK.

Design Manual for Roads and Bridges (DMRB) (2005a). Volume 6 - Road Geometry, Section 3 - Highway Features, Part 5 – the geometric design of pedestrian, cycle and equestrian routes, TA 90/05. London, UK.

Design Manual for Roads and Bridges (DMRB) (2005b). Volume 5 – Assessment and Preparation of Road Schemes, Section 2 – Preparation and Information, Part 4 – Provision for Non-Motorised Users, TA 91/05. London, UK.

Dill, J. & Gliebe, J. (2008). *Understanding and measuring bicycling behaviour: a focus on travel time and route choice*. Oregon Transportation Research and Education Consortium, Oregon, USA.

Dill, J., Goddard, T., Monsere, C.M. & McNeil, N. (2015). Can protected bike lanes help close the gender gap in cycling? Lessons from five cities. Annual Conference of the Transportation Research Board (TRB). Washington DC, USA. 11-15th January.

Dodgson, J.S., Spackman, M., Pearman, A., and Phillips, L.D. (2009). *Multi-criteria analysis: a manual*. Department for Communities and Local Government: London.

Donoghoe, P. (2015). *Parliamentary question 226: written answer 14th May 2015.* Dublin, Ireland.

Doorley, R., Pakrashi, V., Byrne, E., Comerford, S., Ghosh, B. & Groeger, J.A. (2015). Analysis of heart rate variability amongst cyclists under perceived variations of risk exposer. *Transport Research Part F*, 28, pp.40-54.

Downward, P. (2007). *The Economic Impact of Cycle Tourism in North East England.* Loughborough University and Sustrans' Research & Monitoring Unit and Institute of Transport and Tourism at University of Central Lancashire, UK.

Downward, P. & Lumsdon, L. (2001). The development of recreational cycle routes: An evaluation of user needs. *Managing Leisure*, 6(1), pp.50-60.

Downward, P., Lumsdon, L. &Weston, R. (2009). Visitor expenditure: the case of cycle recreation and tourism. *Journal of Sport and Tourism*, 14(1), pp.25-42.

Driscoll, Á., Lyons, S., Morgenroth, E. & Nolan, A. (2013). *Comparing the determinants of mode choice across travel purposes.* Economic and Social Research Institute, Dublin, Ireland.

Duany, A., Plater-Zyberk, E. & Speck, J. (2010). *Suburban Nation: the rise of sprawl and the decline of the American dream.* NY: North Point.

Dublin Cycling Campaign (2014). *Key issues of concern to cyclists in Irish road traffic law.* Available at: http://www.dublincycling.ie/cycling/key-issues-concern-cyclists-irish-road-traffic-law-rtl [Accessed 12th August 2014].

Eisenman, S.B., Miluzzo, E., Lane, N.D., Peterson, R.A., Ahn, G-S & Campbell, A.T. (2009). BikeNet: A mobile sensing system for cyclist experience mapping ACM Transactions on Sensor Networks. *ACM Transactions on Sensor Networks*, 6, pp.1-39.

Elias, W. & Shiftan, Y. (2012). The influence of individual's risk perception and attitudes on travel behaviour. *Transportation Research Part A*, 46, pp.1241-1251.

Englin, J. & Shonkwiler, J. S. (1995). Modeling recreation demand in the presence of unobservable travel costs: toward a travel price model. *Journal of environmental economics and management*, 29(3), pp.368-377.

English, D. and Bowker, J.M. (1996). Sensitivity of Whitewater Rafting Consumer Surplus to Pecuniary Travel Cost Specifications. *Journal of Environmental Management*, 47(1), pp.79-91.

Ensink, B. (2014). *Funding and justifying cycling projects.* Presentation to European Cyclists' Federation conference, Dublin, Ireland, 24th April.

Environmental Protection Agency (EPA) (2015). *Ireland's greenhouse gas emissions projections 2014-2035.* Co. Wexford, Ireland.

European Cyclists' Federation (ECF) (2011). EuroVelo: Guidance on the route development process. Brussels, Belgium.
European Cyclists' Federation (ECF) (2013a). Calculating the economic benefits of cycling in the EU-27. Brussels, Belgium.
European Cyclists' Federation (ECF) (2013b). EuroVelo: European Certification Standard. Brussels, Belgium.
European Cyclists' Federation (ECF) (2014). *EuroVelo website.* Available at: http://www.eurovelo.com [Accessed 22nd August 2014].
European Cyclists' Federation (ECF) (2015). EuroVelo 2: Netherlands. Available at http://www.eurovelo.com/en/eurovelos/eurovelo-2/countries/netherlands [Accessed 10th November 2015].
European Greenways Association (EGWA) (2000a). *Declaration of Lille.* Available at: http://www.aevv-egwa.org/site/1Template1.asp?DocID=145 [Accessed 21st August 2014].
European Greenways Association (EGWA) (2000b). The European Greenways Good Practice Guide: Examples of actions undertaken in cities and the periphery. Brussels, Belgium.
European Greenways Association (EGWA) (2012). *European Greenways Association (EGWA) to coordinate 'Greenways4tour' project.* Available at: http://www.aevv-egwa.org/site/1Alaune.asp?DocID=625 [Accessed 21st August 2014].
European Greenways Association (EGWA) (2013). *Greenways product.* Available at: http://www.aevv-egwa.org/site/1Template1.asp?DocID=714 [Accessed 21st August 2014].
European Road Safety Observatory (ERSO) (2012). *Traffic safety basic facts 2012 – cyclists.* European Commission, Brussels, Belgium.
Ewing, R. & Cervero, R. (2010). Travel and the built environment: a meta analysis. *Journal of the American Planning Association*, 76(3), pp.265-294.
Fabos, J.G. (1995). Introduction and overview: the greenway movement, uses and potentials of greenways. *Landscape and Urban Planning*, 33, pp.1-13.
Fabos, J.G. (Ed.). (1996). Greenways: The beginning of an international movement. Philadelphia: Elsevier.
Fabos, J.G. (2004). Greenway planning in the United States: its origins and recent case studies. *Landscape and Urban Planning*, 68, pp.321-342.
Fahy, F. & Ó Cinnéide, M. (2009). Re-Mapping the urban landscape: community mapping – an attractive prospect for sustainability? *Area*,41, pp.167-175.
Fáilte Ireland (2007). *Strategy for the development of Irish cycle tourism.* Dublin, Ireland.
Fáilte Ireland (2011). *2009 activity tourism report.* Dublin, Ireland.
Fáilte Ireland (2012). *2011 activity tourism report.* Dublin, Ireland.
Fáilte Ireland (2013). *Market research for Galway to Dublin Greenway.* Dublin, Ireland.
Fáilte Ireland/Fitzpatrick Associates (2011). *Great Western Greenway – economic impact case study.* Dublin, Ireland.
Faulks, P., Ritchie, B. & Fluker, M. (2007).*Cycle Tourism in Australia: An investigation into its size and scope.* Sustainable Tourism, Cooperative Research Centre, Australia.
Federal Ministry of Transport, Building and Urban Development (FMTBUD) (2013). *National Cycling Plan 2020: joining forces to evolve cycling.* Berlin, Germany.
Fernández-Heredia, Á., Jara-Díaz, S. & Monzón, A. (2014). Modelling bicycle use intention: the role of perceptions. *Transportation*, published online.
Fishbein, M. & Ajzen, I. (1975). *Belief*, *Attitude*, *Intention*, *and Behavior: An Introduction to Theory and Research*. Reading: Addison-Wesley.
Foran, S. (2002). Irish national cycle facilities manual: a review, comparison with international practice and exploration of the wider issues facing Irish local authorities. Galway, Ireland.
Forester, J. (2012). *Effective Cycling*. Seventh edition. Cambridge: MIT.
Franklin, J. (2002). Segregation: are we moving away from cycling safety? *Traffic Engineering & Control*, 43(4), pp.146-148.
Franklin, J. (2007). Cyclecraft: the complete guide for safe and enjoyable cycling for adults and children. London: Stationery Office.
Fundación de los Ferrocarriles Españoles (FFE) / Spanish Railways Foundation (2013). *Guide to best practices and recommendations for accessible greenways.* Madrid, Spain.
Fundación de los Ferrocarriles Españoles (FFE) / Spanish Railways Foundation (2014). Vías Verdes. Available at: http://www.viasverdes.com [Accessed 22nd August 2014].
Furth, P. (2012). *Bicycling infrastructure for mass cycling: a transatlantic comparison*. In J. Pucher and R. Buehler (eds) City Cycling, Cambridge: MIT, pp. 105-139.

Gallagher, R. & Parkin, J. (2014). *Planning for* cycling. Chartered Institution of Highways and Transportation, London.

Galway Bay FM (2015). Protestors call on Minister to pause Galway to Oughterard Greenway plans. Available at: http://galwaybayfm.ie/protestors-call-on-minister-to-pause-galway-to-oughterard-greenway-plans/ [Accessed 13th December 2015].

Galway City Council (2013). *Galway traffic counts 2012:manual classified junction counts*. Conducted by Abacus Transportation Surveys for Galway City Council.Galway, Ireland.

Garceau, T.J., Atkinson-Palombo, C. & Garrick, N. (2014). Peak travel and the decoupling of vehicle travel from the economy. *Transportation Research Record*, 2412, pp.41-48.

Gardner, G. (1998). Transport implications of leisure cycling. TRL report 347. London, UK.

Garrard, J., Rose, G. & Lo, S. K. (2008). Promoting transportation cycling for women: the role of bicycle infrastructure. *Preventive Medicine*, 46(1), pp.55-59.

Garard, J., Handy, S. & Dill, J. (2012). *Women and cycling.*In J. Pucher and R. Buehler (eds) City Cycling, Cambridge: MIT, pp. 211-234.

Gehlert, T., Dziekan, K., and Garling, T. (2013). Psychology of sustainable travel behaviour.*Transportation Research Part A*, 48, pp.19-24.

Godefrooij, T., Pardo, C., & Sagaris, L. (2009). Cycling-Inclusive policy development: a handbook. GTZ, Eschborn, Germany.

Google (2015). *Google Maps.* Available at: maps.google.com [Accessed 1st July 2015].

Gordon, G. & Parkin, J. (2012). Patterns of use by season, day of week and time of day that lead to identifying distinct cycle route typologies. *Cycling Research International*, 2, pp.104-118.

Goodman, A., Sahlqvist, S. & Ogilvie, D. (2014). New Walking and Cycling Routes and Increased Physical Activity: One- and 2-Year Findings From the UK iConnect Study. *American Journal of Public Health.* 104(9), pp. 38-46.

Gould, P. & White, R. (1993). *Mental maps* (3rd ed.). Boston; London: Allen & Unwin.

Government of Ireland. Road Traffic Act. (1961). Dublin: Stationery Office.

Government of Ireland. Roads Act. (1993). Dublin: Stationery Office.

Government of Ireland. Road Traffic (Traffic and Parking) Regulations. (1997),SI 1997/182 Dublin: Stationery Office.

Grange, S. K., Dirks, K. N., Costello, S. B. & Salmond, J. A. (2014). Cycleways and footpaths: What separation is needed for equivalent air pollution dose between travel modes?. *Transportation Research Part D: Transport and Environment*, *32*, pp.111-119.

Haab, T.C.& McConnell, K.E. (2002). Valuing Environmental and Natural Resources, the Econometrics of Non-Market Valuation, Cheltenham, UK: Edward Elgar.

Haake, B. (2009). The Importance of Bicyclist Education. *World Transport Policy & Practice*, 15(1), pp.47-55.

Hammond, G. & Jones, C. (2011) *Inventory of Carbon & Energy Version 2.0 (ICE V2.0).* Department of Mechanical Engineering, University of Bath, Bath, UK.

Handy, S., Van Wee, B. & Kroesen, M. (2014). Promoting cycling for transport: research needs and challenges. *Transport Reviews*, 34(1), pp.4-24.

Harkey, D.L., Reinfurt, D.W. & Knuiman, M. (1998). Development of the Bicycle Compatibility Index. *Transportation Research Record*, 1636, pp.13-20.

Healy, C. (2015). Farmers throw spanner in the works of coast-to-coast cycle route plans. *TheJournal.ie,* 30th October 2015. Available at: http://www.thejournal.ie/greenway-cycle-route-farmers-objections-roscommon-galway-2417830-Oct2015/

Heinen, E., Van Wee, B. & Maat, K. (2010). Commuting by bicycle: an overview of the literature. *Transport Reviews*, 30(1), pp.59-96.

Heisserer, B. (2013). Curbing the Consumption of Distance? A practice-theoretical investigation of an employer-based mobility management initiative to promote more sustainable commuting. PhD thesis,NUI, Galway, Ireland.

Hellerstein, D. & Mendelsohn, R. (1993).A Theoretical Foundation for Count Data Models. *American Journal of Agricultural Economics,* 75, pp.604-11.

Hellmund, P. C.& Smith, D. (2013). Designing greenways: sustainable landscapes for nature and people. Washington: Island Press.

Hendriksen, I.J.M., Simons, M., Garre, F.G. & Hildebrandt, V.H. (2010). The association between commuter cycling and sickness absence. *Preventive Medicine,* 51, pp.132-135.

Hennessy, R. (2012). Animated timeline map of Irish railways. Available at: http://www.ryaninstitute.ie/facilities/gis-centre/research-projects/railway_map/ [Accessed 9th June 2015].

Hopkinson, P. and Wardman, M. (1996). Evaluating the demand for new cycle facilities. *Transport Policy*, 3(4), pp. 241-249.

Horton, D. (2007). Fear of cycling,in P. Rosen, P. Cox and D. Horton (eds) *Cycling and Society*, Ashgate Publishing, Hampshire, UK., pp.133-152.

Horton, D., Cox, P. & Rosen, P. (2007). Introduction: cycling and society. In P. Rosen, P. Cox and D. Horton (eds) *Cycling and Society*, Hampshire: Ashgate Publishing.

Hunt, J.D. & Abraham, J.E. (2007). Influences on Bicycle Use. *Transportation*, 34, pp.453-470.

Hutton, B. & Rogers, S. (2015). Dublin-Galway cyel route thrown into doubt. *Irish Examiner, 1st November*.

Hynes, S. & Hanley, N. (2006). Preservation versus Development on Irish Rivers: Whitewater Kayaking and Hydro Power in Ireland. *Land Use Policy,* 23, pp.170-180.

Institution of Highways and Transportation (IHT) (1998). Guidelines for Cycle Audit and Cycle Review. London, UK.

Intergovernmental Panel on Climate Change (IPCC). (2007) *IPCC Fourth Assessment Report: Climate Change 2007*, *The Physical Science Basis*, Cambridge, UK and New York, USA.

Irish Sports Council (ISC) (2013). *Irish sports monitor 2013.* Dublin, Ireland.

Irish Sports Council (ISC) (2007). *Irish trails strategy.* Dublin, Ireland.

Jacobsen, P.L., Racioppi, F. & Rutter, H. (2009). Who owns the roads? How motorised traffic discourages walking and bicycling. *Injury Prevention*, 15, pp.369-373.

Jacobsen, P.L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention*, 9, pp.205-209.

Jain, S., Aggarwal, P., Kumar, P., Singhal, S. & Sharma, P. (2014). Identifying public preferences using multi-criteria decision making for assessing the shift of urban commuters from private to public transport: A case study of Delhi. *Transportation Research Part F: Traffic Psychology and Behaviour*, 24, pp.60-70.

Jensen, S.U., Andersen, T., Hansen, W., Kjaergaard, E., Krag, T., Larsen, J.E., la Cour Lund, B. & Thost, P. (2000). *Collection of Cycle Concepts.* Danish Road Directorate,Copenhagen, Denmark.

Jensen, S.U., Rosenkilde, C. and Jensen, N. (2007). *Road safety and perceived risk of cycle facilities in Copenhagen.* Presentation to AGM of European Cyclists Federation

Johnston, R .J., Gregory, D., Pratt, G. & Watts, M. (eds.) (1986). *The Dictionary of Human Geography*. Oxford: Blackwell.

Kang, L. & Fricker, J. D. (2013). Bicyclist commuters' choice of on-street versus off-street route segments. *Transportation*, 40(5), pp.887-902.

Kang, K. & Lee, K. (2012). Development of a bicycle level of service model from the user's perspective. *KSCE Journal of Civil Engineering*, 16(6), pp.1032-1039.

Kay, J.H. (1998). *Asphalt Nation: how the automobile took over America and how we can take it back.* CA: University of California Press.

Kelly, A. (2014a). Parliamentary question 924: written answer, 30th April 2014. Dublin, Ireland.

Kelly, A. (2014b). Parliamentary question 21: written answer, 15th May 2014. Dublin, Ireland.

Kendall, J. & Wright, R. (2015). Parks and multi-use trails in the Dona Ana County comprehensive plan: a health impact assessment. Dona Ana Place Matters, New Mexico, USA.

Kendrick, C. M., Moore, A., Haire, A., Bigazzi, A., Figliozzi, M., Monsere, C. M., & George, L. (2011). Impact of bicycle lane characteristics on exposure of bicyclists to traffic-related particulate matter. *Transportation Research Record: Journal of the Transportation Research Board*, 2247(1), 24-32.

Klobucar, M. S. & Fricker, J.D. (2006). *Feasibility Study for Bicycle Safety: Data Assessment and Network Evaluation*. Publication FHWA/IN/JTRP-2006/19. Department of Transportation and Purdue University, West Lafayette, Indiana, USA.

Krenn, P. J., Oja, P. & Titze, S. (2014). Route choices of transport bicyclists: a comparison of actually used and shortest routes. *International journal of behavioral nutrition and physical activity*, 11(1).

Krizek, K. (2007). Estimating the economic benefits of bicycling and bicycle facilities: an interpretive review and proposed methods. *Essays on Transport Economics*, pp.219-248.

Krizek, K., El-Geneidy, A. & Thompson, K. (2007). A detailed analysis of how an urban trail system affects cyclists' travel. *Transportation*, 34, pp. 611-624.

Laird, J., Page, M. & Shen, S. (2013). The value of dedicated cyclist and pedestrian infrastructure on rural roads. *Transport Policy*, 29, pp. 86-96.

Lamont, M. (2009). Reinventing the wheel: A definitional discussion of bicycle tourism. *Journal of Sport & Tourism*, 14(1), pp.5-23.

Landis, B.W. (1997). Real-Time Human Perceptions: Toward a Bicycle Level of Service.T*ransportation Research Record*, 1578, pp.119-126.

LandPro (2012). *Limited Landscape Estimators and Quantity surveyors, Cost of Excavation*. [online] www.landpro.co.uk/costdata/cost_of_excavation.htm [Accessed 16th October 2012].

Langdon, D. (2010). *Spon's Civil Engineering and Highway Works Price Book.* 24th ed., Abingdon: Spon Press.

Larsen, J., Patterson, Z. & El-Geneidy, A. (2013). Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure. *International Journal of Sustainable Transportation,* 7(4), pp.299-317.

Lawson, A.R., Pakrashi, V., Ghosh, B. & Szeto, W.Y. (2013). Perception of safety of cyclists in Dublin City. *Accident Analysis and Prevention*, 50, pp.499-511.

Lawson, A.R., Ghosh, B. & Pakrashi, V. (2014). Quantifying the perceived safety of cyclists in Dublin. *Proceedings of the ICE – Transport*, 168(4), pp.1-10.

Leyden, K. (2003). Social capital and the built environment: the importance of walkable neighbourhoods. *American Journal of Public Health*, 93(9), pp.1546-1551.

Limerick Cycling Club (2013). *Tuesday League – Nenagh side of Birdhill.* Available at: http://www.limerickcc.com/wp-content/uploads/2013/04/Tuesday-league-3.jpg [Accessed 20th August 2014].

Limerick Post (2012). *Limerick to Nenagh cycle lane nears completion.* Available at: http://www.limerickpost.ie/2012/05/17/limerick-to-nenagh-cycle-lane-nears-completion/ [Accessed 17th May 2012].

Lin, J.J. & Yu, C.J. (2013). A bikeway network design model for urban areas. *Transportation*, 40(1), pp.45-68.

Lin, J.J. and Liao, R.Y. (2014). Sustainability SI: bikeway network design model for recreational bicycling in scenic areas. *Networks and Spatial Economics*, pp.1-23.

Lindsay, R. (2010). *Peatbogs and Carbon, a critical synthesis*. Environmental Research Group, University of East London, London, UK.

Lindsey, G., Maraj, M. & Kuan, S. (2001). Access, Equity, and Urban Greenways: An Exploratory Investigation, *The Professional Geographer*, 53(3), pp.332-346

Lindsey, G., Man, J.,Payton, S. & Dickson, K. (2004). Property Values, Recreation Values and Urban Greenways. *Journal of Park and Recreation Administration,* 22 (3), pp.69-90

Lindsey, G., Wilson, J., Rubchinskaya, E., Yang, J. & Han, Y. (2007). Estimating urban trail traffic: Methods for existing and proposed trails. *Landscape and Urban Planning*, 81(4), pp.299-315.

Lindsey, G., Wilson, J., Anne Yang, J. & Alexa, C. (2008). Urban greenways, trail characteristics and trail use: implications for design. *Journal of Urban Design*, 13(1), pp.53-79.

Litman, T. (2012). Evaluating non-motorized transportation benefits and costs. Victoria, Canada.

Little, C. E. (1995). *Greenways for America*. Baltimore: JHU Press.

Loidl, M. (2014). How GIS can help to promote safe cycling. *Proceedings of the 28th EnviroInfo Conference*. Olderburg, Germany. 10-12th September.

Loomis, J. B. & Walsh, R.B. (1997). Recreation economic decisions: Comparing benefits costs. State College, PA: Venture Publishing.

Lowry, M., Callister, D., Gresham, M. & Moore, B. (2012). Assessment of Communitywide Bikeability with Bicycle Level of Service. *Transportation Research Record*, 2314, pp.41-48.

Lu, D., Yu, S. & Lu, J. (2013). Accessibility and use of urban greenway. Proceedings of the 6th

WSEAS International Conference on Landscape Architecture, Nanjing, China, 17-19th November, pp.58-66.
Lumsdon, L. (2000). Investigating the needs of the recreational cyclist: the experience of the Peak District National Park. *Town Planning Review*, 71(4), pp.477-487.
Lumsdon, L. (2003). Planning for recreational cycling in the UK. *Sustainable Transport: Planning for Walking and Cycling in Urban Environments*, pp.465-474.
Lumsdon, L., Downward, P. & Cope, A. (2004). Monitoring of cycle torism on long distance trails: the North Sea Cycle Route. *Journal of Transport Geography*, 12, pp.13-22.
Lumsdon, L., Weston, R., McGrath, P., Davies, N., Peeters, P., Eijgelaar, E. & Piket, P. (2009). *The European Cycle Route Network EuroVelo – Challenges and opportunities for sustainable tourism.* European Parliament, Directorate General for Internal Policies, Policy Department B: Structural and Cohesion policies, Transport and Tourism.
Lunn, P. & Layte, R. (2011).*The Irish Sports Monitor.* Economic and Research Institute and Irish Sports Council. Dublin, Ireland.
Lydon, M. (2003). Community mapping: the recovery (and discovery) of our common ground. *Geomatica*, 57, pp.131-44.
Lynch, K. (1960). *The Image of the City*. Cambridge Cambridge: MIT.
Ma, L., Dill, J. & Mohr, C. (2014). The objective versus the perceived environment: what matters for bicycling? *Transportation*, 41(6), pp.1135-1152.
Manton, R. & Clifford, E. (2012). A study of travel patterns to NUI Galway: lessons for Smarter Travel in Universities. Irish Transport Research Network (ITRN) Conference. University of Ulster, Jordanstown, UK. 29-30th August.
Manton, R. & Clifford, E. (2013). National Cycle Network Corridor 2 Mullingar-Oranmore: Constraints Study and Route Selection Report. NUI Galway, Ireland.
Manton, R., Duggan, A., Goggins, J. & Clifford, E. (2014). Carbon costs and savings of greenways: creating a balance sheet for the sustainable design and construction of cycling routes. *International Journal of Environment and Sustainable Development*, 13(1), pp.3-19.
Martikainen, P., Nykänen, H., Crill, P. & Silvola, J. (1993). Effect of a lowered water table on nitrous oxide fluxes from northern peatlands.*Nature*, 366, pp 51-53.
Mason, J., Moorman, C., Hess, G., & Sinclair, K. (2007). Designing suburban greenways to provide habitat for forest-breeding birds. *Landscape and Urban Planning*, 80(1), pp.153-164.
Massink, R., Zuidgeest, M., Rijnsburger, J., Sarmiento, O.L. &van Maarseveen, M. (2011). The climate value of cycling. *Natural Resources Forum*, 35, pp 100-111.
Mayo County Council (Mayo CoCo) (2013). Monasteries of the Moy route selection report. Mayo, Ireland.
Mayo County Council (Mayo CoCo) (2014). *Great Western Greenway website.* Available at: www.greenway.ie [Accessed 4th August 2014].
Mayor of London and Transport for London (2013). The mayor's vision for cycling in London: an Olympic legacy for all Londoners. London, UK.
McCarthy, O.T. (2011). The development of an evaluation model for inter-urban cycle routes. Masters thesis, Trinity College Dublin, Ireland.
McCarthy, O. T., Caulfield, B.& Deenihan, G. (2015). Evaluating the quality of inter-urban cycleways. *Case Studies on Transport Policy*. doi:10.1016/j.cstp.2015.11.004
McCool, P. (2013). Developing canal towpath routes in Westmeath. Presentation to National Cycle Network seminar, Department of Transport, Tourism and Sport, Dublin, Ireland.
McCulloch, C. E. & Neuhaus, J. M. (2003). *Generalized linear mixed models*. John Wiley & Sons, Ltd.
McDonald, F. & Nix, J. (2005). *Chaos at the crossroads.* Cork: Gandon.
McDonald, N. (2012). Children and cycling. In J. Pucher and R. Buehler (eds) *City Cycling*, Cambridge: MIT, pp. 235-256.
McRobert, J., Martin, T., Salvador, F. & Ker, I. (2008). *User guide to bicycle and shared path selection – using whole-of-life costing.* Australian Bicycle Council, Sydney, Australia.
Medina, L. & Hernández, S. (2008). Manual for the design of cyclepaths in Catalonia. Government of Catalonia, Barcelona.

Mendoza, J-M., Oliver-Solà, J., Gabarrell, X., Rieradevall, J.& Josa, A. (2012). Planning strategies for promoting environmentally suitable pedestrian pavements in cities.*Transportation Research Part D,* 17(6), pp.442-450.

Meschik, M. (2012). Sustainable cycle tourism along the Danube Cycle Route in Austria. *Tourism Planning & Development*, 9(1), pp.41-56.

Met Éireann (2014). *Monthly data for Athenry weather station.* Irish Meteorological Service Online. Available at: http://www.met.ie/climate/monthly-data.asp?Num=1875 [Accessed 2nd July 2014].

Milachowski, C., Stengel, T. & Gehlen, C. (2011). *Life cycle assessment for road construction and use.* European Concrete Paving Association, Centre for Building Materials, Germany.

Milakis, D. & Athanasopoulos, K. (2014). What about people in cycle network planning? Applying participative multicriteria GIS analysis in the case of the Athens metropolitan cycle network. *Journal of Transport Geography*, 35, pp.120-129.

Mineral Products Association (MPA) (2009).*Sustainable Development Report.* London, UK.

Minnesota State Department of Transport (DoT) (2007). *Bikeway Facility Design Manual.* Minnesota, USA.

Molina, J. (2014). *The Case for Crowdsourcing in Bicycle Planning: An Exploratory Study.* PhD theis, Tufts University, MA, USA.

Møller, M. & Hels, T. (2008). Cyclists' perception of risk in roundabouts. *Accident Analysis and Prevention,* 40, pp.1055–1062.

Mondshein, A., Blumenburg, E. & Taylor, B. (2013). Going mental: everyday travel and the cognitive map. *Access*, 43, pp.2-7.

Mondshein, A., Blumenburg, E. & Taylor, B. (2010). Accessibility and cognition: the effect of transport mode on spatial knowledge. *Urban Studies*, 47(4), pp.845-866.

Moody, S. & Melia, S. (2014). Shared space: Research, policy and problems. *Proceedings of the Institution of Civil Engineers –Transport,*167(6), pp.384-392.

Moore, R. (1994). Conflicts on multiple-use trails: Synthesis of the literature and state of the practice. For Federal Highway Administration and the National Recreational Trails Advisory Committee, USA.

Müller, C., Renou-Wilson, F. & Wilson, D. (2010) *Future Roles of Peatlands.* Johnstown Castle, Co. Wexford, Ireland.

Mundet, L. and Coenders, G. (2010). Greenways: a sustainable leisure experience concept for both communities and tourists. *Journal of Sustainable Tourism*, 18(5), pp.657-674.

Nash, E., Cope, A., James, P.& Parker, D. (2005). Cycle network planning: towards a holistic approach using temporal topology. Transportation planning and technology, 28(4), pp.251-271.

National Association of City Transportation Officials (NACTO) (2011). *Urban Bikeway design guide.* Washington DC, USA.

National Center on Accessibility (NCA) (2014). National trail surfaces study. Indiana, USA.

National Parks and Wildlife Service (NPWS) (2015). *Map Viewer.* Available at: http://webgis.npws.ie/npwsviewer/ [Accessed 9th June 2015].

National Roads Authority (NRA) (2010a). *National Cycle Network Scoping Study*. Dublin, Ireland.

National Roads Authority (NRA) (2010b). *Project Management Guidelines*. Dublin, Ireland.

National Roads Authority (NRA) (2011a). Project Appraisal Guidelines, Unit 13.0 Walking and Cycling Facilities. Dublin, Ireland.

National Roads Authority (2011b). *Manual of Contract Documents for Road Works, Series 800.* NRA, Dublin, Ireland.

National Roads Authority (NRA) (2012a). NRA IAN 03/12: provisions for cyclists and pedestrians on type 2 and type 3 single carriageway national roads in rural areas. Dublin, Ireland.

National Roads Authority (NRA) (2012b). TD 9/12 Road link design. Dublin, Ireland.

National Roads Authority (NRA) (2014a). TD 300/14 Rural cycle scheme design. Dublin, Ireland.

National Roads Authority (NRA) (2014b). TD 27/14 Cross-sections and headroom. Dublin, Ireland.

National Roads Authority (NRA) & Rough O'Donovan (ROD) (2009). Provisions for cyclists and pedestrians on national roads in rural areas: review of Type 3 carriageway cross section. Dublin, Ireland.

National Transport Authority (NTA) (2013a). *National Household Travel Survey 2012.* Dublin, Ireland.

National Transport Authority (NTA) (2013b). *Greater Dublin Area cycle network plan.* Dublin, Ireland.

National Transport Authority (NTA) (2012). *National Cycle Manual.* Dublin, Ireland.

Nayak, R., Miller, D., Nolan, A., Smith, P. & Smith, J. (2008). *Calculating carbon savings from wind farms on scottish peat lands - A new approach*. University of Aberdeen, and Macaulay Land Use Research Institute, Aberdeen, UK.

Nelson, T.A., Denouden, T., Jestico, B., Laberee, K. & Winters, M. (2015). BikeMaps.org: a global tool for collision and near miss mapping. *Frontiers in Public Health*, 3(53), pp.1-8.

Noland, R.B. (1995). Perceived risk and modal choice: risk compensation in transportation systems. *Accident Analysis and Prevention*, 27(4), pp.503-521.

Norton, D. (2008). *Fighting traffic: the dawn of the motor age in the American city*. Cambridge: MIT.

Odoki, J. B., Di Graziano, A. & Akena, R. (2013). A multi-criteria methodology for optimising road investments. *Proceedings of the ICE – Transport*, 168(1), pp.34-47.

O'Sullivan, M. (2015). Cycleway land war intensifies as CPO gets go-ahead. *Irish Independent*. 22nd February.

Organisation for Economic Co-operation and Development (OECD) (2014). *Average annual wages.* Available at: https://stats.oecd.org/Index.aspx?DataSetCode=AV_AN_WAGE [Accessed 14th August 2014].

Palau, R., Forgas, S., Blasco, D. & Ferrer, B. (2012). An analysis of greenways from an economic perspective. *Tourism Planning & Development*, 9(1), pp.15-24.

Parkin, J., Wardman, M. & Page, M. (2007a). Models of perceived cycling risk and route acceptability. *Accident Analysis and Prevention*, 39, pp.364-371.

Parkin, J., Ryley, T. & Jones, T. (2007b). Barriers to cycling: an exploration of quantitative analyses. In P. Rosen, P. Cox and D. Horton (eds) *Cycling and Society*, Hampshire: Ashgate, pp.67-82.

Parkin, J., Wardman, M. & Page, M. (2007c). Estimation of the determinants of bicycle mode share for the journey to work using census data. *Transportation*, 35, pp. 93-109.

Parkin, J. and Coward, A. (2009). Comparison of methods of assessing cycle routes. *Proceedings of the ICE – Municipal Engineer*, 162, pp.7-14.

Parkin, J. (2010). Planning walking networks and cycling networks. In D. Banister and M. Givoni (eds) *Integrated transport: from policy to practice*. London: Routledge, pp. 163-176.

Parkin, J. & Koorey, G. (2012). *Network planning and infrastructure design*. In J. Parkin (ed.) *Cycling and Sustainability*, London: Emerald, pp.131-160.

Parkin, J. (2014). Cycling design guidance: developments and remaining issues. Presentation, *Cycling and Society*, Northumbria University, 14-16th September.

Peñalosa, E. (2013). *Why buses represent democracy in action.* Presentation to TEDCity2.0, TimeCentre, New York, USA. Available at: http://www.ted.com/talks/enrique_penalosa_why_buses_represent_democracy_in_action#t-607775 [Accessed 14th December 2013].

Pettengill, P., Lee, B. & Manning, R. (2012). Traveler Perspectives of Greenway Quality in Northern New England. *Transportation Research Record*, 2314, pp.31-40.

Philbin, P. (2014). *The greenway forward: opportunities for tourism.* Presentation to The Greenway Forward for Tourism, Health & Sport conference, Dundalk, Co. Louth, 9th April.

Ploeger, J. (2003). Infrastructure planning for cycling.In R. Tolley (ed.) *Sustainable transport*, Cambridge: Woodhead, pp. 267-281.

Pourjafar, M. & Moradi, A. (2015). Explaining Design Dimensions of Ecological Greenways. *Open Journal of Ecology*, 5, pp.66-79.

Prendergast, P. & Rybaczuk, K. (2005). Using visualisation techniques in planning to improve collaborative governance in Ireland. In *Proceedings of the 10th International conference on Information and Communication Technologies in Urban Planning and Spatial Development and Impacts of ICT on Physical Space,* pp.235-243.

Preston, J. (1996). Cost-benefit and multi-criteria analysis for rail infrastructure. European Commission, Brussels, Belgium.

Pucher, J. & Dijkstra, L. (2000). Making walking and cycling safer: lessons from Europe. *Transportation Quarterly*, 54(3), pp.25-50.

Pucher, J. & Buehler, R. (2007). At the frontiers of cycling: policy innovations in the Netherlands, Denmark, and Germany. *World Transport Policy and Practice*, 13(3), pp.8-57.

Pucher, J. & Buehler, R. (2009). Cycling for a few or for everyone: The importance of social justice in cycling policy. *World Transport Policy & Practice*, *15*(1), pp.57-64.

Pucher, J., Buehler, R. & Seinen, M. (2011). Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. *Transportation Research Part A*, 45, pp.451-475.

Pucher, J. & Buehler, R. (2012). International overview: cycling trends in Western Europe, North America and Australia, in J. Pucher and R. Buehler (eds.) *City Cycling*, Cambridge: MIT, pp. 211-234.

Raidió Teilifís Éireann (RTÉ) (2015). 'The growing war between cyclists and motorists, what's happening on our streets?'. 26th May.

Rengert G.F. and Pelfrey, W.V. (1997). Cognitive Mapping of the City Center: Comparative Perceptions of Dangerous Places IN David Weisburd and Tom McEwen, eds (1997) *Crime Mapping and Crime Prevention*, pp.193-217, Willow Tree Press, New York.

Renou-Wilson, F., Bolger, T., Bullock, C., Convery, F., Curry, J., Ward, S., Wilson, D. and Muller, C. (2011) *A Protocol for Sustainable Peatland Management in Ireland.* Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Reid, C. (2014). *Roads were not built for cars.* Washington*:* Island.

Ribeiro, P., Rodrigues, D.S. & Taniguchi, E. (2015). Comparing stardard and low-cost tools for gradient evaluation along potential cycle paths. *WSEAS Transactions on Environment and Development*, 11, pp.29-40.

Road Safety Authority (RSA) (2013). *Road deaths in Ireland 1959-2009.*Ballina, Co. Mayo, Ireland.

Road Safety Authority (RSA) (2014). Provisional Review of Road Crashes 2014. Ballina, Co. Mayo, Ireland.

Roche, E. (2013). *An examination of Ireland as a cycle tourism destination – people, product and promotion.* BSc thesis, School of Hospitality Management and Tourism, Dublin Institute of Technology, Ireland.

Roscommon County Council (Roscommon CoCo) (2012). *NCN Funding Scheme 2012/13 application.* Roscommon, Ireland.

Roughan O'Donovan (2009). Provisions for cyclists and pedestrians on national roads in rural areas: a review of Type 3 Single Carriageway Cross Section. For National Roads Authority, Dublin, Ireland.

Roughan O'Donovan (2013). *R292 Sligo to Strandhill cycleway.* Available at: http://www.rod.ie/wp-content/uploads/2013/03/sli3_re.jpg [Accessed 21st August 2014].

Roughan O'Donovan (2014a). N56 Cloghboie to Boyoughter. Available at: http://www.rod.ie/n56-cloghbolie-to-boyoughter/ [Accessed 15th September 2014].

Roughan O'Donovan (2014b).N59 Derrylea Cycleway. Available at: http://www.rod.ie/n59-derrylea-cycleway/ [Accessed 15th September 2014].

Roulet, N. T., Ash, R., Quinton, W. & Moore, T. (1993). Methane flux from drained northern peatlands: effect of a persistent water table lowering on flux. *Global Biogeochemical Cycles*, *7*(4), pp.749-769.

RPS (2011). *N86 Dingle to Annascaul and Gortbreagoge to Camp Road Improvement Scheme : Environmental Impact Statement*. Prepared for Kerry County Council. Galway, Ireland.

RPS (2012). *Connemara Greenway – Clifden to Oughterard Environmental Impact Statement.* Prepared for Galway County Council. Galway, Ireland.

Rybarczyk, G., & Wu, C. (2010). Bicycle facility planning using GIS and multi-criteria decision analysis. *Applied Geography*, 30(2), pp.282-293.

Saelensminde, K. (2004). Cost-benefit analyses of walking and cycling track networks taking into account insecurity, health effects and externals costs of motorized traffic. *Transportation Research Part A*, 38, pp.593-606.

Safe Cycling Ireland (2015). Petition for a minimum overtaking distance when drivers overtake bicycle riders. Available at: https://www.change.org/p/petition-for-a-minimum-overtaking-distance-when-drivers-overtake-bicycle-riders [Accessed 15th October 2015].

Sager, B.A. (2002). Is the constitution of a greenway trail netowkr associated with cycling commuter use? Masters thesis, College of Architecture, Planning, and Landscape Architecture, University of Arizona.

Sahlqvist, S., Goodman, A., Jones, T., Powell, J., Song, Y., Ogilvie, D. & iConnect consortium. (2015). Mechanisms underpinning use of new walking and cycling infrastructure in different contexts: mixed-method analysis. *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), p.24.

Saldaña, J. (2012). *The coding manual for qualitative researchers.* London: Sage.

Salici, A. (2013). Greenways as a sustainable urban planning strategy. In M. Özyavuz (ed.) *Advances in Landscape Architecture*. Hampshire: Intech.

Sanders, R. (2014). Roadway design preferences among drivers and bicyclists in the Bay Area. Transportation Research Board Annual Meeting, Washington DC, 12-16th January.

Sanders, R. (2015). Perceived traffic risk for cyclists: the impact of near miss and collision experiences. *Accident Analysis & Prevention*, 75, pp. 26-34.

Schepers, P., Fishman, E., Beelen, R., Heinen, E., Wijnen, W., & Parkin, J. (2015). The mortality impact of bicycle paths and lanes related to physical activity, air pollution exposure and road safety. *Journal of Transport & Health,* 2(4), pp.460-473.

Schepers, P. and Wolt, K.K (2012). Single-bicycle crash types and characteristics. *Cycling Research International,* 2, pp.119-135.

Schoon, J.G. (2010). *Pedestrian facilities: engineering and geometric design*. London: Thomas Telford.

Scottish Natural Heritage (SNH) (2003). *Windfarms and Carbon Savings.* Technical Guidance Note, Inverness, UK.

Searns, R. M. (1995). The evolution of greenways as an adaptive urban landscape form. *Landscape and urban planning*, 33(1), pp.65-80.

Sener, I. N., Eluru, N. & Bhat, C.R. (2009). An analysis of bicycle route choice preferences in Texas, US. *Transportation*, 36(5), pp.511-539.

Shackel, S. C. & Parkin, J. (2014). Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles over-taking cyclists, *Accident Analysis & Prevention*, 73. pp.100-108.

Shafer, C. S., Lee, B. K. & Turner, S. (2000). A tale of three greenway trails: user perceptions related to quality of life. *Landscape and Urban Planning*, 49(3), pp.163-178.

Short, J. & Caulfield, B. (2014). The safety challenge of increased cycling. *Transport Policy*, 33, pp.154-165.

Smith, T.M.F. (1983). On the validity of inferences from non-random samples. *J. R. Statist. Soc. A*, 146(4), pp.394-403.

Snizek, B., Nielsen, T.A.S. & Skov-Petersen, H. (2013). Mapping bicyclists' experiences in Copenhagen. *Journal of Transport Geography*, 30, pp.227-233.

Spears, S., Houston, D. & Boarnet, M.G. (2013). Illuminating the unseen in transit use: a framework for examining the effect of attitudes and perceptions on travel behaviour. *Transportation Research Part A*, 58, pp.40-53.

Stipple, H. (2001).*Life cycle assessment of road – a pilot study for inventory analysis.* IVL Swedish Environmental Research Institute Ltd, Stockholm, Sweden.

Sundh, I., Nilsson, M., Mikkela, C., Granberg, G. & Svensson, B.H. (2000). Fluxes of Methane and Carbon Dioxide on Peat-Mining Areas in Sweden.*Ambio,* 29(8), pp.499-503.

Sustrans (2007). *The economic impact of cycle tourism in North East England.* Bristol, UK.

Sustrans (2009). *Connect2 greenways guide.* Bristol, UK.

Sustrans (2010). *Moving forward, a year of delivering smarter travel choice.* Bristol, UK.

Sustrans (2012). Cycle path surface options. Technical Information Note No.8. Bristol, UK.

Sustrans (2014). Millions of people on the move: usage and benefits of the National Cycle Network in 2013. Bristol, UK.

The Guardian (2013).*Over 1,000 cyclists stage die-in protest outside Transport for London HQ.* Available at: http://www.theguardian.com/environment/bike-blog/2013/dec/01/stop-killing-cyclists-die-in-tfl-protest [Accessed 1st July 2015].

Thogerson, J. (2006). Understanding repetitive travel mode choices in a stable context: a panel study approach. *Transportation Research Part A,* 40, pp.621-638.

Tierney, D. (2015). New efforts to solve impasse over greenway. *Connacht Tribune*. 9th May.

Tilahun, N.Y., Levinson, D.M. & Krizek, K.J. (2007). Trails, lanes, or traffic: valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A*, 41, pp.287-301.

Timperio, A, Crawford, D., Telford, A. & Salmon, J. (2004). Perceptions about the local neighbourhood and walking and cycling among children. *Preventive Medicine*, 38, pp.39-47.

Transport Infrastructure Ireland (TII) (2015). Galway/Roscommon Greenway landowner consultaton report. Dublin, Ireland.

Transport Scotland. (2009) *Scottish Transport Analysis Guide*. Glasgow, UK.

Transport Scotland (2011). *Cycling by Design 2010.* Glasgow, UK.

Transportation Research Board (TRB) (2011). *Highway Capacity Manual 2010.* Washington DC, USA.

UK Department of Energy and Climate Change (DECC) and Department for Environment, Food and Rural Affairs (Defra) (2011).*Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*. London, UK.

UK Department for Transport (UK DfT) (2008). *Cycle Infrastructure Design.* Local Transport Note 2/08. London, UK.

UK Department for Transport (UK DfT) (2010). Guidance on the Appraisal of Walking and Cycling schemes, Transport Analysis Guidance (TAG) Unit 3.14.1.London, UK.

UK Department for Transport (UK DfT) (2014). *British Social Attitudes Survey 2013: Public attitudes towards transport.* London, UK.

UK Department for Transport (UK DfT)/Cyclists' Touring Club (CTC)/Bicycle Association/Institute for Highways and Transportation (1996). *Cycle-friendly infrastructure.* London, UK.

UK Roads Board (2003). *Application Guide AG26 (Version 2) Footway and cycle route design, construction and maintenance guide.* Berkshire, UK.

Vanderbilt, T. (2008). *Traffic: why we drive the way we do (and what it says about us.* NY: Knopf Doubleday:.

Van den Dool, D. & Murphy, J. (2014). Cycling on rural roads. *Journal of the Australasian College of Road Safety*, 25(4), pp. 62-71.

Veith, G. & Eady, P. (2011) *Cycling aspects of Austroads guides.* Austroads, Sydney, Australia.

Vigar, G. (2002). The politics of mobility: transport, the environment and public policy. London: Spon.

Von Haaren, C.& Reich, M. (2006). The German way to greenways and habitat networks. *Landscape and Urban Planning*, 76(1), pp.7-22.

Wann, J. (2013). Biodiversity survey of the abandoned railway between Creeslough and Burton port, Co. Donegal. Belfast, Northern Ireland.

Walsh, C., Jakeman, P., Moles, R. & O'Regan, B. (2008). A comparison of carbon dioxide emissions associated with motorised transport modes and cycling in Ireland. *Transportation Research Part D,*13, pp.392-399.

Walton, D. & Smith, K. (2007). *Economic valuation of cycling and walking.* Lower Hutt, New Zealand.

Wardlaw, M.J. (2014). History, risk, infrastructure: perspectives on bicycling in the Netherlands and the UK. *Journal of Transport and Health*, 1(4), pp. 243-250.

Waste & Resources Action Programme (WRAP) (2011).*Asphalt Pavement Embodied Carbon Tool (asPECT).* Banbury, UK.

Waterways Ireland (2015). *Our waterways.* Available at: http://www.waterwaysireland.org/ [Accessed 9th June 2015].

Westmeath County Council (2013). Athlone to Mullingar shared cycleway and footway Part 8 planning application. Westmeath, Ireland.

Weston, R., Davies, N., Peeters, P. & Eijgelaar, E. (2012). *The European Cycle Route Network EuroVelo – Challenges and opportunities for sustainable tourism.* European Parliament, Directorate General for Internal Policies, Policy Department B: Structural and Cohesion policies, Transport and Tourism.

Whannell, P., Whannell, R. & White R. (2012). Tertiary student attitudes to bicycle commuting in a regional Australia university. *International Journal of Sustainability in Higher Education*, 13, pp.34-45.

Whelan, C. (2015). Councillors vote to protect landowners along proposed greenway route. *Galway Advertiser*. 29th January.

Wickham, J. (2006). *Gridlock: Dublin's transport crisis and the future of the city*. Dublin: New Island.

Winchester, C. (2014). *Railways of Ireland*. Gloucestershire: Amberley.

Winters, M., Babul, S., Becker, H.J.E.H., Brubacher, J.R., Chipman, M., Cripton, P., Cusimano, M.D., Friedman, S.M., Harris, M.A., Hunte, G., Monro, M., Reynolds, C.C.O., Shen, H. & Teschke, K. (2012). Safe cycling: how do risk perceptions compare with observed risk?. *Can J Public Health*, 103(9), pp.S42-S47.

Wisconsin State Department of Transport (DoT) (2009). *Wisconsin Bicycle Facility Design Manual.* Wisconsin, USA.

Wooliscroft, B. & Ganglmair-Wooliscroft, A. (2014). Improving conditions for potential New Zealand cyclists: an application of conjoint analysis. *Transportation Research Part A: Policy and Practice*, 69, pp.11-19.

World Health Organization (WHO) (2011). Health Economic Assessment Tools (HEAT) for walking and for cycling. Copenhagen, Denmark.

Zeile, P., Resch, B., Dörrzapf, L., Exner, J. P., Sagl, G., Summa, A. & Sudmanns, M. (2015). Urban Emotions –tools of integrating people's perception into urban planning. Proceedings REAL CORP 2015 Tagungsband. Ghent, Belgium. 5-7th May.