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Using Place Rank to Measure Sustainable Accessibility

Amaya Vega

School of Business and Economics, National University of Ireland Galway, Ireland.

Room, 338, JE Cairnes Building, University Road, National University of Ireland Galway, Galway, Ireland.

Tel.: (+353)(0)91 495679

E-mail: amaya.vega@nuigalway.ie

Abstract

Sustainability and its implications for transport planning is an area of growing interest to researchers, transport practitioners and policy makers. This study draws from recent research on the concept and measurement of sustainable accessibility in urban areas. The paper focuses on the particular case of small urban areas, where walking and cycling represent a significant proportion of the overall travel mode share. The methodology suggested in this paper departs from the use of traditional gravity-based measures of accessibility and sustainability, which tend to focus on motorised modes of travel. Instead, the present study suggests an extension of the Place Rank accessibility method to incorporate a measurement of sustainability through the multi-modal analysis of commuting trips for the City of Galway, Ireland. The paper concludes that the use of a multi-modal approach to the measurement of sustainable accessibility offers an additional insight into the nature of urban commuting and the spatial distribution of employment in small cities, where the understanding of non-motorised travel-to-work mode use is of great importance for urban transport planning and practice.

1. Aims and scope

The role of accessibility as a tool for transport planning has been acknowledged in recent studies (Straatemeier, 2008). Accessibility-based analysis offers the benefits of the integration of the urban land use and transport systems, which is widely recognised as essential to the achievement of sustainable development (Banister, 2002). This is based on the generally accepted idea that a more sustainable environment can be attained through the promotion of mixed land uses and alternative forms of travel such as public transport and non-motorised travel modes (Kwok and Yeh, 2004; Straatemeier, 2008).

The measurement of accessibility in urban areas tends to focus on the use of motorised modes of travel as indicators of accessibility and sustainability (see for example Shen, 1998; 2001). However, given the compact spatial distribution of activities in small cities, these are typically characterised by larger shares of non-motorised travel - cycling and walking - as the main forms of travel. While motorised travel tends to be most sensitive to travel times and levels of network congestion, non-motorised travel choices tend to include factors that may be more qualitative, experiential or difficult to measure (Page, 2005). This represents a major limitation for local/regional transport planning authorities as the detailed travel-specific data that is generally required to compute locational measures of accessibility – such as the widely used gravity-based measure – may be either unavailable or highly unreliable in the case of small cities (see Iacono et al. (2010) for a detailed discussion on non-motorised accessibility). As a result, walking and cycling as main modes of travel are often excluded from the analysis of accessibility (Handy and Clifton, 2001; Krizek, 2005; Iacono et al., 2010) and consequently, their potential contribution to the overall levels of sustainability in urban areas can be overlooked.

Cheng et al. (2007) suggest a measure of sustainable accessibility as an alternative tool to support the design of policies for land use and transport planning. The authors use spatial conflict analysis to identify ways of achieving a balance between accessibility and sustainability. Gravity-based measures of accessibility are combined with a travel distance-based measure of (environmental) sustainability. The methodological framework suggested here draws from the literature on sustainable accessibility while trying to address the limitations for small cities outlined above.

A multi-modal accessibility-based approach is suggested where a flow-based measure of accessibility by travel mode is weighted by an energy performance index for each origin-destination pair. The spatial information that can be obtained from the actual flow by travel mode weighted by the carbon-based energy consumption for each particular trip is used in the computation of a mode-specific indicator of sustainable accessibility. This way, the contribution of non-motorised forms of travel to the levels of accessibility and sustainability is taken into account. This measure is an extension of El-Geneidy and Levinson's (2011) Place Rank index to take into account the level of sustainability of each individual trip. The use of a flow-based measure implies that the indicator is based on actual choices of origins and destinations and therefore, it measures realised rather than potential opportunities (El-Geneidy and Levinson, 2011).

An application of the suggested methodology is carried out for the City of Galway, Ireland. In spite of being the fastest growing city in Ireland, Galway is still considered a small city by international standards, with just below 75,000 inhabitants. The city serves as the capital for the Border Midlands and Western (BMW) Region and it is designated Regional Gateway for the West of Ireland in the National Spatial Strategy 2002-2020 (NSS). Travel to work data from the 2006 Census of Population of Ireland (CSO, 2006) is used for the analysis. Results from a traditional gravity-based measure of accessibility are compared with the results obtained from the suggested weighted flow-based measure. The computational process is carried out iteratively for all individuals in the study area and their choice of main mode of travel to work by residential origin and employment destination.

The paper is organised as follows. In section 2 a brief review of the accessibility concept and its importance for transport planning is outlined. The methodological framework is presented in Section 3. Section 4 contains the case study for the city of Galway and the results form the analysis. Finally, conclusions and recommendations are offered in Section 5.

2. Accessibility and sustainability in transport planning

The role of accessibility in the dynamic process of integration of the urban land use and transport system is widely recognised (Borzacchiello et al., 2010). The benefits of adopting an accessibility-based approach in urban transport planning have been highlighted by researchers from various disciplines for over a decade (Banister, 2002). The importance of accessibility as a criterion for the assessment of transport policies has been emphasised in the more recent literature where accessibility analyses have been suggested as tools for raising policy design questions and indentifying alternative solutions in the earlier phases of the planning process (Straatemeier, 2008; Bristow et al. 2009).

The growing interest in accessibility, or the ability to reach activities and destinations, has been further underlined by an increase in the research concerned with the challenges faced by strategic transport planning with regards to sustainable transport or sustainable mobility (Feitelson, 2002; Jeon et al., 2008; Banister, 2008). The potential contribution of an accessibility-driven transport policy agenda to the sustainability discourse has been discussed in the literature (see Farrington, 2007). The objectives of resource efficiency maximisation related to the notion of sustainability in transport planning are very much in line with the idea of improving accessibility with lower carbon-resource consumption. From a sustainability perspective, urban transport planning cannot be treated in isolation from land use and the environment without compromising sustainability goals (Geerlings and Stead, 2003).

Accessibility is a concept widely studied in scientific research for a wide range of purposes and applications. Many studies using accessibility indicators contain a review of the accessibility concept and different approaches to measuring it (see for example, Handy and Niemeier, 1997; Geurs and Ritsema van Eck, 2001; Halden, 2002; Geurs and van Wee, 2004; Martin and Reggiani, 2007; Willigers et al., 2007). There is a wide variety of indicators to measure accessibility, which reflects the existence of numerous approaches and methods (Geurs and Ritsema van Eck, 2003). Most studies agree that the specific formulation of an accessibility measure depends on the particular aim of the study and that the definition of accessibility greatly depends on the application for which it is used (Borzacchiello et al., 2010). Several formulations of accessibility have been suggested in the literature, which may lead to different results for the same transport network and land use context (Reggiani and Bucci, 2007; Borzacchiello et al. 2010).

The concept of accessibility has been studied in the context of the various dimensions of sustainability – economic, environmental and social - in Bertolini et al., 2005; Cheng et al., 2007; Farrington, 2007; and Curtis, 2008. Bertolini et al., (2003) use the concept of sustainable accessibility to refer to the identification of interdependencies and trade-offs at the strategic planning level between transport and land use developments to ensure that acceptable levels of sustainability are achieved in the urban system. The concept of sustainable accessibility offers a framework for achieving a balance between seemingly contradictory policy objectives such as enhancing the accessibility of the urban region and improving the sustainability of the transport system (Cheng et al., 2007).

A major challenge in the measurement of accessibility is finding the right balance between measures that are theoretically and empirically sound and those that are sufficiently plain to be implemented in the strategic transport planning process (Bertolini et al., 2005). The use of complex modelling tools, which require large amounts of data has been identified as a major limitation in the use of accessibility indicators in transport planning (Straatemeier, 2008). The importance of finding the right balance between the computational and data requirements and their ease of use and interpretability for transport planners and practitioners is a recurrent theme in the literature (Handy and Clifton, 2001, Bertolini et al., 2005, for example).

More related to the specific aim of this paper, a number of studies have drawn attention to the limited applications of accessibility indicators for non-motorised modes such as walking and cycling (Handy and Clifton, 2001; Krizek, 2005; Iacono et al. 2010). Some of the most widely used indicators of accessibility – such as the gravity-based measure - are difficult to apply to the study of non-motorised travel as alternative qualitative factors may play a more important role than the traditionally used travel times in the case of motorised modes (Iacono et al., 2010). Measuring non-motorised accessibility is particularly relevant in the case of small cities, where recent research for Belgium has found that cycling is one of the most preferred modes of travel to work due to less dense road traffic and often limited public transport services (Vandenbulcke et al., 2009). The importance of cycling and walking for sustainable accessibility in small urban areas requires a multi-modal approach, which is the focus of the next section.

3. Methodology: using Place Rank as a multi-modal approach to the measurement of sustainable accessibility in Small Cities

The methodological framework suggested in this paper is an extended version of the Place Rank measure of accessibility (see El-Geneidy and Levinson, 2011 for details) modified to account for sustainability. The objective with this extension on Place Rank is to be able to measure the levels of sustainable accessibility by travel mode at each geographical location in the study area.

The conceptual framework draws from Cheng et al. (2007) and it is based on the concept of conflicts in the planning process. Under this framework, the levels of accessibility and sustainability are not only interdependent, but also contradictory with regard to policy objectives (Cheng et al., 2007). The potential conflicts between accessibility and sustainability are classified into four cases or scenarios based on whether the levels of both indicators are above/below a certain acceptable standard for accessibility/sustainability, which can be either the mean or the median. This leads to in the identification of geographical areas where the levels of accessibility are more/less sustainable (see Cheng et al, 2007 for details on their methodology).

From an empirical perspective, the analysis of conflicts in Cheng et al., (2007) is based on the combination of a traditional gravity-based measure of accessibility and a distance-based indicator of sustainability. This is computed as a single-mode indicator of accessibility. The gravity-based measure focuses on the attractiveness or value of the destination (or opportunity) to be reached. The main assumption made is that the value of the opportunity is equal for all users subject to the impedance or the cost of getting to the desired destination, which is usually the travel distance or travel time. According to this indicator, the level of accessibility of a particular point or region is positively related to the volume of economic activity at the destination, and inversely proportional to the distance/travel time between origin and destination. Therefore, it measures the level of economic potential regardless of whether the actual trips occur or not. The mathematical expression for this indicator is the following:

$$A_i = \sum_j W_j f\left(c_{ij}\right) \tag{1}$$

Where:

A_i The level of accessibility at origin location *i*

W_j The level of attractiveness of the destination location *j,* such as the number of jobs or the total population

$f(c_{ij})$ The impedance function or the measurement of the spatial separation between origin *i* and destination *j*.

Various functional forms have been used as measurements of spatial separation. The negative exponential function is the type of impedance function most closely related to travel behaviour theory (Handy and Niemeier, 1997).

In order to assist in the comprehensive analysis of accessibility and sustainability in small cities, where a larger proportion of trips take place by non-motorised modes, this paper suggests an alternative methodological framework. An extension on a flow-based measure of accessibility – Place Rank (see El-Geneidy and Levinson, 2011 for details) – is weighted by an index of energy performance for each trip and travel mode so that areas with low levels of sustainability – high share of motorised mode use and long travel distances - rank lower in terms of sustainable accessibility.

An extended version of Boussauw and Witlox (2009) index of energy performance for commuting is used to measure sustainability. The level of energy performance is computed for each origin-destination pair and normalised so that values range between 0 and 1. The mathematical formulation of the energy performance index is as follows:

$$F_{ij} = \frac{D_{ij} * \sum_{m} \overline{E}_m * C_{m,ij}}{\sum_{m} E_{ij,0}} \quad (2)$$

$$C_{m,ij} = \frac{S_{m,ij} * \overline{D}_m}{\sum_{m} S_{m,ij} * \overline{D}_m} \quad (3)$$

Where:

F_{ij} The energy performance index for each origin-destination trip *ij*

D_{ij} The distance travelled between origin *i* and destination *j*

E_m The mean energy consumption per passenger/km at average occupancy measuring the level of CO2 Emissions for the considered mode *m*;

$C_{m,ij}$ Correction factor to keep the relationship between mode and distance travelled – described in Equation (3) for mode *m* and for origin-destination pair *ij*

$S_{m,ij}$ Share of the considered mode *m* as the main transport mode in the total number of trips for each origin-destination pair *ij*

D_m Average distance of each individual trip by the considered mode *m*;

Place Rank highlights the most and least attractive areas based on their implicit value more than their ease of reach. It is based on the methodology developed by Brin and Page (1998) used by search engines such as Google to rank Web pages. The Place Rank of an area is determined based on the number of people travelling to this area to reach an opportunity. The power of the contribution of an individual person depends on the attractiveness of the zone of origin. Place rank redistributes the total number of people involved in the studied activity between the zones in a manner that it is weighted based on the zones attraction and the power of the links (see El-Geneidy and Levinson, 2011 for details). In addition, Place Rank measures of accessibility do not require the definition of a travel impedance function as it is already embedded in the flow data (El-Geneidy and Levinson, 2011) therefore, addressing the limitations in terms of travel data availability outlined in previous sections. The use of a flow-based measure means that the indicator is based on actual choices of origins and destinations, thus measuring realised rather than potential opportunities.

In this paper, the original trip table in the computation of the Place Rank model is weighted by the normalised index of energy performance for each individual trip. The mathematical formulation of the resulting model for sustainable accessibility is as follows:

$$P_{i,t} = \frac{R_{i,t}}{O_i} \quad (4)$$

$$E_{ij,t} = E_{ij,0} * F_{ij} * P_{i,t-1} \quad (5)$$

$$R_{j,t} = \sum_{i=1}^{I} E_{ij,t} \quad (6)$$

$$R_{i,t} = R_{j,t}^{T} \quad (7)$$

$$\text{If } R_{i,t} = R_{i,t-1}, stop; Else(Eq.(4)) \quad (8)$$

Where:

$P_{i,t}$ The power of each person leaving origin *i* in iteration *t*; $P_{i,t} = P_{j,t}^{T}$

$R_{j,t}$ The Place Rank for area *j* in iteration *t*, $R_{j,0} = \sum_{i} E_{ij,0}$

I Total number of *i* areas

$E_{ij,t}$ The weighted trip table, the number of people leaving origin *i* to reach activity in *j* weighted by the energy performance index, $E_{ij,0}$ is the original trip table.

O_i The number of people originating in area *i*; $O_i = \sum_{j} E_{ij,0}$

The computation is carried out iteratively for at least two iterations and for each mode of travel considered in the analysis. The Place Rank is determined when the difference between two consecutive iterations is equal to zero (stability).

Place Rank measure of accessibility does not represent a substitute indicator to the gravity model or any other locational measure of accessibility. It has been considered in the literature as complementary rather than competing with existing measures of accessibility in the process of understanding land use and transport interactions. For small cities, Place Rank offers the possibility of carrying out multi-modal analyses of accessibility and sustainability that take into account the contribution of non-motorised forms of travel without the need for large amounts of travel-specific data.

4. Results from the multi-modal analysis of sustainable accessibility to employment in the city of Galway, Ireland

In this section, results from the methodological framework described above are presented for the particular case of the journey-to-work in the City of Galway, Ireland. Results for a single-mode analysis of sustainable accessibility using a traditional gravity-based model are presented for comparison purposes. However, while the merits and limitations of Place Rank have been explored in recent studies (El Geneidy and Levinson, 2006; Cerda, 2009), carrying out comparisons between this method and other measures of accessibility is beyond the scope of this paper.

During the 1990s Ireland experienced the Celtic Tiger, a period of unprecedented economic growth characterised by a significant and rapid increase in living standards and employment. The rise in income levels had an enormous effect on property prices, which escalated very rapidly, as well as on car ownership rates. The property bubble that followed this period contributed to the development of new housing estates far away from the main urban employment centres, extending even further the commuter belt around Irish cities. Mobility-based transport planning practices and the relatively limited provision of public transport facilities in urban areas accelerated even further the rates of car dependency, which increased by over 20% in the period 2002-2006 (CSO).

The study area defined for the purpose of this research is the Galway Metropolitan Smarter Travel Area (GMSTA). The area – mapped in Figure 1 - serves as the capital for the Border Midlands and Western (BMW) Region and it is designated Regional Gateway for the West in the National Spatial Strategy 2002-2020 (NSS). With regard to commuting patterns, walking and cycling in Galway represent nearly double the national average and constitute the second most used mode of travel for combined work and school trips. In spite of these patterns of non-motorised modal use, the study area is increasingly suffering from severe traffic congestion levels. Previous research on commuting patterns for the GMSTA have suggested that Galway has the potential to support higher levels of walking and cycling as a form of 'active travel' (MVA Consultancy, 2010), which makes it a relevant case study for the methodology suggested in this paper.

[Figure 1]

Data from the 2006 Place of Work Sample of Anonymised Records (POWCAR) is used for the analysis. Released by the Central Statistics Office of Ireland (CSO), POWCAR provides a full sample of anonymised records from the Census of Population of Ireland, which is carried out every five years. POWCAR contains information on persons who at the time of the census were (i) enumerated in a private household; (ii) 15 years old or over; (iii) enumerated at home, and (iv) their present principal status was working for payment or profit. It also provides information on the characteristics of the households, means of travel, distance and journey times to work as well as place of residence and place of work[1]. The spatial unit of analysis is the electoral district, which is the smallest geographic unit of analysis available in Ireland.

The computational process is carried out for all individuals in the study area and their choice of mode of travel to work by residential electoral district (origin) and electoral district of employment (destination). Four modes of travel to work are considered: car and public transport (motorised) and cycling and walking (non-motorised).

Figure 2a shows the results from the analysis of sustainable accessibility using a traditional gravity-based measure of accessibility and a distance-based measurement of sustainability (see Chen et al., 2007 for details on this methodology). ArcGIS network analysis is used to generate congestion-adjusted road travel times between electoral districts of origin and destination, the origin-destination matrix. A negative exponential impedance function is used in the computation of the gravity measure. The impedance parameter was computed in a previous study of accessibility for the same study area (see Rau and Vega, 2012 for details). The attraction factor is the level of employment at each employment destination.

In Figure 2b, the results from the analysis of sustainable accessibility using the extended – weighted – version of Place Rank are presented for all modes of travel. Results from Figures 2a and 2b show that the largest levels of sustainable accessibility are found in Galway City Centre and in the main employment sub-centre in the study area to the East of the city. Overall, the levels of sustainable accessibility are remarkably higher in the East than in the West of the GMSTA. This is primarily related to the spatial distribution of employment, with a number of large international corporations located on the eastern side of the city. However, small differences in relative sustainable accessibility are found between both measures – gravity-based versus Weighted Place Rank - when applied to all modes of travel.

[Figures 2a and 2b]

The full benefits of using the extended version of Place Rank are shown in Figures 3 to 6, where the results from the multi-modal analysis of sustainable accessibility suggested in this study are presented. This approach provides an additional insight into the nature of

[1] 2006 Irish Census of Population. Place of Work Census of Anonymised Records (POWCAR) User Guide. (www.cso.ie/census/documents/ PlaceofWork-SARUserGuide2006.pdf)

sustainable accessibility in the city of Galway by explicitly incorporating non-motorised modes into the analysis.

Figures 3 and 4 show the results for the motorised travel modes, car and public transport respectively. In both cases, the levels of sustainable accessibility remain higher in the East than in the West of city. However, this pattern is more pronounced in the case of the private car.

[Figure 3]

[Figure 4]

Figures 5 and 6 show the results for the non-motorised modes of travel to work in Galway, walking and cycling respectively. The map of sustainable accessibility for walking – Figure 5 - follows the patterns previously described for car and public transport, but with an additional electoral district (Oranmore) in the Eastern border of the region with high levels of sustainable accessibility. The longer distance from this electoral district to the city centre and the main Galway employment sub-centres is an indication of a potentially high level of employment self-containment in this district.

[Figure 5]

Figure 6 shows the results of sustainable accessibility for cycling. In this case, the results from the analysis of sustainable accessibility break with the previous trends found with other travel modes, i.e. higher levels of sustainable accessibility in the city centre and main employment centres and lower levels elsewhere, in particular in the West of the city. There is a corridor of high sustainable accessibility for cycling from the city centre to the North and East of the city. Also, additional electoral districts present high levels of sustainable accessibility in the West of the city, which corresponds with a major employer in the city, the university.

[Figure 6]

The levels of sustainable accessibility by public transport, walking and cycling relative to the sustainable accessibility scores obtained for the private car are illustrated in Figures 7a, 7b and 7c. This exercise provides a further understanding of the patterns of sustainable accessibility in the GMSTA and illustrates an additional application of the multi-modal approach suggested in this paper.

[Figures 7a, 7b and 7c]

In Figure 7a, peripheral electoral districts in the West of the GMSTA show the largest levels of public transport/car sustainable accessibility ratios. This is an indication of the relatively poor levels of sustainable accessibility by car in this part of the city – primarily due to severe traffic congestion – rather than an indication of a good provision of public transport. In Figure 7b, the walking/car ratios of sustainable accessibility are high in the East of the GMSTA and the western districts adjacent to the city centre, where the university and most of the university student accommodation residences are located. A similar pattern is found for the cycling/car ratio in Figure 7c, with the main differences between both Figures - 7b and 7c – found on the relative weight of walking and cycling with respect to car use in the Eastern electoral districts of the city.

The results from the multi-modal analysis of sustainable accessibility using a weighted version of Place Rank show that patterns of accessibility can vary significantly from the use of traditional single-mode aggregated measures of sustainable accessibility to the use of a multi-modal approach. While general patterns of sustainable accessibility remain the same, the spatial distribution of areas with high/low levels of sustainable accessibility varies for each of the travel modes considered in the analysis. This is particularly relevant in the case of cycling, for which the overall levels of sustainable accessibility shift northwards and westwards from the city centre.

5. Conclusions and recommendations

This article presents an alternative methodological framework for the measurement of sustainable accessibility in small urban areas. A multi-modal approach is suggested to incorporate the analysis of non-motorised modes to the study of accessibility and sustainability in an urban transport planning context. This is particularly relevant in the case of small cities, where the share of walking and cycling as the main mode of travel to work is generally large. The practical relevance of the suggested methodological framework for the day-to-day transport planning practice relies on the possibility of carrying out robust analyses of the sustainability of urban transport mobility patterns without the need for large amounts of mode-specific travel data. As a result, it can be potentially implemented in the study of the sustainability of alternative trip purposes – besides the journey to work - such as education (journey to school), shopping and health.

The main contribution of this paper is a novel methodological framework for the measurement of sustainable accessibility in a multi-modal urban environment. An extended version of the Place Rank measure of accessibility (El-Geneidy and Levinson, 2011) is presented to account for levels of sustainability of each individual commuting trip and this is illustrated for the city of Galway, Ireland. The objective of this methodology is to measure the levels of sustainable accessibility by travel mode at each geographical location in the study area.

While gravity-based measures focus on the potential of opportunities for interaction and depend on the existence of detailed travel data such as travel times to measure the spatial separation of activities, the suggested methodology measures realised opportunities as it is based on actual travel flows. This makes the application of sustainability-weighted Place Rank potentially more cost-efficient than the aforementioned traditional accessibility measures as it can be used in cases where only flow data is available. This cost element is increasingly important in countries like Ireland, where severe restrictions in government spending require alternative approaches to assist in the design of transport interventions that maximise the efficiency of the current transport system in a sustainable manner. In addition to these practical considerations for transport and accessibility planning, the full benefits of using the suggested multi-model methodological framework rely on its complementarity with other accessibility models, which has been acknowledged in previous studies of accessibility and Place Rank (El-Geneidy and Levinson, 2011).

Results from the analysis presented in this paper show that the adoption of a multi-modal approach to the measurement of sustainable accessibility provides an additional insight into the nature of urban commuting and the spatial distribution of employment by assisting transport planners in the identification of priority areas for transport intervention. This is relevant in the context of the urban transport planning process and in particular, within the strategic planning approach of transport prioritisation or travel demand management, where the allocation of resources such as money, road space and traffic priority favours higher value trips and energy-efficient modes.

The paper highlights the application of this methodology to small cities, where the share of walking and cycling as the main mode of travel to work tends to be large. The methodology can be applied to larger cities with available flow data. However, limitations related to the nature of long-distance commuting trips need to be assessed, as these trips are likely to involve more than one main mode of travel, such as a car-public transport combination through the use of a park-and-ride facility.

In this article, an alternative methodological framework has been suggested to measure sustainable accessibility. The adoption of a multi-modal approach represents a step forward into the understanding of the nature of accessibility and sustainability in urban areas as well as a practical tool for the support and design of land use and transport planning strategies aimed at promoting accessibility and sustainability by reducing vehicle travel.

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List of Figures

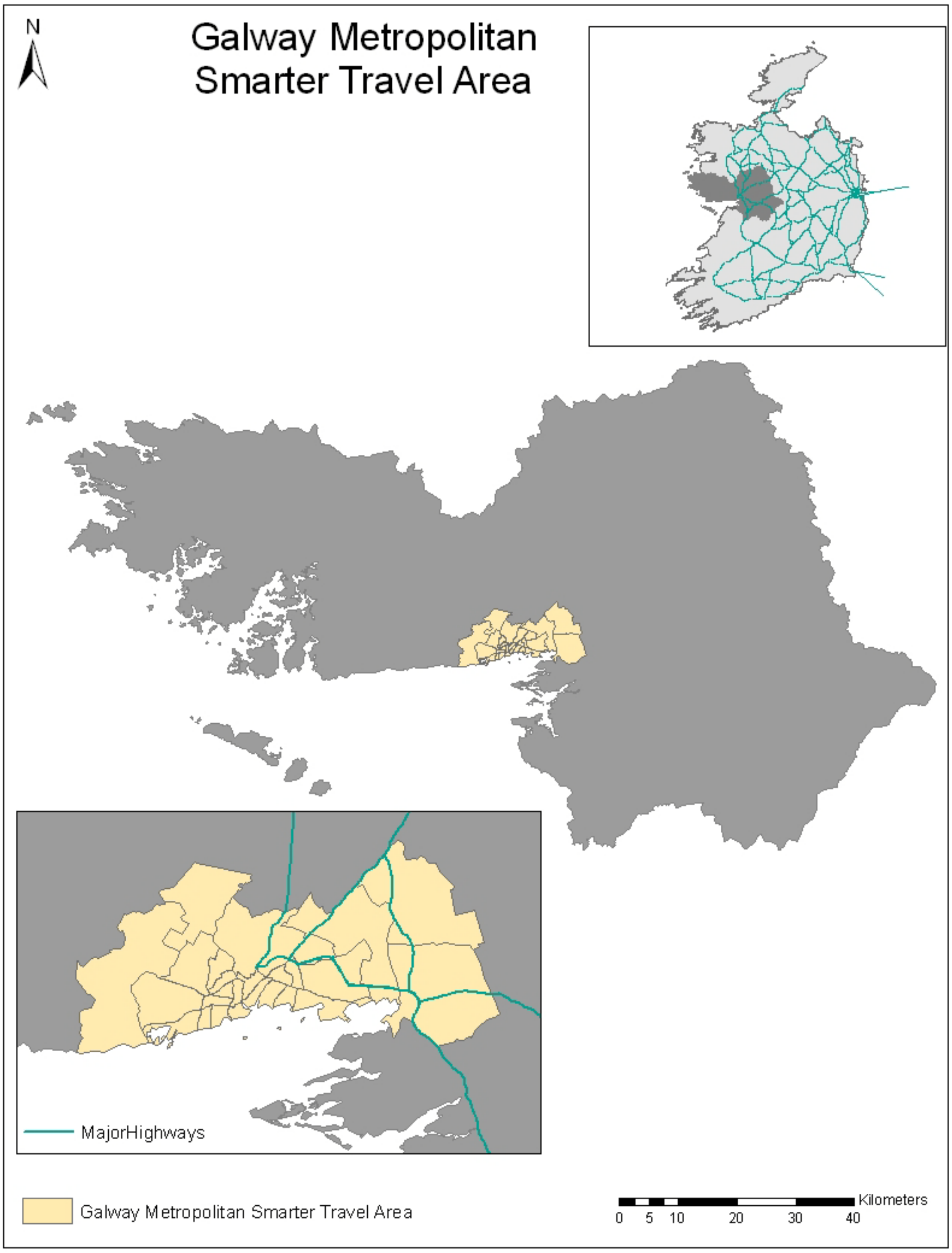

Figure 1: The Study Area: The Galway Metropolitan Smarter Travel Area (GMSTA)

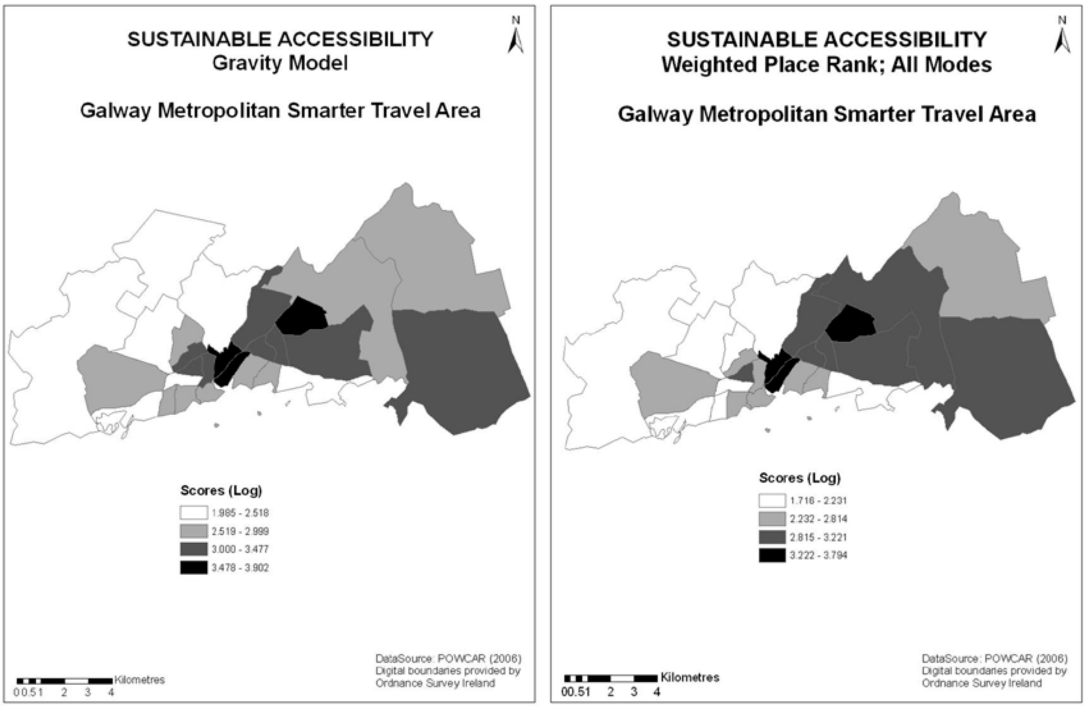

Figure 2: Figure 2a: Sustainable accessibility levels in the GMSTA using a gravity-based approach and a distance-based sustainability indicator. Figure 2b: Sustainable accessibility levels in the GMSTA using the extended – weighted – version of Place Rank for all modes of travel

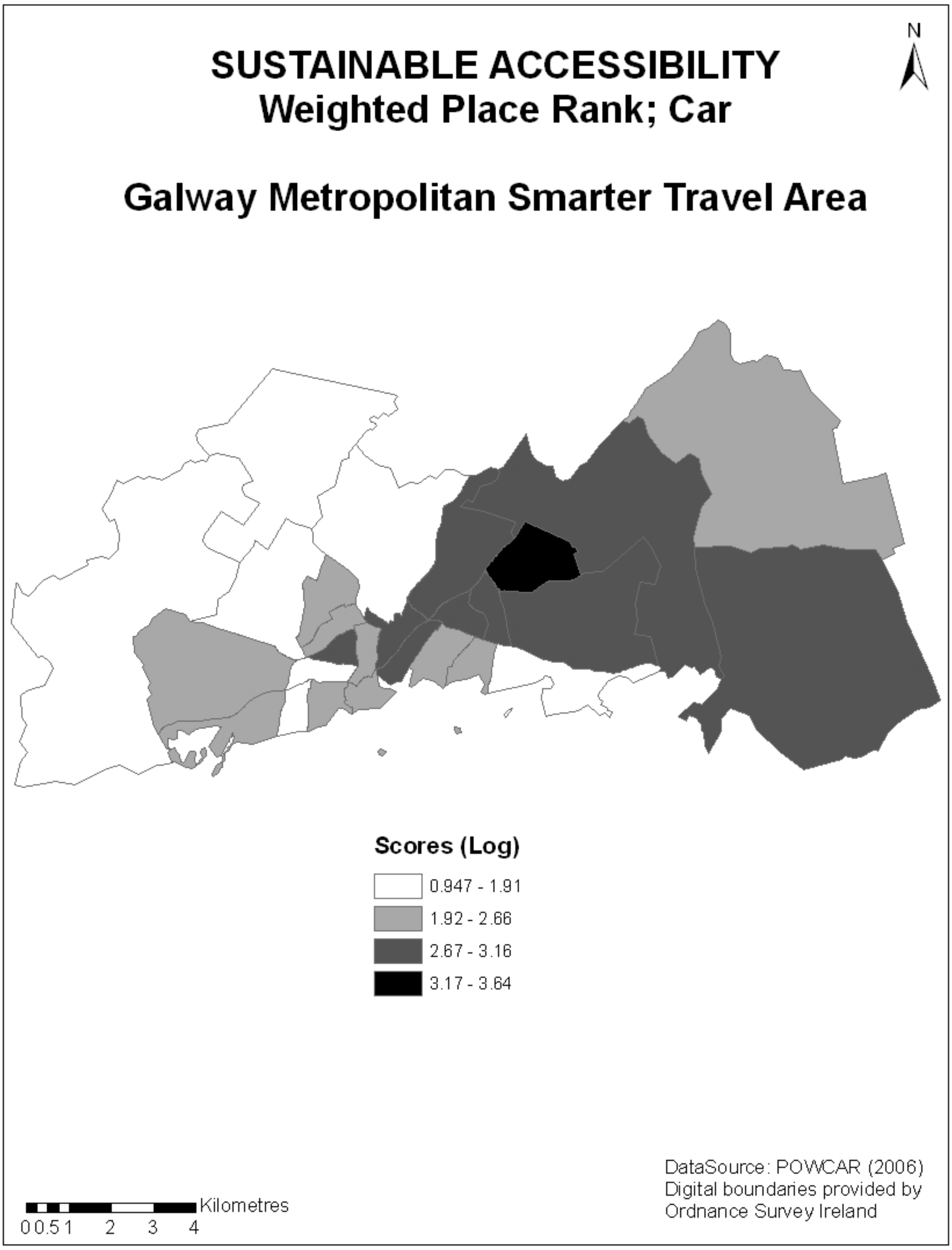

Figure 3: Sustainable accessibility levels in the GMSTA using Place Rank weighted by an index of energy performance for each individual trip. Travel mode: car

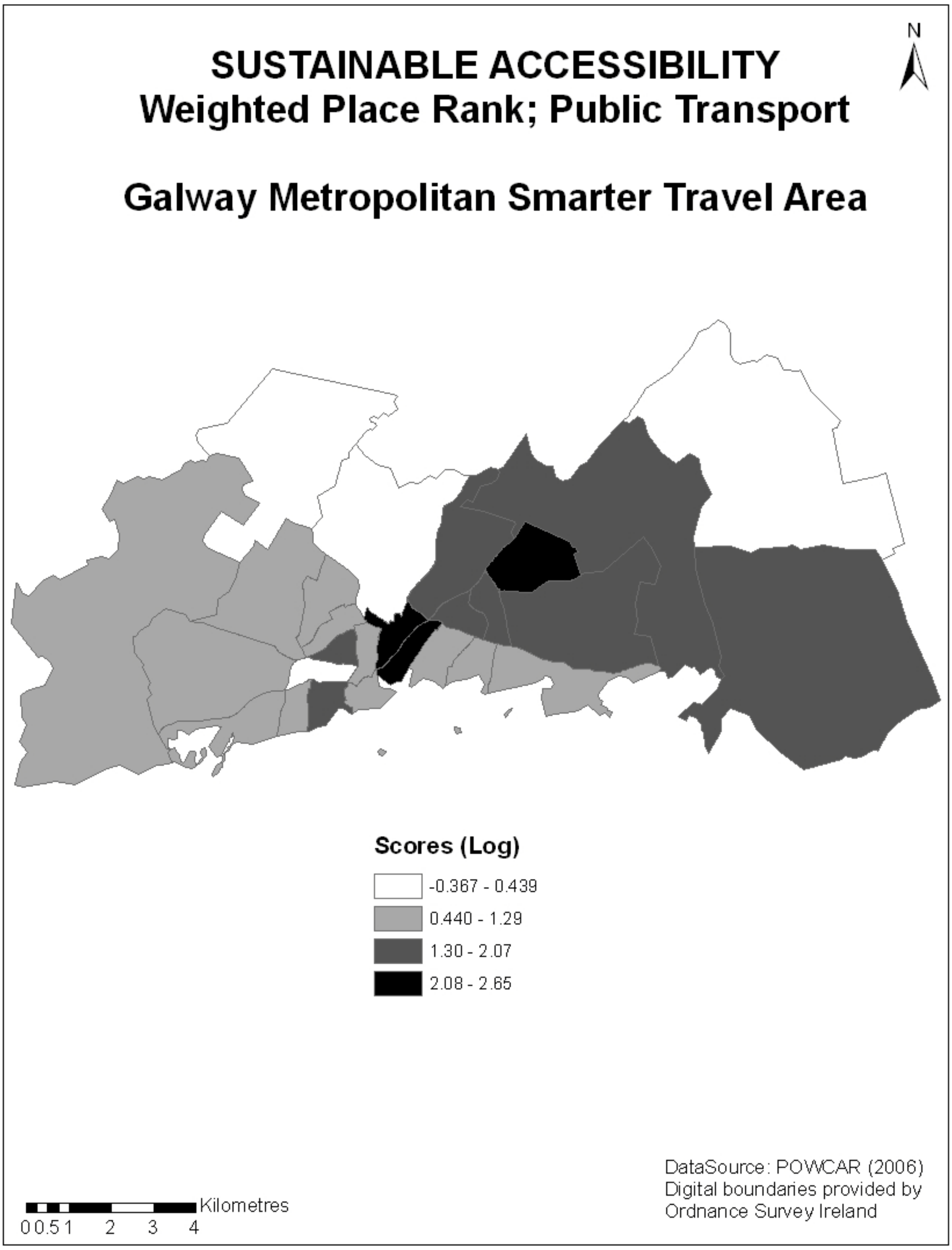

Figure 4: Sustainable accessibility levels in the GMSTA using Place Rank weighted by an index of energy performance for each individual trip. Travel mode: public transport

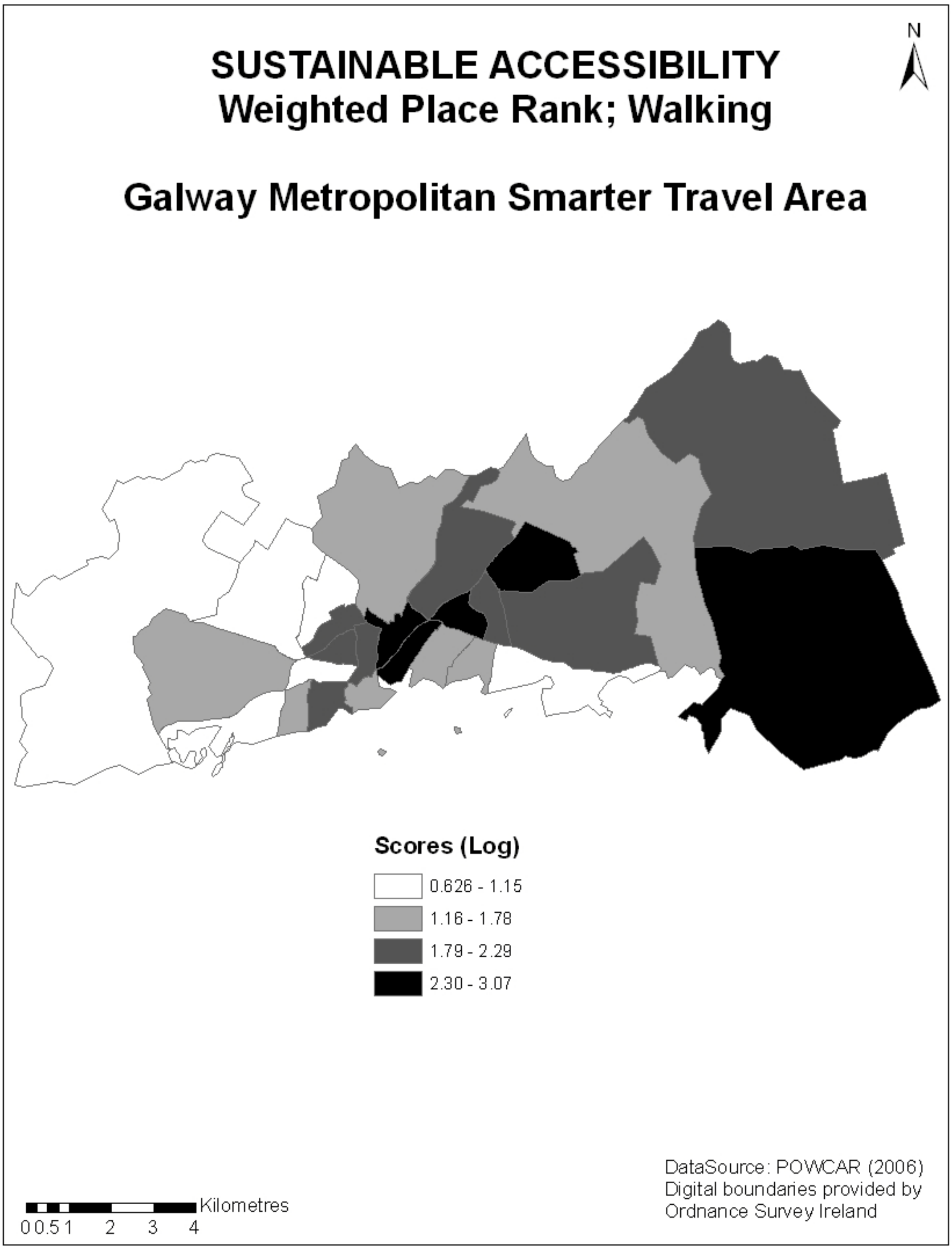

Figure 5: Sustainable accessibility levels in the GMSTA using Place Rank weighted by an index of energy performance for each individual trip. Travel mode: walking

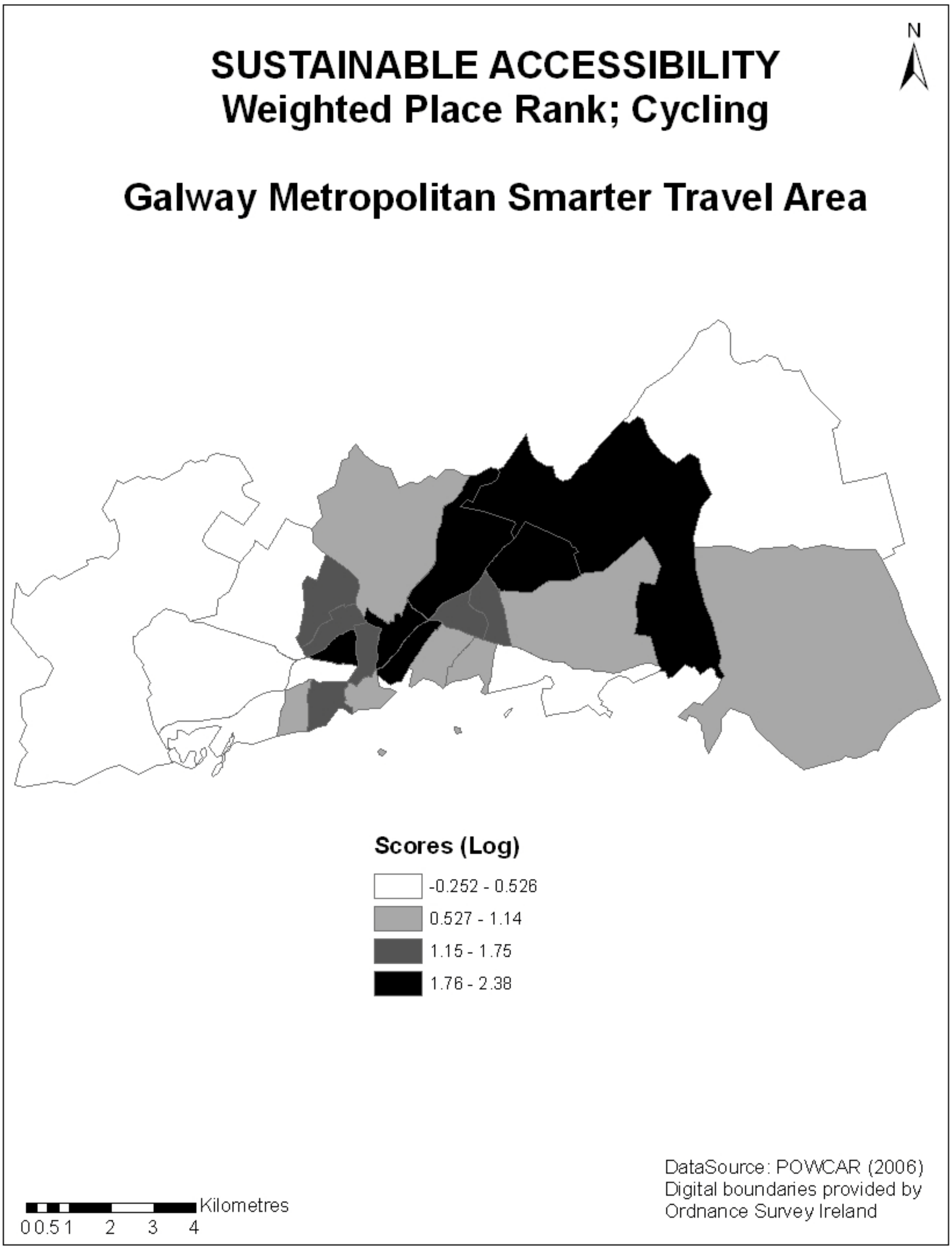

Figure 6: Sustainable accessibility levels in the GMSTA using Place Rank weighted by an index of energy performance for each individual trip. Travel mode: cycling

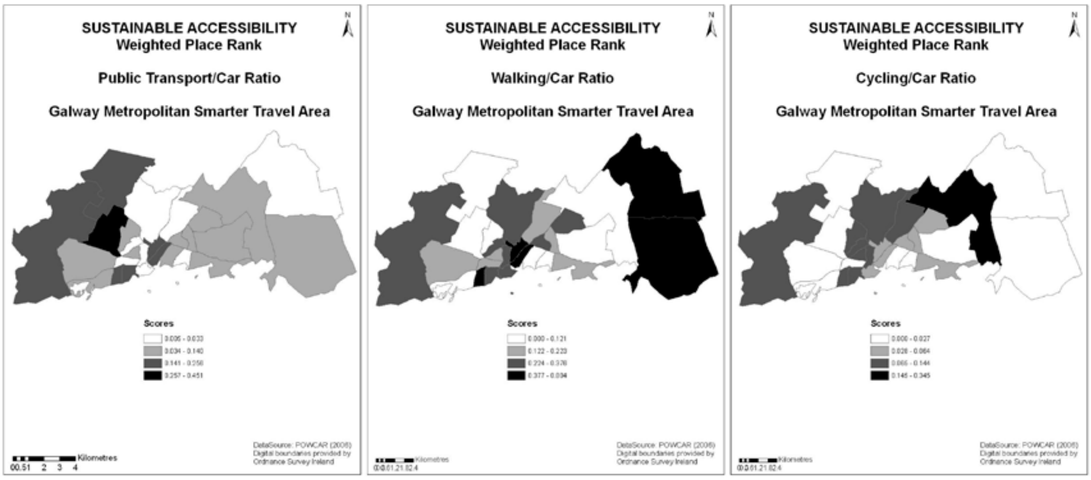

Figure 7: Figure 7a: Sustainable accessibility levels public transport/car ratio. Figure 7b: Sustainable accessibility levels walking/car ratio. Figure 7c: Sustainable accessibility levels cycling/car ratio