

Transport Development and Poverty Reduction in Northeast Brazil



Trinity College Dublin

Coláiste na Tríonóide, Baile Átha Cliath

The University of Dublin

Rodolfo Gomes Benevenuto

Dissertation submitted to the Department of Civil, Structural & Environmental
Engineering at Trinity College Dublin for the partial fulfilment of the requirements for
the Degree of:

Doctor of Philosophy

May, 2020

Declaration

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my own work.

I agree to deposit this thesis in the University's open access institutional repository or allow the library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

Rodolfo Gomes Benevenuto

"Like slavery and apartheid, poverty is not natural. It is man-made and it can be overcome and eradicated by the actions of human beings. Overcoming poverty is not a gesture of charity. It is an act of justice."

Nelson Mandela

Summary

The recent shift in focus from the income-based to the multidimensional understanding of poverty has revealed that the global goal of ending poverty requires more than isolated and remedial actions. Integrated efforts from scholars and practitioners across the range of human knowledge are rather necessary to meet the agenda of 'leaving no one behind' and uplift over 700 million people out of extreme poverty. This thesis examines the key contributions that transportation development can promote to alleviate several dimensions of exclusion and the structures underpinning the intergenerational poverty transfer. The particular challenges and research gaps on this theme in the context of Northeast Brazil are addressed throughout this research. While the transport-poverty nexus has long been explored in the academic literature of wealthier and more urbanised regions, this thesis sets out theoretical frameworks and practical tools that are applicable to regions where poverty is widely and severely spread. The research developed in this thesis delves into the transportation and poverty literature from three distinct perspectives: theoretical (i.e. links between transport and poverty in the Global South), ex-post (i.e. social outcomes of transport experiences) and ex-ante (socially inclusive transport planning).

A transport policy analysis framework showing the various dimensions of transport-related exclusion present in the Global South is initially proposed with reference to the literature. To illustrate the links between transport and poverty, the accessibility to healthcare and urban centres of nearly half-million low-income families from rural Northeast Brazil is statistically and spatially evaluated. This first set of findings show that 53.5% of them are living farther than 5 km from the nearest primary care centre and over 49% are at a distance greater than 10km from the closest urban centre, where majority of the essential services are located. Meanwhile, from the ex-post perspective, a quasi-experimental analysis is developed particularly tailored to the Northeast Brazil, drawing on open access data only. Whilst the results suggest a wide range of positive social effects that are associated with recent transport infrastructure investments in Northeast Brazil, they also point out to negative outcomes of these interventions upon the

average income of people living in extreme poverty. This fact emphasises the necessity for ex-ante assessments of the social dimension and the distributional impacts of transport interventions.

Finally, extensive work was subsequently conducted to develop a spatial accessibility poverty index that could be fed into a comprehensive screening framework of transport needs. This final ex-ante approach draws upon the theoretical framework initially proposed to shed light on how inclusive transportation can be objectively planned to tackle the poverty cycles more effectively. The results point out to priority lines of actions derived from a hierarchisation of the transport-related exclusion dimensions that can help guide targeted transport initiatives at the local and regional level. Findings call attention to several sub-regions in Northeast Brazil that are affected by multiple hotspots of transport-related exclusion and, thus, should be prioritised by future transport interventions. In summary, the exploratory nature of this thesis raises evidence that can be a valuable input to highlight the essential role that transport academics and practitioners ought to play in order to stand up to poverty when developing new transport policies.

Acknowledgements

The first person who believed that this project was worthy to be pursued was Prof Brian Caulfield. His mentorship, encouragement, and support throughout all the research challenges over the past three years have made this academic endeavour an enjoyable and productive experience. To him, I express my profound admiration, respect, and gratitude.

This project could not have been completed without the support of inspiring people from Fundação Estudar who have not only funded me but also encouraged me to dream big and strive for socially-inclusive progress in Brazil. In the same way, I am grateful for the Trinity College Dublin for awarding me the Postgraduate Research Studentship and for making this project a real transformative student experience.

I would like to also thank my research fellows from the Centre for Transport Research Páraic Carroll, Shreya Dey, and Mohammadamin Rezaei for their lifesaver pieces of advice and support in the day-to-day challenges. Special thanks to my two tireless interns, Fernando Fernandez and André Mançaneira who were of crucial help during the busiest time of this PhD. Also, deep gratitude to my amazing colleagues from the Civil Engineering department Alex, Hoa, Unni, Charu, Himanshu, Saps, John, Matthew, Sheila, Saheba, and Radison who have made my days brighter with their friendship and have helped me in the numerous demonstrations undertaken during these years.

My gratitude goes also the researchers and practitioners who have directly contributed to this project. Thank you to Prof. Niamh Harty for her thoughtful feedback on my transfer report and final thesis, as well as for the GIS classes and so many TA opportunities extended to me. Thank you to Prof. Steven Jones for so many valuable suggestions given to me on his careful review of my thesis and for being such a kind and thoughtful examiner during the viva. Thank you to Robson Brandão, José Farias, Lautemyr Canel, Joyce Silva and Renato Arruda from SUDENE for all their instrumental contributions especially during my time in Recife. Thank you to Thiago Guimarães for the most productive visit in Dublin

and all the transport equity works for the NECTAR workshop. Thank you to Dra. Guiga and Paulinho for your support since my application process and then later in Chapter 3 (even being in the middle a fantastic backpacking trip around the globe).

My sincere gratitude also to our loved hosts who have generously received my wife and I in our yearly Brazilian expeditions, Nati Maeda, Daniel Almeida, Érico e Ingrid Melo, Mateus e Mira Menes, Sandra and Sofia Loiola, Tio Silvio e Tia Rose. Thanks also to the brothers and sisters from the Brazilian community in Dublin, Bruno, Dani, Higor, Lou, Cadu, Fafá, Gustavo, Catarina, Lucy, Gui, Zuka, Fernando, Naiara, Leandro, Bruna, Telminha, Renatinho, Marquinhos, and so many others who have wholeheartedly supported me emotionally and spiritually.

At last, I would like to thank some people whom I owe more than I can ever repay. My parents Bárbara and Aparecido Benevenuto, for teaching me everything valuable I know and for supporting me with absolute and unconditional love in every decision I made since I gave up my job in Brazil to start this PhD. My sister Carol, for being my academic role model since my day one in school, and for always giving me reasons to smile with Paulo and baby Rafa Moreira. My wife Sarah Benevenuto, for being the best companion I could ever wonder to have in the ups and downs of this journey, for being my counsellor and supporter after every fall, for keeping me sane during long days and nights of work, for being always by my side. To all of you, my deepest gratitude and eternal love.

Table of Contents

1. CHAPTER 1: INTRODUCTION	1
1.1. Background and rationale	1
1.2. The case study choice: Northeast Brazil.....	3
1.2.1. Socioeconomic context	3
1.2.2. Transportation context.....	8
1.3. Research objectives	12
1.4. Thesis layout.....	14
1.5. Research design	18
2. CHAPTER 2: LITERATURE REVIEW	20
2.1. Introduction	20
2.2. Methodology	22
2.3. A conceptual framework for poverty and transport	24
2.4. Empirical insights	35
2.4.1. Intersectionality and travel behaviour	35
2.4.2. Prioritisation by accessibility analysis	37
2.4.3. Private agendas of policymakers.....	38
2.4.4. Transport and intergenerational poverty transfer	40
2.5. Gaps in the literature and research agenda.....	42
2.6. Policy Implications.....	44
2.6.1. Transport policy analysis framework	44
2.6.2. The Sustainable Development Goals	44
2.7. Conclusions	46
3. CHAPTER 3: ACCESSIBILITY EVALUATION AT THE HOUSEHOLD LEVEL....	48
3.1. Introduction	48
3.2. Public health challenges in Rural Northeast Brazil	50
3.3. Data and Methods.....	55
3.3.1. Households in Extreme Poverty	56
3.3.2. Public services and Basic amenities.....	60
3.3.3. Accessibility estimate	63
3.4. Results and Discussion	65
3.4.1. Cisterns as a proxy for low-income households.....	65
3.4.2. Access to urban amenities	66
3.4.3. Access to healthcare	70
4. CHAPTER 4: SOCIOECONOMIC OUTCOMES OF TRANSPORT INTERVENTIONS	77
4.1. Introduction	77
4.2. Context of the case study.....	81

4.3.	Data and Methods.....	83
4.3.1.	Data collation	83
4.3.2.	Difference in Difference Matching technique	88
4.3.3.	Propensity Score Matching	91
4.4.	Ex-post evaluation Results.....	94
4.4.1.	Propensity Score Matching	94
4.4.2.	Sensitivity analysis of the propensity scores.....	96
4.4.3.	Social outcomes.....	99
4.5.	Policy implications.....	106
4.6.	Conclusion	107
5.	CHAPTER 5: ACCESSIBILITY EVALUATION AT THE MUNICIPALITY LEVEL	109
5.1.	Introduction	109
5.2.	Data and Methods.....	111
5.2.1.	Mapping opportunities.....	111
5.2.2.	The spatial accessibility poverty indices	113
5.2.3.	Municipalities profile analysis	125
5.3.	Results and Discussion	127
5.3.1.	Sensitivity analysis of the travel impedance models	127
5.3.2.	Factor analysis.....	135
5.4.	Conclusion	142
6.	CHAPTER 6: A SCREENING FRAMEWORK OF TRANSPORT NEEDS.....	145
6.1.	Introduction	145
6.2.	Social impacts of transport interventions	147
6.3.	Methodology	150
6.3.1.	Selection and normalisation of proxies	150
6.3.2.	Weighting the transport-related exclusion dimensions.....	154
6.3.3.	Prioritisation scores calculation	158
6.3.4.	Cluster analysis and evaluation of priority regions.....	159
6.4.	Results and Discussion	160
6.4.1.	Weighting factors	160
6.4.2.	Incremental spatial autocorrelation.....	165
6.4.3.	Local spatial cluster analysis	168
6.5.	Conclusion	172
7.	CHAPTER 7: DISCUSSION	174
7.1.	Key findings and implications	174
7.2.	Policy recommendations	182
7.2.1.	Federal level	183
7.2.2.	State level	185
7.2.3.	Municipality level	186
8.	CHAPTER 8: CONCLUSIONS	188

8.1. Thesis summary	188
8.2. Main contributions	191
8.3. Critical assessment	192
8.4. Future research	193
PUBLICATIONS	195
REFERENCES	196
APPENDIX A: Performance indicators for MCDAs	238

List of Figures

Figure 1.1: Wealth inequality measured by GINI coefficient. Adapted from WB (2019c)4	
Figure 1.2: Human Development Index across municipalities in Brazil	5
Figure 1.3: Federal transportation network in SUDENE area (Extended Northeast), Brazil	9
Figure 1.4: Four guiding principles of the SUMP. Adapted from Ministério das Cidades (2007)	10
Figure 1.5: Urban transport policy milestones in Brazil	10
Figure 1.6: Transport modes used by low-income population in Northeast Brazil (retrieved from Googlestreet view® in 2019)	12
Figure 1.7: Overall research design	19
Figure 2.1 : Frequency distribution of the transport-related exclusions dimensions addressed in the reviewed papers	33
Figure 2.2: Spatial distribution of publications addressing Transport and Poverty in the Global South	34
Figure 2.3: Diagram to illustrate the potential contributions of transport development to the structures, processes, and livelihood strategies that can affect inter-generational poverty transfer	41
Figure 3.1: Vital statistics in Brazilian states. i) Life Expectancy [years] in the colour scale and ii) Under 5 mortality [per 1000 live births] in the symbol scale	51
Figure 3.2: Life expectancy [years] of states in Northeast Brazil comparing urban and rural rates	53
Figure 3.3: Under 5 mortality [per 1000 live births] of states in Northeast Brazil states comparing urban and rural rates	53
Figure 3.4: Life expectancy [in years] stratified by quintiles of average income and clustered by share of the rural population	54
Figure 3.5: Under 5 mortality [per 1000 livebirths] stratified by quintiles of average income and clustered by share of the rural population	55
Figure 3.6: Typical cistern and low-income household in Rural Northeast Brazil	56
Figure 3.7: Beneficiary from Programme 1 Million of Cisterns (ASA, 2018)	57

Figure 3.8: Spatial distribution of cisterns in extended Northeast Brazil (SUDENE Area)	58
Figure 3.9: Sample of accuracy checking of cisterns location (screenshot taken from ArcMap 10.6.1)	60
Figure 3.10: Low-income households under the urban influence area - Municipalities of Brejo de Madre de Deus and Poção (Source: ArcGIS online)	64
Figure 3.11: Descriptive statistics of the cistern plotting accuracy	66
Figure 3.12: Frequency distribution of households by geodesic distance to Local Centre	67
Figure 3.13: Frequency distribution of households by geodesic distance to Zone Centre	67
Figure 3.14: Frequency distribution of households by geodesic distance to Sub-regional centre	68
Figure 3.15: Frequency distribution of households by geodesic distance to Regional centre	68
Figure 3.16: Frequency distribution of households by geodesic distance to Metropolis	69
Figure 3.17: Frequency distribution of households by geodesic distance to Primary care unit	71
Figure 3.18: Frequency distribution of households by geodesic distance to Hospitals or Emergency care unit	71
Figure 3.19: Distribution of distances by remoteness from health services thresholds	72
Figure 3.20: Concentration of low-income households (proxied by cisterns) located farther than 10 km from any healthcare centre	74
Figure 4.1: Road BR-232 - The original motorway on the left with just two lanes, and the widened stretch with four lanes on the right (Source: Googlemaps Streetview)	80
Figure 4.2: Location of motorway BR-232 in Pernambuco state	80
Figure 4.3: Transport infrastructure priority in Pernambuco state according to National Logistic Plan (EPL, 2018)	82
Figure 4.4: Catchment area of the motorway BR-232 with poverty rates (%) before the completion of the project (year 2000)	88
Figure 4.5: Schematic summary of methodological alternatives	89
Figure 4.6: Methodology summary using DIDM technique	94
Figure 4.7: Frequency distribution of Propensity Scores by group	95
Figure 4.8: Sensitivity analysis of the propensity scores across municipalities. A) Original PS B) PS calculated without the Healthcare centres variable C) PS calculated without the Schools variable D) PS calculated without the RAI variable E) PS calculated without the GDP variable F) PS calculated without the Share of Urban population variable	98
Figure 4.9: Variables with opposing conclusions depending on the method of analysis	104
Figure 5.1: Urban centres in extended Northeast Brazil (SUDENE area)	112
Figure 5.2: Calculation of Local Accessibility using Kernel Density method	119

Figure 5.3: Calculation of Local Accessibility using Friction Surface method	122
Figure 5.4: Spatial Accessibility Poverty by three different thresholds of Urban Influence	129
Figure 5.5: Spatial comparison of SAP indices by travel impedance model, with the colour scales classified by quintiles.	131
Figure 5.6: Spatial comparison of SAP indices by travel impedance model, with the colour scales classified by equal intervals	132
Figure 5.7: Graphical comparison of SAP index by different travel impedance models with coincident quintiles highlighted	133
Figure 5.8: Income poverty rates by SAP quintile	139
Figure 5.9: Basic Housing facilities by SAP quintile	139
Figure 6.1: Overall methodology of the screening framework of transport needs.....	150
Figure 6.2: Steps of AHP method applied to calculate the TRE dimensions' weights	154
Figure 6.3: Distribution of weights estimated by AHP to each transport-related exclusion dimension.....	162
Figure 6.4: Distribution of weights derived from AHP by each indicator	164
Figure 6.5: Incremental global spatial autocorrelation analysis (Moran's I) of the prioritisation scores of the transport-related exclusion proxies.....	167
Figure 6.6: Local spatial cluster (Getis-Ord Gi*) analysis of the prioritisation scores of the eight transport-related exclusion dimensions.....	170
Figure 6.7: Priority areas at 99% of confidence based on the transport-related exclusion screening framework applied to Northeast Brazil.....	171

List of Tables

Table 1.1: Population with restricted access to basic services and jobs. Adapted from IBGE (2018a)	6
Table 1.2: Poverty lines commonly applied in Brazil and respective figures from 2017. Adapted from IBGE (2018b)	8
Table 2.1 : Summary of the reviewed papers	29
Table 3.1: Description of elements analysed in the Geospatial object-based-image analysis	59
Table 3.2: Urban centre hierarchy	62
Table 3.3: Healthcare centres classification in Brazil	63
Table 4.1: National and regional figures of the socioeconomic indicators included in the model	86
Table 4.2: Propensity score strata descriptions	96
Table 4.3: Standard deviation of the variables considered in the PS estimate	97
Table 4.4: Comparison of estimated outcomes by DID and DIDM	102
Table 4.5: Outcome variable means	103

Table 5.1: Catchment areas by each urban centrality level.....	117
Table 5.2: Statistical difference among quintiles - Kruskal Wallis test.....	138
Table 5.3: Factor analysis of the municipalities by SAP quintiles.....	140
Table 6.1: Summary of transport impacts on poverty.....	149
Table 6.2: Judgment rules applied to each pair of transport-related exclusion dimensions	155
Table 6.3: Matrix showing a sample of the computed weights - Ipupiara, Bahia state	156
Table 6.4: Matrix showing a sample of the computed weights – Bom Jesus das Selvas, Piaui state	157

List of Equations

Equation 3.1	59
Equation 4.1	90
Equation 4.2	90
Equation 4.3	93
Equation 4.4	93
Equation 5.1	114
Equation 5.2	116
Equation 5.3	116
Equation 5.4	124
Equation 6.1	158
Equation 6.2	158

Abbreviations

2SFCA	2 Step Floating Catchment Area
AHP	Analytical Hierarchy Process
BRT	Bus Rapid Transit
CBA	Cost Benefit Analysis
DID	Difference-In-Difference
DIDM	Difference-In-Difference Matching
FCA	Floating Catchment Area

GDP	Gross Domestic Product
GIS	Geographic Information System
GTFS	General Transit Feed Information
HDI	Human Development Index
IBGE	Brazilian Institute of Geography and Statistics (<i>Instituto Brasileiro de Geografia e Estatística</i>)
INDE	National Infrastructure of Spatial Data (<i>Infraestrutura Nacional de Dados Espaciais</i>)
ISA	Incremental Spatial Autocorrelation
KD	Kernel Density
MAUP	Modifiable Area Unit Problem
MDCA	Multi-Dimensional Criteria Analysis
MDG	Millennium Development Goal
NASF	Family health support nucleus (<i>Núcleo de Apoio a Saúde da Família</i>)
P1MC	Programme of 1 Million Cisterns (<i>Programa 1 Milhão de Cisternas</i>)
PCI	Per Capita Income
POI	Point of Interest
PS	Propensity Score
PSM	Propensity Score Matching
SAP	Spatial Accessibility Poverty
SDG	Sustainable Development Goal

SUDENE	Superintendency for the Development of the Northeast (<i>Superintendência de Desenvolvimento do Nordeste</i>)
SUMP	Sustainable Urban Mobility Plan
SUS	Brazilian Public Health (<i>Sistema Único de Saúde</i>)
TRE	Transport-related exclusion
UNDP	United Nations Development Programme
UPA	Emergency Care Unit (<i>Unidade de Pronto Atendimento</i>)
UBS	Primary Healthcare Centre (<i>Unidade Básica de Saúde</i>)

CHAPTER 1: INTRODUCTION

1.1. Background and rationale

One of the boldest goals ever set by the United Nations is to eradicate extreme poverty everywhere in all its forms by 2030 (UN, 2019a). In fact, huge strides have been achieved over the past 30 years, especially looking at the reduction of global poverty, decreasing from 43 percent in 1990 to 21 percent in 2010¹ (Inchauste et al, 2014). Yet, the pace of this decline is decelerating, and recent data has shown that if this trend continues, poverty will not end by 2030 (UN, 2019b). From a practical standpoint, the absolute number of people still struggling in these conditions remains over a staggering figure of 736 million in 2019² (UN, 2019a), which is approximately the total population in Europe. This fact does not only show how far we are, as a global community, from achieving this goal, but also how many more researchers and practitioners from across the range of human knowledge are still needed to deepen efforts towards this direction.

In the realm of transportation research, studies devoted to evaluating the links between poverty and transport have long been published in the literature. Despite being often overlooked in mainstream transport planning (Vasconcellos, 2003; World Bank, 2006; Geurs et al, 2009; Jones and Lucas, 2012b; Van Wee and Geurs, 2011), the potential contributions of the transportation sector to poverty reduction have been investigated in several countries since the late 1960s (Ornati

¹ Considering the lower-bound poverty line in 1990 of 1 USD a day (at 1993 purchasing parity power) and then updated to 1.25 USD in 2010, at 2005 prices (Economist, 2013).

² This figure considers the extreme poverty line as 1.9 USD a day (at 2011 purchasing parity power).

et al, 1969; Wachs and Kumagai, 1973; Hanson and Hanson, 1980; Armstrong-Wright, 1986; Booth et al, 2000; Setboonsarng et al, 2006; Porter et al, 2014; Benevenuto and Caulfield, 2019).

In recent years, the conceptualisation and measurement of transport disadvantages have garnered the attention particularly from academics and decision-makers of the Global North, for being considered as a key driver of social exclusion and inequality (Cass, 2005; Lucas, 2012; ITF, 2017a). This phenomenon has been illustrated by a number of studies pointing out that accessibility constraints tend to deepen socio-spatial inequalities leading to multidimensional deprivations and, eventually, poverty traps (Lucas et al., 2016a, Porter, 2007; Cervero et al., 2002). In this sense, accessibility, as the ultimate goal of most transportation (Litman et al., 2003), has been also proposed to be understood and planned as a fundamental human capability³ since it plays a central role in enabling people to meet their needs and promote a healthy human flourishing (Pereira et al., 2017).

Nevertheless, despite some parallels that can be drawn, the theoretical frameworks, planning tools, and policy recommendations derived from economically developed countries where research is mostly developed to, as a rule, cannot fully address the challenges and particularities of the Global South⁴ (Rynning et al, 2018; Lucas et al., 2016a). For instance, while the academic dialogue on accessibility constraints in highly deprived rural areas of the global North has increasingly focused on issues such as forced car ownership (Walks, 2018; Currie and Senbergs, 2007; Banister, 1994), symmetrical conditions in the developing countries require solutions to people who are forced to live in a walking world (Porter, 2002; Benevenuto and Caulfield, 2019).

There are also substantial disparities in terms of data between these two contexts. The replicability of ground-breaking research tailored to wealthier

³ According to Nussbaum (2011) human capabilities are “sets of freedoms and opportunities available for individuals to choose and to act, resulting from [...] a combination of personal abilities and the political, social and economic environment”.

⁴ Since the 1970's the term 'Global South' has been ever more used to refer to low- and middle-income countries located in Asia, Africa, Latin America and the Caribbean (UN, 2004).

countries usually depends on timely and disaggregated data relating social exclusion and transport, which often times is not available in less urbanised and low-income contexts (Dimitriou, 2013). This research conundrum, added to other factors that are further explored in the following chapters, have continuously evolved in a debilitating transfer of knowledge to public policies and a perpetuation of the paternalistic and arbitrary fashion that prioritisation of investments and policies are done in the transportation realm (Di Ciommo, 2016).

Beyond the necessity of identifying these transport-poverty interactions and understanding the social outcomes of transport policy malfunctions which happened in the past, ultimately the most critical question to be answered is how to enhance the planning of future transportation. While the economic and environmental aspects of transport appraisals have been widely recognised and well researched, there have been relatively few attempts to include poverty and other social dimensions into these frameworks (Geurs et al, 2009).

In this sense, this thesis focuses on addressing the potential contributions of transport development to poverty reduction from the following three different perspectives: theoretical, ex-post, and ex-ante. This research dedicates particularly more attention to the Northeast Brazil region, where this topic has been consistently neglected in both academic and public policy realms. Hence, a further rationale for this case study choice and its current socioeconomic and transport contexts are provided in the following Section.

1.2. The case study choice: Northeast Brazil

1.2.1. Socioeconomic context

Brazil is classified as an upper middle-income country (World Bank, 2019a), with the eighth largest economy in the world (World bank, 2019b). Yet, this bulky Gross Domestic Product (GDP) is distributed in a sharply uneven fashion across regions and income groups. Figure 1.1 presents a comparison of income

inequality measured by the GINI⁵ coefficient, highlighting Brazil as one of the most unequal countries among its peers from BRICS⁶ and Latin America.

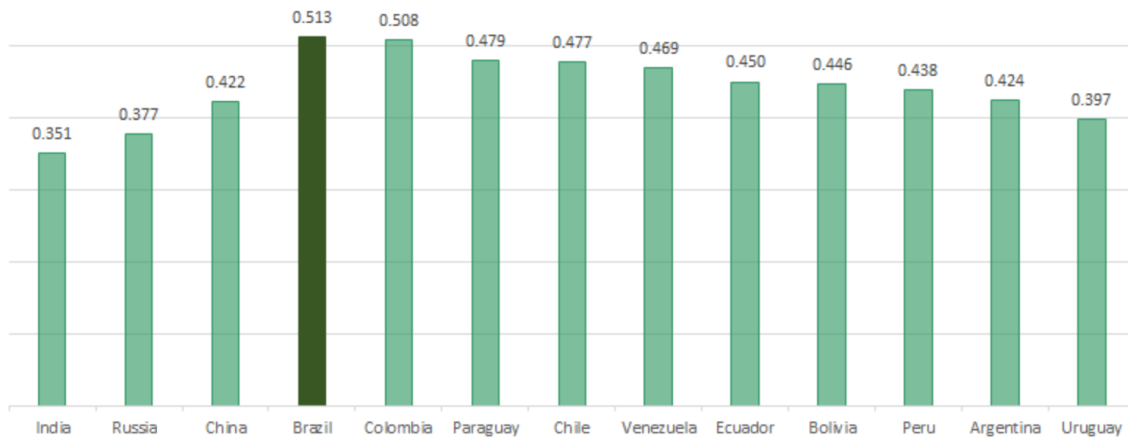


Figure 1.1: Wealth inequality measured by GINI coefficient. Adapted from WB (2019c)

The same pattern of wealth concentration is also found when comparing regions within Brazil. For instance, while the GDP per capita in the Southeast region was equivalent to €9,991.55 in 2016, the Northeast region presented a figure 60% smaller (IBGE, 2016). Likewise, these spatial inequalities can be portrayed by the Human Development Index⁷ (HDI) across municipalities. As shown in Figure 1.2, higher levels of HDI's are as a rule concentrated in the Southern regions.

⁵ The Gini coefficient is an indicator that measures income or wealth inequality, being zero for perfect equality, and 1 (or 100%) for maximal inequality.

⁶ BRICS is the acronym for Brazil, Russia, India, China and South Africa - the five major emerging national economies.

⁷ The Human Development Index (HDI) is widely used to measure wellbeing, in which higher values of the HDI indicator represent higher levels of life expectancy, education, and per capita income.

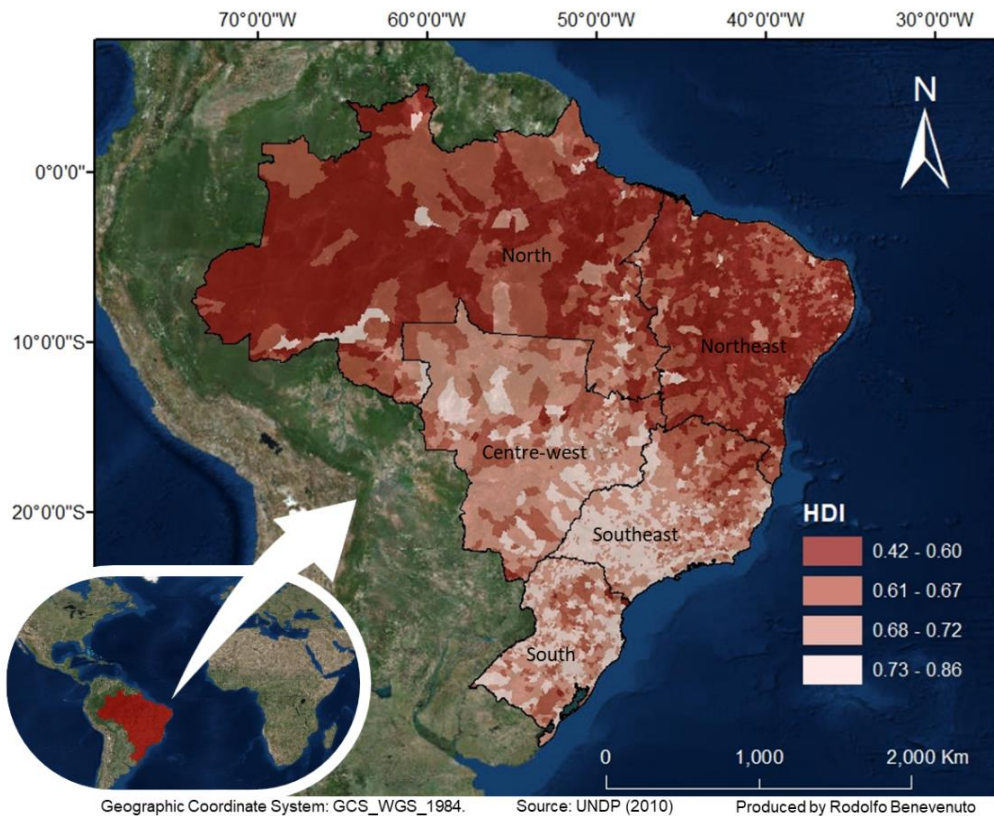


Figure 1.2: Human Development Index across municipalities in Brazil

The Northeast region is one of the five macro-regions in Brazil, which is composed of nine member states and has total population of 56.8 million people (IBGE, 2019a), which is equivalent to the population of countries like South Africa or Italy. In total area it is comparable to countries such as Mongolia or Iran, and it has an HDI comparable to countries like Guatemala or Namibia (UNDP, 2019; UNDP, 2016). As shown in Table 1.1, this is the Brazilian region that as a rule presents the most worrying figures of access restriction to basic services (education⁸, sanitation⁹) and job¹⁰ opportunities.

⁸ Access restriction to education is measured by the relative number of people aged between 6-14 who were not attending school, plus population aged 15 or older who were illiterate, plus population aged 16 or over who have not completed elementary school (deducting double counting) (IBGE, 2018a)

⁹ Access restriction to sanitation is measured by the percentage of people residing in households that did not have access to three sanitation services simultaneously (i.e. garbage collection, water supply, and sewage system) (IBGE, 2018a).

¹⁰ Access restriction to jobs is measured by the unemployment rate among population aged 14 years and older (IBGE, 2018a).

Table 1.1: Population with restricted access to basic services and jobs. Adapted from IBGE (2018a)

Region	Jobs	Education	Sanitation
Northeast	15.3%	34.7%	58.8%
North	13.1%	28.4%	82.3%
Centre-west	10.8%	26.9%	49.3%
Southeast	13.2%	24.1%	13.0%
South	8.1%	28.5%	35.9%
Brazil	12.7%	28.2%	37.6%

Since the extent of this underdevelopment pattern also covers the north part of the region immediately below (Southeast), the Brazilian Federal Government has also incorporated these municipalities within the scope of the Superintendency for the Development of the Northeast (SUDENE). Consequently, Chapter 5 and 6 also reflect the same extended Northeast area, which is composed of a total of 1,990 municipalities from 11 different states.

In the early 1970's the Northeast Brazil was considered the least developed region of the entire western hemisphere (Galeano, 1972) and in recent years it was still considered to have the largest pocket of rural poverty in Latin America (Coirolo and Lammert, 2008). In fact, according to the latest Brazilian Census (UNDP et al, 2010), this region accounts alone for more than half (63%) of the population living in extreme poverty in Brazil. Considering that the total population in extreme poverty in Brazil is approximately 12.6 million people, this means that 7.9 million of them are in the Northeast region.

Nonetheless, the amount of people living in these circumstances may vary depending on which definition of poverty is being considered. In fact, several bodies of scholarships have been dedicated to conceptualising poverty over the past years (Sen, 1982; Ravallion, 1988; Spicker, 1999; Alkire and Foster, 2008; Santos, 2009). Whilst the World Bank definition for extreme poverty¹¹ is internationally more accepted, other definitions have been also disseminated within subnational public policy and academic dialogues.

¹¹ Per capita income of less than 1.9 USD a day (at 2011 purchasing parity power).

Particularly in the Brazilian context, families with monthly per capita income up to 85¹² Brazilian *reais* (i.e. approximately 25 USD) are considered by the Federal Government to be in extreme social vulnerability and, therefore, are eligible to receive federal social welfare (e.g. *Bolsa Familia* cash transfer programme). Considering this poverty line, recent statistics have shown that three states from Northeast Brazil (Bahia, Sergipe, and Piauí) have presented the highest increase in extreme poverty between 2014 and 2017 in the country. Moreover, in Maranhão state (also in Northeast region) this extreme poverty rate applies to 12% of the total population in 2017, being the worst state-wise figure of Brazil.

Recent evidence using the same income-poverty threshold has shown that the national poverty rate increased from 3.2% to 4.8% since 2014 (Valor, 2018). These trends show that, despite great improvements over the last three decades, extreme poverty rate has returned to increase in 2014 in Brazil, and in the Northeast region, this setback has been more intense than anywhere else (Valor, 2018).

Furthermore, another income-based definition of poverty of 5.5 USD per capita a day is recommended by the World Bank to upper middle-income countries like Brazil. Taking this threshold into account, evidence has also highlighted the same inversion in the decreasing trend of poverty rates presented over the last 3 decades (IBGE, 2017a). Between 2016 and 2017 2.7 million people were added to the share of Brazilian population living under this income threshold. The majority of them are also from Northeast Brazil, and particularly from rural areas (IBGE, 2017a), which is in line of global trends (UN, 2017). Finally, Table 1.2 presents a summary of the most usually applied income-poverty lines in Brazil comparing the national figures with those from the Northeast region.

¹² This threshold is increased to R\$ 170.00 (50 USD) if a child or an adolescent of up to 17 years is part of the family.

Table 1.2: Poverty lines commonly applied in Brazil and respective figures from 2017.**Adapted from IBGE (2018b)**

Poverty line	Brazil		Northeast Region	
	Percentual [%]	Absolute [1,000 people]	Percentual [%]	Absolute [1,000 people]
Total population	100.0%	207,004	100.0%	57,080
Less than 1/4 of the min. wage	13.0%	26,910	25.0%	14,270
Between 1/4 and 1/2 of the min. wage	17.7%	36,639	24.9%	14,212
Less than R\$ 85	4.7%	9,729	9.0%	5,137
Between R\$ 85 and R\$ 170	4.1%	8,487	8.5%	4,851
Less than 1.9 USD ¹³	7.4%	15,318	14.7%	8,390
Less than 3.2 USD ¹²	13.3%	27,531	25.8%	14,726
Less than 5.5 USD ¹²	26.5%	54,856	44.8%	25,571

1.2.2. Transportation context

In the Brazilian transportation context, since the foundation of the now-defunct Transportation Planning Agency (GEIPOT) in 1965 until the recently published Sustainable Urban Mobility Plans (SUMP), very little attention has been paid to the potential contributions of transport development to poverty reduction. Even in the academic literature few noticeable exceptions have shed some light on the transport-poverty nexus in Northeast Brazil (Iimi et al, 2015; Maia et al, 2016).

Evidence has shown that the Federal guidelines for transport appraisals and planning are poorly detailed, lack clear criteria, and are driven mainly by economic and environmental evaluations (Paranaíba, 2017; Dabelm and Brandão, 2010). For instance, the Normative Instructions N° 27 (Ministério das Cidades, 2017) and N° 28 (Ministério das Cidades, 2018) that currently regulate how transport projects are selected to be funded by the Brazilian Federal Government (*Pro-Transporte* Programme) do not include any prerequisite related to social assessments.

¹³ These values are at 2011 purchasing parity power.

In terms of the transportation infrastructure, the Northeast network is composed of approximately 416.7 thousand kilometres of roads (of which only 16.8% is paved), 7.3 thousand kilometres of railways and 0.5 thousand kilometres of waterways (excluding the shore) (MTPA, 2018). Only 10% of the road network is managed by the Federal Government (motorways depicted in Figure 1.3), leaving the rest to the states' and municipalities' administration. Perhaps due to this high level of governance decentralisation and a large number of unpaved roads, several concerning gaps still remain in the spatial datasets¹⁴ that map this road network, especially in rural areas. The spatial distribution of this transportation network is presented in Figure 1.3.



Figure 1.3: Federal transportation network in SUDENE area (Extended Northeast), Brazil

In terms of urban mobility, an emerging policy dialogue around this issue started in 2001, when the City Statute established that municipalities of over 500 thousand inhabitants were then obliged to deliver a Director Plan, addressing transport and mobility plans for the urban areas. However, only after 2007 the

¹⁴ Either in Governmental datasets or in open platforms such as HERE maps®, Google maps®, and OpenStreetMap®.

first Federal guidelines were released, establishing four principles to guide the elaboration of SUMP, one of them being “Social Inclusion”, as further illustrated in Figure 1.4.



Figure 1.4: Four guiding principles of the SUMP. Adapted from Ministério das Cidades (2007)

Another important transport policy milestone in Brazil was the sanctioning of the federal law Nº 12.587 in 2012, also known as the Urban Mobility law (Brasil, 2012). Among other regulations, this legislation has defined that municipalities of over 20,000 inhabitants became obliged to deliver a SUMP in order to receive Federal funding for urban mobility projects. Three years later a second SUMP guidelines book was released in 2015 and a new deadline was defined for the submission of the municipalities SUMP (Ministerio das Cidades, 2015). The summary of these urban transport policy milestones is presented in Figure 1.5.

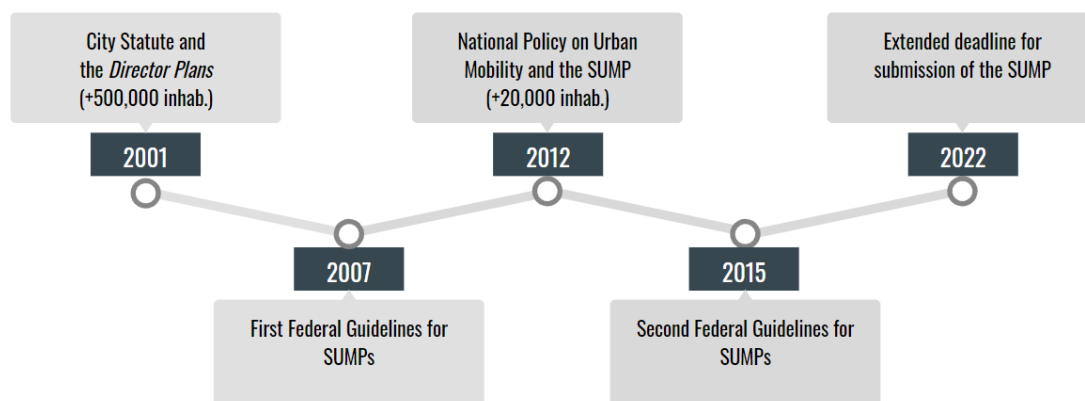


Figure 1.5: Urban transport policy milestones in Brazil

According to the foregoing legislation, 1,762 municipalities (31.6% of the total) are required to prepare their SUMP in Brazil since their population are greater

than 20,000 inhabitants. However recent data provided by the Ministry of Regional Development (former Ministry of Cities) to this study have shown that only 181 municipalities have delivered their SUMP. Moreover, 75% of those municipalities which are obliged and have not delivered it yet have declared that their SUMP are not even being prepared. On top of that, a report from IBGE (2017) has shown that 1,418 municipalities (25.5%) have declared that there is no competent body currently in charge of local transport policies.

Unsurprisingly, 33.6 million people in Brazil live in municipalities where there is no public transport by bus (IBGE, 2017b). Even being a region predominantly based on road transport, the Northeast region accounts alone for over half of this population (18 million). IBGE (2017b) points out that there is no bus (as a mode of public transport) in 60.9% of the municipalities in Northeast Brazil. This number is nearly twice higher than the Southeast region's statistics, where only 31.4% of the municipalities do not provide bus services as a public transport mode.

To fill this gap of formal public transport, other modes such as vans, taxis, and moto-taxis assume a central role in the local transportation. For instance, IBGE (2017b) reveals that moto-taxi is a public transport mode present in nearly 70% of the secondary cities in Brazil (i.e. between 20 and 100 thousand inhabitants). Based on a case study in Campina Grande (Paraíba state), Junior and Filho (2002) concludes that 48% of the moto-taxi users live with less or equal than the minimum national wage (i.e. around U\$ 368.00 per month, in 2010 purchasing power parity according to the conversion rate provided by OECD (2018)).

Likewise, informal vans and adapted trucks are also other highly disseminated modes of public transport available in smaller municipalities of Northeast Brazil. Their operation usually starts from a fixed terminal and the route is defined based on the passengers' demand. Based on a mixed methods study in Recife (Pernambuco state), Oliveira and Andrade (2016) concludes that there has been a substantial growth in informal transportation in low-income areas especially due to poor quality or lack of public transport. Figure 1.6 illustrates some of the most popular modes of transport utilised by the low-income population in small municipalities of Northeast Brazil.



Figure 1.6: Transport modes used by low-income population in Northeast Brazil
(retrieved from Googlestreet view® in 2019)

In summary, even considering the recent advances in the political arena, the concept of “social inclusion” in the Brazilian transport policies is still defined and understood as a relatively high-order principle. Meanwhile, the number of people struggling in poverty and those facing major transport limitations are highly concentrated in the Northeast Brazil. Therefore, this thesis focuses on this region as a case study to further explore the potential contributions of transport development to poverty reduction.

1.3. Research objectives

The overarching goal of this research is to promote a new standard of transport development in Northeast Brazil strongly committed to the goal of poverty eradication. For this purpose, the following three research questions and five objectives are be addressed throughout the thesis.

i) How is transport development linked to poverty reduction in the Global South context?

Objective 1: The first research objective is to develop a theoretical framework adapted to the Global South context that can help guide transport policies to tackle more effectively the poverty trap. The core idea is to explore by which channels transport development can be instrumental in breaking cycles of intergenerational poverty transfer.

Objective 2: The second objective that also addresses this research question is to evaluate, by means of spatial accessibility indicators, how critical is the current situation of people living in extreme poverty in Northeast Brazil, in terms of access to basic services.

ii) How can we measure the social outcomes of transport interventions?

Objective 3: The third objective of this research is to develop a framework that uses only publicly available data for ex-post assessments of how people living in different levels of poverty have been affected by transport interventions in the Northeast Brazil context.

iii) How can transport be planned to tackle poverty?

Objective 4: The fourth objective of this thesis is to develop an accessibility indicator capable of measuring at the municipality level for the whole Northeast Brazil region the transport-related exclusion caused by the lack of access to basic services and opportunities (e.g. health, education, shopping, etc).

Objective 5: Finally, the fifth objective of this research is to apply the proposed theoretical concept (objective 1) and the spatial accessibility indicator (objective 4) into a screening framework to assess the transport issues in Northeast Brazil that are more likely to be reinforcing poverty traps both at the municipality and regional level.

1.4. Thesis layout

This thesis is structured to deliver the chapters in the same sequence of the three research questions earlier stated. Chapters 2 and 3 are focused on exploring the question of how transport development is linked to poverty reduction. Chapter 4 is presented as a standalone section dedicated to address the question of how the social outcomes of transport investments can be measure. Finally, building on the debate set out by the first chapters, Chapter 5 and 6 provide an answer to the third research question on how transport can be planned to tackle poverty. To conclude, the last two chapters (7 and 8) finish the thesis with a broader discussion about the findings, policy recommendations, and a conclusion. Thus, this thesis is organised into eight chapters, the first being this introduction, and the remaining ones outlined as follows.

Chapter 2

Chapter 2 addresses the first objective of this research and it is done by means of a comprehensive literature review on the topic of transport and poverty focused on the Global South. This review included the state-of-the-art publications not only in academic journals but also produced by multilateral organisations (e.g. World Bank, United Nations, Organisation for Economic Co-operation and Development, etc). Drawing on the seminal framework proposed by Church et al (2000), this Chapter puts forward the transport-poverty nexus adapting this framework to the Global South context and setting out a theoretical foundation for the thesis. Relevant findings and methodologies are assessed and categorised by this updated theoretical framework. The main research gaps found in the literature are also summarised, pointing out to limitations in terms of data (spatial-, socioeconomic-, and transport-related data), and methods to measure the transport needs of people living in extreme poverty and to assess (ex-post) the social outcomes of transport interventions. The convergence of the studies, as well as the insights and gaps of research are also presented at the end of this Chapter, shedding light on the essential role of transport policy in reducing poverty.

Chapter 3

To address the data limitation found in the literature, an innovative dataset is proposed to proxy a representative sample of low-income households in the case study region and assess their spatial accessibility to basic services (e.g. healthcare, education, etc) at a household level. This analysis uses the dataset containing the location of water tanks (i.e. cisterns) provided by the Brazilian Federal Government to low-income families in Northeast Brazil. Nearly half a million rural low-income households from this region are spatially tracked by means of this novel and highly accurate proxy. Combining the location of these households with other spatial datasets, this Chapter applies Geographic Information System (GIS) techniques to assess how the low levels of spatial access to basic services and opportunities (e.g. healthcare, education, jobs, etc) can offer an insurmountable barrier for people living in extreme poverty. This step of the research is essential to show how indirect datasets can be harnessed to provide accessibility evaluations in data-poor regions. Moreover, it demonstrates how low-income families are virtually prevented from accessing basic public services and better life-chances due to this spatial hurdle. Taken together with the previous Chapter, these two steps of the research provide both a theoretical and a practical answer to the question of how transport development is linked to poverty reduction.

Chapter 4

To tackle the methodological challenges in ex-post assessments of transport projects' impacts on poverty, identified in the literature review, a quasi-experimental study using publicly available data is then proposed in Chapter 4. This Chapter aims to answer the second research question by providing a standalone method for measuring the social outcomes of transport interventions particularly tailored to cope with the data challenges in the Global South context. In this sense, Chapter 4 builds on the difference-in-difference matching technique and open access data to evaluate the ex-post social impacts of a large transport project performed in Northeast Brazil, namely, the project to widen the BR-232 motorway. This quasi-experimental study sets out debate as to what extent large transport infrastructure interventions like this have also resulted in socio-

economic progress for the least advantaged population living nearby. This part of the research is essential to evaluate the hypothesis of whether the population in extreme poverty benefit from large transport infrastructure investments. The findings highlight the importance of considering the interactions between transport and poverty at an early stage of the transport planning process in order to develop a fair transport system capable of not only providing regional economic growth but also of breaking cycles of poverty.

Chapter 5

In response to the last research question and aiming at the fourth objective of this thesis, Chapter 5 presents an index for measuring spatial accessibility poverty at a municipality level tailored to rural Northeast Brazil, but potentially replicable globally. Despite providing an unprecedented statistical evaluation of the accessibility patterns of low-income people in Rural Northeast Brazil, the measurements developed in Chapter 3 are still limited to the municipalities which presented the proxy. Thus, this Chapter extends the accessibility measurement performed in Chapter 3 to a broader context, unlocking accessibility audits for all municipalities within the case study region. The core of its methodology relies on a gravity-based model composed of floating catchment area techniques coupled with two travel impedance models (Kernel Density and Friction Surface). The index conjugates one factor of intensity (i.e. how spatially excluded is the population from the basic services?) and one factor of extent (i.e. how many people are being affected by this spatial accessibility poverty?). Beyond being highlighted in choropleth maps, the areas mostly affected by this spatial accessibility poverty are also assessed in terms of socio-economic indicators. Once again, this method harnesses a fairly basic amount of spatial data into a simple and well-grounded index that can be used in local and regional transport planning. This step of the research is particularly valuable for identifying the subregions that should be prioritised when tackling transport-related exclusion from facilities in the region. From a methodological standpoint, even though specifically tailored to the Northeast Brazil region, the SAP index puts forward the state-of-the-art transportation planning since it presents a solid method for

estimating spatial accessibility using data that is as a rule publicly available globally.

Chapter 6

Drawing on the theoretical framework proposed in Chapter 2 and the spatial accessibility poverty index designed in Chapter 5, this Chapter develops a socially-driven tool to screen the transport needs that are most likely to be reinforcing cycles of poverty in Northeast Brazil. This framework uses the Analytic Hierarchy Process (AHP) to explore the relative importance of each transport-related exclusion dimension within all municipalities in Northeast Brazil. Moreover, the spatial patterns of each dimension are identified by means of cluster analysis of the municipalities to highlight subregions that are affected by similar issues, as well as priority areas that are affected by multiple transport-exclusion dimensions simultaneously. Despite focusing on the Northeast Brazil region, the screening framework that is proposed can be also replicated in other regions worldwide since it requires only fairly basic level of data that is typically collected by Census surveys globally. As a complement to the previous step, this socially-driven screening framework and the resulting evidence base provide an objective answer to the third research question. As the final contribution of this research, the evidence that is raised in this Chapter can potentially replace the arbitrary, paternalistic or even utilitarian transport planning standards that are currently leading to the perpetuation of the intergenerational poverty transfer.

Chapter 7

Chapter 7 presents a macro discussion in order to clearly answer the three research questions presented earlier. This discussion connects the debates set out by the previous chapters and proposing policy recommendations derived from the thesis' findings targeting each level of governance in Brazil (municipality, state and federal level).

Chapter 8

To conclude, a summary of the main contributions articulated throughout the thesis, the limitations of this research, as well as an outlook for future research are presented in this last Chapter. This Chapter clarifies how the five objectives of this research were achieved throughout the thesis and concludes by calling attention to the crucial role that transport academics and practitioners ought to play in order to stand up to poverty.

1.5. Research design

This Section describes how the present research project is designed, explaining graphically the line of reasoning adopted throughout the thesis to address the research questions and the specific objectives set out in Section 1.3. Ultimately, the function of this research design is to ensure that the obtained evidence fully answer the research questions.

As the three research questions approach the poverty-transport nexus from three different perspectives, a few different methods are appropriately selected to answer each question. Therefore, a separate methodology chapter is not included in this thesis. Rather, for the sake of clarity, the research methods that were mentioned earlier in Section 1.4, as well as their advantages and limitations, are discussed in further detail in the Chapters 2, 3, 4, 5 and 6.

On the whole, the design that is proposed narrows down from a comprehensive literature review on the theme to a specific screening tool of transport needs that builds on the insights, evidence and theoretical frameworks generated throughout this research. Figure 1.7 presents a flow chart diagram that illustrates the train of thought developed in this thesis, pointing out the steps of research, the interconnections of chapters and the guiding questions covering each step.

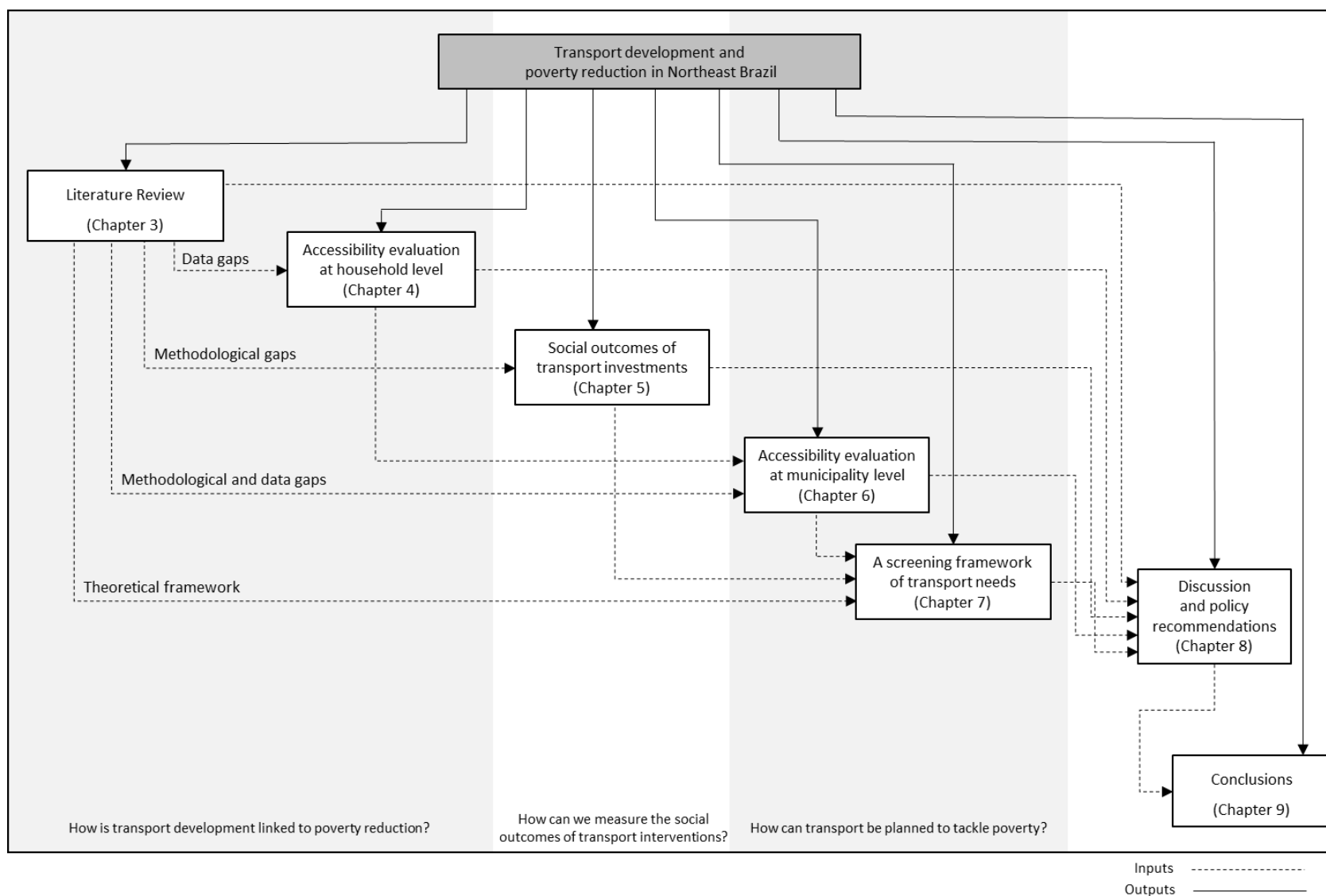


Figure 1.7: Overall research design

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The most widely used index to measure poverty is based only on individual income. According to the World Bank (2017), this index is defined by an international poverty line, which considers a person who lives with less than 1.90 USD a day in 2015 purchasing parity power (PPP¹⁵) as extremely poor. Based on this poverty indicator, the primary objective of the United Nations Development Programme (UNDP) is to lift 736 million people out of extreme poverty by 2030 (UN, 2019a). However, evidence has shown that poverty is neither related nor perceived as just lack of income (Narayan et al., 2000; Alkire and Santos, 2014; UN, 1995).

One of the largest and most comprehensive surveys about poverty published to date, to the best of the authors' knowledge, is "The Voices of the Poor" (Narayan et al., 2000), which summarises 40,000 experiences of poor people from 50 different countries around the world. The findings of this report assert that poverty is perceived as consisting of many interlocking dimensions, in which lack of access to basic infrastructure, rural roads, transportation are frequently pointed out as remarkable factors (Narayan et al., 2000). In that sense, new models, such as the one proposed by Alkire-Foster (2011), have suggested a non-monetary approach to measure poverty. These models consist of multidimensional analysis at a household level composed of a variety of indicators mostly related to health, education, employment, living standards, and empowerment (Alkire-Foster,

¹⁵ PPPs are the rates of currency conversion that try to equalise the purchasing power of different currencies (available at: <https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm>)

2011). When considering the multidimensional concept, it is estimated that some 1.3 billion people are still living in poverty globally (UN, 2019a).

Indeed, not all cases of low scores on these indicators are necessarily due to lack of mobility or transport disadvantage. Hence, it is essential in the realm of transport planning and policy to identify, track and map where exactly poverty is mainly linked to transport issues in order to provide more effective strategies that may accelerate the extreme poverty eradication process. This transport-related exclusion is also often referred to as ‘transport poverty’ (Lucas, 2012; Lucas et al., 2016a), which is caused by direct and indirect interactions of transport disadvantage and social disadvantage.

The studies dedicated to evaluating the connections between poverty and mobility were initially developed during the late 1960s (Ornati et al., 1969). In the following decades, this theme was also researched by several other authors from different institutions (Wachs and Kumagai, 1973; Hanson and Hanson, 1980; Armstrong-Wright, 1986; Gannon and Liu, 1997; Hammer et al., 2000; De Luca, 2007; Titheridge et al., 2014).

Nevertheless, the extent of studies on this subject is not comprehensive enough in geographical terms and has not included most of the regions where poverty is widely spread (Porter, 2014), especially in rural areas (IFAD, 2011). Additionally, many of the existing methodologies applied to wealthier and more urbanised countries are not applicable to emerging-market and low-income countries due to the disparity of data availability and the level of aggregation of the data (Dimitriou, 2013). Rynning et al. (2018) also recognise that, despite some parallels which can be drawn, there are fundamental differences in the premises, requirements, and constraints of mobility and accessibility between developing post-colonial cities and those from the Global North. Furthermore, Lucas et al. (2016a) highlight that there is a need for a specific transport poverty evidence-base tailored to the Global South, given the more extreme intensity and extent of the problem within the developing world. To the best knowledge of the author, except for the publication derived from this Chapter (Benevenuto and Caulfield, 2019) no other literature overview addressing the transport-poverty nexus in the entire Global South has been published in an academic journal to date.

Under these circumstances, this Chapter aims to present an overview that highlights some underexposed insights about the central role that transport policies can play in the poverty reduction process of the Global South. This Chapter, therefore, contributes to the literature by (i) extending and adapting Church et al.'s (2000) framework of transport-related exclusion to the particularities of the Global South; (ii) summarising and categorising relevant findings and methodologies applied to date in this geographical context; and (iii) pointing out important insights and gaps of research that require attention to shed light on the importance of transport policy for tackling poverty. Finally, this Chapter concludes by connecting these insights and gaps to propose a convergence of the reviewed studies emphasising the importance and urgency of a new standard of transport policies strongly committed to the goal of eradicating poverty.

2.2. Methodology

Due to the complex nature of the problem, this Chapter follows the model of research synthesis proposed by Pawson (2005) for a literature review. Besides being an effective method for providing theoretical understanding and empirical evidence of complex interventions targeted to policy making, this realist approach has also been extensively cited¹⁶, including in studies addressing similar topics (Ormerod et al., 2015; Titheridge et al., 2014). Based on this model, the following four steps were utilised to develop this literature overview: conceptualisation of the theme and scope; search for relevant evidence; appraisal of the studies and data extraction; and synthesis of the evidence.

The scope of this overview, which was already briefly introduced in Section 2.1, is also further detailed in Section 2.3 when the conceptual framework of poverty and transport is presented. The search for relevant evidence (step 2) was initially carried out in two large databases of Transport research, namely, Science Direct and Web of Science. The keywords and Booleans applied to these search engines were: “transport” OR “mobility” AND “poverty”. Moreover, only papers

¹⁶ To date this method has been cited by over 1,700 other papers according to www.scholar.google.com

published after 2003¹⁷ were considered in this overview, and the inclusion criteria were:

- Publications based on Global South countries' datasets; and
- Publications reporting evidence-based interactions between poverty and transport.

Furthermore, following guidelines proposed by Wee and Banister (2016), after selecting the first 31 papers from the systematic search, other relevant publications were gathered by snowballing backward (reviewing the references of the articles previously identified) and forward (reviewing publications citing the papers initially collected). After full textual analysis, 9 articles were then included following the same inclusion criteria. Thus, 40 papers were deemed fit for the purpose of this overview. It is worth noting that even though only English-language literature has been considered in this review, 10 out of the 20 countries addressed in the selected papers do not have English as their official languages¹⁸.

Given the different backgrounds, data restrictions related to a comparable poverty measure, and the wide range of methodologies applied in the assessed studies, instead of deploying a meta-analysis based on statistical correlations (or even causations) between transport development and poverty reduction, this Chapter concentrates on appraising the studies and extracting the evidence (step 3) through a qualitative framework to offer a panoramic overview of these themes in the Global South to date. The final step, synthesis of the evidence, is drawn in terms of empirical insights (Section 2.4) including policy recommendations for breaking chronic poverty through transport development (Section 2.4.4), as well as gaps in the literature and research agenda (Section 2.5). The findings in the next sections of this Chapter are also published in Benevenuto and Caulfield (2019).

¹⁷ This timely cut line was applied taking into account the publication of the study *Making the Connections* (Social Exclusion Unit, 2003), widely recognised as a milestone for identifying the inter-relationship between transport disadvantage and social exclusion (Lucas, 2012).

¹⁸ Non-English-speaking countries addressed in this Literature Review include: Brazil, Chile, China, Colombia, Ecuador, Ethiopia, Laos, Nepal, Uruguay, and Venezuela.

2.3. A conceptual framework for poverty and transport

Few relationships in the dynamics of expansion and transformation of the urban space are as evident as the one established between land use and transport development (Nigriello, 1992). Early reflections under the Marxist framing have pointed out that the transport network is intertwined in the urban fabric with other layers to compose the 'social space' (Lefebvre, 1974). Likewise, Harvey (1980) also recognises the mechanism how transport and spatial patterns can play on the urban development, creating a socially unjust city, where the worse-off are pushed to live in crowded and very small places with poor access to opportunities. Hansen (1959) also argues that accessibility shapes land use, linking, therefore, social outcomes such as urban poverty to urban and transport planning.

However, recent authors have suggested that the relationship between transport and poverty is still marginal in the traditional approaches of mainstream transport planning, which have inevitably entailed in the perpetuation of socio-economic, environmental and spatial inequalities in cities (Levy and Davila, 2017, Levy, 2013; Lucas, 2012; Vasconcellos, 2001).

Particularly in the academic literature, several frameworks have been published to date describing how transport relates to social exclusion (Currie and Delbosc, 2010; Cass et al. 2005; Wixey et al., 2005; Hine and Mitchell, 2017; Church et al., 2000). Despite being two different social constructs, poverty and social exclusion have still an undeniable intersection, since people who are socially excluded are as a rule also poor, particularly if poverty is defined in a multidimensional way (Khan et al., 2015).

Generally, the arguments to make a firm distinction of these concepts are based on the idea of a unidimensional concept of poverty (i.e. income-poverty) (Kenyon et al. 2002). However, a substantial body of literature has been dedicated to addressing the multidimensional concept of poverty over the past few decades. This update in the understanding of poverty is clearly seen in the definition of absolute poverty established by the United Nations at the Copenhagen summit in 1995,

"[Absolute poverty is] a condition characterised by severe deprivation of basic human needs, including food, safe drinking water, sanitation facilities, health, shelter, education and information. It depends not only on income but also on access to services" (UN, 1995).

This literature review builds on Church et al.'s (2000) seven categories, not only because it is one of the most recognised frameworks on this topic, but also because it is compatible to the concept of multidimensional poverty previously described. Each one of the seven transport-related exclusion dimensions proposed by Church et al. (2000) is revisited and illustrated by real examples from the Global South in the following items. As already pointed out by Hernandez and Titheridge (2016), while some of Church et al.'s (2000) dimensions can overlap, especially in the context of severe deprivation, they provide initial criteria to distil the mechanisms by which transport policies can effectively contribute to breaking cycles of poverty. Alongside the seven dimensions established by Church, the present Chapter proposes the introduction of an eighth dimension that refers to the transport-related exclusion based on one's social position (i.e. gender, race, ethnicity, religion, etc). Further clarifications and examples of this new dimension are provided below.

- I. **Physical exclusion:** This refers to physical barriers at a micro-level that affect the mobility of certain groups of people (e.g. people with visual, hearing or mobility disabilities). Kabia et al. (2018) report that women with mobility and visual disabilities in Kenya were either denied transport or charged a higher fee because their boarding process requires greater assistance, and this was viewed to be more time-consuming for the transport providers.
- II. **Geographical exclusion:** Authors have shown that the location where one lives has a great influence on his/her accessibility to transport services. Vasconcellos (2005) explains that although people in extreme poverty of São Paulo's (Brazil) urban fringe spend proportionally a greater share of their income on transport than any other social strata, they have less than half of the mobility level than the richest on average and have almost no contribution to transport externalities.

- III. **Exclusion from facilities:** Beyond the exclusion from the transport network there is the exclusion from key facilities such as hospitals, schools, shops which is often argued to be one of the reasons behind the poverty trap. Farrow et al. (2005), for example, confirm that greater access to markets is highly associated with lower levels of food poverty in Ecuador.
- IV. **Economic exclusion:** Affordability is frequently pointed out as the biggest barrier to access the transport system for low-income people (Vasconcellos, 2005; Lau, 2010; Lucas, 2011; and Adeel, 2016). Guzman et al. (2017b) state that if appropriate subsidies are applied on bus and Transmilenio (Bogotá's BRT) fares, the job-accessibility for low-income workers may increase up to 28.3%.
- V. **Time-based exclusion:** This feature explains how lengthy journey times may exclude even more vulnerable groups that are time poor mostly due to other time-consuming responsibilities (e.g. household and child-care duties). Motte-Baumvol and Nassi (2012) report that women from Rio de Janeiro (Brazil) have lower mobility than men due to a heavier burden on women in family care, even having the same transport opportunities for both genders.
- VI. **Fear-based exclusion:** Exclusion can be even more exacerbated due to unsafe public space and services. Anand and Tiwari (2006) maintain that due to the absence of footpaths, poor location of bus shelters, high steps of public buses, and risk of sexual harassment while traveling, women's mobility is very reduced in Delhi (India), which is inextricably linked to poverty.
- VII. **Space exclusion:** This dimension refers to restrictions on access for certain groups of people in particular areas or routes (e.g. gated communities, or areas under control of militias). Hernandez and Titheridge (2016) explain that local criminal groups are responsible for physically restricting neighbourhood's mobility by even imposing tolls to the right to circulate in certain areas of Soacha (Colombia). Despite these restrictions

being sometimes enforced by non-official authorities, it is still a different case than the fear-based exclusion since it prevents the accessibility of people not only by the feeling of insecurity but literally by spatial selective barriers just as in a gated community.

- VIII. **Social position-based exclusion:** This transport-related exclusion dimension, that is proposed, refers to the prevention from moving in public space due to censure, social control or any other restriction based on one's social position (i.e. gender, race, ethnicity, cast, religion, etc). Remarkable and not so old examples of this range from the 'white-only' carriages that operated until the early '90s in South Africa (Seekings, 2008) to the ban on women's driving (Rajkhan, 2014) that occurred until the year 2018 in Saudi Arabia. The inevitable legacy of historic cases like these is still currently perceived in the form of discrimination of public and private transport users (Cano, 2010; Seiler, 2007). For instance, Adeel et al. (2016) reports that women face additional mobility constraints in Pakistan such as lack of walking, permission from home and need for veiling and escort during travel due to social and cultural patterns. Similarly, Özkazanç and Sönmez (2017) report that in Turkey women have been excluded from public transport because they face pressure from society to be home before dark, as well as harassment in traffic simply due to the very fact that they are women. The outcomes of such gendered segregation in mobility have been also revealed by several other authors from Ghana, Malawi, South Africa, Colombia, Lesotho, India, Kenya and China in statistical, spatial and qualitative findings (Kabia et al., 2018; Rodriguez et al., 2016; Hernandez and Titheridge, 2016; Lau, 2013; Porter et al., 2012; Vajjhala and Walker, 2010; Anand and Tiwari, 2006). Evidence of transport-related exclusion based on the social position has been also raised by the survey and interviews performed by Lau (2013) in China. The author reports that one of the limiting factors on low-income migrant workers' travel patterns is that they cannot receive social welfare (and thus cannot afford longer and more expensive trips) due to the very fact that they are not recognised as local citizens. Another facet of this dimension is reported by Ramos & Musumeci (2005) revealing that in Brazil the

proportion of people with black and brown skin colour among those who declared to have been stopped by the police while walking or using public transport was higher than the corresponding share of these racial groups in the population. Thus, considering the lack of coverage of these aspects in the original seven categories proposed by Church et al. (2000), it is argued that the Social Position-based dimension should be also recognised into future studies using such a framework in order to ensure clear evaluations of the intersectionality of these social features and its outcomes upon the travel patterns of the most vulnerable population.

The summary of the main insights from the 40 evaluated papers on the transport-poverty nexus, as well as further information on their methodology and the type of transport-related exclusion that they have addressed are provided in Table 3.1. The evaluated papers are presented in chronological order.

Table 2.1 : Summary of the reviewed papers

Study / Country	Main method applied	Type of exclusion	Insights on the transport impact upon poverty
Agbenyo et al. (2018), Ghana	Mixed methods	II and III	Communities which have poor access to basic social services like healthcare as a result of the bad transport network are pushed to a poverty pocket. They are entangled in poverty traps in which it is impossible for them to escape without external assistance.
Evans et al. (2018), Uganda	Mixed methods	II and III	Transport policies should not undermine or ban informal transport modes (such as <i>bodas</i>) since they are essential in servicing low and very low-income residential areas.
Kabia et al. (2018), Kenya	Focus groups and interviews	I, II, III, IV, V and VIII	Findings show that unfriendly public means of transport and higher costs on due to an accompanying person have contributed to low-income women with disabilities foregoing healthcare.
Lionjanga and Venter (2018), South Africa	Difference-in-difference approach	II, III, IV and V	The results suggest that the significant changes in the accessibility of low-income population derived by the new BRT line are driven by improved affordability rather than spatial coverage enhancements.
Vasconcellos (2018), Brazil	OD survey analysis	II, IV and V	Low-income citizens remain victims of a haphazard and unreliable bus system, facing lengthy travel times and discomfort on a daily basis. Mobility-related negative externalities escalated in larger cities, which suffered pollution, severe congestion, road accidents, and urban disruption.
Hernandez, (2018), Uruguay	Cumulative opportunity indicator	II, III, and IV	The percentage of job opportunities a person living in a low-income is almost 5 times less than in a middle-income area and 7 times less than the in a high-income area. This is directly related to poverty and social exclusion and constitutes a field of contestation and dispute among social classes.
Fuenmayor et al. (2017), Venezuela	Spatial economic model	III, IV and V	Increases in the transport fare mainly affect smaller poor families (less than 4 members), once it makes their opportunities shrink and the value of their owned-homes decrease.
Guzman et al. (2017)a, Colombia	Location-based accessibility analysis	III	Exclusion from facilities can be potentially addressed through policies that alleviate travel costs for low-income groups such as targeted subsidies, and land-use incentives for the redistribution of jobs and education centres.
Stifel and Minten (2017), Ethiopia	Household interview	IV	Households in remote areas consume 55% less (mostly food) than households nearer to the market, their diets are less diverse, they are more food insecure, and the school enrolment rates of their members are 25% lower.

Guzman et al. (2017)b, Colombia	Gravity model	IV, V, III	If appropriate subsidies are applied on bus fares and Transmilenio (Bogotá's BRT) fares, the job-accessibility for low-income workers may increase up to 28.3%.
Sadhu and Tiwari (2016), India	Discrete choice model	II, III, IV and V	The traditional transport planning does very little for the mobility of the urban poor, who depend predominantly on short pedestrian travels.
Rodriguez et al. (2016), Colombia	Difference-in- difference approach	IV and VIII	Fare's subsidy appears to be increasing productivity by allowing informal workers to have better mobility and accessibility to economic opportunities and thus higher earnings.
Naimanye and Whiteing (2016) Ghana/Uganda	Expert weighting survey	III	In order to mitigate existing road sector inequities, enhance sustainability and offer equality of transport opportunities, a goal programming model that highly prioritises multidimensional poverty is recommended for rural road scheme selection in sub-Saharan Africa.
Qin and Zhang (2016), China	Difference-in- difference approach	II	Findings indicate that road connections improve household agricultural income and reduce poverty. Evidence has shown that road access enhances agricultural income by 27.1% in rural areas of China.
Stifel et al. (2016), Ethiopia	Willingness-to-pay approach	II, III and IV	A hypothetical feeder rural road project that reduces the transport costs for the most remote households by 50 US Dollars per metric ton, has the potential to result in benefits worth roughly 35% of household consumption for these households.
Hernandez and Titheridge (2016), Colombia	Qualitative Content Analysis	All types	Informal transport is pointed as an essential factor in helping vulnerable people to overcome social exclusion, once it allows flexibility in the geographical, economic and social aspects.
Deng et al. (2016), China	Primary Component Regression	II and III	In order to promote socially inclusive public transport, the needs of socially disadvantaged groups should be taken into account when distributing public transport funding.
Adeel et al (2016), Pakistan	Binary Logit model	IV, VI, and VIII	The study found that affordability of transportation is the toughest mobility challenge for urban residents of low and middle-income groups of Rawalpindi Islamabad.
Vermeiren et al. (2015), Uganda	Household survey	I, II, IV and V	BRT could be leverage for socio-economic development of deprived neighbourhoods if two crucial criteria are met: (1) the BRT is physically accessible from these neighbourhoods, (2) the BRT-fares are made affordable for the lowest social classes.
Asomani-Boateng et al. (2015), Ghana	Ex-post average comparison	II, III, IV and V	The analysis revealed that road improvements led to a dramatic growth (390.4%) in the household income during the initial phase of the program of improvements and maintenance of rural feeder roads.

Fang and Zou (2014), China	Multilevel econometric model	II, IV	Results show that transportation infrastructure is also a determining factor in leading to rural poverty traps. Improvements in transport infrastructure can increase the living standards of young generations and break the intergenerational transmission of poverty.
Bocarejo, et al. (2014), Colombia	Difference-in- difference approach	II and IV	Metrocable of Medellín has had a positive and measurable impact on access to activities by the low-income population, although this outcome is also attributed to localised ease of access to specific centres of activity.
Porter et al. (2013), Tanzania	Household survey	All types except VII	Transport is clearly a major hurdle for many older people in the study settlements – particularly for their daily domestic water and fuel needs, but also for accessing healthcare.
Li and Da Costa, M. N. (2013), China	OLS Linear regression	IV	Highways, railways and waterways development were found to be negatively associated with income inequality in urban areas. Higher mobility may further alleviate income inequality.
Lau (2013), China	Questionnaire survey	I, II, IV, VIII	The lower the respondents' incomes, the more likely they were to use slower transport modes to reach their workplaces, thus, excluding them from seeking distant employment opportunities.
Motte-Baumvol and Nassi (2012), Brazil	Logistic model	II and IV	Income is not the only dimension of poverty which is correlated to immobility. Employment status and education level were found with a very strong effect on the mobility level of the poorer areas' population of Rio de Janeiro city.
Venter (2011), South Africa	Binomial probit model	I, II, IV and VII	People living in displaced urban settlements or in isolated rural locations face long commute distances, poor road conditions and few travel alternatives, which combine to raise the cost of motorised travel and perceptions of the severity of transport affordability problems.
Dillon et al. (2011), Nepal	Hedonic and panel data analysis	IV and V	Increasing access to rural roads also has distributional consequences. The likelihood of escaping poverty increases by 0.51% for a 10% reduction in travel time in the area studied.
Vajjhala and Walker (2010), Lesotho	Participatory mapping	II, III, VIII	The maps generated through this study reveal significant differences in mobility of vulnerable people, with implications for access to and use of diverse services, such as healthcare, education, banking, the postal system, and pension distribution.
Salon and Gulyani (2010), Kenya	Logit model	IV and V	Poorest residents of Nairobi who are forced to walk long distances because they cannot afford other modes, they are highly impacted by a physical and time burden on their basic travel needs.
Lau (2010), China	Questionnaire survey	I, II, III, IV and V	The survey shows that low-income residents experience geographical exclusion from employment because of accessibility problems arising from the spatial mismatch and jobs-housing imbalance.

Khandker, S. R. (2009), Bangladesh	Panel quantile regression	IV	A road improvement project in the evaluated villages has led to an approximate 5% reduction of moderate and extreme poverty.
Zou et al. (2008), China	Regression model	IV	The lack of transport infrastructure is a key reason for economic underdevelopment in the west, rural areas. The inequality of transport is a reason for income inequality. Reduction of road inequality will help to reduce income inequality more directly.
Fan and Chan-Kang (2008), China	Multi-equation model	II and IV	Results show that 226 people from Northern regions of China were lifted above the poverty line for every additional kilometer of low-quality road in rural areas.
Anand and Tiwari (2006), India	HH surveys and focus group	IV, V, VII, VIII	Results show that low-income women in Delhi lack mobility due to gender-based restrictions, inferior access to transport means, high dependence on low-quality public transport, and a lack of availability of affordable modes of travel.
Warr (2005), Laos	Estimated regression equation	II, III, IV and V	All-weather road access lowered poverty incidence by around 6%. Moreover, approximately 13% of the decline in rural poverty incidence between 1997–98 and 2002–03 can be attributed to improved road access alone.
Vasconcellos (2005), Brazil	OD survey analysis	I, II, IV and V	Although extreme poor people of São Paulo spend proportionally a greater share of their income on transport than any other social strata, they have a less than half of the mobility level than the richest in average.
Farrow et al. (2005), Ecuador	Geographically weighted regression	II, III, VIII	Findings confirm that greater access to markets is associated with lower levels of food poverty in Ecuador.
Lofgren et al. (2004), Zambia	Computable General Equilibrium	II and IV	The analysis indicates that 10% increase on the length of feeder roads in remote rural areas result in a decrease of 7.3% on poverty headcount.
Bryceson et al. (2003), Uganda/ Zimbabwe	HH surveys and focus group	II, III and IV	The research findings confirm that relative immobility is a defining feature of the poor in both urban and semi-urban settings and this holds true for macro, meso and micro levels.

When analysing the frequency distribution of the eight dimensions that are covered by these studies (in Table 2.1), overall the authors tend to converge towards the Geographic, From facilities, and Economic dimensions of transport-related exclusions. Figure 2.1 summarises this distribution of dimensions that have been addressed in the 40 the reviewed papers.

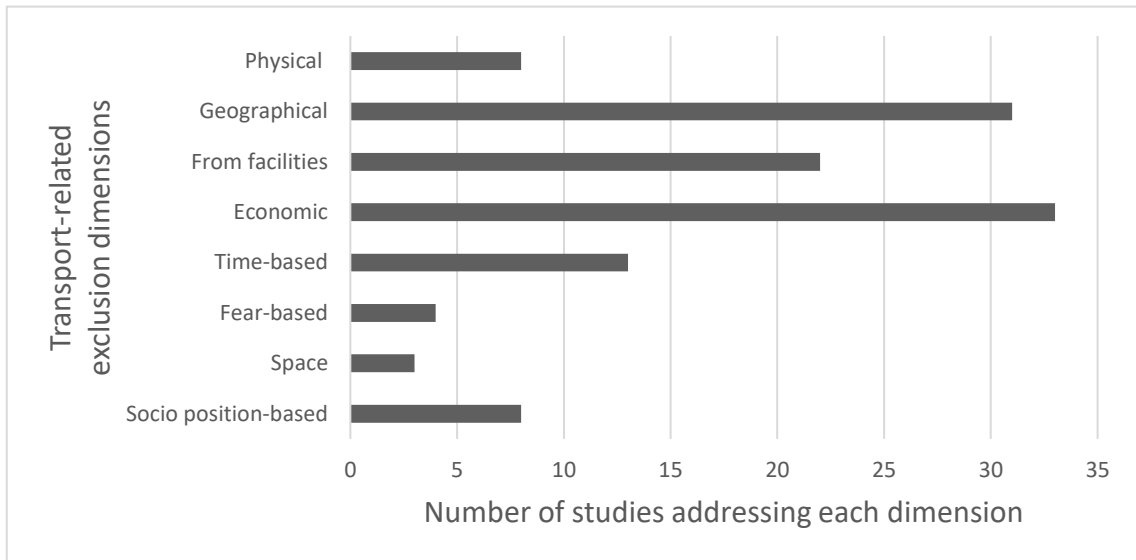


Figure 2.1 : Frequency distribution of the transport-related exclusions dimensions addressed in the reviewed papers

In terms of spatial distribution, among the 20 countries depicted in the reviewed papers, China and Colombia stand out as the two most targeted countries for this kind of analysis, accounting for 8 and 5 studies each respectively. Figure 2.2 represents the spatial distribution of them. Even though the majority of the reviewed studies (48%) have addressed urban areas alone, it is important to remark that 20% of them have presented analysis covering both rural and urban contexts and 32% of them have addressed the transport-poverty nexus in rural contexts alone. Moreover, just one study has been found covering this topic in rural areas of a Latin American country (Farrow et al., 2005)

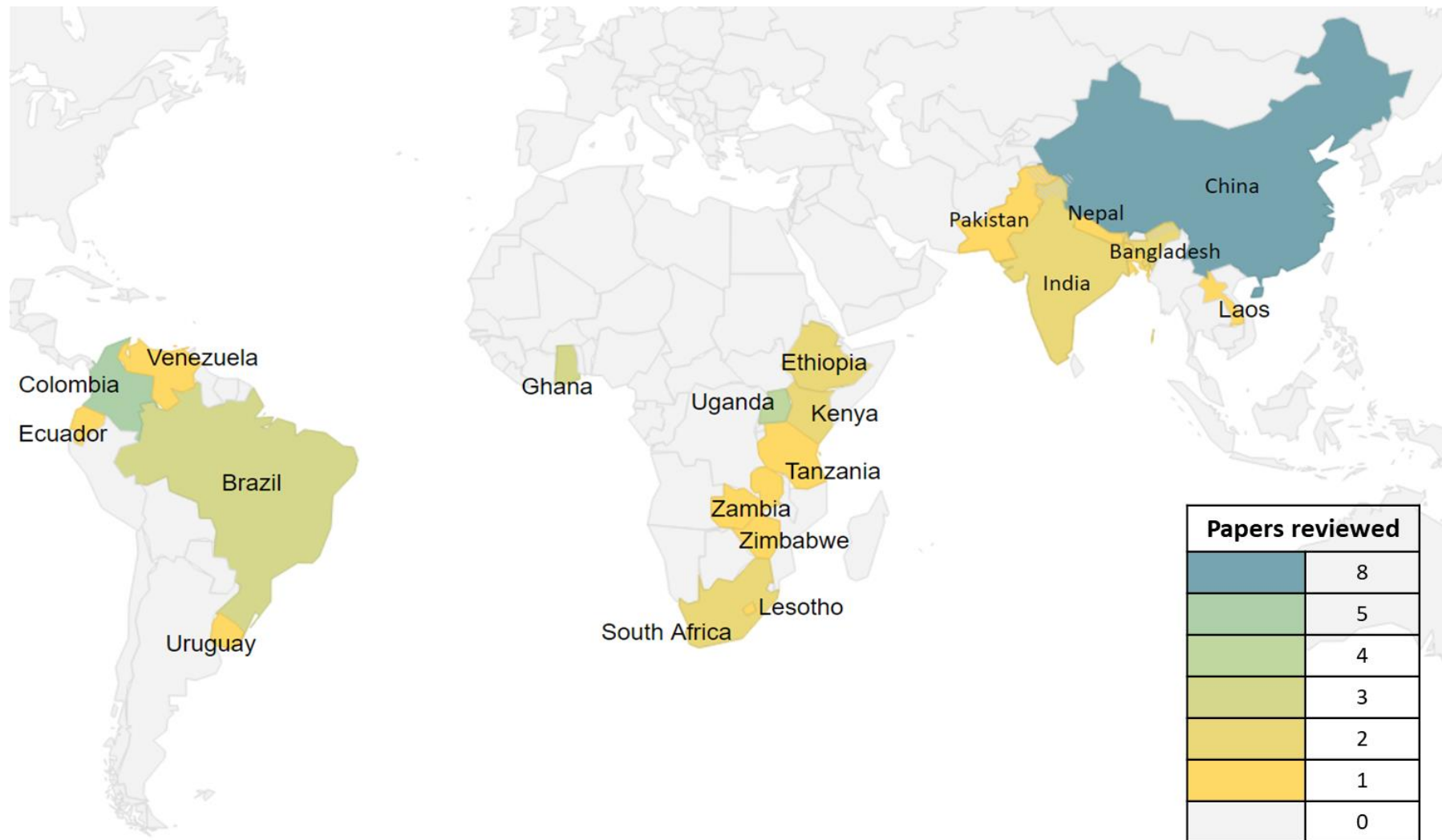


Figure 2.2: Spatial distribution of publications addressing Transport and Poverty in the Global South

2.4. Empirical insights

The reviewed papers converge around the extent and severity of the multi-dimensional poverty and social inequalities present in the Global South that arises from transport-related exclusion in its various forms. However, the traditional links and mechanisms illustrating this relationship have been already reported in similar reviews of literature from urban Latin America (Blanco et al., 2018), rural Sub-Saharan Africa (Porter, 2014, Jones and Walsh, 2013), as well as from more general contexts (Booth, 2000; Setboonsarng, 2006). Hence, this Section aims at summarising some underexplored empirical insights on how to better tackle poverty through transport development.

2.4.1. Intersectionality and travel behaviour

Over the past few years, authors have increasingly evaluated the relationship between transport and poverty through the lens of an intersectional view of exclusion (Kabia et al., 2018; Oviedo et al., 2017; Levy, 2013). The concept of intersectionality was originally coined by Crenshaw (1989) when proposing that the intersectional exclusion experienced by black women is even greater than the sum of racism or sexism experienced separately. After its inception, other interlocking and mutually reinforcing vectors of exclusion have been also considered to expand this concept to class, ethnicity, disabilities, age, religion, etc (Nash, 2008). Two out of all these vectors appear to have received particularly more attention in recent studies addressing the impact of intersectionality on travel behaviour.

Firstly, gender has been widely considered as a crucial factor that affects how low-income people benefit from the development of transport services and infrastructure. Authors have argued that transport policies must be gender-sensitive to be effective in tackling poverty since women face different challenges than men in accessing, using and paying for transport services (Babinard et al., 2010; Salon and Gulyani, 2010; Anand and Tiwar, 2006). Cook et al. (2005)

illustrate this, pointing out that the better the quality, reliability and security of the transport services, the more parents from India, Thailand, and China are prone to allow girls to carry on with their education and to participate in social and economic activities outside the villages, which is an essential step to enabling low-income girls to improve their future livelihood and well-being. A more extreme example reported by Babinard et al. (2010) underlines that, if not well planned, the opening of new transport corridors in localities where poverty is most spread may result in trafficking of girls and women, especially in remote localities. Kabia et al. (2018) report that the intersections of gender, poverty, and disability in Kenya have resulted not only in limited mobility for them but also in less awareness about health services since they are usually excluded from public participation forums due to negative stereotypes attributed to them.

The second major aspect found was that transport policies targeting these people should first consider the impact of income poverty on travel patterns (Vasconcellos, 2018; Sadhu and Tiwari, 2016; Motte-Baumvol and Nassi, 2012; Lau, 2010). Some authors have demonstrated empirically that in many regions the concept of travel choice cannot be applied to people living in extreme income poverty, because mostly there is no choice but walking (Sadhu and Tiwari, 2016; Salon and Gulyani, 2010; and Cook et al., 2005). In fact, low-income people may continue to use non-motorised transport even on a brand-new road since they do not have automobiles nor enough resources to afford a new one (Porter, 2002; Setboonsarng, 2006; and Raballand et al., 2011). Similarly, authors have also stressed how vital informal transport¹⁹ is for helping vulnerable people to overcome social exclusion since it is usually the only type of public transport flexible enough to overcome geographical, economic and social barriers (Evans et al., 2018; Hernandez and Titheridge, 2016). In that sense, it is argued that large investments in transport infrastructure construction that disregard informal and non-motorised transports are not enough to guarantee poverty alleviation.

¹⁹ Informal transport, also referred as paratransit, are usually provided in form of unregulated minibuses, passenger-adapted trucks, vans, microvans, station wagons, three-wheelers, motorcycles taxis and pedicabs.

These examples attempt to illustrate the travel pattern outcomes of intersecting social features and transport-related exclusions. These insights shed light on the importance of not only evaluating the outputs of transport development (such as road length, or quantity of buses delivered), but also of evaluating the outcomes of it, such as accessibility improvement and social development.

2.4.2. Prioritisation by accessibility analysis

A nearly ubiquitous policy recommendation of the reviewed studies is that accessibility analysis (including the spatial, social and economic distributional effects) should be an essential driver of transport appraisals utilised in the prioritisation process of transport investments. This would be conducted with traditional travel demand, cost-benefit and wider economic benefit analysis. This type of assessment is paramount in identifying the differences in access to life-enhancing opportunities (education, healthcare, employment, etc) among different locations (rural/urban, centre/peripheral areas), socio-economic features (e.g. income groups, age, gender, ethnicity, etc), and transport modes resulting in more transparent and equitable transport planning.

Vasconcellos (2011) argues that equity audits are needed to overcome the ‘more common, limited pseudo-scientific technical approach to urban transport appraisal’. Reinforcing previous studies (Bryceson et al., 2003; Lau, 2010) Guzman et al. (2017) also conclude that the redistribution of current levels of accessibility should be guided by assessments of access to employment and education between income groups. Particular attention to the most vulnerable income groups has been also consistently suggested as a high priority for achieving a fair transport system (Vermeiren et al., 2015; Li and Da Costa, 2013). Drawing on expert opinion surveys and empirical evidence from Ghana and Uganda, Naimanye and Whiteing (2016) hold that the allocation of funds for rural roads should be poverty-centred²⁰ to provide equality of transport opportunities. In a systematic reflection on the key theories of justice (utilitarianism,

²⁰ Naimanye and Whiteing (2016) argues that multi-dimensional poverty index should be a guiding factor in the allocation of funds for rural roads in Sub-Saharan Africa

libertarianism, intuitionism, Rawl's egalitarianism, and capability approach) Pereira et al. (2017) propose a framework for evaluating transport policies by detailed analysis of their distributional effects. According to the authors, such a framework should consider accessibility to key destinations, preservation of individuals' rights, prioritisation of disadvantaged groups, reduction of inequalities of opportunities, and finally, mitigation of transport negative externalities.

2.4.3. Private agendas of policymakers

When considering transport projects led by the public sector, some political dimensions that are often overlooked in academic studies, also need to be explored to shed light on the reasons why transport policies have not been more effective in tackling poverty. As highlighted by Benitez et al. (2010), there are at least four power- and money-seeking private agendas in the realm of infrastructure policymakers which negatively affect transport development. These are described below.

- *Populism/re-election*: Excessively strong focus on fitting infrastructure projects to the electoral calendar (short-term), instead of following an appropriate long-term development agenda. Remarkable preference for what is visible rather than necessary investments;
- *Patronage*: Support and bolster power for an elite control over a sector. It is a mechanism of long-term power-hunt that focuses on prioritisation of certain people to control strategic departments (e.g. regulatory institutions, state agencies) to facilitate for party allies controlling the country;
- *Industry-friendliness*: Agreements made among politicians and private sector representatives in order to achieve revenues for the party or new business for party allies in exchange of assuring future concession contracts or more profitable projects for specific private companies;
- *Corruption*: Increase personal incomes by illegal appropriation of fractions of projects' budgets usually in exchange for manipulating the bidding process to assure that specific contractors will be hired.

It is argued that infrastructure development is often hampered and misdirected by these private agendas of decision-makers, especially in countries from the Global South where there is weak accountability and low-performance evaluation of this sector (Benitez et al., 2010). The likely consequences of these setbacks in the political arena can be illustrated in the following situations:

- Prioritisation of transport projects based on bribes, rather than appropriate planning (Benitez et al, 2010)
- Subsidies to enhance accessibility and affordability frequently get lost in corruption (Benitez et al, 2010)
- Limited access to information (data) of transport sector performance to ensure less accountability (Benitez et al, 2010)
- Weaken of regulatory agencies and technical departments (Benitez et al, 2010)
- Great expenses with many pre-feasibility studies with no continuity because of low credibility of political decisions (Benitez et al, 2010)
- Allocation of resources driven by industry-friendliness and patronage, rather than by social return (Asomani-Boateng et al., 2015)
- High appetite for transport infrastructure investments particularly during periods leading to elections, rather than following a consistent long-term investment plan (Asomani-Boateng et al., 2015)
- Transport investments focused on what is visible rather than what is needed (Benitez et al, 2010)
- Favourability of specific suppliers, reducing market competition and worsening the transport service quality
- Distribution of public resources based on clientelism, such as the case of the cisterns addressed in next Chapter (Sergio et al., 2010)
- Frequent unclear renegotiation of concession contracts resulting in money evasion to corruption schemes (Guasch, 2004)
- Selection of projects focusing on flagship construction (media-attractors), rather than maintenance of remote rural roads (Setboonsarng, 2006)
- Expansion of transport contracts without concern on affordability for the poorest (Fuenmayor et al., 2017)

2.4.4. Transport and intergenerational poverty transfer

Sachs (2008) suggested that poverty will not be ended by sheer will power nor by ethical commitment alone. Rather, it will be ended only by bringing the best of our thinking and science together with the ethical commitment of scholars and practitioners from across the range of human knowledge (Sachs, 2008). Therefore, this Section by no means aims to offer a panacea for such a complex problem. Conversely, what is proposed is how transport planners and practitioners could more effectively contribute to a multi-dimensional solution.

Vakis et al. (2016) define as 'chronic poor' people who are born into poverty and may never escape from it. Based on surveys and the analysis of Censuses in Latin America and the Caribbean, these authors have concluded that the main difference between the chronic poor and those who escaped poverty is essentially the access to services, subscribing to the view that accessibility is not only inextricably linked with, but it can also reinforce cycles of poverty. Porter et al. (2007) observe that poor health and education, as well as poor job opportunities, are likely to be transferred to the next generation if the same circumstances of lack of social networks and poor access to health and education services are maintained. Fang and Zou (2014) also emphasise that improvements in transport infrastructure can increase the living standards of young generations and break the intergenerational poverty transfer.

In that sense, drawing upon the eight transport-related exclusion categories (described in Section 2.3) and the relationship of transport disadvantage and social exclusion proposed by Lucas (2012), Figure 2.3 summarises the key strategies of transport development and their potential accessibility outcomes. These could tackle the structures, processes, and livelihood strategies that can affect inter-generational poverty transfer, according to Hulme et al. (2001).

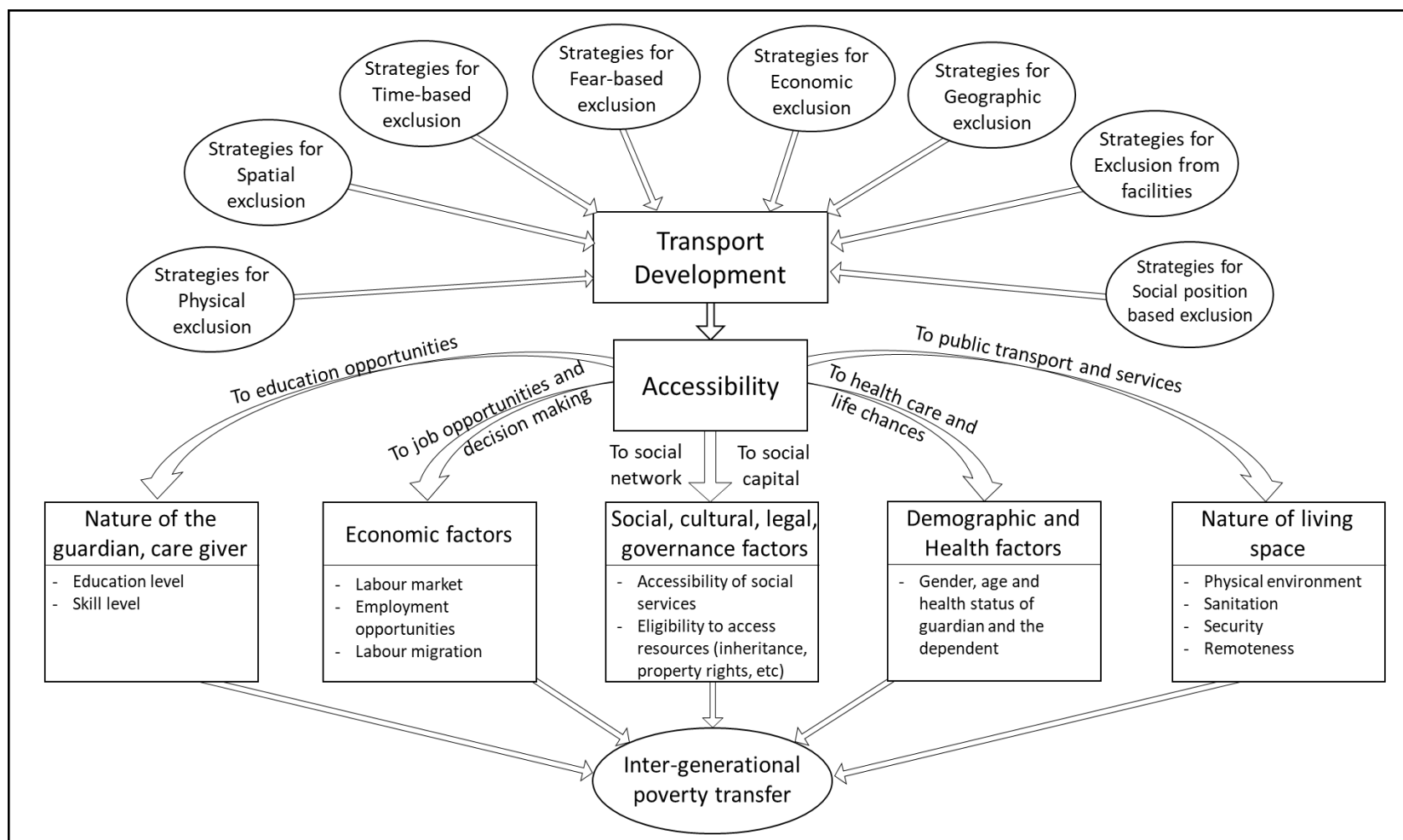


Figure 2.3: Diagram to illustrate the potential contributions of transport development to the structures, processes, and livelihood strategies that can affect inter-generational poverty transfer

2.5. Gaps in the literature and research agenda

Although there is an increasing body of knowledge underpinning links between Transport and Poverty in the Global South, several omissions and limitations have been persistently reported. Many authors attribute the gaps of research inter-relating transport improvements and poverty alleviation to the lack of reliable data (Sanchez, 2008; Salon and Gulyani, 2010; Porter, 2014). In fact, the Millennium Development Goals (MDG) Report (2015) considers the following dimensions as the major challenges in terms of data collection: (1) Poor data quality; (2) lack of timely data and; (3) unavailability of disaggregated data. The same report also points out that almost half of 155 assessed countries lack adequate data to monitor poverty.

In terms of transport-related data, even larger limitations have been consistently reported on the availability and accuracy of maps of the transport network (i.e. roads, footpaths, cycle lanes, railways, etc), General Transit Feed Specification (GTFS) data (including routes, timetables and location of stops of public transport), travel surveys, level of infrastructure quality/maintenance, location of opportunities and services (i.e. schools, healthcare, jobs, parks, etc) (Pritchard et al., 2019; Pereira, 2019; Oloo, 2018; Evans et al., 2018).

As a result, this lack of accurate, timely and disaggregated poverty and transport-related data warps the perception about the transport metabolism²¹ (Vasconcellos, 2005) and misleads planners and decision-makers to a less socially-driven transport development. Dimitriou (2013) suggests that this scenario of data deprivation results in a trade-off between model sophistication and data availability, which usually result in the creation of simplistic and sometimes unrealistic transport planning models.

²¹ The term “transport metabolism” has been proposed by Vasconcellos (2005) to illustrate the process of transport-related consumption of resources (e.g. public space, fuel) and production of externalities (e.g. pollution, accidents, congestion).

In terms ex-post studies, the reviewed papers' methodologies tend to converge around quasi-experimental methods (also called nonexperimental evaluation or observational study) when assessing the impacts of transport investments (e.g. construction of rural roads, BRT's, metro cables, pro-poor subsidies on fares, etc) on poverty reduction (Qin and Zhang, 2016; Rodriguez et al., 2016; Bocarejo et al., 2014; Khandker, 2009). However, Ravallion (2007) asserts that this methodology is quite data demanding and, therefore, limitations in the spatial and timely disaggregation of this data might give rise to endogeneity (i.e. invalidation of causal claims due to non-observed variables) and heterogeneity (i.e. differences between groups not due to chance) issues when assessing the treatment effect (i.e. the outcomes) of transport investments on poverty reduction.

In complement to the current level of evidence addressing transport-related exclusions, authors have emphasised that further investigations are needed disaggregating analysis by:

- Services: Education (primary/secondary) and Healthcare (emergency/basic care) should be also disaggregated by public/private provider (Fuenmayor, et al. (2017);
- Socio-economic features: including income groups (Guzman et al., 2017b), gender (Anand and Tiwari, 2006) and age-specific analysis (Porter, 2013);
- Transport modes: including informal (Evans et al., 2018) and non-motorised modes (Motte-Baumvol and Nassi, 2012);
- Location: rural/urban (Fan and Chan-Kang, 2008) and central/peripheral areas (Rodriguez et al., 2016);
- Job opportunities: separating by job requirements (Pereira, 2019) and including informal jobs (Pritchard, 2019).

Thus, the research chapters (3 to 6) of this thesis seek to address these research gaps, presenting innovative datasets and methodologies to cope with the limitations mentioned above.

2.6. Policy Implications

2.6.1. Transport policy analysis framework

In the literature on transport policy, much has been written on implications and approaches in the developed world, whereas the developing world has garnered comparably much less attention, as discussed in Lucas et al. (2016a). This Chapter builds upon the seminal transport policy analysis framework published by Church et al. (2000) and adapts it into the Global South context. The study in this Chapter describes how issues in transport policy analysis in the Global South are different from the rest of the world and how new analysis tools are required.

The adaptation of the Church et al. (2000) framework comes in the addition of an eighth stage to the seven-stage framework that examines transport-related exclusion. This additional stage is demonstrated, with reference to the literature, to be appropriate for the Global South and its addition adapts a framework developed for London to this region. One of the main contributions of this Chapter is to demonstrate that the issues in the Global South for transport policy appraisal may not be fully addressed using tools from developed countries. The approach documented provides policymakers and practitioners with an alternative framework to address transport policies in cities and regions in the Global South.

2.6.2. The Sustainable Development Goals

The 2030 agenda for Sustainable Development defined by the UN in 2015 sets out an ambitious strategy to shift the world on to a sustainable and resilient path. This strategy comprises of 17 Sustainable Development Goals (SDGs) with 169 targets in total. The Partnership on Sustainable, Low Carbon Transport²² highlights 12 targets of the SDG's that directly (Targets 3.6, 7.3, 9.1, 11.2, 12.c)

²² The SLoCaT Partnership on Sustainable Transport is a multi-stakeholder partnership of over 90 organizations representing UN organizations, Multilateral and Bilateral development organizations, NGOs and Foundations, Academe and the Business Sector (SLoCaT, 2019).

or indirectly (Targets 2.3, 3.9, 6.1, 11.6, 12.3, 13.1, and 13.2) related to transport. However, these targets are limited to topics related to road safety, air pollution, access to transport systems, and productivity improvements.

During the negotiation window of the SDG's agenda, Njenga and Odero (2014) have highlighted that the transport sector, despite acting as a key enabler to the achievement of various goals, has only been marginally recognised in the proposed specific targets. Drawing upon this critique, this Chapter has demonstrated how transportation development is also intrinsically connected to targets related to poverty reduction and the universalisation of access to basic services and life opportunities. This association is explicitly illustrated in Figure 2.3 (page 40) in which the inter-generational poverty transfer is shown as a result of several accessibility restrictions. Thus, beyond the 12 targets identified by the SLoCaT, it is argued that transport strategies addressing the 8 transport-related exclusion dimensions may also offer an effective path in the achievement of the specific seven targets described below:

Target 1.4: *By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.*

Target 2.1: *By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round*

Target 2.3: *By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment*

Target 3.7: *By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and*

education, and the integration of reproductive health into national strategies and programme

Target 3.8: *Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all*

Target 4.2: *By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education*

Target 4.5: *By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations*

2.7. Conclusions

Overall, this literature overview suggests that the scarcity of poverty and transport-related data about the most disadvantaged regions (UN, 2015b) limits the development of solid and effective research about transport-related exclusion in the Global South (Porter, 2002; Salon and Gulyani, 2010). Under this low level of research, and many misperceptions about the impacts of intersectionality on travel patterns (Levy, 2013), transport policy recommendations that should be guided by disaggregated accessibility and equity analysis (Vasconcellos, 2011) are frequently inaccurate and socially unjust (Pereira et al., 2017). In a political context of low transparency and low accountability that also lacks this evidence-based policy recommendations, policy-makers are likely to mislead transport investments towards their own private agendas (Benitez, 2010). As a result, debilitating and unconstrained transport and urban development are perpetuated, reinforcing cycles of chronic poverty (UN, 2016; Hulme et al., 2001).

By pointing out and connecting these underexplored insights on the transport-poverty nexus in the Global South, this Chapter has argued that new transport

policies should comprehend strategies to address the eight transport-related dimensions of exclusion, if the goal is to end poverty in all its manifestations by 2030. The gravity and urgency of lifting 1.3 billion people out of poverty are translated by Narayan et al.'s (2000) definition of poverty:

“Poverty is pain. Poor people suffer physical pain that comes with too little food and long hours of work; emotional pain stemming from the daily humiliations of dependency and lack of power; and the moral pain from being forced to make choices such as whether to pay to save the life of an ill family member or to use the money to feed their children. “

Undeniably, while many political leaders insist on claiming that we are finally the generation that can end extreme poverty, this will not come true until professionals from across the range of human knowledge start working strongly committed towards this direction. This Chapter has raised evidence that can be a valuable input to call particular attention to the essential role that transport academics and practitioners ought to play in order to stand up to poverty when developing new transport policies.

CHAPTER 3: ACCESSIBILITY EVALUATION AT THE HOUSEHOLD LEVEL

3.1. Introduction

There is a growing body of literature dedicated to evaluating spatial access to public services including methods based on minimum travel-distance (Apparicio et al., 2008), gravity models (Haynes et al., 2003), kernel-density estimation (Spencer and Angeles, 2007), and floating catchment areas (Luo and Wang, 2003). However, mostly due to a lack of accurate data, especially spatial data, quantitative research on this topic still falls short in the context of low-income and remote rural areas globally (Serajuddin, 2015).

As already discussed in Chapters 1 and 2, poverty is a multidimensional phenomenon directly related to the lack of access essential services (such as healthcare, education) (Narayan et al., 2000; Alkire and Santos, 2014). Nonetheless, while accessibility has been long recognised as central in the social inclusion agenda of rural areas (Farrington and Farrington, 2005), this transport-related dimension of poverty has remained understudied in quantitative studies in several low-income regions from the rural Global South (Benevenuto and Caulfield, 2019; IFAD, 2011). In the context of Northeast Brazil, which contains the largest percentage of people in extreme poverty of the Country and where the majority of these people still live in rural areas (IBGE, 2010a), very few quantitative studies exist examining access to these basic services (Garcia-Subirats et al., 2014).

Yet, a few notable exceptions dedicated to specific health outcomes have pointed to the same direction of the international studies on this agenda. De Souza et al. (2000), for instance, have shown that healthcare accessibility was reported by

mothers as a determinant factor leading to delays in seeking professional care when their infants had potentially life-threatening symptoms. Likewise, other authors have also reported that the greatest impediments in the utilisation of healthcare for the Brazilian rural population are related to difficulties of geographical access, either perceived by long journey times, lengthy distances or low availability of transport (Osorio et al., 2011; Travassos, 2006). In fact, lengthy distances to healthcare centres have long been recognised as a major determinant of the utilisation of public services such as healthcare (Shannon et al., 1969; Stock, 1983; Thaddeus and Maine, 1994; Adedini et al., 2014; Fluegge et al., 2018). Gabrysch and Campbell, 2009 explains that low spatial accessibility of healthcare exerts a twofold burden, firstly by discouraging from seeking care, and secondly by being an actual impedance to reaching medical care once the decision to seek it has been made.

Healthcare accessibility has gained a lot of recent attention in Brazil due to the structural changes in the program “Mais Médicos” (More Doctors), which since 2013 has added 4917 physicians to work in remote and deprived areas of Brazil (Santos et al., 2017). However, there is still no evidence published to date (to the best of the author’s knowledge) showing either the health outcomes associated with this initiative or the current level of spatial accessibility of health services in rural and deprived areas.

This Chapter proposes a novel strategy to measure the spatial burden that is potentially preventing the low-income population in rural Northeast Brazil from accessing basic services. Whilst much has been written on the transport and social exclusion dialogue of more economically vibrant and data-rich contexts, the present Chapter contributes to the literature by i) assessing accessibility to basic services in an often-overlooked region; ii) proposing an innovative proxy for a quantitative accessibility evaluation of the rural Northeast Brazil; iii) shedding light on the transport issues that undermine public health in rural low-income contexts; iv) devising practical policy recommendations to address the concerning health and social outcomes of the case study region.

Since this Chapter provides further analysis on healthcare accessibility, beyond the overall accessibility measurements, a brief overview of the health challenges

in rural Northeast Brazil is initially provided to set the background for this analysis. Then, combining the urban and healthcare centres' locations with a proxy for the low-income households' location, this Chapter proposes a quantitative accessibility evaluation at the household level in the Northeast Brazil context. The distances between households facing income poverty and healthcare centres are calculated by means of GIS tools and then described spatially and statistically. Finally, some policy recommendations are drawn upon these findings, and the gaps that still need to be further studied in this field are identified. The results in the next sections of this Chapter are also published in Benevenuto et al. (2019).

3.2. Public health challenges in Rural Northeast Brazil

Despite the investment in public policies and the creation of Brazil's publicly funded healthcare system (SUS) in 1988, which follows a guiding principle of equity, regional and socio-economic disparities are still prevalent in the overall health outcomes in Brazil (Szwarcwald et al., 2016; Rasella et al., 2013; Barros et al., 2011). Evidence shows that the North and Northeast regions, which have the lowest average income (IBGE, 2010a), have historically presented the most unsatisfactory rates of several health indicators that are usually associated with limited accessibility of health services (Albuquerque, 2017; Szwarcwald et al., 2016; Victoria et al., 2011). These concerning trends are hereafter represented and further considered by two specific indicators, namely, life expectancy at birth, and mortality in children younger than 5 years (i.e. under-5 mortality).

Life expectancy is a particularly suitable indicator to measure the impact of healthcare accessibility since it summarises the social, health, and general well-being conditions of a population by considering mortality rates in their different age groups. All causes of death are contemplated when estimating this indicator, including diseases and external causes, such as violence and accidents (UNDP et al., 2010). Likewise, Under-5 Mortality is an internationally applied indicator also widely used to evaluate coverage and adequate access to healthcare (Walker, 2013; Gabrysch and Campbell, 2009). This is due to the fact that some of the main strategies to reduce its occurrence (i.e. timely treatment,

immunisation, and skilled care during pregnancy and childbirth) (WHO, 2015) depend on the services mostly, or sometimes only, provided at healthcare centres.

The Human Development Atlas in Brazil (UNDP et al., 2010) reports that the levels of Life Expectancy are consistently lower in the North-eastern states of Brazil, whereas the Under-5 mortality is substantially higher for the same states. These differences are depicted in Figure 3.1 to highlight the spatial pattern of these statistics.

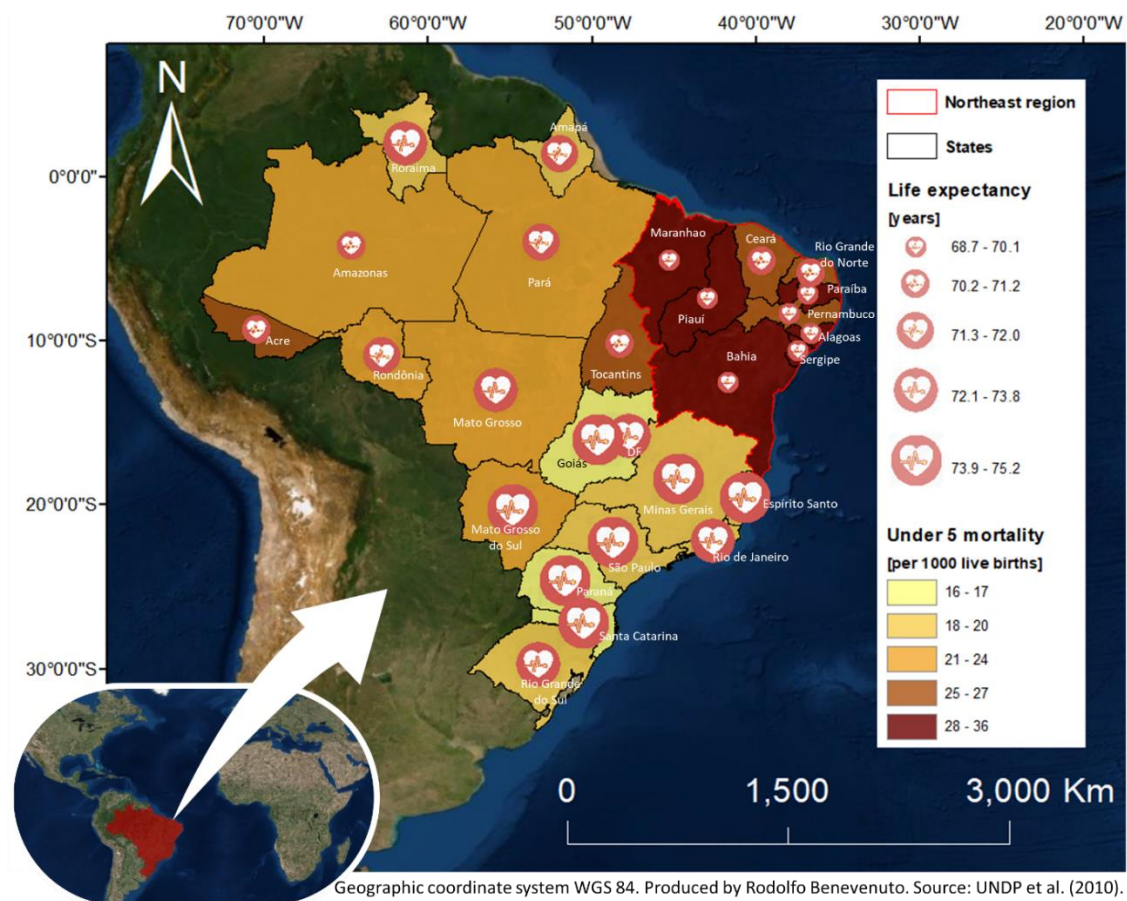


Figure 3.1: Vital statistics in Brazilian states. i) Life Expectancy [years] in the colour scale and ii) Under 5 mortality [per 1000 live births] in the symbol scale

The health indicators applied in this Chapter can be found in more recent datasets (IBGE, 2013). Yet, as the present analysis builds on data from the latest

Census²³ (IBGE, 2010a) to keep the consistency among variables, older health indicators are used. Perhaps the most concerning limitation of the Brazilian Health Database (i.e. DATASUS) is that despite the thorough disaggregation levels in terms of socio-economic, demographic and health variables, this database falls short in disaggregation of spatial details.

Currently, there is no disaggregation publicly available of these datasets for urban/rural areas at a municipality level, or by areas smaller than a municipality (i.e. electoral division, census sector, etc). In that sense, location-based comparisons and correlations of health indicators become limited to the few health indicators included in the Brazilian Census, which is also timewise limited (once every 10 years) and only disaggregated by location (urban/rural) at the state level.

Nevertheless, when comparing these state-wise health indicators by location it is possible to spot major disparities between urban and rural areas in the Northeastern states. Figure 3.2 and Figure 3.3 point out that the difference in Life Expectancy can be up to 3.4 years lower in rural areas compared to urban areas in the same state (e.g. Sergipe state). Similarly, the rate of Under 5 mortality (per 1000 live births) is up to 44% higher in rural areas compared to the urban figure of the same state (also Sergipe).

²³ The Brazilian Census is updated every 10 years. Therefore, the next one is planned to be released in 2020.

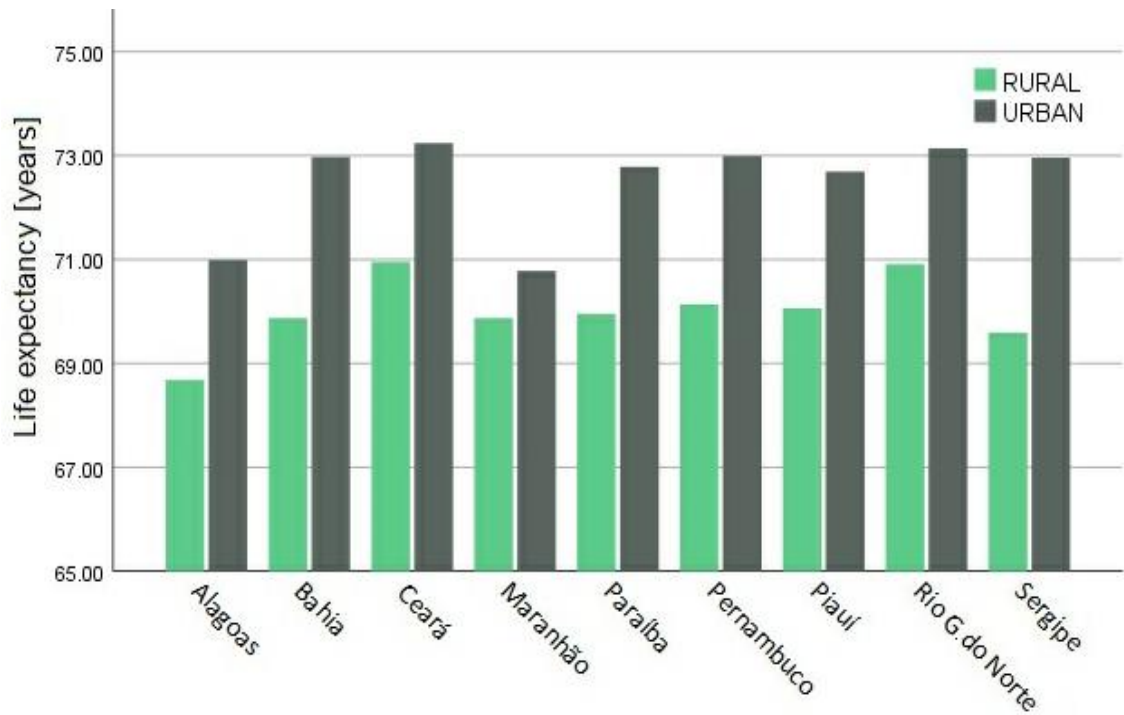


Figure 3.2: Life expectancy [years] of states in Northeast Brazil comparing urban and rural rates

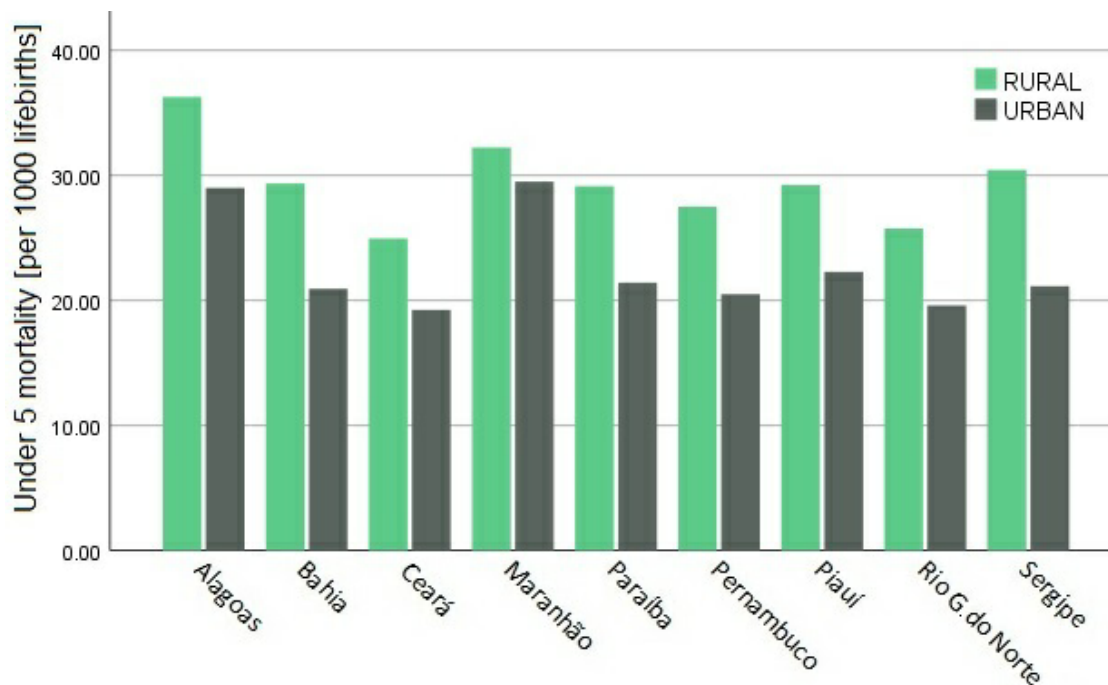


Figure 3.3: Under 5 mortality [per 1000 live births] of states in Northeast Brazil states comparing urban and rural rates

When the municipalities' statistics are analysed in groups of similar shares of rural population and average income, other clear trends emerge. As expected, the location and income differences appear to reflect the performance of the

assessed health indicators, following trends previously described in similar studies (Szwarcwald et al., 2016; Rasella et al., 2013; Victoria et al. 2011). More interestingly, what stands out in Figure 3.4 and Figure 3.5 is that the differences in life expectancy and Under 5 mortality are much more exacerbated by the rurality levels in lower average income municipalities (first, second and third quintile) than the affluent ones.

While life expectancy in the richest quintile is virtually not affected by the share of the rural population, people living in highly urbanised municipalities²⁴ of the second poorest quintile live on average 3 years more than those from municipalities with higher rurality levels²⁵ from the same income quintile. Similarly, Figure 3.4 and Figure 3.5 indicate that, in the second quintile of average income, the Under-5 mortality is 44% higher in municipalities with a greater share of rural population²⁴ than the more urbanised ones²³.

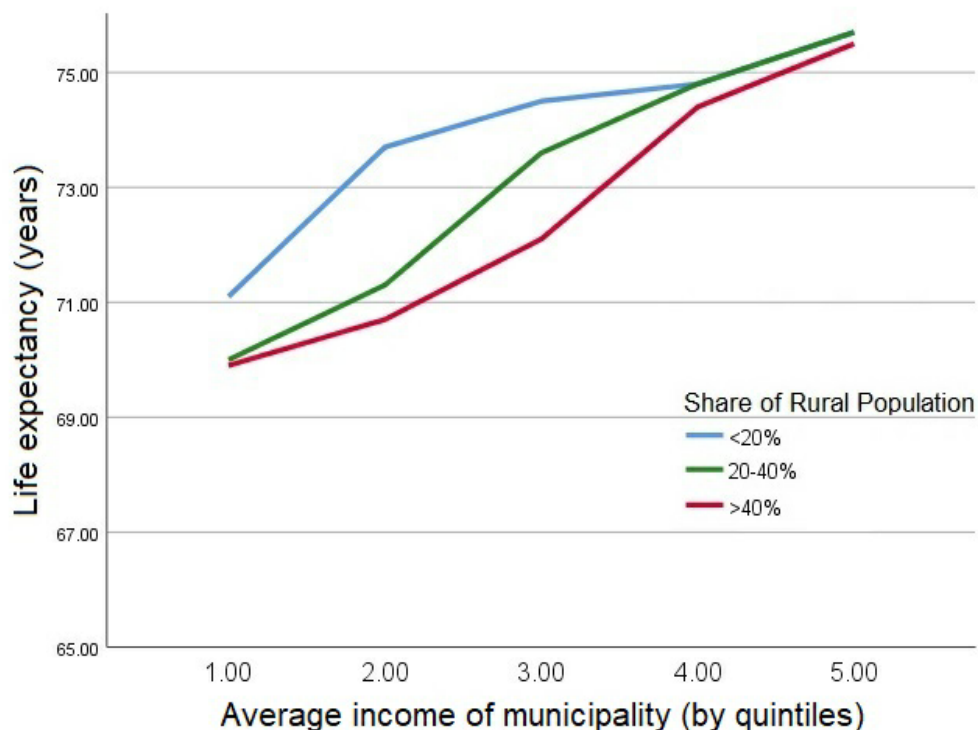


Figure 3.4: Life expectancy [in years] stratified by quintiles of average income and clustered by share of the rural population

²⁴ Rural share less than 20%

²⁵ Rural share greater than 40%

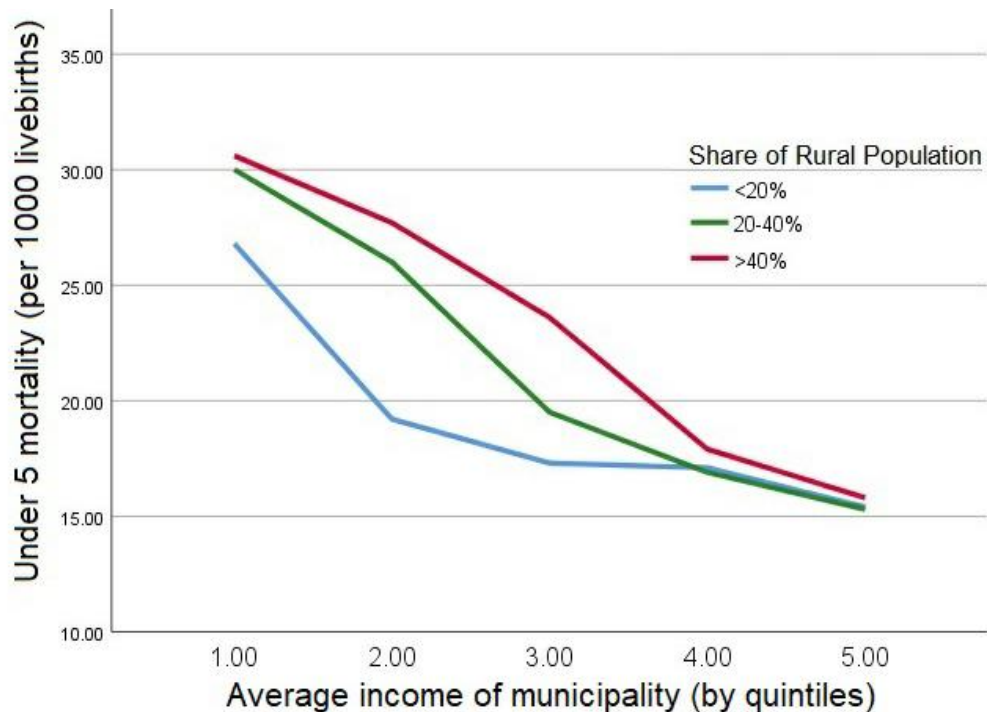


Figure 3.5: Under 5 mortality [per 1000 livebirths] stratified by quintiles of average income and clustered by share of the rural population

Thus far, this Section has attempted to provide a brief summary of the health challenges particularly affecting rural low-income families of Northeast Brazil. The next Section describes the data and methods utilised in this Chapter for evaluating a spatial barrier that is potentially preventing these families from accessing healthcare and other essential services.

3.3. Data and Methods

This section provides a further description of the data and the methods applied to this accessibility analysis. Section 3.3.1 and 3.3.2 provide a rationale for the proxies that are proposed in this Chapter, showing how existing open access datasets can be harnessed to track the location of the households in extreme poverty and basic services in Northeast Brazil. Section 3.3.3 propose a method that is suitable for estimating spatial accessibility in the case study context.

3.3.1. Households in Extreme Poverty

Datasets showing the precise coordinates of households living in extreme poverty are rarely publicly available. Either because they are considered sensitive information or simply due to the absence of this spatial data, these coordinates have been substantially underexplored in quantitative accessibility evaluations. In this sense, this Chapter proposes an innovative variable as a proxy for mapping these households.

Due to the very dry climate and a constant lack of water resources in Northeast Brazil, the Brazilian Federal Government launched in 2003 the project P1MC (Programme for 1 Million Cisterns). This project aimed to deliver 1 million water tanks (cisterns) to families considered to be living below the poverty line in the semi-arid region of Northeast Brazil (ASA, 2018). Since the extent of the climate and economic underdevelopment pattern also covers the north part of the immediate region below (Southeast), the Brazilian Federal Government has also incorporated these municipalities within the scope of this programme. Figure 3.6 and Figure 3.7 present aerial and front views of a typical cistern provided by this project. As can be seen in Figure 3.7, the cisterns are numbered and registered in a geospatial database. It is also important to note that not all low-income households in this region have been beneficiaries of this program.



Figure 3.6: Typical cistern and low-income household in Rural Northeast Brazil

A dataset composed of 493,659 locations (Latitude and Longitude) of these cisterns has been provided by the *Articulação do Semi-Árido Brasileiro* (ASA²⁶) in cooperation with the Superintendency for the Development of Northeast Brazil (SUDENE²⁷) for the present academic purpose. Each cistern is usually located a few meters from at least one low-income household registered in the social programmes of the Federal Government. While other proxies such as night-time lights, often used to measure poverty in Sub-Saharan Africa (Noor et al., 2008), would inevitably fall short in spatial and socioeconomic accuracy, these cisterns are only given to families considered in extreme poverty after a thorough analysis by the social workers from the local government. Therefore, it is argued that this dataset represents one of the most accurate and representative proxy to track the location of rural low-income households in rural Northeast Brazil. Figure 3.8 presents these points plotted over Northeast Brazil, showing its wide coverage in the region. Further evidence of the accuracy of this dataset is provided in the following sections.



Figure 3.7: Beneficiary from Programme 1 Million of Cisterns (ASA, 2018)

²⁶ ASA is a network composed of more than 3.000 civil society organizations of different purposes including NGOs, rural unions, farmers associations, cooperatives, and other entities that act in defence of the rights of people living in the Semi-arid region of Northeast Brazil.

²⁷ SUDENE is a Brazilian governmental agency in charge of planning and stimulating the social and economic development of the Northeastern region of Brazil.

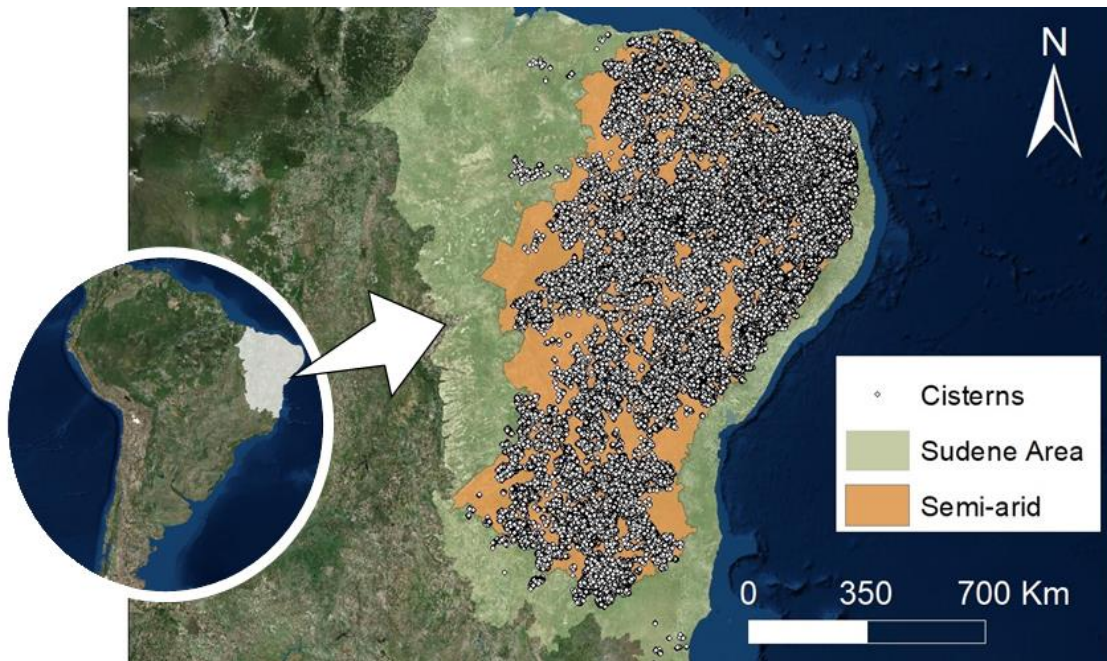


Figure 3.8: Spatial distribution of cisterns in extended Northeast Brazil (SUDENE Area)

This cistern location dataset is the result of an effort of ASA of compiling a number of smaller datasets containing the cisterns' locations in different sub-regions in Northeast Brazil. Since the cisterns of each of these sub-regions have been mapped by different governmental agencies for different purposes using a few different coordinate systems, the complete location dataset compiled by ASA has never been used before. In that sense, an accuracy checking of such complete dataset was carried out.

Considering that these cisterns present a very regular pattern of elements for image interpretation, a geospatial object-based-image analysis as described by Blaschke (2010) was conducted to perform a systematic scanning of the plotting accuracy. According to Lillesand et al. (2014), the fundamental elements of this image interpretation can be described by five key elements, as shown in Table 3.1. The features verified for each of these elements in the present analysis are also described in the third column of Table 3.1.

Table 3.1: Description of elements analysed in the Geospatial object-based-image analysis

Element	Description	Features verified
Shape	General form, configuration or outline of the object	Regular circle
Size	Must be considered in the context of the image scale.	4 meters in diameter at a 1:1000 scale
Pattern	Relates to the spatial arrangement of the object	Surrounded by at least one house
Tone	Refers to the relative brightness or colour of the object	Opaque whitish
Texture	It is the frequency of tonal change on an image	Regular smooth

Since the satellite imagery datasets that are publicly available for this region present a spatial resolution of 10 meters or higher²⁸, and the cistern diameter is around 4 meters, the object-based-image analysis had to be done manually using the world imagery basemap layer available in ArcMap 10.6.1²⁹, as shown in Figure 3.9. In this sense, to determine the accuracy of this plotting (i.e. the cisterns dataset), the distances between the plotted coordinates and the closest visible cistern (that met all the image interpretation criteria) were individually measured for a sample of 384 points (randomly selected). The traditional sampling formula (Equation 3.1) proposed by Krejcie and Morgan (1970) has been used to calculate a representative sample size for this dataset:

$$n = \frac{N \cdot p \cdot (1 - p) \cdot \left(\frac{Z_{\alpha}}{2}\right)}{p \cdot (1 - p) \cdot \left(\frac{Z_{\alpha}}{2}\right) + (N - 1) \cdot E^2} \quad \text{Equation 3.1}$$

Where:

- n is the sample size to be estimated (384 points)
- N is the population size (493,659 for this case)

²⁸ For example Sentinel-2 (available at <https://sentinel.esa.int/>) or Landsat-8 (available <https://landsat.gsfc.nasa.gov/>)

²⁹ The resolution of this basemap offered by ArcMap 10.6.1 is less than 1 meter per pixel.

- $Z_{\frac{\alpha}{2}}$ is the critical value that corresponds to the desirable confidence degree (in this case 1.96 for a confidence degree of 95%, assuming a normal distribution)
- p is the likelihood of the expected event (assumed as 50% when unknown)
- E is the adopted error margin ($\pm 5\%$ for this case)



Figure 3.9: Sample of accuracy checking of cisterns location (screenshot taken from ArcMap 10.6.1)

3.3.2. Public services and Basic amenities

This Section describes the datasets that were utilised to proxy the location of public services and basic amenities in this analysis. In the Brazilian context, substantial progress has been achieved on the compilation of spatial data since 2008 when the National Spatial Data Infrastructure (INDE³⁰) was created. However, the clear majority of public services' and basic amenities' locations (latitude/longitude) remain still unknown at a national level, especially in the rural and suburban contexts. For example, regarding the education centres, recent efforts are being made by the Federal Government to deliver the full mapping of

³⁰ INDE portal: <http://www.inde.gov.br/>

these services by the next educational census (i.e. by 2020). However, at the time that this thesis was written (i.e. 2019), only the list of addresses of the schools and centres of education (including private and public ones) was available on-demand via the National Institute of Educational Studies and Research (INEP). While the geo-codification³¹ of this list can achieve a fair level of accuracy for urban addresses, the rural ones are mostly too vague to be geocoded (rural roads with no name, or no number, or broken zip code). Similarly, the location (Latitude/Longitude) of essential services such as public transport, social assistance centres, police stations, and other basic amenities (e.g. supermarkets, grocery shops, pharmacies) are as a rule not consistently available for Northeast Brazil. In fact, among these points of interests, the only country-wide and accurate spatial dataset currently available is the location of healthcare centres. These are made available by the Ministry of Health that will be further discussed later in this Section.

Nonetheless, since these public services and basic amenities are primarily concentrated within the urban centres (IBGE, 2008; Church et al., 2000), it is reasonable to assume the geolocation of each urban centre (i.e. city hall coordinates) as an aggregated proxy for public services and basic amenities' locations at a larger scale. For instance, from the list of addresses of education centres mentioned above, it is possible to conclude that 87% of the education centres that offer high school are located in the urban areas. Moreover, this premise has been also used by recent studies (Weiss et al., 2018; Headey et al. 2018), to demonstrate how access to urban centres stratifies the educational, economic and health status across different communities. The variety and complexity of services and amenities offered in each centre are dependent on the urban hierarchy of each centre. Following the traditional hierarchisation method proposed by IBGE (2008) this Chapter considers the five different levels of centrality in Brazil, as described in Table 3.2.

³¹ Computational process of transforming an address into a pair of coordinates (latitude and longitude).

Table 3.2: Urban centre hierarchy

Hierarchy	Quantity of urban centres considered	Population range [thousand inhabitants each]
Metropolis	6	From 1,393 to 2,675
Regional centre	27	From 134 to 1,014
Sub-regional centre	66	From 23 to 334
Zone centre	220	From 8 to 126
Local centre	1,765	From 1 to 87

Beyond population size, different services are taken into consideration when composing these centrality levels, for example, higher education provision, banking services, number of business offices, hospitals, coverage areas of television stations and internet, etc (IBGE, 2008). Overall, this hierarchy is mainly based on i) the number and complexity of services available in each urban centre, and ii) by the influence that each centre exerts on the surrounding municipalities (IBGE, 2008).

Even though other studies have been published since 2008 updating the regional divisions of the Country (IBGE, 2016; IBGE, 2017), they do not propose any different hierarchisation method for urban centrality. Rather, they based their population arrangements and regional divisions on the same seminal paper (IBGE, 2008), confirming, thus, that this urban hierarchisation method is still valid nowadays. Moreover, no municipalities have been created in this region since 2008.

Another accessibility measurement is also proposed using one of the few public services location datasets that is consistently available for all regions in Brazil, that is, the location of healthcare centres. As described in Table 3.3, this dataset contains the location of four different types of healthcare centres (Ministério da Saúde, 2018):

Table 3.3: Healthcare centres classification in Brazil

Type of healthcare centre	Quantity in Brazil	Description
Basic care unit	40,612	These units are known in Brazil as the UBS (i.e. acronym for <i>Unidade Básica de Saúde</i>). They are the main place where interdisciplinary primary care professionals operate for a specific population in each geographic area. It is preferably the first contact of the patient in the healthcare network.
Family health support nucleus	4,417	These centres are known in Brazil as NASF (i.e. acronym for <i>Núcleo de Apoio a Saúde da Família</i>) was created in 2008 by the Brazilian Ministry of Health, with the intention to expand the scope and spectrum of care actions on the primary care and to increase its effectiveness. The medical specialities available in each NASF depend on the local health needs.
Emergency care unit	425	Also known as UPA (i.e. acronym for <i>Unidade de Pronto Atendimento</i>), they are part of the Emergency Care Network. Its objective is to concentrate the healthcare of intermediate complexity, forming a network organized in conjunction with Basic Attention and Hospital Attention, decreasing queuing in hospital emergency rooms, as well as increasing the service capacity of the Brazilian Healthcare system (i.e. SUS). As they are also a recent government initiative, there are only 425 of this kind of units.
Hospital	3,406	Centres of a wide range of medium and high complexity healthcare services.

3.3.3. Accessibility estimate

Accessibility-related studies commonly use GIS tools³² to estimate service areas based on driving/cycling/walking distances or time from an origin, for example, a household, or neighbourhood, to the closest point of interest, such as schools, hospitals, or even job opportunities (Pereira, 2018; Guagliardo, 2004). The accuracy level of this estimates deeply relies on the quality of the transport network datasets³³.

³² Mostly by means of *OpenTripPlanner*, *QGIS*, *ArcGIS®*, or *Sugaraccess®*

³³ For example: General Transit Feed Specification (GTFS) datasets

In contrast, Rural Northeast Brazil is predominantly covered by non-paved secondary and tertiary roads and footpaths that are in many cases not mapped either by the Government authority³⁴ or by large mapping platforms (HERE maps®, Google maps®, and OpenStreetMap®). Figure 3.10 depicts the discrepancies between the catchment areas using Driving distance (estimated by ArcGIS online) and linear radius methods (buffers) from small towns in Pernambuco state in Northeast Brazil. The location of the mapped roads can be seen along the reddish areas and lines depicted in Figure 3.10. As can be noted in this Figure, if this method of travel impedance was used, several households (white dots) would wrongly appear to be not connected to the road network.

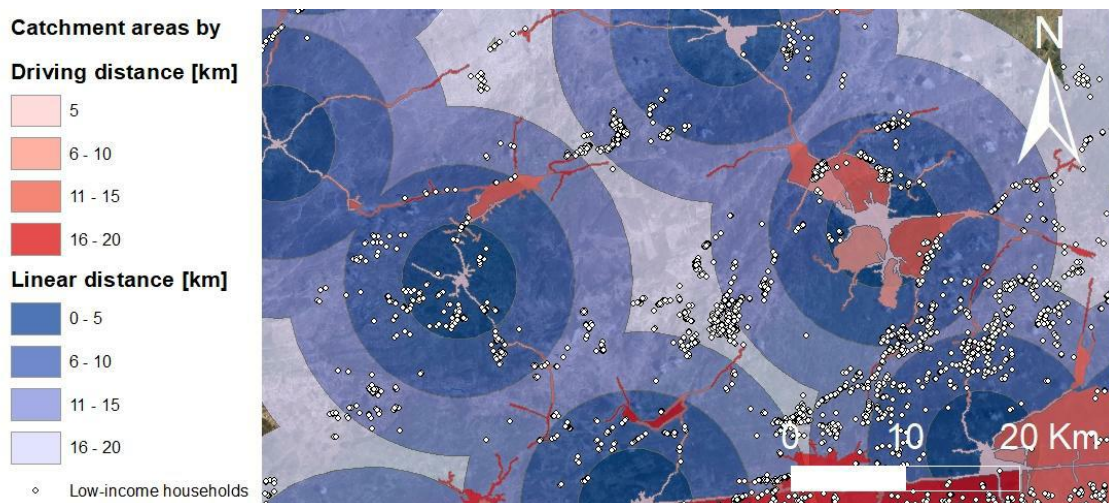


Figure 3.10: Low-income households under the urban influence area - Municipalities of Brejo de Madre de Deus and Poção (Source: ArcGIS online)

As shown in Figure 3.10, many roads that connect low-income households to urban centres and healthcare centres are not mapped, creating serious gaps in the service areas estimated by driving distance (reddish scale). Moreover, if only the areas where transport-related data is available were selected to be assessed, a significant caveat would be introduced in the analysis as these areas are as a rule more urbanised and economically vibrant. Therefore, in order to include also areas that have been persistently overlooked in the academic literature (perhaps, precisely for not having accurate and timely transport-related data), a simpler travel impedance method had to be adopted.

³⁴ Brazilian National Transport Infrastructure Department (DNIT)

Tanser et al. (2006) argue that conventional models using network analysis are not appropriate for areas where people mostly walk to the nearest service, and public transport is unregulated, and its coverage is temporal and spatially sporadic. Therefore, following other studies of healthcare accessibility in similar contexts of the Global South (Francis et al., 2009; Tanser et al., 2006; Noor et al., 2003; Tanser et al., 2001), the present methodology applies the Geodesic³⁵ method to provide a comprehensive and consistent spatial distance evaluation.

Even though this method does not include extra distances caused by natural barriers (rivers, cliffs, etc) and road curvature, it enables consistency to be maintained among all regions despite the gaps of the mapped transport network. As demonstrated earlier in this Section (Figure 3.10), any estimate of travel impedance based on this road network dataset would be result a rather inconsistent output. Thus, despite its limitations, the linear distance method provides a much more conservative estimate of the travel distances.

3.4. Results and Discussion

3.4.1. Cisterns as a proxy for low-income households

The geospatial object-based-image analysis performed with the 384 cisterns' locations has shown that these points are on average 104.83 meters away from the real cistern observed on the satellite view. Figure 3.11 shows the descriptive statistics and a frequency distribution graph of these plotting imprecisions, highlighting that 81.4% of the cases have an inaccuracy of less than 200 meters. Only for 0.8% of the cases (8 points), no cistern was identified in a search radius of 3,000 meters - which is still in accordance to the error margin of 5% expected from this sample size.

³⁵ The Geodesic method consist of the measurement of distance along the shortest route between two points on the Earth's surface.

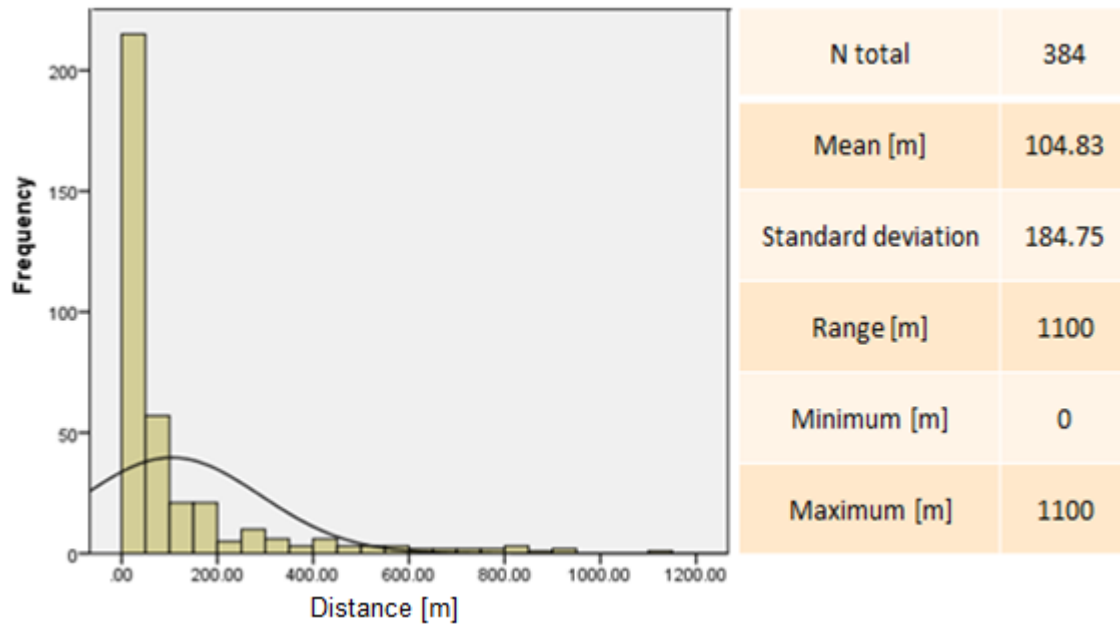


Figure 3.11: Descriptive statistics of the cistern plotting accuracy

Given the relatively low inaccuracy of the plotted points evaluated in the sample, the cisterns' locations dataset can be considered as a good proxy for the rural low-income households in Northeast Brazil. This dataset represents an accurate and representative collection of information that can be utilised for better understanding of the spatial burden faced by low-income families in this region.

Nevertheless, spatial analysis (e.g. prioritisation areas) using this dataset should be done with more caution. Once again it is important to note that the absence of cisterns in a given municipality does not mean absence of households in extreme poverty. Therefore, the following analysis primarily focuses on describing statistically the limited accessibility patterns of these households, rather than creating a regional index of accessibility based on this proxy. In the following sections, the accessibility patterns of these households are spatially and statistically described.

3.4.2. Access to urban amenities

The statistical description of the spatial burden separating low-income households and to the closest urban centre of each centrality level defined in Table 3.2 are presented in Figure 3.12-Figure 3.16.

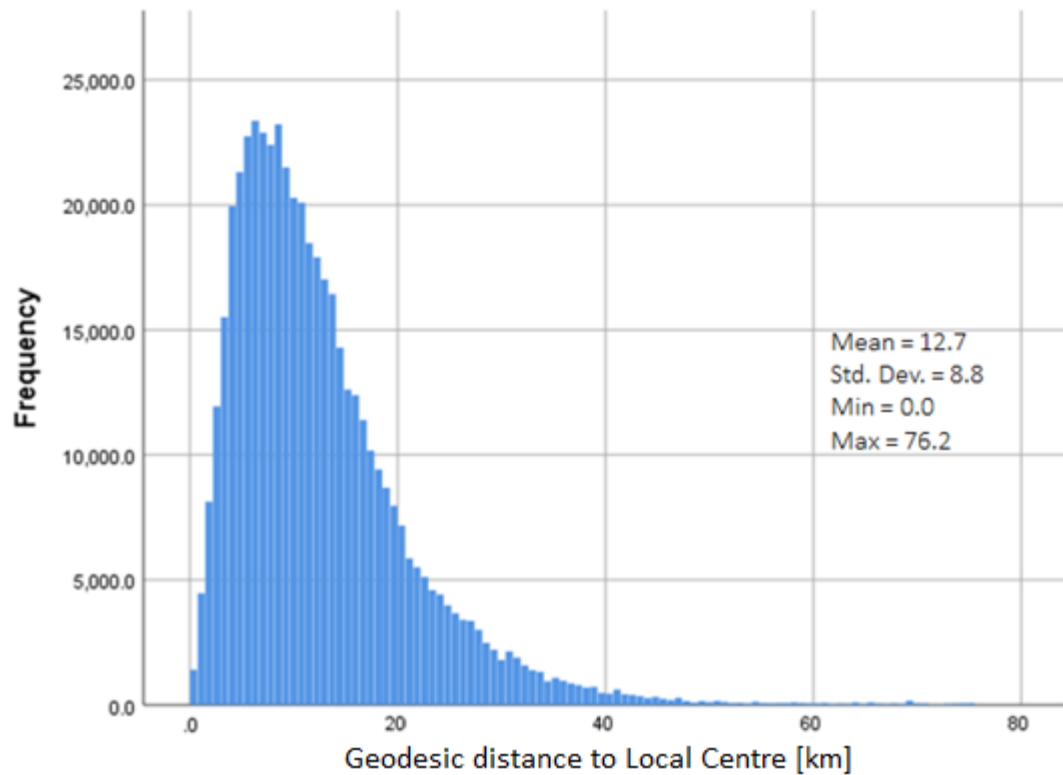


Figure 3.12: Frequency distribution of households by geodesic distance to Local Centre

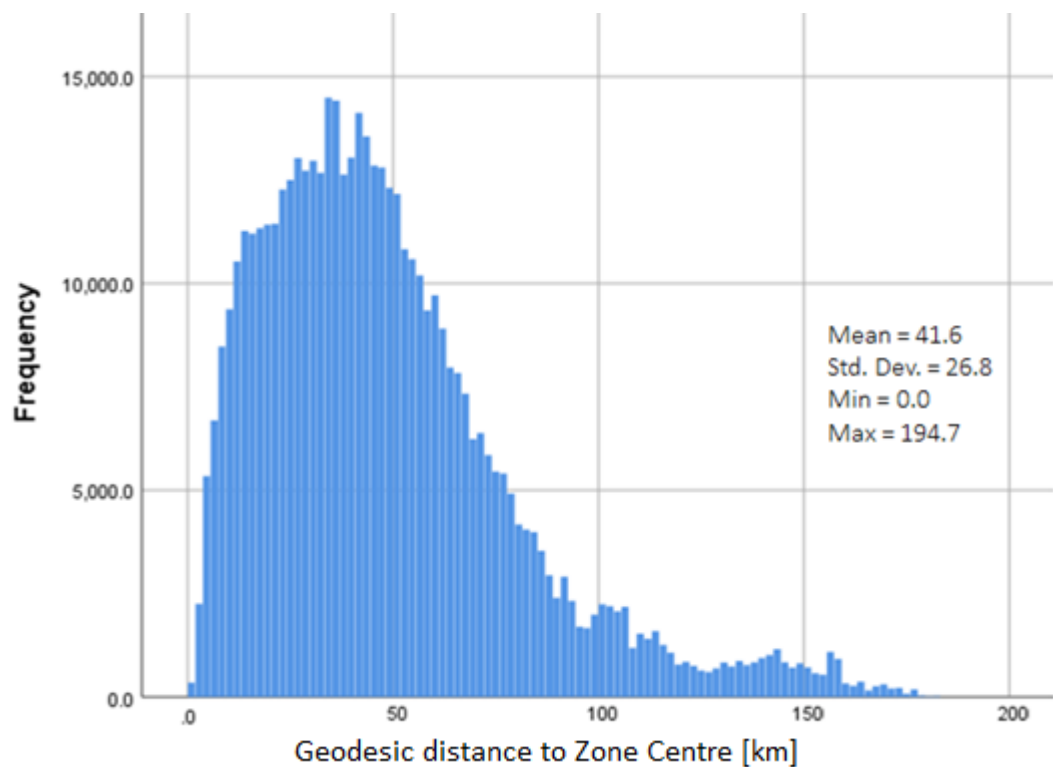


Figure 3.13: Frequency distribution of households by geodesic distance to Zone Centre

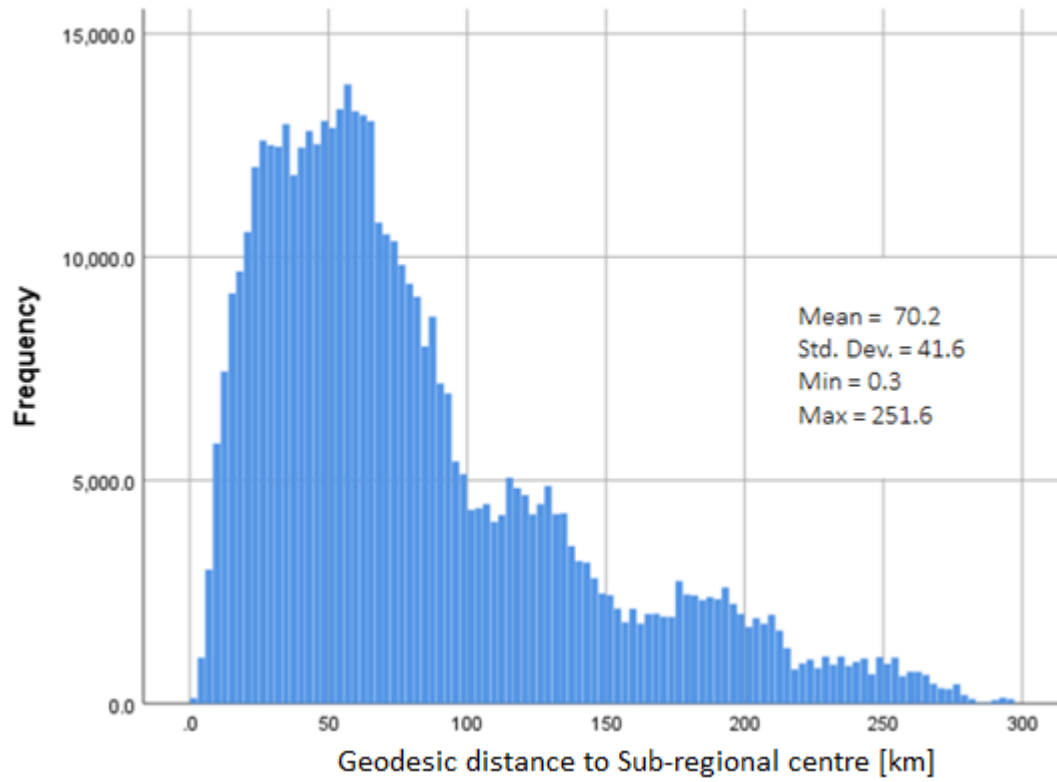


Figure 3.14: Frequency distribution of households by geodesic distance to Sub-regional centre

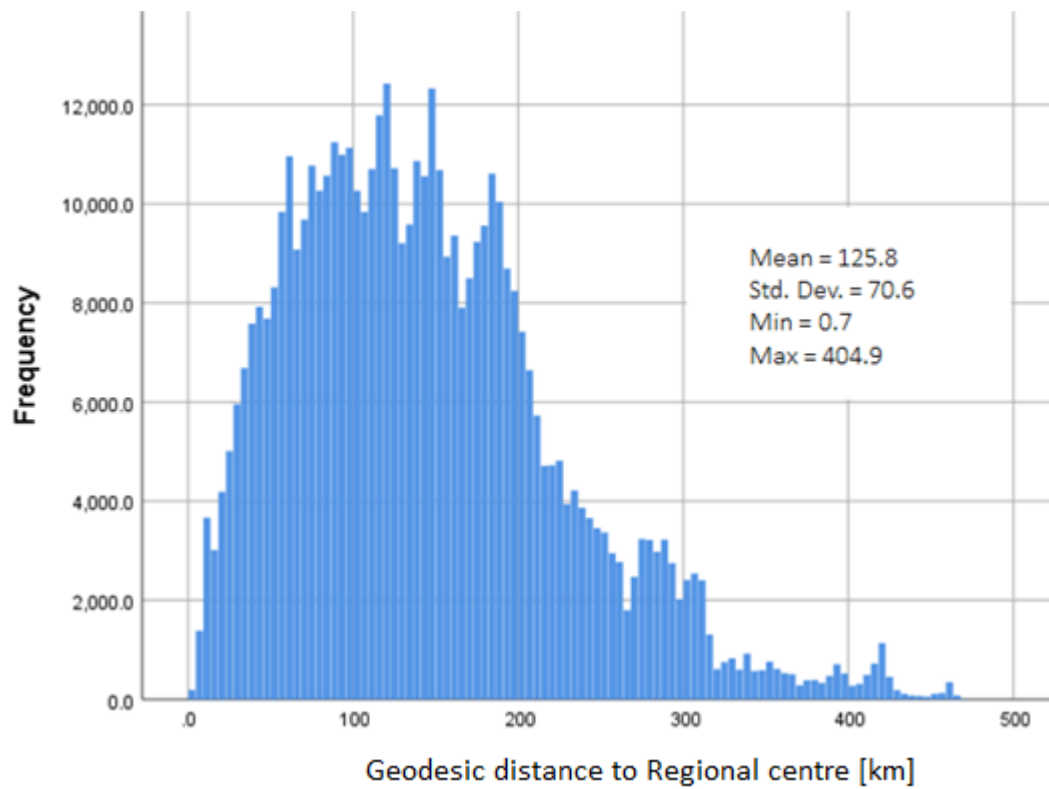


Figure 3.15: Frequency distribution of households by geodesic distance to Regional centre

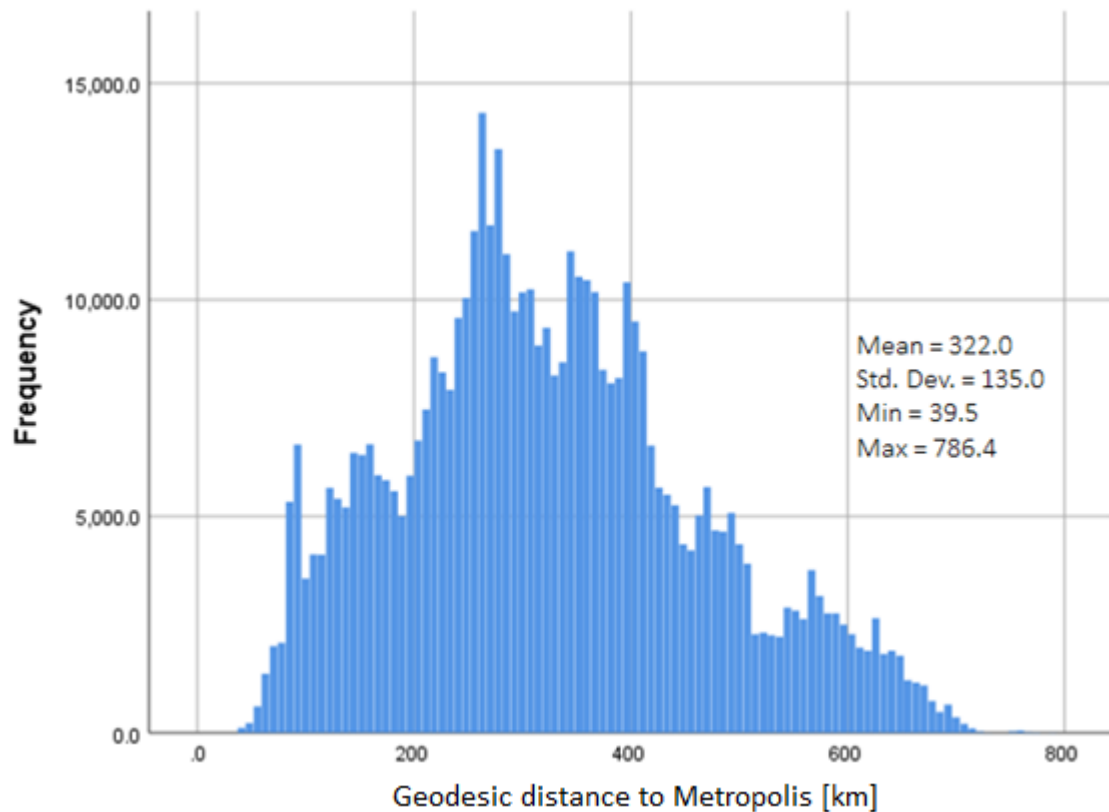


Figure 3.16: Frequency distribution of households by geodesic distance to Metropolis

The distances presented in Figure 3.12 to Figure 3.16 illustrate the lack of access to basic services and amenities that almost half-million households face in this case study region. In addition, these graphs also depict the vast accessibility inequalities in Northeast Brazil, especially when looking at the urban centres of higher hierarchy. Even though the services and amenities assessed in this analysis are aggregated by a proxy (urban centres), these findings present an unprecedented quantitative assessment of the overall accessibility of the low-income families in Rural Northeast Brazil.

Beyond the high averages, the findings also show that nearly half of the assessed households (242,300) are currently living farther away than 10 km from any urban centre. These results once again subscribe to the view that many basic services remain mostly inaccessible for a substantial portion of the rural families living in poverty in Northeast Brazil. This fact not only represents a major hurdle faced by these families nowadays but also points out a potential explanation as to why poverty reduction has not been sustained and effectively addressed in this region over the past decades.

As the centrality levels are mainly defined by the number and complexity of services³⁶ available in each urban centre, it can be also argued that the reachable services and amenities from rural low-income households are mostly basic, such as primary schools and primary healthcare.

Beyond providing a representative measurement on the broad level of accessibility to urban centres, these findings also point out to land use and population distribution issues. These concerning spatial burden on rural low-income households suggest that a polycentric fashion of urban development could also support the promotion of universal access to essential services. Likewise, Weiss et al. (2018) hold that transport infrastructure development might also play an important role in this process by reducing the travel time to reach these services. Further elaboration on this topic is provided in Chapter 4 by illustrating the social outcomes of a transport infrastructure intervention with a case study in Northeast Brazil.

3.4.3. Access to healthcare

The distances from the 493,659 low-income households to the nearest healthcare centre were calculated for both types of healthcare units using Geodesic distance. A summary of the findings related to access to health services are presented in Figure 3.17 and Figure 3.18. When the closest healthcare facility is evaluated, considering both hospitals, emergency, and primary care units, 96,508 rural low-income households (approximately 20% of the sample) are found farther than 10 km the closest health centre as measured by geodesic distance. Considering that people in extreme poverty mostly live in a walking world and that Geodesic measurements are often underestimated, it is argued that people living under such a spatial burden are virtually excluded from the public healthcare system and require urgent action from policymakers.

³⁶ Such as higher education provision, banking services, number of business offices, coverage areas of television stations and internet, etc (IBGE, 2008).

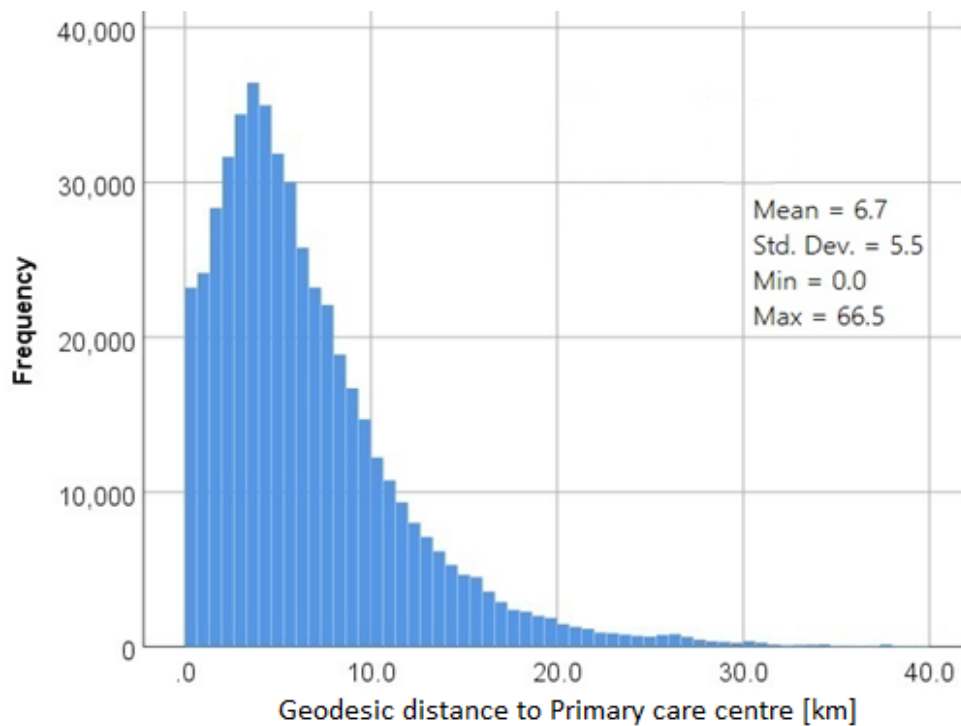


Figure 3.17: Frequency distribution of households by geodesic distance to Primary care unit

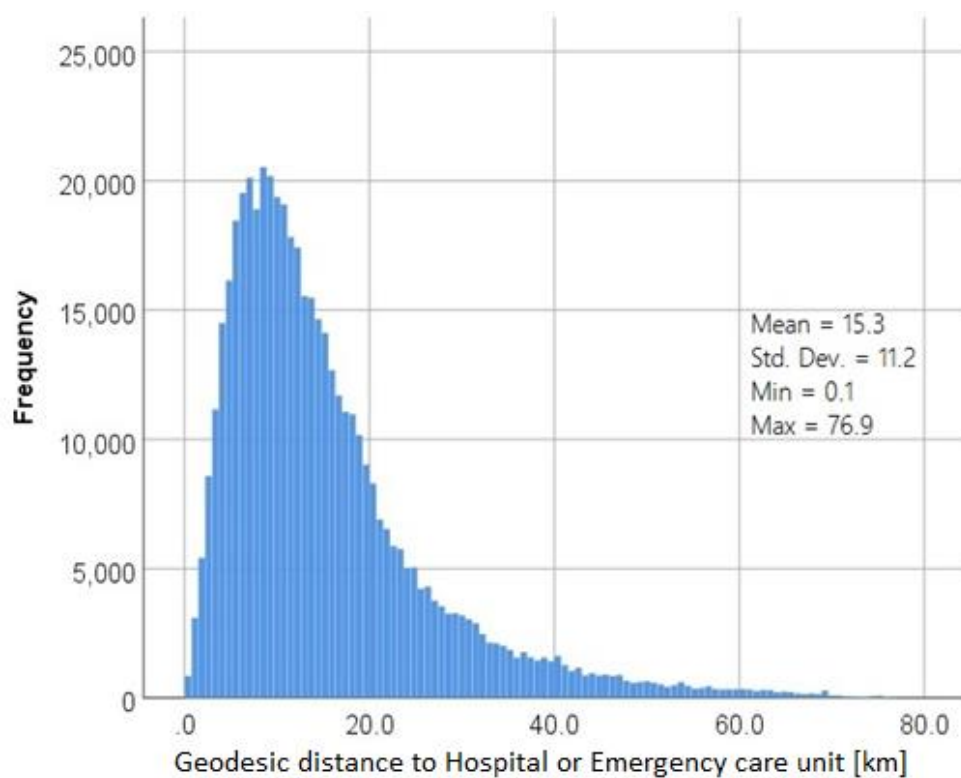


Figure 3.18: Frequency distribution of households by geodesic distance to Hospitals or Emergency care unit

Previous studies assessing the spatial accessibility of health services by linear distances have applied threshold distances of up to 5 km for Primary care and 25 km for Hospitals and emergency care to define remoteness from health services (Bell et al., 2012; Jordan et al. 2004). Figure 3.19 summarises the distribution of the assessed households in 5 different strata of remoteness from health services.

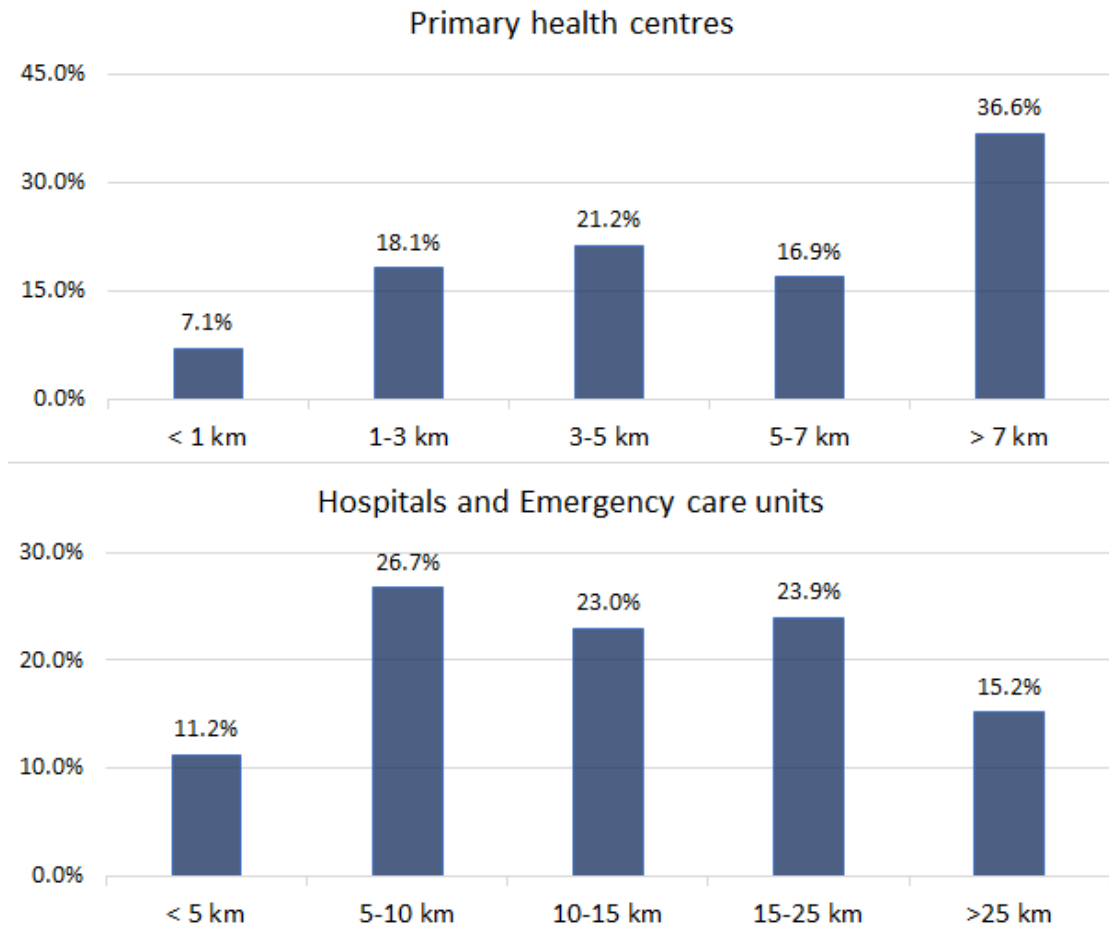


Figure 3.19: Distribution of distances by remoteness from health services thresholds

Since the proxy used here is not evenly distributed among the Northeastern municipalities, any quantitative correlation between the average spatial burden of the municipalities and their respective health indicators could lead to biased interpretations of the data. That said, on the other hand, it is undeniable that at a macro level such a lengthy distances separating low-income families from health services contribute directly to the poor health indicators described in Section 3.2.

Neutens et al. (2014) argue that there is convincing evidence showing that spatial barriers between patients and health services providers contribute to lower healthcare utilisation, which entails a limited uptake of preventive services and eventually gives rise to poorer health outcomes. Particularly in the Northeast Brazil context, Macinko et al. (2007) have reported evidence supporting the hypothesis that higher physician supply is associated with lower infant mortality. Macinko et al. (2007) also state that the real vital statistics from deprived rural areas (for instance the ones shown in Section 3.2) are likely to be even worse than what it is measured since there is evidence of undercounting of child mortality in these places³⁷.

The implemented public policies and investments in primary healthcare, including the *Mais Médicos* program, that were carried out in recent years, have contributed to improving the living conditions of the population located at remote and deprived regions of Northeast Brazil (Silva et al., 2018). However, in the Semi-arid region, which is at the heart of Northeast Brazil, and where rurality and poverty levels are higher, doctors and healthcare infrastructure remain still scarce (Nogueira et al., 2016). This lack of biomedical professionals in these areas is also evident in the study *Demografia Médica no Brasil*, conducted in 2018 (Scheffer et al., 2018), which shows that there are 8.4 times more doctors per 1,000 people in the Northeastern capitals than in the secondary and tertiary municipalities.

It is argued that the simple location (latitude/longitude) collection of the low-income households registered in Social Programs (like P1MC) would enable a significant step forward in the Brazilian Transport and Public health planning. While this spatial data remains unavailable, the presented dataset stands as an accurate and statistically significant (nearly half a million households) proxy for representing the quantitative accessibility patterns of families living under these conditions.

Although the proxied dataset is still of limited use for ranking priority areas, Figure 3.20 is an attempt to highlight areas with a higher concentration of rural low-

³⁷ It is estimated that only 78.1% of the infant deaths in Northeast region were registered in 2010 (Datusus, 2010).

income households (mapped by the cisterns) located farther than 10 km from any healthcare centre. Figure 3.20 exemplifies the type of spatial prioritisation analysis that could be done in future (when most of low-income households become mapped) to evaluate healthcare accessibility of people in poverty. This map calls attention to the potential benefits for action prioritisation that could be achieved by enhancing the collection of spatial data.

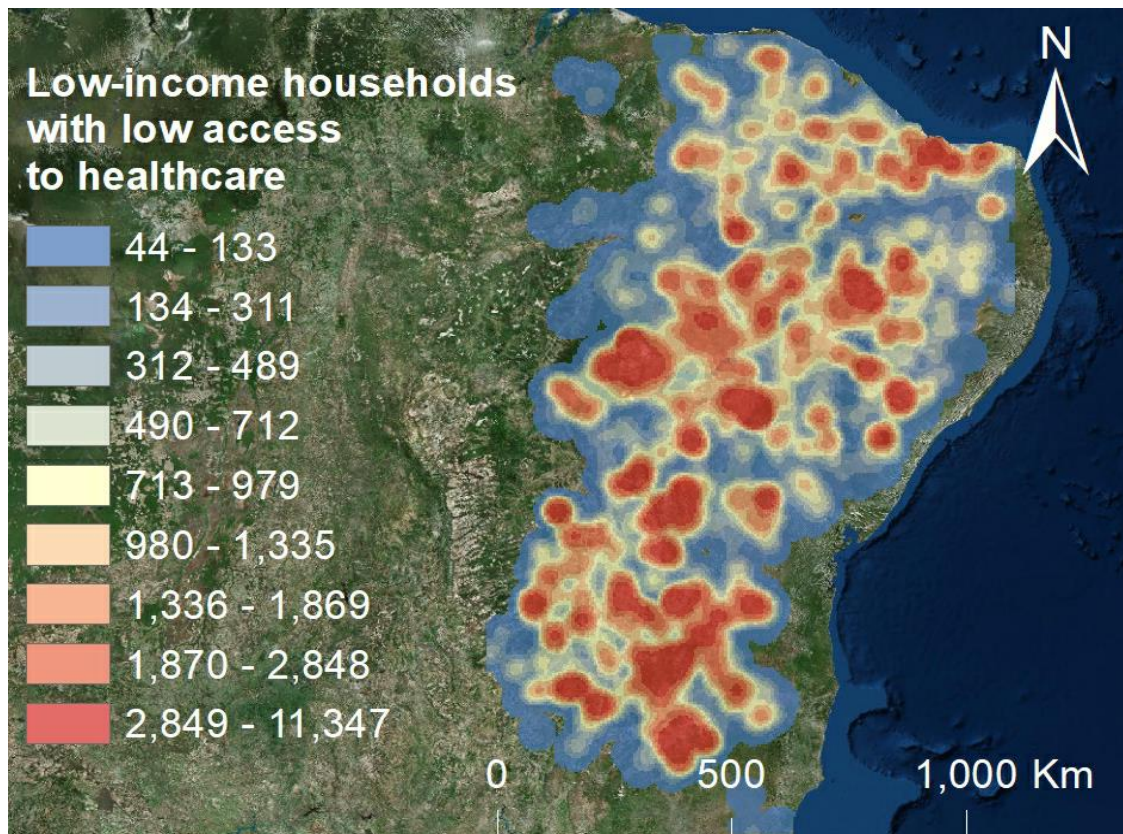


Figure 3.20: Concentration of low-income households (proxied by cisterns) located farther than 10 km from any healthcare centre

4.3. Conclusion

This Chapter explored the accessibility to urban and healthcare centres at a household level of low-income families in rural Northeast Brazil by means of an innovative proxy, namely, the cisterns' locations. There is enough evidence to support the use of this dataset as a proxy for the rural low-income households' location of this region since its inaccuracy is less than 105 meters and the sample size is substantially representative (493,659 households). Considering that each cistern supplies water for an average of 5 people (Assis, 2012), it is estimated

that this location dataset may represent the location of nearly 2.5 million people living in extreme poverty in Northeast Brazil.

However, it is important to remark that some municipalities do not have any mapped cistern within their perimeter. In that sense, we maintain that this dataset should be mainly used for drawing statistical analysis, rather than geospatial rankings and density evaluations. In other words, the absence of mapped cisterns in some municipalities should not be taken as an indicator of the absence of low-income households.

Thus, although it is possible to spot some priority areas that are at most risk of being denied access to health services due to the spatial burden (as shown in Figure 3.20), further research is required to develop indicators applicable to all municipalities of this region. More accurate and disaggregated results will also require a comprehensive mapping of the transport network, as well as the full geocodification of addresses of the families registered in the Federal Social Programs, like P1MC.

The findings show that 53.5% of the rural low-income population in Northeast Brazil are living farther than 5km (i.e. approximately an hour of walking) from the nearest Primary care centre and over 49% are at a distance greater than 10km (i.e. approximately two hours of walking) from the closest urban centre. These results emphasise that the majority of this rural low-income population, who mostly live in a walking world, experience an insurmountable spatial burden preventing them from accessing basic public services and urban amenities.

Overall, this Chapter strengthens the idea that it is necessary to create multidisciplinary teams to devise strategies as well as creative and lasting solutions to address the barriers of transportation, social disparities and access to health. As shown in the previous sections, transport also has a direct impact on health indicators. Therefore, it is essential to bring together transport and health professionals to promote more effective solutions to the current public health challenges that affect specially the least advantaged segments of population. Future research is needed to further investigate the impacts of transport infrastructure investments and accessibility improvements on health

outcomes of remote and deprived areas such as rural Northeast Brazil. The limitation of both spatial data and health data at a municipality and rural/urban level, are likely to be additional challenges in this work. Thus, it is recommended the use of innovative proxies (like cisterns' locations) as auxiliary tools for public policy planning and decision making.

CHAPTER 4: SOCIOECONOMIC OUTCOMES OF TRANSPORT INTERVENTIONS

4.1. Introduction

The first studies that examine the links between poverty and transport were published in the late 1960's and since then have become ever more frequent in the academic literature (Ornati et al., 1969; Wachs and Kumagai, 1973; Hanson and Hanson, 1980; De Luca, 2007; Guzman et al., 2017b). A substantial amount of evidence has been published on ex-post evaluations of the contributions of transport infrastructure development to poverty reduction in many different countries (Stifel et al., 2016; Dillon et al., 2011; Dercon et al., 2009; Fan and Chan-Kang, 2008; Warr, 2005; Lofgren et al., 2004).

Dercon et al., (2009), for instance, used generalised methods of moments to evaluate the socioeconomic effects of road improvements in rural Ethiopia. Their study has shown that the provision of access to all-weather roads has reduced poverty rates and increased consumption growth by 6.9 and 16.3 percentage points, respectively. Likewise, results reported by Fan and Chan-Kang (2008) show that 226 people from Northern regions of China were lifted above the poverty line for every additional kilometre of low-quality road in rural areas. Furthermore, Warr (2005) asserts that approximately 13% of the decline in rural poverty incidence which occurred between 1997–98 and 2002–03 in Laos can be attributed to improved road access alone.

Nonetheless, it is still unclear what effects transport infrastructure investments have in alleviating the most extreme levels of poverty. In fact, some authors advocate that people living in extreme poverty do not equally benefit from road constructions or roads improvements projects, mostly because walking is the

only travel mode available/affordable for them (Salon and Gulyani, 2010; Setboonsarng 2006; Cook et al., 2005; Porter, 2002). Similarly, Hansen et al. (2011) also argue that transport infrastructure interventions only impact people's well-being after a long chain of intermediate outcomes that interact with other investments, private as well as public, and geographical conditions.

Khandker and Koolwal (2011), for example, report that the benefits of rural road investments to households in rural Bangladesh have varied substantially over time. In a dynamic panel data study, these authors have concluded that while non-agricultural wage employment has risen in the long term, other positive effects initially observed on school enrolment, transport costs and per capita expenditure have attenuated over time.

Whilst policy recommendations derived from this literature suggest more public spending in transport infrastructure to foster economic development in remote and disadvantaged areas, a central question that requires attention is to what extent this development results real improvements in the well-being of the neediest population living nearby these projects.

From a political philosophy perspective, Pereira et al. (2017) reinforced this question by applying the difference principle of the Rawl's Egalitarianism theory³⁸ (Rawls, 1999) to transport justice. They conclude that, through the lens of this principle of justice, transport infrastructure and other transport related investments can only be considered fair if they improve the accessibility levels of the least advantaged groups.

Therefore, this Chapter addresses this recurrent issue of transport planning and aims to develop a framework of an ex-post social impact assessment of transport projects particularly tailored to the Brazilian context. The methodology draws upon the literature to employ a quasi-experimental approach performed by

³⁸ Rawls (1999) defines the difference principle as a key concept of his theory of Justice, which governs the distribution of primary goods (e.g. wealth, positions of responsibility and power, government services). This principle maintains that inequalities in the distribution of primary goods are only permissible if it maximises the minimum level of them among the least advantaged population (similar to the maximin criterion, commonly referred to in the Economics literature).

means of a difference in difference matching (DIDM) technique since it has been considered an effective and robust method for this type of analysis by various authors in similar contexts (Chein and Pinto, 2017; Iimi et al., 2015; Rand, 2011; Rauniyar et al., 2011; Hansen et al., 2011).

This framework is then applied to a case study in Northeast Brazil, in which the social impacts of a large transport project are analysed. The selected project for this case study is the widening of the BR-232 motorway. There are at least three main reasons to believe that this particular transport infrastructure intervention is an appropriate and paradigmatic example to be investigated by this framework.

Firstly, the project was carried out during the latest intercensal period, between the years 2000 and 2010, which enables the Census' Demographic Database to be used for longitudinal comparisons. Whilst traditional panel data studies rely on expensive household surveys that require a lot of manpower to be performed and are often limited to a few social indicators and few communities, this study proposes the use of census data that are publicly available and provide a comprehensive range of socioeconomic indicators of all municipalities before and after the infrastructure investment.

Secondly, this motorway (BR-232) has been only partially widened, leaving another considerable stretch with very similar socioeconomic, environmental and spatial characteristics rather suitable to be used as a control group. Figure 4.1 presents pictures of this motorway showing the two different stretches, the original and the widened one.



Figure 4.1: Road BR-232 - The original motorway on the left with just two lanes, and the widened stretch with four lanes on the right (Source: Googlemaps Streetview)

Thirdly, this motorway is located in the Northeast region of Brazil, which beyond being an understudied region, is the region where extreme poverty is most widely spread in Brazil (Coirolo and Barbosa, 2002). Further details of the case study context are explored in Section 4.2 by shedding light on some socioeconomic and transport infrastructure characteristics of this region. Figure 4.2 presents the location of this motorway in Pernambuco state, highlighting the stretch that has received the widening project (in red) and the stretch that still remains with the original number of lanes (in green).

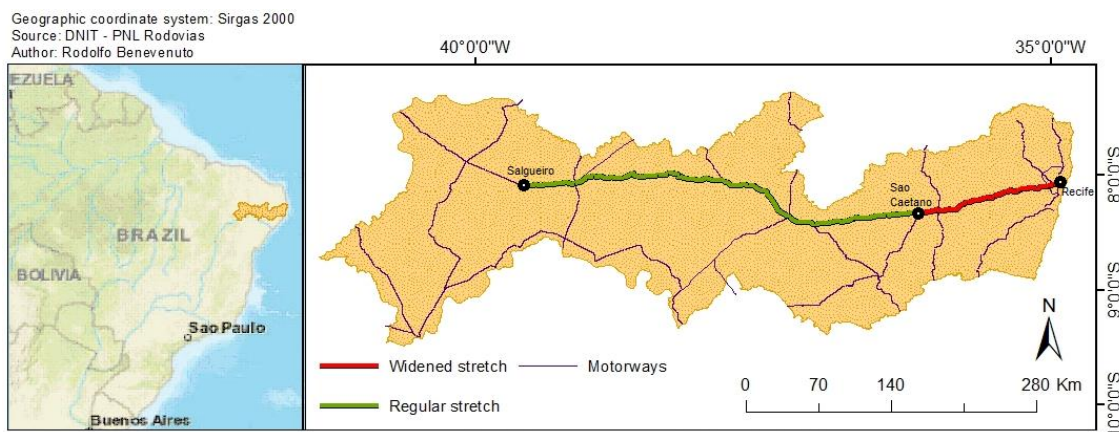


Figure 4.2: Location of motorway BR-232 in Pernambuco state

Under these conditions, this Chapter aims to propose a well-grounded framework that uses publicly available data to evaluate how people living in different levels of poverty are affected by transport interventions in the Brazilian context. The remaining sections of this Chapter are divided into the brief description of the case study context; the methodology that is proposed and the required data; the presentation of the graphs and tables which resulted from this study; the discussion and policy implications that derive from this analysis; and, at last, a

brief conclusion calling attention to the urgent necessity of considering systematic social impact analysis in transport projects appraisals and prioritisation.

4.2. Context of the case study

The state of Pernambuco, alongside with Bahia, was the place of the first Portuguese settlements in the Americas. Similar to other North-Eastern states in Brazil, the vestiges of its colonial past are still clearly visible nowadays. For instance, high levels of income inequality and political control by the same families whose origins date back to the sugar plantations of the 16th and 17th centuries are issues still present in the region (Griesse, 2007).

Even though during the period of the sugarcane cycle Pernambuco was considered to be the richest part of Brazil and the richest sugarcane producing area of the World (Franca and Hue, 2014; World Bank, 2002), nowadays 41.4% of its population live below the poverty line³⁹, being one of the poorer states of Brazil (IBGE, 2018b).

This state was included in the intercontinental study on poverty published by World Bank study, *Voices of the Poor* (Narayan et al., 2000). According to the population of Pernambuco interviewed by the authors of this study, unemployment was the main reason causing poverty in the state. Nearly two decades later, data from the Brazilian Institute of Geography and Statistics (IBGE, 2018b) shows that the unemployment rate increase of most concern over the past years in Brazil happened in Pernambuco, increasing from 8.1% in 2014 to 16.9% in 2017.

Pernambuco's area is 98,938 km² (about the size of South Korea, Guatemala, or Hungary). This state is the 19th largest in area of Brazil and it is divided into four intermediate regions (centred around the municipalities of Recife, Caruaru, Serra Talhada, and Petrolina) and 185 municipalities (IBGE, 2017c). Its total population is 9,496,294 according to the latest estimate (IBGE, 2018a), accounting for the 7th largest state in population of Brazil.

³⁹ Considering the poverty line of U\$ 5.5 a day, suggested by the World Bank to Brazil.

In terms of transport infrastructure, all main cities in Pernambuco are connected to the capital, Recife, through 41,657 km of roads, of which only 5,548 km are paved (GEIPOT, 2000⁴⁰). In a recent survey published by the Brazilian National Confederation of Transport (CNT, 2018), 94,9% of the state road network was considered in either regular, bad or extremely bad condition. Moreover, Railway transport is still very limited in areas close to the Recife metropolitan region, and waterway transport is restricted to the São Francisco basin (southwest border with Bahia state).

Four transport infrastructure projects have been recently announced as the future priority for this state by the National Logistic Plan (EPL, 2018). These projects refer to improvements in the roads BR-232 (between Salgueiro and Parnamirim), BR-316 (between the municipality of Parnamirim and Piauí state), BR-116 (between the municipality of Salgueiro and Bahia state), BR-101 (between the municipality of Palmares and Alagoas state). Figure 4.3 highlights the stretches of these roads in Pernambuco state that are planned to be improved until 2025.

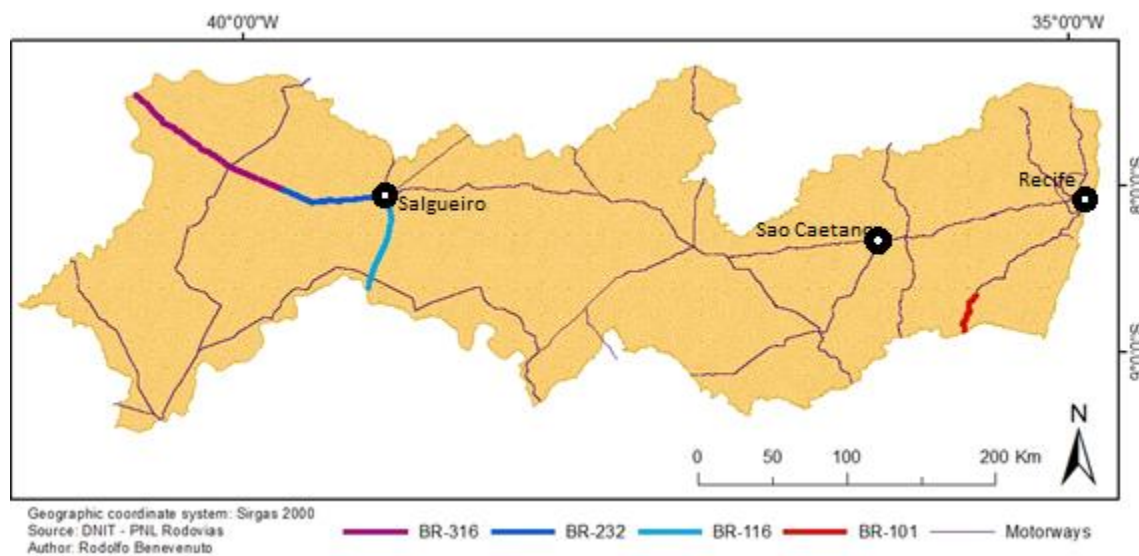


Figure 4.3: Transport infrastructure priority in Pernambuco state according to National Logistic Plan (EPL, 2018)

It is important to emphasise that this plan, as well as the previous investments plans for transport infrastructure in Brazil have been solely driven by economic

⁴⁰ No more up to date figure has been found in official sources by the authors.

and environmental analysis, disregarding, therefore, the social dimension and distributive effects at the planning stage. In the following sections of this Chapter, a case study will be provided, analysing whether the investment in the BR-232 has promoted, even if unintentionally, any improvement in any of the main poverty dimensions in the municipalities more closely affected by this intervention.

4.3. Data and Methods

4.3.1. Data collation

Traditionally, ex-post studies assessing the social impacts of transport infrastructure require a substantial amount of data to be collected, usually by questionnaires in two or more periods of time, before and after the intervention – ruling out the possibility of doing this kind of studies on projects that occurred in the past. Moreover, ex-post evaluation methods normally require data collection in several different locations, for example communities, villages, or households that received the intervention (i.e. treatment) as well as the control ones. Mu and Van de Walle (2007), for instance, reports that 3,000 households from 200 different communes were surveyed in four different years to collect the needed database for their study.

Besides being very costly and time-consuming, these methods can also give rise to politically difficult situations, as reported by Iimi et al. (2015). Before even starting the surveys, the authors report that the State Government of Tocantins (Brazil) decided not to interview people in the control group (which would not receive the intervention), because this could trigger frustration and dissatisfaction with the government, once they would know in advance that other communities would receive more transport investments than theirs. In this case, Iimi et al. (2015) had to use as a control group the population who was located around one transport intervention that due to a long delay in the project happened to not receive the treatment on time.

Under these circumstances, the study presented in this thesis proposes an innovative methodology that requires publicly available census data alone for evaluating the social impacts of transport interventions. The advantages of using this kind of data are that i) it can be applied to projects that happened in the past; ii) it has one of the most comprehensive ranges of socioeconomic indicators at a municipal level; iii) census data are commonly available by all over the Global South; iv) it is reliable, official and free of cost information; and finally v) it is available in a time frame that usually is long enough for capturing all the direct and indirect benefits of a large transport intervention.

4.3.1.1. Social indicators

The main datasets utilised for this study were the Demographic Censuses of year 2000 and 2010, collected by the Brazilian Institute of Geography and Statistics (IBGE) and made available by the Atlas of Human Development in Brazil (UNDP, 2010). From the original datasets, 26 socioeconomic indicators at a municipality level have been collated to compose a multi-dimensional evaluation of poverty for the referred region. The selection of such a range of indicators builds on the concept of multi-dimensional poverty, widely explored in public economics and welfare literature (Narayan et al., 2000; Alkire and Santos, 2014). The following dimensions are included in the present analysis:

- Health: This dimension includes two basic health indicators that are included in the Brazilian census, namely, the life expectancy (in years) and the child mortality (in child deaths/1,000 live births);
- Education: This set of indicators is related to illiteracy and school enrolment (including creche, primary and secondary school, and higher education);
- Income: This dimension includes income indicators that measure intensity (average income) and extent (share of population) of three different poverty levels (i) extreme poverty (monthly per capita income up to R\$ 70.00⁴¹); (ii) poverty (monthly per capita income up to R\$ 140.00) and; (iii)

⁴¹ The minimum wage in 2010 was R\$ 510.00 a month – around U\$ 368.00 in 2010 purchasing power parity according to the conversion rate provided by OECD (2018)

vulnerable to poverty (monthly per capita income up to R\$ 255.00), also disaggregated by overall and child poverty;

- Wellbeing: This block comprises the Human Development Index (HDI) and its disaggregation by income, education, and longevity;
- Housing conditions: This set includes indicators related to the housing characteristics such as the percentage of households with piped water, waste collection, electricity, or sewage facilities;
- Inequality: This dimension is evaluated by means of the GINI index⁴², which measures the degree of income inequality experienced by a municipality;
- Unemployment: Finally, this is presented as the unemployment rates for each municipality, considering the share of the population of 18 years of age or more who were unemployed at the same month when the census data was collected.

Table 4.1 presents the indicators described above showing a comparison between the national figures and the values for the municipalities assessed in this Chapter. Further explanations for selecting criteria of this sample of municipalities are given in the Section 4.3.1.2.

⁴² The Gini Index is a measure of income inequality, varying from 0 (perfect equality) to 1 (maximum inequality) (UNDP, 2010).

Table 4.1: National and regional figures of the socioeconomic indicators included in the model

Variable	Brazil	Sample of municipalities
Life expectancy [years]	73.9	71.0
Child mortality [child deaths/1000]	16.7	24.5
Creche enrolment rate [%]	55.0	56.2
Primary School enrolment rate [%]	92.1	92.1
High School enrolment rate [%]	43.4	33.0
Higher education enrolment rate [%]	14.0	6.1
Illiteracy (age of 15+) [%]	9.6	26.1
Average income per capita of the extremely poor [R\$]	31.7	34.4
Average income per capita of the poor [R\$]	75.2	72.2
Average income per capita of the vulnerable to poverty [R\$]	142.7	124.8
Extreme poverty rate [%]	6.6	18.4
Child extreme poverty rate [%]	11.5	26.8
Poverty rate [%]	15.2	36.9
Child poverty rate [%]	26.0	52.8
Vulnerability to poverty rate [%]	32.6	62.6
Child vulnerability to poverty rate [%]	49.4	78.7
HDI overall	0.7	0.6
HDI education dimension	0.6	0.5
HDI longevity dimension	0.8	0.8
HDI income dimension	0.7	0.6
Share of households with piped water [%]	92.7	72.5
Share of urban households with waste collection [%]	97.0	93.5
Share of households with access to electricity [%]	98.6	99.2
Share of households without sewage/water facilities [%]	6.1	15.2
GINI index	0.6	0.5
Unemployment rates [%]	7.3	8.9

4.3.1.2. Road infrastructure

The motorway BR-232, which is analysed in this case study, is considered as the transport backbone of the Pernambuco state since it crosses the majority of the state and it is the main east-west road connection of Pernambuco state. It starts at the capital, Recife, and goes 552 km inwards to the countryside, connecting

main cities like Caruaru, Salgueiro, Sao Caetano, and Serra Talhada. The widening project was performed between 2001 and 2005 only in the stretch between Recife and Sao Caetano (142 km).

According to the responsible authorities, only two other transport infrastructure projects of construction and widening of motorways were performed during this intercensal period in the Pernambuco state. Both projects (at the BR-101 and BR-104) were carried out on the east part of Pernambuco state, that is, at the same side of the widened stretch of BR-232. The information about the road network including dates, dimensions and its spatial distribution have been provided by the Brazilian National Transport Infrastructure Department (DNIT, 2018).

Two groups of municipalities were then identified: those within the influence area of the widened stretch of the motorway (treatment group) and those along the original stretch of the motorway (control group). Several authors have applied the concept of buffer zones (from 5 to 300 km) to estimate the influence area of a road over the surrounding communities (Chein et al., 2017; Asomani-Boateng et al., 2015; Ortega et al., 2014, Danida, 2010). The rationale for the size definition of these buffers, however, is not clear in any of these studies.

It is undeniable that large transport infrastructure interventions would cause a long sequence of direct and indirect socioeconomic effects that may reverberate and affect communities much farther than any predefined buffer. Nevertheless, following Tobler's first law of Geography⁴³, it is reasonable to assume that a higher impact would, as a rule, affect communities that are closer to the intervention. In this sense, a few characteristics can be broadly considered to define the influence area around a given transport intervention.

In the present study, the average size of municipalities, presence of spatial barriers (e.g. rivers, mountains, shore, etc), type of infrastructure intervention, population distribution and density, as well as the aggregation level of the

⁴³ When discussing urban growth in Detroit region, Tobler (1960) states what he calls as the first law of Geography: "everything is related to everything else, but near things are more related than distant things".

available data have been considered when estimating the influence area. Moreover, as municipalities from the same state have generally more similar characteristics of investments and public policies that could affect the local socioeconomic indicators (i.e. potential sources of endogeneity), an appropriate distance band limit is the border of the Pernambuco state. Therefore, a buffer zone of 20 km (on either side of the motorway) was applied to define the municipalities of the treatment and control groups of this study. As Figure 4.4 shows, the proposed catchment area results in a comprehensive sample of municipalities along the motorway BR-232 that is also confined within the territory of Pernambuco state. Figure 4.4 also displays the poverty rate distribution in the year 2000 of the municipalities around motorway BR-232.

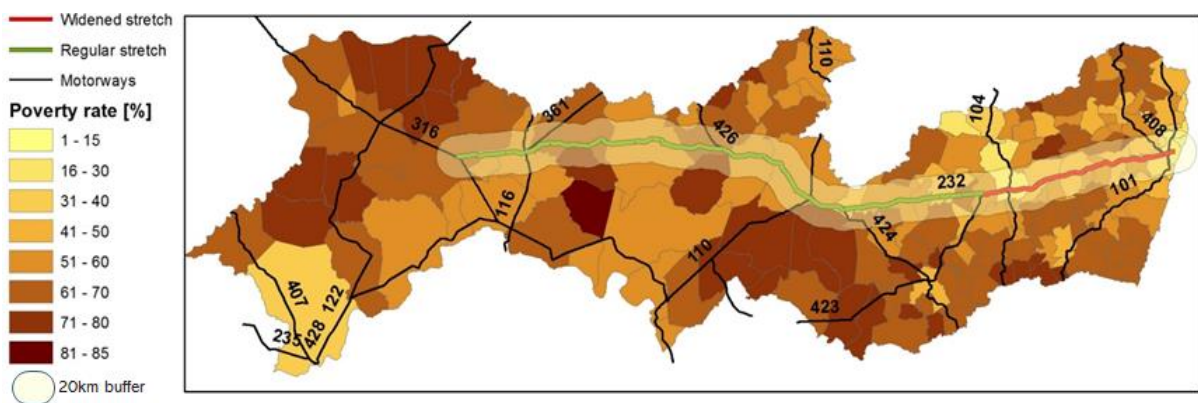


Figure 4.4: Catchment area of the motorway BR-232 with poverty rates (%) before the completion of the project (year 2000).

4.3.2. Difference in Difference Matching technique

This Section aims not only to describe the main method used in this Chapter, but also to give a clear rationale for the selection of the econometric tools and datasets that are applied. Figure 4.5: presents a brief summary of the main potential methods considered in this Chapter, highlighting in each step the adopted models/datasets (in blue), and the rejected methodological alternatives (in grey) that did not meet the particularities of the case study context. The rationale for the adoption of each of these methods/datasets are further addressed in this Section.

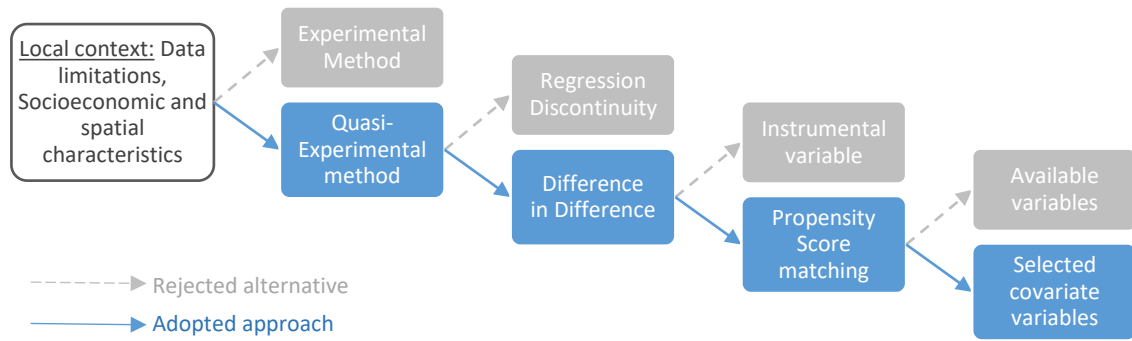


Figure 4.5: Schematic summary of methodological alternatives

Assessing social outcomes of transport investments means understanding the context in which an intervention happens and the channels through which the impacts are expected to occur (Hansen et al., 2011). In the context of large infrastructure interventions, one of the most suitable and referenced approaches used for capturing these outcomes is the quasi-experimental design (Hansen et al., 2011; Ravallion, 2007). This approach, also known as a nonexperimental, or observational, study (Ravallion, 2007), draws comparisons between groups to test for the effect of an intervention. Differently from the ‘experimental method’ in which samples are randomly assigned to treatment and control groups before the treatment, this empirical study estimates the effect of a treatment that have already occurred in the past. Thus, the target population is selected without random assignment.

Among the methods that are suitable to this type of studies, the DID technique stands out as a particularly interesting model. The core principle of this method is to draw causal relationships between an intervention and its outcomes based on a longitudinal comparison between a treatment and a control group (Cook et al., 2002). One of its main advantages is that the pre- and post-test observations can be done using datasets such as the censuses, which are globally available and periodically updated. Allied to this, the DID model also compares the effects of an intervention between control and treatment groups, thus reducing the bias of single difference comparisons. Furthermore, it has been extensively adopted for analysing different effects of transport interventions in similar contexts of the Global South (Lionjanga and Venter, 2018; Chein and Pinto, 2017; Qin and Zhang, 2016; Rodriguez et al., 2016; Iimi et al., 2015; Bocarejo et al., 2014).

A commonly used alternative to DID technique is the Regression Discontinuity design, which is applicable in experiments where cut-off criteria in the pre-treatment measures are used to identify participants in need of the intervention (William, 2006). Nevertheless, Lionjanga and Venter (2018) assert that this method is not suitable to evaluate the impact of transport interventions that do not present these cut-off criteria to determine the placement of intervention.

Hence, the DID method is adopted in the present study since it proposes an intuitive and well-grounded impact assessment that is suitable to most transport interventions. Based on this method, the social outcomes of the BR-232 motorway widening project are calculated as follows:

Equation 4.1

$$\Delta Y(m_i) = Y(m_i|t = 1) - Y(m_i|t = 0)$$

Equation 4.2

$$SocialOutcome = \Delta Y(m_i|G = 1) - \Delta Y(m_i|G = 0)$$

Where $\Delta Y(m_i)$ is the effect over time t (in which 1 represents the year 2010 and 0 the year 2000) observed in a vector of socioeconomic indicators Y (presented in Table 4.1) of the municipality m_i . The final social outcome (*SocialOutcome*) is then obtained by the difference between the effect $\Delta Y(m_i)$ of the treatment and control group. The dummy variable G differentiates the control and treatment group (being 1 the treatment and 0 for the control group).

To cope with observed confounding factors intrinsically associated with the context where the treatment takes place, many authors have suggested techniques such as Instrumental Variables (IV) or Propensity Score Matching (PSM) to be used alongside the DID technique (Chein and Pinto, 2017; Iimi et al., 2015; Chagas et al., 2012; Van de Walle, 2009; Gachassin et al., 2010; Lokshin and Yemtsov, 2005; Cook et al., 2002).

Instrumental variables are often applied in quasi-experimental studies to control for endogeneity between the assignment into control/treatment group and the outcome. However, since the present case study considers only municipalities along the same motorway (i.e. the group assignment is spatially restricted) in the samples, the use of Instrumental Variables is not applicable. In this sense, PSM emerges as the most appropriate method to reduce the bias when estimating the treatment effects caused by potential confounding factors of the samples.

So far, this Section has explored the reasons behind the selection of this methodological approach, which is also known as the Difference-in-Difference-Matching (DIDM) technique. The next Section will provide a further rationale for the selection of covariates applied in the calculation of the propensity scores.

4.3.3. Propensity Score Matching

Rosenbaum and Rubin (1983) define a propensity score (PS) as the conditional probability of assignment to a particular group (control or treatment) considering a number of observed covariates. Several confounding variables have been applied throughout the literature for the formulation of propensity scores in similar studies (Chein and Pinto, 2017; Iimi et al., 2015; Mu and Van de Walle, 2011; Lokshin and Yemtsov, 2005; Escobal and Ponce, 2002; Cook et al., 2002). Ravallion (2007) states that these scores must be calculated based on a range of pre-exposure control variables, which can also include pre-treatment values of the outcome indicator.

Therefore, the PS offers a single numeric description of the initial context of the samples (municipalities/villages/neighbourhoods) in the analysis. In the context of transport studies, these confounding variables addressed in the literature mentioned above can be summarised in the following three levels in this study:

- Demographics: total population, GINI index, economic dependency per household, ethnicity rates, GDP per capita, poverty rates, etc;
- Number of facilities/services available: such as schools, enterprises, industries, police stations, banks (with credit availability) post offices,

restaurants, markets, hospitals and motorways, as well as coverage of sewage, water piped, electricity, phone and internet resources;

- Land use: urbanisation rates, population density, size of arable areas, rural accessibility index (RAI), the presence of other infrastructure construction projects, etc.

Despite the lack of consensus on which variables should be included in PS calculation, according to Austin (2011) several studies in the literature have applied either i) all the baseline covariates, ii) just those that affect the outcome, iii) just those that are associated with the treatment assignment, or iv) both (i.e. true confounders). Brookhart et al. (2013) assert that these variables can be also selected based on expert knowledge, as well as more empirical data-driven analysis relating the variables, the outcome and the treatment being analysed.

Nonetheless, as explained by Rosenbaum and Rubin (1983), as the number of confounding variables increase, the number of subclasses defined by the propensity scores also grows. This issue often results in several subclasses (also called strata) that do not contain both treated and control samples within the same PS range, reducing, therefore, the number of matchings (Rosenbaum and Rubin, 1983). Hence, it is essential to balance the number of confounding variables that compose the PS and the number of matchings resulted by them.

In the absence of a clear method defined in the literature, a number of trials with different combinations of the confounding variables mentioned above were carried out to determine the baseline covariates that would be considered in the composition of the PS for this case study. It was found that variables with extreme levels of variations - either too much (e.g. total population), or too little (e.g. GINI index) – have not resulted in a good balance between the number of confounding variables and number of matchings. Therefore, after this pre-assessment of the baseline variables the following five have been selected:

1. Gross Domestic Product (GDP)
2. Urban population rate (%)
3. Rural Accessibility Index (RAI)
4. Number of schools

5. Number of healthcare centres

The propensity scores (PS) are most commonly estimated by a logistic regression (Brookhart et al., 2013), which calculates the probability ($Prob$) of a given municipality (with a vector of its initial conditions indicators m_i) to receive the treatment according to its pre-treatment characteristics. Equation 4.3 represents how the propensity scores are given (Austin, 2011; Chein and Pinto, 2017).

Equation 4.3

$$PS(m_i) = Prob(G = 1|m_i) \quad (0 < PS(m_i) < 1)$$

A sensitivity analysis based on the one-factor at a time (OAT) screening technique (Campolongo and Saltelli, 2007) is also proposed to clarify which factors have a higher influence on the outputs of the PS model. For doing so, the PS's are recalculated five times disregarding one of the baseline covariates at a time and then comparing the output variation in a graphical form.

Once the scores were calculated, six different strata were defined to maximise the number of municipalities included in the model as well as to preserve the recommended comparability level (less than a quintile each) among the groups. The municipalities were then ranked by PS and the matching process was done by proximity. The comparison between indicators from Treatment and Control groups was finally performed for every stratum according to Equation 4.4.

Equation 4.4

$$WSOi = \frac{1}{nt_{total}} \sum_j n_j * SocialOutcome_j$$

Where, the weighted social outcome (wso) of a given indicator (i) is calculated by the DID ($SocialOutcome$) given by Equation 4.2 for each stratum (j), weighted by the number of municipalities (n) included in each of these strata. Finally, Figure 4.6 presents a schematic summary of the methodology applied in this Chapter, separating each step of the DIDM technique.

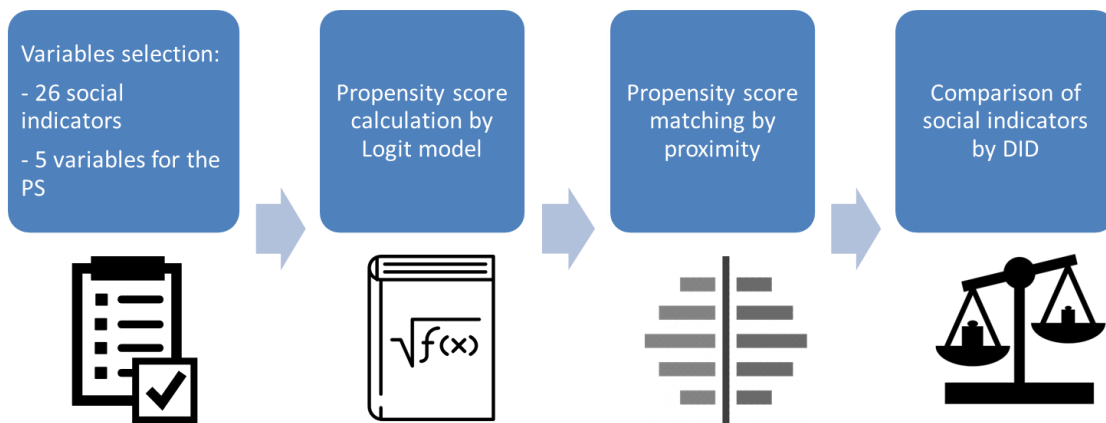


Figure 4.6: Methodology summary using DIDM technique

4.4. Ex-post evaluation Results

4.4.1. Propensity Score Matching

The first outputs of the proposed method were the PS calculated by the Logit Model for each municipality. Figure 4.7 depicts the frequency distribution of the PS dividing the municipalities by control (blue) and treatment (red) groups. As can be observed, municipalities from the treatment group tend to have higher PS than municipalities from the control group. This result is a direct consequence of the higher urbanisation, as well as economic (GDP) and infrastructure (schools and healthcare centres) development⁴⁴ levels of the municipalities along the widened stretch when compared to the control group.

This fact points to the heterogeneity issue that a simple comparison of outcomes (i.e. simple DID) between the two groups could lead to. Therefore, by undertaking a comparison of municipalities with similar propensity scores (i.e. by DIDM), the potential bias created by these confounding factors tend to be attenuated.

⁴⁴ Factors considered in the Logit model to estimate the PS.

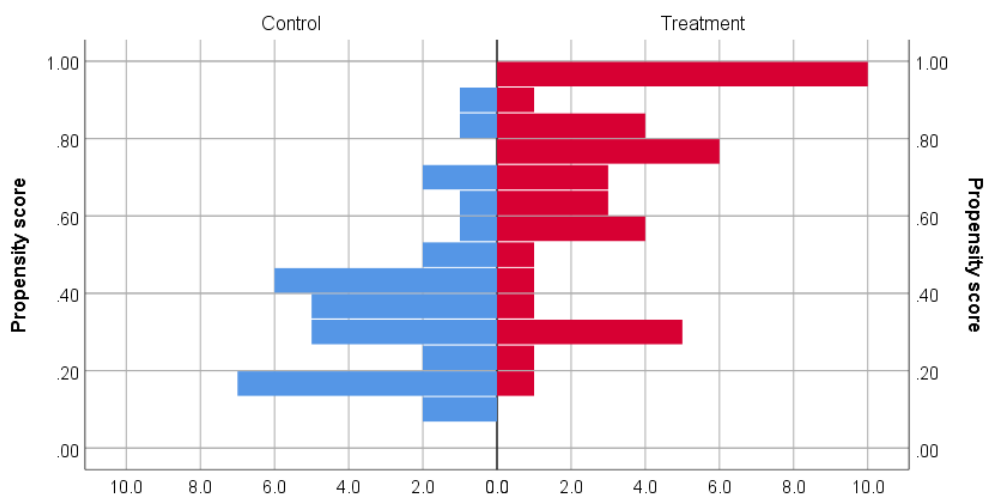


Figure 4.7: Frequency distribution of Propensity Scores by group

As previously described, the only two transport infrastructure projects delivered to this region in this intercensal period (other than the BR-232 widening project), were performed both along the widened stretch. Hence, any potential endogeneity which originated from these two projects would only exacerbate the differences between treatment and control group and would not diminish potential social impacts assessed by the model. Moreover, it is also assumed that investments in any sector (including new public transport services) other than transport infrastructure, are expected to be either very local (therefore dissolved in the averages or mitigated by PSM technique) or with similar effects throughout all considered municipalities since they are spatially concentrated in the same state. In other words, as large infrastructure investments are predominantly done at the state level in Brazil, and only municipalities from the same state (Pernambuco) have been selected in this study⁴⁵, further endogeneity factors tend to be evenly distributed throughout the municipalities, not affecting any of the groups specifically.

Once the PS's are calculated, the definition of the matching strata could then be carried out. Based on the distribution of PS's across municipalities, six different strata were proposed to maximise the number of matchings, while also keeping a comparable range of PS between the groups. In this sense, the municipalities

⁴⁵ As described above in Section 4.3.1.2, only municipalities within 20km from either side of the road have been included in the samples.

with too high or too low PS (i.e. outliers) were not included in the DIDM analysis since no comparable municipalities were found within the considered samples.

As a result, from the original sample of 76 municipalities (35 from the control and 41 from treatment group), only 51 municipalities (23 from control and 28 from treatment group) were deemed fit for comparison within the six different PS strata. Simply put, 25 municipalities of the original sample had to be disregarded for not having a comparable pair in their opposing group.

Table 4.2 describes the PS strata showing the number of municipalities and the PS range of each stratum. It is worth mentioning that the PS range of each stratum varies from 0.07 (stratum 2) up to 0.12 (stratum 6), which demonstrates that all the comparable municipalities present a relatively small variation of baseline characteristics (proxied by the PS). Table 4.2 shows, while the total number of control and treatment municipalities considered in this study are similar, the number of municipalities from the Control group is higher in the lower strata.

Table 4.2: Propensity score strata descriptions

Strata	PS range	Group	Number of municipalities
1	0.19 < PS < 0.30	Control	5
		Treatment	4
2	0.31 < PS < 0.38	Control	8
		Treatment	3
3	0.45 < PS < 0.54	Control	4
		Treatment	4
4	0.55 < PS < 0.63	Control	2
		Treatment	5
5	0.67 < PS < 0.76	Control	2
		Treatment	6
6	0.80 < PS < 0.92	Control	2
		Treatment	6
Total	0.19 < PS < 0.92	Control	23
		Treatment	28
Total			51

4.4.2. Sensitivity analysis of the propensity scores

Figure 4.8 illustrates the sensitivity analysis showing how the PS's values respond to variations of the input baseline covariates. The PS's of the

municipalities are presented in ascending order to facilitate the interpretation of the graphs. In summary, the importance of an input variable in the composition of the PS's can be observed by the amount of variations occurred when the PS's are calculated without that variable. In other words, when an input covariate is not included in the PS model and the generated PS's are still very similar to the original PS, it means that this particular input variable does not contribute significantly to the estimate of the original PS.

The graphs presented in Figure 4.8 show that the higher impact on the PS is caused by the percentage of the urban population in a municipality. This finding highlights that these municipalities have quite similar levels of urbanisation when compared to the others from the same group, that is, municipalities from treatment group are overall more urbanised, and municipalities from control group are overall more rural. In statistical terms, this means that the *share of urban population* is the best explanatory variable of the proposed model to indicate whether a municipality belongs to the treatment group or not. At the second level of influence (with minor variations), there are other three variables, namely, GDP, RAI, and the number of schools. Lastly, the number of healthcare centres present the lowest level of influence, causing nearly no substantial variation when it is not included in the PS model.

Interestingly, while the standard deviation (in terms of percentage of the average) of the *share of urban population* was much lower than other variables, it has presented the highest impact on the sensitivity analysis of the PS. This fact highlights that wider variations of the input indicators do not necessarily imply in a higher impact on the generated PS. Table 4.3 presents the standard deviation values of such variables in terms of percentage of the average.

Table 4.3: Standard deviation of the variables considered in the PS estimate

Variable	Std. Dev.
Number of schools	146%
Number of healthcare centres	192%
GDP	443%
Share of urban population	35%
RAI	41%

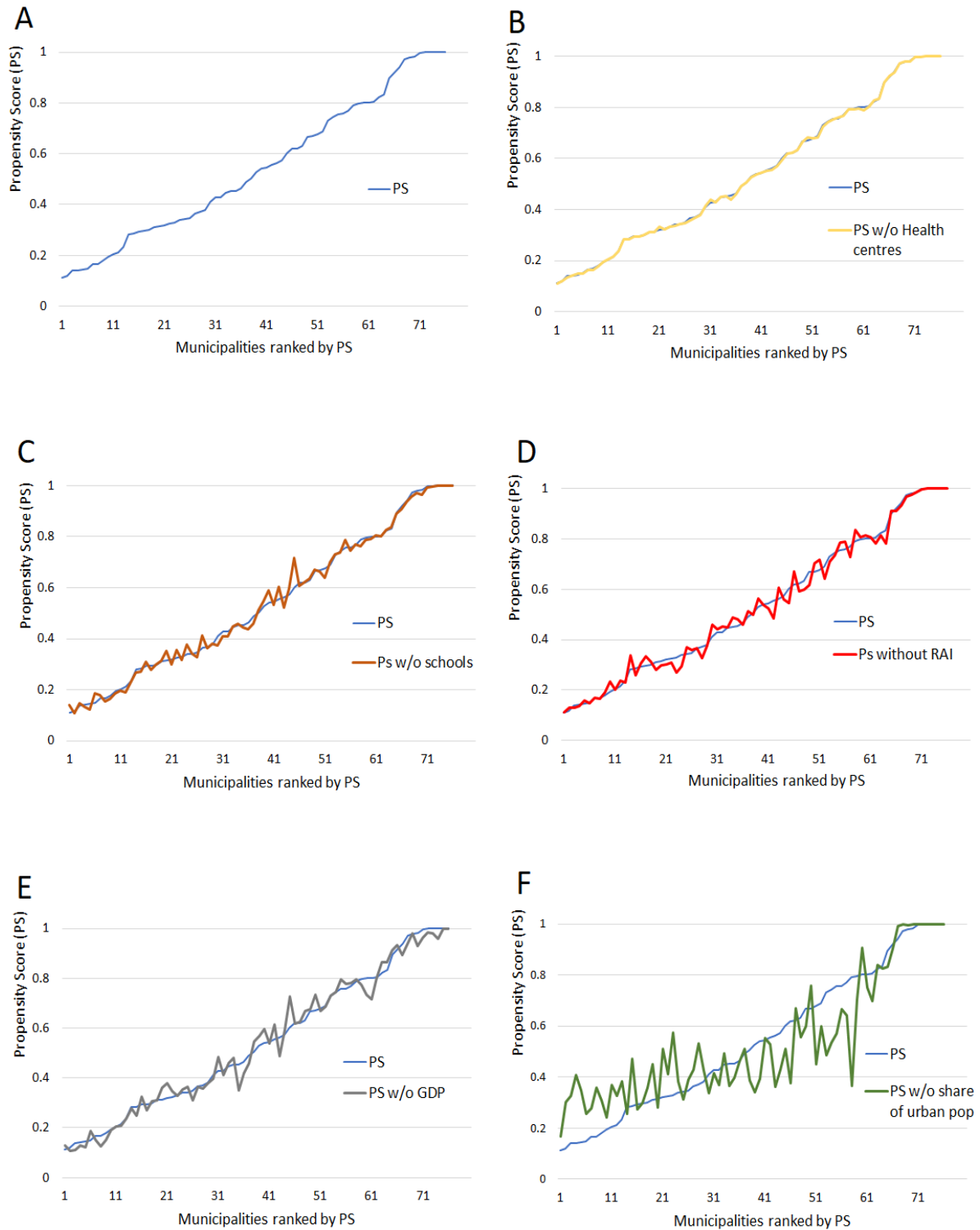


Figure 4.8: Sensitivity analysis of the propensity scores across municipalities. A) Original PS B) PS calculated without the Healthcare centres variable C) PS calculated without the Schools variable D) PS calculated without the RAI variable E) PS calculated without the GDP variable F) PS calculated without the Share of Urban population variable

4.4.3. Social outcomes

4.4.3.1. Broad socioeconomic results

A summary of the social outcomes of the BR-232 motorway widening project is presented in Table 4.4. This table shows a comparison between outputs obtained by two different methods previously described in Section 4.3.2, the DID technique (Equation 4.2) and the DIDM technique (Equation 4.4). For a better understanding of the social effects depicted in Table 4.4, the means of the 26 evaluated indicators are presented in Table 4.5 separating by time (before and after the project) and by group (treatment and control municipalities).

The purpose of this set of indicators presented in Table 4.4 and Table 4.5 is to assess how people living in different poverty levels have benefited from the BR-232 transport investment. In general, the evaluated socioeconomic indicators have improved over time in both groups of municipalities (treatment and control). The only two exceptions among the twenty-six assessed outcomes were (i) the *average income per capita of the extremely poor* population, which has decreased (i.e. worsened) in the treatment group and increased (i.e. improved) in the control group, and (ii) the *share of households without sewage/water facilities* which has decreased (i.e. improved) in the treatment group and increased (i.e. worsened) in the control group.

Eleven out of the twenty-six assessed indicators (i.e. 42%) have presented in both methodologies (DIDM and DID) greater positive effects in the municipalities which have received the treatment. This shows that, in general, there was an overall social benefit of the project to widen the BR-232 motorway. Six out of these eleven, have presented substantial differences in the treatment group when compared to the control group⁴⁶. It is worth noting that the results reveal that *creche enrolment rate* was the indicator most affected by the widening project. The findings show that municipalities along the widened stretch of BR-

⁴⁶ For example, child mortality (9.03 pp more reduction), average income per capita of the population vulnerable to poverty (R\$ 4.71 more), child poverty rate (3.78 pp more reduction), poverty rate (3.32 pp more reduction), and the primary school enrolment rate (3.26 pp more).

232 had over 9.9% percentage points (pp) more creche enrolment after the completion of the project than the other ones. The indicators related primary and high school enrolment also present the same trend of positive effects on education. These results are in line with findings from similar research published by Lebo and Schelling (2001), who have reported that primary school enrolment of girls in well-connected villages in Bhutan is three times higher than the unconnected ones.

Perhaps contrary to what was expected, the *average income per capita of the poor*, the *share of urban households with waste collection*, and the *share of households with access to electricity* have improved less in the treatment group than in the control group. By analysing Table 4.5, it is possible to conclude that the access to electricity has improved more in the control group because the original share of households with access to electricity in the treatment group was already very high in the year 2000 (i.e. 96.7%). Leaving, thus, less room for improvement when compared to the original figure of the control group (i.e. 88.5%). The same argument can be made to explain lower improvements in the treatment municipalities in waste collection when compared to the control ones.

Finally, the findings also reveal that wellbeing and inequality indicators (i.e. HDI's and GINI index) have not presented significant differences between the groups. According to the data provided in Table 4.5, it is possible to conclude that both dimensions have improved nearly at the same rate within the analysed time frame. Section 4.5 presents a discussion on how the reported findings relate to each other and how they can be interpreted to derive evidence-based policy recommendations for future transport interventions.

In summary, all these findings (Table 4.4) are broadly consistent with earlier studies (Asher and Novosad, 2018; Gibson and Olivia, 2009; McMulloch et al., 2007, Cook et al., 2005) showing that transport infrastructure investments have fostered social development in various ways. In a context where transport infrastructure has been substantially underinvested over the recent years (Amann et al., 2016), these findings support the increasing evidence base, particularly in Northeast Brazil, that shows how transport development could tackle multi-dimensional poverty in this region.

The results showing a reduction on the less severe levels of poverty reported in Table 4.4 further support the idea stressed by Calderón and Servén (2004), that infrastructure investments should be at the top of the poverty reduction agenda. After evaluating a large panel data encompassing over 100 countries, Calderón and Servén (2004) found that transport infrastructure investments (among other infrastructure investments) were positively associated with economic growth and negatively associated with inequality.

Similar to the results presented here for unemployment reduction, Gibson and Olivia (2009), also assert that improvements in access to transport and electricity infrastructure have unleashed non-farm enterprise development in rural Indonesia, which has been considered as the most promising path out of rural poverty in the region (McMulloch et al., 2007). Likewise, Asher and Novosad (2018) conclude that 4 years after the completion of new feeder roads in India, the main observed benefit in the assessed villages was the connection of rural workers to new employment opportunities out of agriculture.

In this sense, the findings from the Northeast Brazil reported in this Section provide some support to these earlier studies. As described above, several socioeconomic indicators have shown higher improvements in the region where the road widening project was performed, compared to the control areas. Nevertheless, despite the positive impact on the broad socioeconomic outcomes of the case study region, a further analysis is still needed to compare how the least advantaged population have benefitted from the same transport investment.

Table 4.4: Comparison of estimated outcomes by DID and DIDM

Variable	DIDM	DID
Life expectancy [years]	1.50	0.49
Child mortality [child deaths/1000]	-9.03	-1.78
Creche enrolment rate [%]	9.94	4.22
Primary School enrolment rate [%]	3.26	2.01
High School enrolment rate [%]	1.98	-0.78
Higher education enrolment rate [%]	-1.50	-0.27
Illiteracy (age of 15+) [%]	-0.97	0.51
Average income per capita of the extremely poor [R\$]	-2.06	-3.29
Average income per capita of the poor [R\$]	-0.22	-0.66
Average income per capita of the vulnerable to poverty [R\$]	4.71	3.66
Extreme poverty rate [%]	-0.27	2.43
Child extreme poverty rate [%]	-1.35	1.83
Poverty rate [%]	-3.32	-1.85
Child poverty rate [%]	-3.78	-3.55
Vulnerability to poverty rate [%]	-0.70	-2.29
Child vulnerability to poverty rate [%]	-0.05	-2.13
HDI overall	0.02	0.00
HDI education dimension	0.01	0.00
HDI longevity dimension	0.02	0.01
HDI income dimension	0.00	-0.01
Share of households with piped water [%]	4.30	-0.92
Share of urban households with waste collection [%]	-6.09	-7.79
Share of households with access to electricity [%]	-2.75	-7.30
Share of households without sewage/water facilities [%]	-9.35	-10.53
GINI index	-0.01	-0.01
Unemployment rates [%]	-1.91	-3.51

Table 4.5: Outcome variable means

Variable	Before (2000)		After (2010)	
	Control	Treatment	Control	Treatment
Life expectancy [years]	65.3	66.0	70.3	71.5
Child mortality [child deaths/1000]	55.6	53.9	26.4	22.9
Creche enrolment rate [%]	36.3	38.4	52.8	59.1
Primary School enrolment rate [%]	89.0	87.5	91.8	92.3
High School enrolment rate [%]	15.1	15.9	33.0	33.0
Higher education enrolment rate [%]	2.0	2.0	6.2	5.9
Illiteracy (age of 15 or more) [%]	36.1	32.8	27.6	24.8
Average income p.c. of the extremely poor [R\$]	33.9	37.8	34.1	34.7
Average income p.c. of the poor [R\$]	59.8	71.2	66.5	77.2
Average income p.c. of the vulnerable to poverty [R\$]	89.9	107.3	113.4	134.5
Extreme poverty rate [%]	38.1	25.2	24.1	13.6
Child extreme poverty rate [%]	52.0	36.1	34.4	20.3
Poverty rate [%]	62.4	52.1	43.4	31.3
Child poverty rate [%]	76.8	66.6	60.2	46.4
Vulnerability to poverty rate [%]	82.0	75.4	67.3	58.5
Child vulnerability to poverty rate [%]	90.7	85.3	82.8	75.2
HDI overall	0.4	0.5	0.6	0.6
HDI education dimension	0.3	0.3	0.5	0.5
HDI longevity dimension	0.7	0.7	0.8	0.8
HDI income dimension	0.5	0.5	0.6	0.6
Share of households with piped water [%]	43.1	57.4	65.4	78.7
Share of urban households with waste collection [%]	72.3	82.2	92.4	94.5
Share of households with access to electricity [%]	88.5	96.7	98.7	99.6
Share of households without sewage/water facilities [%]	12.0	20.7	16.2	14.4
GINI index	0.6	0.6	0.5	0.5
Unemployment rates (age of 18 or more) [%]	9.5	16.0	7.2	10.3

4.4.3.2. Opposing results

Figure 4.9 highlights the four indicators that have presented significant opposing conclusions in Table 4.4 depending on the method of analysis (DID or DIDM). In this graph, the social outcomes with negative values represent greater improvements in the control group.

The opposing sign of these five cases does not mean that treatment has had a negative impact over these social indicators. Rather, by analysing Table 4.4 and Table 4.5 it is possible to conclude that both groups have improved in these four indicators. In this sense, the opposing signals simply demonstrate that improvements in the treatment group were higher than in the control group only when the DIDM technique was applied.

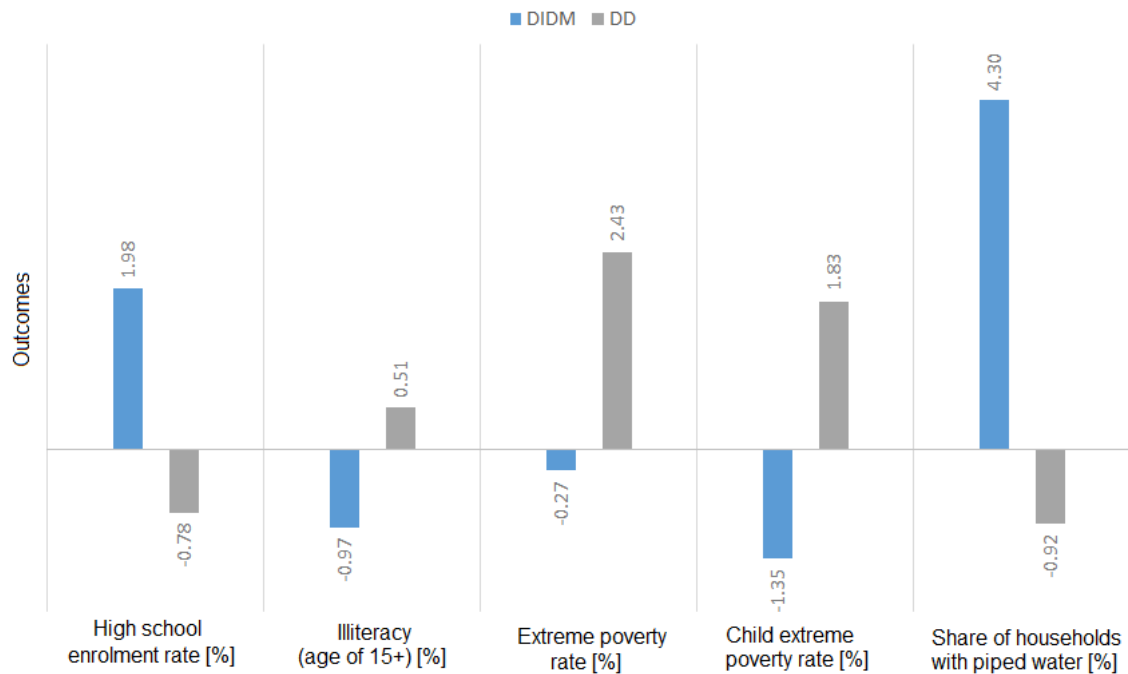


Figure 4.9: Variables with opposing conclusions depending on the method of analysis

Despite the regional similarities of the municipalities within the influence area of the BR-232 motorway, other essential information embedded in the PS can offer a better context when applying the DID comparisons. These findings emphasise the importance of coupling the DID technique with the PSM in order to reduce the impact of confounding factors that might affect the evaluated outcomes.

4.4.3.3. Impacts on the least advantaged population

Even though substantial socioeconomic progress was found to be associated with the infrastructure intervention in the case study, these results should be interpreted with caution. The indicators related to the monetary dimension of poverty show that there has been a different impact on people living in extreme poverty and on people living in less severe levels of income poverty.

Whilst the average income per capita of people in *poverty* and people who are *vulnerable to poverty* have improved more in the treatment group over time, the same indicator for people in *extreme poverty* has actually decreased after the intervention. In other words, people surviving in extreme poverty in municipalities that received the transport project saw their average income decreasing over time.

Additionally, the improvement in the treatment group was only modestly higher than the control one (0.23 percentage points) in terms of extreme poverty reduction. These differences point to a trend suggested by other studies (Salon and Gulyani, 2010; Setboonsarng, 2006; Cook et al., 2005; Porter, 2002) that extreme poverty is not necessarily alleviated by large transport infrastructure investments.

Similar to these findings, Khandker and Koolwal (2011) in a dynamic panel data study performed in rural Bangladesh also point out that households in extreme poverty may not be as able as the better off population to capture the productivity and cost reductions benefits of a road project. Likewise, Setboonsarng (2006) argue that despite evidence that transport infrastructure can indeed promote poverty reduction, this process is not automatic, and often the non-poor and less poor population benefit more from these investments than the neediest. Without complementary assistance to the poorest, Setboonsarng (2006) explains, these benefits are typically captured by the local elite.

Thus, the findings reported in this case study from Northeast Brazil support earlier evidence, showing that the benefits of a new transport infrastructure might vary significantly even among groups of lower income levels. This has important implications for planning new transport interventions, especially where extreme poverty is most spread, like in rural Northeast Brazil. The results of this ex-post assessment ultimately highlight the need to assess the distributional impacts and screening the transport-related needs at a local level prior to massive transport infrastructure investments. In the next Chapter, this topic is further addressed in order to present tools for preventing this unequal socioeconomic progress and tackle poverty more effectively.

4.5. Policy implications

This study set out with the aim of structuring a framework capable of evaluating the social outcomes of transport interventions in Northeast Brazil using publicly available datasets only. Regarding the framework, the comparisons between the results obtained by DID and DIDM have highlighted potential misperceptions of a 'context-less' analysis. As displayed in Figure 4.9, a set of five indicators have resulted in opposing conclusions when the outputs of these two methods were compared. This contrast emphasises the importance of using the PSM technique when estimating causal treatment effects in panel data studies like this. The findings strongly support the idea that if the context of the quasi-experiment study is not considered, the results may lead to biased conclusions being made on the relationships between a transport investment and its outcomes.

Whilst the results point to a wide range of positive socioeconomic effects that can emerge from the road widening project, they also call attention to the necessity of evaluating the distributive impacts of transport investments. As shown by indicators of average income per capita, it is not guaranteed that improvements on the transport infrastructure will result in welfare gains for the population in most need. This particular case study demonstrates that people in extreme poverty living in municipalities along the widened stretch had actually a decrease in their average income per capita after the completion of the project.

In that sense, it is argued that transport infrastructure projects should be complemented by further public policies targeting specifically these low-income groups that cannot directly benefit from these investments. These policies should be able to address the dimensions of transport-related exclusion that are most likely to be reinforcing cycles of poverty in each municipality. Particularly in the case of Northeast Brazil, these complementary measures should not disregard informal public transport and active modes since they are the main mobility alternatives used by people under the most severe levels of poverty.

The findings reported in this Chapter highlight the need for distributional impact appraisals across different social groups and the need for screening the specific

transport needs at a local level, especially prior to large-scale transport infrastructure investments. In the next chapters, additional tools and reflections are provided on how to identify in ex-ante assessments the priority regions and transport-related needs of each region that demand primary action in this sense.

4.6. Conclusion

This Chapter has sought to evaluate the social outcomes of a transport infrastructure intervention in Northeast Brazil by developing and applying a well-grounded ex-post assessment framework. Whilst many transport infrastructure projects have been advertised as key investments to promote regional economic growth, this Chapter sheds light on to the extent to which this development has also resulted in socioeconomic benefits to the least advantaged population.

Overall, the reported findings subscribe to the view that transport infrastructure investments broadly contribute to the reduction of multidimensional poverty. This conclusion is particularly illustrated in this case study by the greater positive impacts in eleven socioeconomic indicators of the municipalities on the region of this transport project.

Nonetheless, this Chapter has also demonstrated that people living in the most severe levels of poverty do not equally benefit from large transport infrastructure investments. This is mostly supported by the decrease of the *average income per capita of the extremely poor* and by the modest decline of the *extreme poverty rate* in the municipalities along the widened stretch of BR2-232 when compared to the municipalities of the control group.

Thus, the proposed framework draws attention to a recurrent misperception that occurs when the distributional impacts of transport infrastructure interventions are disregarded at the planning stage. Despite overall socioeconomic progress, the findings have shown that complementary actions are still needed to ensure that these investments will result in a fair distribution of their benefits to society. It is argued that these additional interventions should be guided by ex-ante social impact analysis performed when appraising and prioritising transport

interventions. This topic receives further attention in Chapter 6 when a socially driven framework is proposed to screen the transport needs at a local level.

In terms of the methodology, it is possible to conclude that the framework proposed in this Chapter is particularly suitable for the case study region, considering its data limitations. Perhaps the main advantage of this framework is that it does not require expensive surveys and highly disaggregated data to be performed since it is based on publicly available data only. Thus, it unlocks a myriad of possibilities of case studies to assess other transport interventions which occurred in the past during intercensal periods, and to explore their social effects over time.

Future research, however, is still needed to address limitations related to the endogeneity and aggregation of spatial data highlighted throughout this Chapter. For regions where data is more spatially disaggregated, the same framework can be refined into areas smaller than a municipality to further explore spatial distributional effects. Moreover, the inclusion of other types of investments (other than transport infrastructure) as a means to reduce the bias potentially caused by endogeneity factors is highly recommended in further studies exploring this research line.

Finally, this Chapter also makes a strong case for the debate about the large transport infrastructure investments that are currently in the pipeline of Pernambuco state (e.g. BR-316, BR-116, BR-101), as well as throughout the whole Country (EPL, 2018). The evidence reported by this study emphasises that these transport infrastructure interventions must not be disconnected from the local needs, and the distributional impacts must be considered at the planning stage if poverty eradication is a goal to be achieved within this generation.

CHAPTER 5: ACCESSIBILITY EVALUATION AT THE MUNICIPALITY LEVEL

5.1. Introduction

Studies addressing the multidimensional concept of poverty have shown that monetary indicators, although important, do not capture many essential factors of deprivation experienced by the poor (Alkire and Seth, 2015; Narayan et al., 2000). Thus, other dimensions of poverty like access to education, health, and living standards have been increasingly incorporated in social studies to promote more comprehensive assessments and better policy recommendations for tackling poverty (Alkire and Foster, 2011). Evidence recently published by the World Bank has shown that the primary difference between those who have escaped chronic poverty and those still trapped in it is not income, but access to essential services (Vakis et al., 2016).

From a transport planning standpoint, as already mentioned in previous chapters, the links between poverty and accessibility have been clarified in the literature (Benevenuto and Caulfield, 2019). Nevertheless, while the conceptualisation and measurement of accessibility disadvantages in the Global North already plays a central role in the social inclusion research and policy debate (Church et al., 2000; Farrington and Farrington, 2005; Velaga et al., 2012; ITF, 2017b), the same agenda has garnered comparatively much less attention in the Global South, where poverty is more wide-spread. Moreover, in spite of the increasing body of research dedicated to evaluating access to house facilities (e.g. electricity, sanitation) and healthcare services in rural Global South (e.g. Luo et al., 2017; Nesbitt et al., 2014), only few notable exceptions have been dedicated to evaluating quantitatively the overall accessibility poverty in these contexts

(Weiss et al., 2018; Iimi et al., 2016; Roberts et al., 2006; Sarkar and Ghosh, 2008).

The Rural Access Index (RAI) proposed by Roberts et al. (2006) and restructured by Iimi et al. (2016) has delivered a substantial contribution by establishing a quantitative indicator of rural accessibility for more than 170 countries. However, such an index presents only the ease of access to the rural transport network⁴⁷, which generally does not mean access to basic services. In a context where travel distances are predominantly high (Porter, 2014) and where the population in poverty mostly live in a walking world, access to the transport network might not be a sufficient indicator to assess real accessibility in rural areas.

Another significant contribution to the modelling of rural accessibility globally is the map of travel time to cities proposed by Weiss et al. (2018). This study builds on a method developed by Nelson (2008) that estimates the speed at which humans move through the landscape based on a Global Surface Friction map⁴⁸. Whilst such a study provides a comprehensive and rational overview to assess the global inequalities in terms of access to the nearest city⁴⁹, it neglects the overlapping influences of other smaller urban centres not characterised as cities.

In the absence of GTFS⁵⁰ data covering rural areas, Starkey et al. (2013) propose the use of local surveys to estimate indicators such as *fare price per passenger kilometre*, and *transport frequency on normal days* in rural areas of several Sub-Saharan Countries. Despite reporting an unprecedented amount of data of rural transport services in these regions, the results cannot be generalised to farther afield as they only reflect the local supply of rural transport. Moreover, the replication of this method in larger areas would necessarily require costly and time-consuming surveys.

⁴⁷ The RAI index estimates the share of people living farther than 2km from any all-season road.

⁴⁸ This Global map shows at a resolution of 1x1km the travel impedance (minutes per meter) based on several spatial datasets such as spatial distribution of roads, railroads, rivers, bodies of water, topographical conditions, land use, and national borders.

⁴⁹ Which is defined as a contiguous area with population density of at least 1,500 inhabitants/km², or a built-up land cover coincident with a population of at least 50,000 inhabitants (Weiss et al., 2018).

⁵⁰ GTFS or General Transit Feed Specification is a common format for public transport data that combines spatial and tabular datasets including routes, stops and timetables.

In this context, where no quantitative indicator of accessibility is available or accurate enough to foster equitable and inclusive transparent planning, the prioritisation of transport interventions inevitably assumes a biased, arbitrary and paternalistic fashion (Di Ciommo, 2018). The research presented in this Chapter attempts to fill this research gap and support an evidence-based transport planning that may mitigate the current status of subjectivity in social appraisals of transport interventions. Drawing upon the literature, this Chapter constructs two Spatial Accessibility Poverty (SAP) indices to offer innovative and well-grounded tools for transport planning in remote areas of the Global South. As a result, while addressing the limitations of previous studies, the indices that are proposed also aim to catalyse actions to reduce the transport-related exclusion in rural areas caused by the lack of access to basic facilities (e.g. health, education, financial facilities). Even though this research is particularly tailored to the Brazilian context, it is potentially replicable in other countries with similar characteristics of poor spatial data.

5.2. Data and Methods

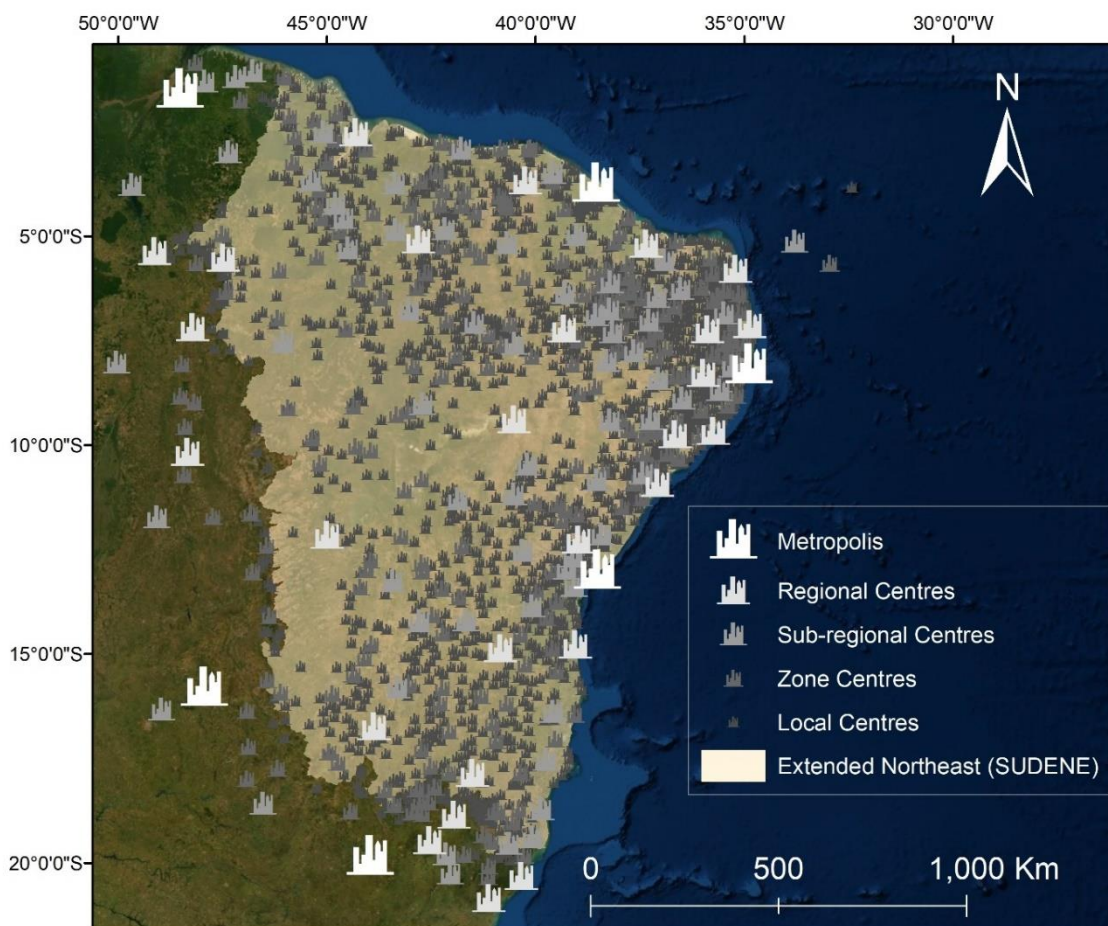
5.2.1. Mapping opportunities

As already explained in Chapter 3, several basic facilities' coordinates⁵¹ and job opportunities locations remain still unknown at a national level in Brazil, especially in the rural and suburban areas (Benevenuto et al., 2018). Nonetheless, since these points of interest are primarily concentrated within the urban centres (IBGE, 2008; Church et al., 2000), it is reasonable to assume the geolocation of each urban centre (i.e. city hall coordinates) as an aggregated proxy for public services and basic amenities' locations at a larger scale. This premise has been also used by recent studies (Weiss et al., 2018; Headey et al.

⁵¹ Location of schools, police stations, social service centres, healthcare centres, supermarkets, financial facilities, etc.

2018), to demonstrate how access to urban centres stratifies the educational, economic and health status across different communities.

The variety and complexity of services and amenities offered in each centre are dependent on the urban hierarchy (i.e. the centrality level) of each centre. Following the same approach described in Chapter 3, the present Chapter considers the traditional centrality hierarchisation method proposed for Brazil by IBGE (2008), which stratifies the Municipalities of this case study region in five different levels of centrality (weights) as described in Table 3.2 (Chapter 3), and further illustrated in Figure 5.1.



Geographic coordinate system: WGS 1984. Produced by Rodolfo Benevenuto. Source: IBGE (2008)

Figure 5.1: Urban centres in extended Northeast Brazil (SUDENE area)

5.2.2. *The spatial accessibility poverty indices*

Over the past two decades, there has been an increasing body of research assessing spatial accessibility by estimating floating catchment areas (FCA) of opportunities, their distance decay effects, and the population attended by the given Point Of Interest (POI) (Luo and Wang, 2003; Geurs and van Wee, 2004; Schuurman et al, 2010; Dai, 2010; Polzin et al., 2014; Shaw and Sahoo, 2019). Radke and Wu (2000) have introduced a simple and effective gravity-based measure aiming to achieve a fair and equal distribution of social programs. This model, later named as Two Step Floating Catchment Area (2SFCA) by Luo and Wang (2003), defines the service area of a given POI by a threshold travel time/distance while also accounting for the availability of this POI over its surrounded demands (Luo and Wang, 2003). Later studies have also introduced three ways of conceptualising the distance decay effect in this model, calling it Enhanced Two Step Floating Catchment Area (E2SFCA): the continuous functions, the discrete variables, or a hybrid of these two (Luo et al., 2017; Wang, 2012; Guagliardo, 2004).

One of the main advantages of using this FCA techniques to measure accessibility is to be able to incorporate the overlapping influences of different POI's around the same location. This is particularly important since bypassing the nearest service is a phenomenon frequently observed in places where populations have more than one option of the same service to choose from (McGrail and Humphreys, 2009). Additionally, in the context of the present Chapter, by considering the different levels of influence from all urban centres in this case study, it becomes possible to account for the availability of POIs of different levels of complexity. For example, while the availability of primary schools can be accounted by the FCA of local centres, the range of specialised hospitals (or any other service of higher complexity) can be accounted by the FCA of centres of higher position in the hierarchy (i.e. Regional Centres and Metropolis). In this sense, by using FCA of urban centres the issue of measuring accessibility based only on the nearest urban centre (Weiss, 2018) can be avoided.

While the present Chapter proposes the urban centres as proxies for the supply of services (i.e. POIs), the demand for these services in rural locations is based on the latest population distribution grid available in Brazil (IBGE, 2010b). A clear limitation that emerges from this dataset is that the population is assumed to be homogeneously distributed in each rural cell of 1 km². However, this dataset still provides the most spatially disaggregated data of the population distribution in Brazil considering its continental dimensions, showing the number of people living in every 1x1km cell throughout the whole Country⁵² (IBGE, 2010b). In order to classify these grid cells into urban/rural areas, the land use characterisation map established by IBGE (2014) is then overlaid to this population grid. To avoid a border/edge problem, urban centres from the surrounding areas of the cells within the case study region were also included, as shown above in Figure 5.1. Moreover, since the POI in this case study is an aggregated proxy (i.e. an Urban Centre) for several other POIs, no population-to-provider ratio is applied to account for local competition⁵³. These competition ratios could mislead the proposed model and potentially underestimate the availability of opportunities (POIs) in highly populated urban centres. Since the centrality level of each urban centre is also dependent on the number of its inhabitants, urban centres with large populations would, as a rule, represent a higher number of POI's, rather than only higher competition for them (or less availability of POI's). In this sense, the Local Accessibility in each rural location can be simply calculated by an aggregation of Urban influences (of the five different centrality levels) weighted by the travel impedance separating them from each grid cell, as it is shown in Equation 5.1:

Equation 5.1

$$A_j = \sum_{i=1}^5 \frac{U_i}{Y_{ji}}$$

⁵² Within urban areas this population grid resolution is further disaggregated at 200x200m cells.

⁵³ Traditionally, in 2SFCA models the ratio between demand and supply of each location is computed to account for the competition of the population sharing the same POI (Wang, 2012).

Where

A_j is the Local Accessibility measured at the location j

U_i is the Centrality level of the Urban centre (representing the size or the number of the opportunities). This has values of 1 to 5

Y_{ji} is the Travel impedance between location j and i (i.e. demand and supply, respectively)

A number of different factors can influence the travel impedance in these accessibility measurements, varying from concrete concepts such as spatial distance, up to more sophisticated and hard-to-measure dimensions such as the feeling of insecurity in public space (Church et al., 2000). The factors applied to estimate the ease of movement in these models are as a rule dependent on the quality of transport-related datasets (e.g. road network, GTFS) and the level of accuracy expected from the analysis. In this Chapter it is proposed two different travel impedance models that can be implemented in the context of limited spatial data such as Northeast Brazil. The appreciation of these two methods seeks a further understanding on how the SAP indicators respond to these two different inputs in a sensitivity analysis. The first model applies a Kernel Density (KD) decay function to create FCAs of geodesic distances (i.e. buffers) from the urban centres. The second approach uses the Global Surface Friction map (Weiss et al., 2018) to estimate the FCAs of urban centres of different centrality level based on the travel time needed to reach them from every rural cell. Sections 5.2.2.1 and 5.2.2.2 provides a further explanation of these methods. Finally, Section 5.2.2.3 presents a further rationale and a methodological description of the aggregation of this Local Accessibility measurements at a grid cell level into an SAP indicator at a municipality level.

5.2.2.1. Kernel Density Model (SAP-KD)

The KD function applied to this research consists of a continuously gradual decay function within a threshold distance and with no effect beyond, as shown in Equation 5.2 and Equation 5.3. These formulas draw upon the quartic kernel function proposed by Silverman (1986) and it is automatically utilised when KD maps are generated by means of ArcGIS 10.5. In the proposed model several KD maps were independently generated using the same formula but with

different threshold distances to estimate the FCAs of the urban centres by each centrality level.

Equation 5.2

$$Z_j = \begin{cases} \frac{1}{(dist_{max})^2} \sum_{i=1}^n \left[\frac{3}{\pi} \cdot \left(1 - \left(\frac{dist_i}{dist_{max}} \right)^2 \right)^2 \right] & , \text{if } dist_i < dist_{max} \\ 0 & , \text{otherwise} \end{cases}$$

Equation 5.3

$$Y_j = \frac{1}{Z_j}$$

Where:

Z_j is the urban influence score generated by the urban centres surrounding the rural cell j

j is the number of urban centres within the threshold distance (i.e. only if $dist_i < dist_{max}$)

$dist_{max}$ is the threshold distance (also called as search radius) that is further discussed later

$dist_i$ is the distance between the rural cell j and the urban centre i .

Y_j is the travel impedance calculated by the Kernel Density model

References for threshold distances/time applied to FCAs can be mostly found in the literature addressing healthcare accessibility (Neutens, 2015; and Yang et al., 2006), as well as access to employment, leisure and public transport services (Langford et al. 2012). These studies often apply thresholds for driving time for estimating FCA to specific services. For example, 30 minutes of driving for primary care, 45 minutes for obstetrical services, and 90 minutes for general surgeries (Polzin et al., 2014; and Fortney et al., 2000). Radke and Mu (2000) state that thresholds distance/time are needed in planning services to determine if a particular demand is covered. In addition, even if a maximal distance is not specified in a KD distance-decay function, geoprocessing tools from platforms such as ArcGIS apply specific algorithms to determine a default search radius either way (ESRI, 2019). Yet, there is not a precise threshold distance/time to define an urban centre influence based on its centrality level. In this way, drawing upon previous studies in the literature, this research proposes three reasonable

sets of threshold distances for this purpose. These sets are then evaluated in a sensitivity analysis of the SAP-KD index following similar methodologies already applied by other authors (Pereira, 2019; Luo and Wang, 2003).

The first set of threshold distances presented in Table 5.1 is based on the findings of Benevenuto et al. (2018). It presents the average distances from nearly half a million households in extreme poverty to the closest urban centre of each centrality level in Rural Northeast Brazil. The second threshold set is a recommendation obtained in semi-structured interviews with five regional planning specialists from the Superintendency for the Development of the Northeast (SUDENE). Finally, the third one is based on the average distance from the centroid of the rural cells⁵⁴ in Northeast Brazil to the closest urban centre of each centrality level. Even though the values for Metropolis and Regional Centre of threshold 1 and 3 much closer to each other than to threshold 2, the values for Zone and Sub-regional centres are the opposite. Therefore, the SAP generated from the mean value of these thresholds is not greatly skewed towards any of the threshold distances.

Table 5.1: Catchment areas by each urban centrality level.

Centrality level	Threshold distance 1	Threshold distance 2	Threshold distance 3
Metropolis	320 km	100 km	340 km
Regional Centre	125 km	80 km	125 km
Sub-regional Centre	70 km	60 km	85 km
Zone Centre	40 km	40 km	45 km
Local Centre	10 km	20 km	15 km

In this way, fifteen maps of the urban influence are then generated (five for each set of thresholds) using the KD distance-decay function (Equation 5.2 and 5.3) and considering the urban hierarchy defined in Table 5.1. The travel impedance scores calculated by the FCA maps of all centrality levels are applied to Equation

⁵⁴ The rural cells are 1x1km cells of the population distribution grid that are located in rural areas.

5.1, and then assigned as a single attribute of Local Accessibility in each rural cell of the case study region. Figure 5.2 presents a graphical description of this process for one set of threshold distances. The creation sequence of the urban FCAs for each centrality level is presented at the upper part of the figure. At the lower part, a zoomed snapshot of the overlapping FCA's over the rural cells is presented to indicate how the urban influence scores are accounted and assigned to each cell.

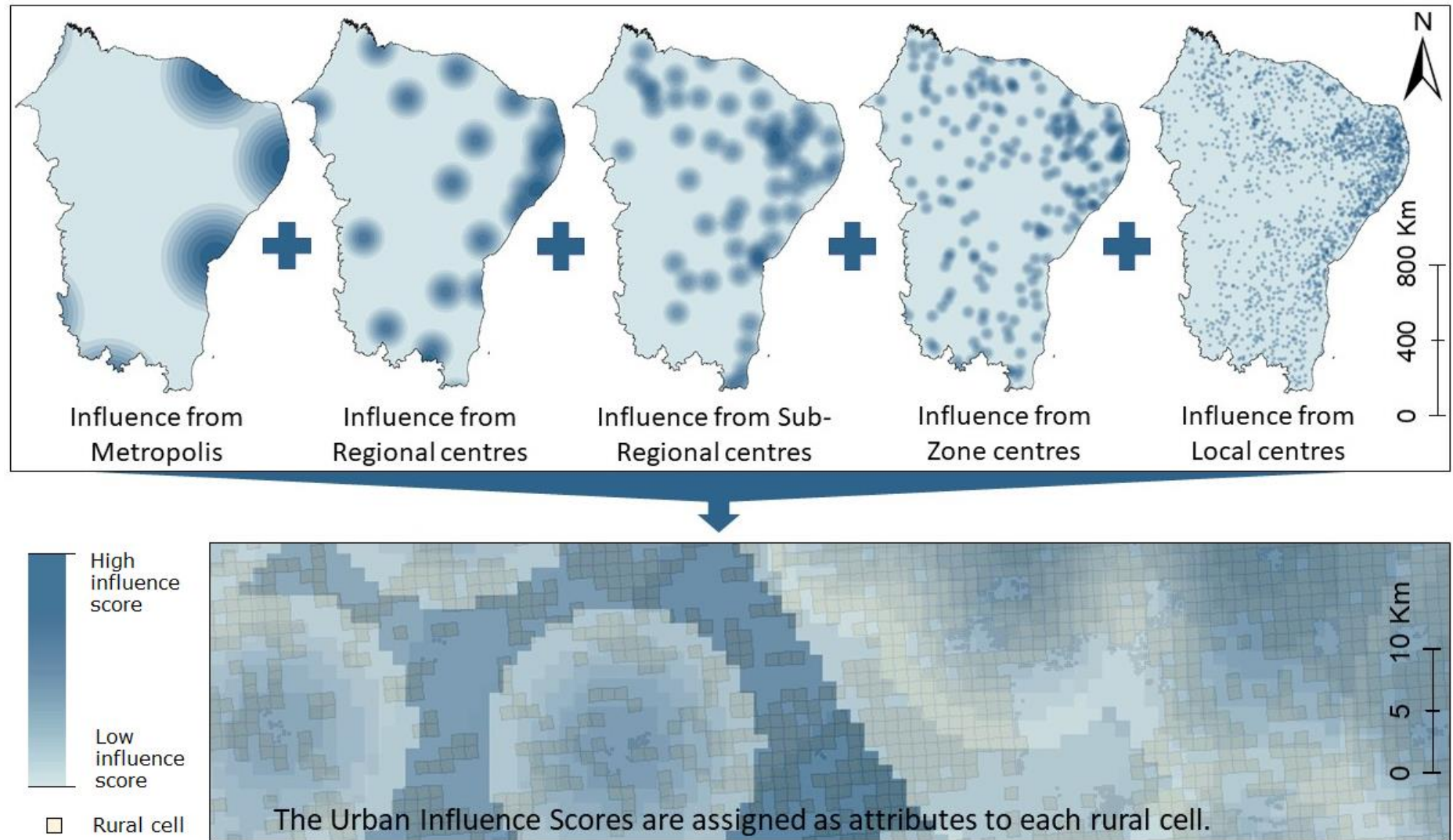


Figure 5.2: Calculation of Local Accessibility using Kernel Density method

5.2.2.2. Friction Surface Model (SAP-FS)

The second travel impedance model that is proposed is based on the Global Friction Surface method published by Weiss et al. (2018). As already mentioned, this database estimates the speed at which humans move on average through the landscape based on several proprietary and open-source spatial datasets, that include information about the transport network (roads, railways, navigable rivers), the terrain (land use, national borders) and other geographic features (elevation⁵⁵, slope⁵⁶). The combination of these inputs results in a Friction Surface map at a resolution of 1x1km that represents the estimated time in minutes required to cross each grid cell.

This method was originally proposed with data from two decades ago by Nelson (2008), and then it had a significant update with inputs from 2015 by Weiss et al. (2018). In this new version, a substantial improvement in the input data quantity and quality has been achieved by incorporating two major roads datasets from Open Street Map⁵⁷, and from the Google roads⁵⁸ database. In this sense, even though this database does not represent a perfect representation of the current transport infrastructure in Northeast Brazil, it offers a solid and well-grounded model of travel impedances. The following examples present some of the relevant travel speed assumptions that are considered in this model (JRC, 2019) to illustrate how these travel impedances are estimated in each grid cell:

- 0.5 min per km (i.e. 120km/h) if there is a Motorway
- 1 min per km (i.e. 60km/h) if there is a Major road
- 2 mins per km (i.e. 30km/h) if the terrain is covered by artificial/urban areas
- 24 mins per km (i.e. 2.5km/h) if the terrain is covered by sparse herbaceous or shrub
- 36 mins per km (i.e. 1.67km/h) if the terrain is covered by cultivated or managed areas

⁵⁵ There is an attenuation factor in the ease of movement for altitudes higher than 2000 meters.

⁵⁶ Uphill and downhill travels present slower travel speeds.

⁵⁷ www.openstreetmaps.org

⁵⁸ www.maps.google.com

Based on this Friction Surface (FS) raster data and the urban centre locations, the travel time from anywhere in Northeast Brazil to the closest urban centre of each centrality level could be calculated. This measurement was performed using a cost-distance algorithm available in ArcMap 10.6.1, which calculates the least accumulative cost distance for each cell to the nearest source (i.e. urban centre) over the friction surface. Even though this travel impedance model does not require the definition of threshold times in the calculation of the FCA of each centrality level, travel times that are too long tend to be neglectable in the final account of the Local Accessibility since they are inversely proportional. Finally, Figure 5.3 summarises the process of how the five travel impedance maps are generated and subsequently aggregated following into another Local Accessibility measurement at each rural cell.

It is also worth mentioning, that whilst 1x1km of resolution is an extremely accurate grid size at a global level of analysis, it can mask a significant variation of travel impedance within a single grid cell, especially since this travel impedance is directionless. As already discussed by Benevenuto et al. (2019), several gaps in the mapped road network are still present in the available databases from the government (DNIT⁵⁹), private (Google maps, Here maps⁶⁰), and opensource (Openstreetmaps). In this sense, even though the FS method offers a far more accurate method for representing travel impedances between two points than a Geodesic distance-based model, the FS model may occasionally fall short in consistency, especially in remote regions where the quality of the mapped transport network is more limited.

⁵⁹ National Department of Transport Infrastructure - www.dnit.gov.br

⁶⁰ <https://wego.here.com/>

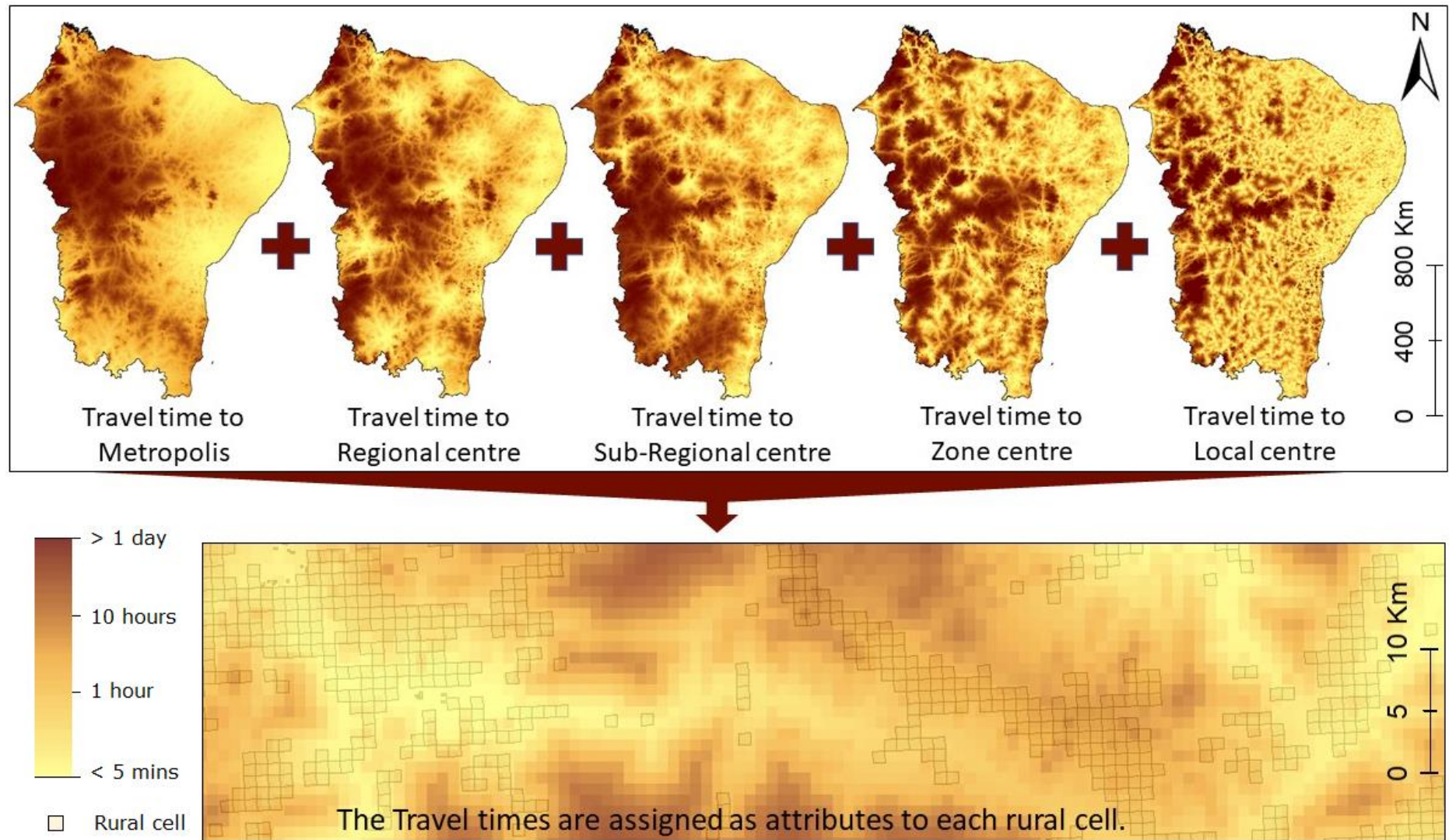


Figure 5.3: Calculation of Local Accessibility using Friction Surface method

5.2.2.3. Spatial Accessibility Poverty (SAP) indices at a municipality level

The SAP indices (KD and FS) are intended to provide a quantitative tool for transport planning that could support evidenced-based decisions (e.g. resources allocation) at the municipality level or at a higher scale. This is particularly important in the Brazilian context where very little attention has been paid to accessibility audits in transport appraisals (Pereira, 2019; Vasconcellos, 2003). Hence, this Section proposes a weighted aggregation of the Local Accessibility indicators calculated above for each rural cell into an SAP index at a municipality level. This aggregated indicator will facilitate the applicability of such an index in regional transport appraisals and in the resource allocation process. As the municipality is the smallest political-administrative division in Brazil, the majority of the socio-economic and demographic indicators utilised in the country are also calculated at this level.

In order to implement this aggregation of the SAP index, a model is proposed that conjugates two factors: severity (how spatially excluded is the population from the basic facilities?) and the extent factor (how many people are being affected by this spatial accessibility poverty?). This approach was first applied to assess the size and scope of accessibility poverty by Martens and Bastiaanssen (2014). However, this study has its methodology based on the sufficientarianism principle, which stresses that transport policies should give absolute priority to address the accessibility needs of people who fall below a minimum level of accessibility (Martens et al., 2014). In this sense, the very objective propositions and insightful discussions on this topic, also presented by Martens (2016), still leave the question on how to define an absolute accessibility poverty line (similarly to an income poverty line) open to debate. From a theoretical standpoint, the definition of such a line is most controversial because, among other reasons, it would be morally hard to defend absolute priority to those just below the threshold over those just above it (Martens et al., 2014).

Hence, the present Chapter proposes a novel accessibility poverty index also based on the same two factors (severity and extent) but grounded on a

prioritarian approach. This method is based on a distributive rule that suggests that a gain has a higher value when it is offered to the people in the worst-off position (Martens et al. 2014, Pereira et al., 2017). In other words, instead of defining an arbitrary line that will establish priorities of investment until an alleged eradication the accessibility poverty, a prioritarian model may be continuously used to shape a more equitable distribution of transport investments also in the long run. In mathematical terms, instead measuring the severity of SAP by the difference between the accessibility in a given place and the accessibility poverty line (sufficientarianism), the prioritarian approach measures the severity of SAP by the difference between the local accessibility and the maximum level of accessibility of the region (as shown in Equation 5.4). Therefore, even if more refined accessibility measurements become available in future (e.g. when GTFS data become consistently available), the proposed SAP index can still be adapted to provide an objective accessibility assessment that can help guide future transport investments.

The severity dimension of the proposed model is, therefore, composed of the normalised difference between the maximum Local Accessibility of the entire region (A_{max}) and the Local Accessibility of each rural cell (i). The Extent dimension is represented by the number of people living in each rural cell, working then as a weighting factor for each rural cell. As a result, the SAP index expresses how low the average accessibility experienced by the population of a given municipality is by the summation of the severity factor weighted by the extent factor, as shown in Equation 5.4:

Equation 5.4

$$SAP_j = \frac{1}{N_j} \sum_{i=0}^{q_j} n_i \cdot \left(\frac{A_{max} - A_i}{A_{max}} \right)$$

Where:

A_i the local accessibility at rural cell i

A_{max} the maximum local accessibility of a cell in the entire case study region.

n_i the population of the rural cell i

q_j the number of rural cells in the municipality j

N_j the total population of the municipality j

SAP_j the Spatial Accessibility Poverty index of the municipality j

It is worth mentioning that the well-known modifiable areal unit problem (MAUP)⁶¹ (Openshaw, 1984) could arise in the model when aggregating the influence scores to create the SAP index to each municipality. Still, according to previous studies in the literature (Dark and Bram, 2007; Hay et al., 2001), a weighting function (e.g. the cell population) might reduce the effect of the MAUP when aggregating spatial data by incorporating object-specific measures throughout the analysis of the upscaled data. Therefore, since the SAP index is based on an aggregation of several⁶² small cells (1x1km) per municipality, which are weighted by the ratio of the population located on each cell, the MAUP caveat tends to be reduced. Nevertheless, further applications of the SAP index should be done carefully.

5.2.3. *Municipalities profile analysis*

Additional factor analysis is proposed to further investigate the interactions of the SAP index with potential socio-economic patterns of the municipalities experiencing higher levels of accessibility poverty. Drawing upon studies addressing income poverty (Gwatkin et al., 2000; Vyas and Kumaranayake, 2006), the comparisons among municipalities are made by quintiles of accessibility poverty. As two SAP indicators are being proposed, only the municipalities that were classified in the same quintile of both SAP indicators (SAP-FS and SAP-KD) are taken into consideration (i.e. 45% of the total). The descriptive statistics summary of nineteen socio-economic and demographic indicators is then evaluated at this step. These indicators are taken from the latest Brazilian Census (IBGE, 2010a) and the list, although not exhaustive, can

⁶¹ MAUP is a source of statistical bias that refers to the fact that the observed values may vary depending on how the data is aggregated into spatial boundaries (Openshaw, 1984).

⁶² On average there are nearly 600 rural cells in each municipality in this case study region.

provide a fair overview of basic dimensions required for the human flourishing in a rural environment.

It is possible to further classify the vector of selected indicators from the perspective of five general domains of capabilities deprivations⁶³. The dimensions listed below have been selected for convenience mainly based on the existing census data (IBGE, 2010a) that are available for all municipalities and are disaggregated by location (rural/urban):

- Freedom of Movement (SAP indicators, road density⁶⁴, car, and motorbike ownership)⁶⁵
- Housing Facilities (toilet, electricity, sewage disposal⁶⁶)
- Education (illiteracy rates⁶⁷ and density of rural schools)
- Health (density of rural healthcare centres and hospitals⁶⁸)
- Income (income-poverty levels)

The descriptive statistics of other municipality-wise characteristics are also included, such as GDP, population size and density, and share of the rural population. Moreover, since there is no data available of the income-poverty levels by municipality that are also disaggregated by location (rural/urban) for the entire region, for the Income domain it was considered three poverty lines dependent on the per capita income (PCI) of rural families:

- Extreme Poverty when $PCI < \frac{1}{4}$ of the minimum national wage⁶⁹

⁶³ For further reflections on this, see Sabina Alkire (2007) 'Choosing Dimensions: The Capability Approach and Multidimensional Poverty'.

⁶⁴ This indicator was calculated by of GIS tools based on the federal motorways only (EPL, 2019).

⁶⁵ No public transport mode has been considered into this study due to the scarcity of GTFS data and the presence of several informal operators providing intermittent transport services in this region.

⁶⁶ An adequate sewage disposal has been considered when the household has access to either the general sewage network or a septic tank.

⁶⁷ The rates for illiteracy consider the percentage of people of 10 years of age or more who are illiterate.

⁶⁸ The only information health-related that is available from the census (IBGE, 2010a) for all municipalities that is also disaggregated by location (urban/rural) are the numbers of population with any mental, visual, motor or hearing impairment. Therefore, only the number of health care centres has been considered in the Health domain. This dataset has been provided on demand by the Ministry of Health via <https://esic.cgu.gov.br/>

⁶⁹ The minimum wage in 2010 was R\$ 510.00 a month – around U\$ 368.00 in 2010 purchasing power parity according to the conversion rate provided by OECD (2018)

- Poverty when PCI is between $\frac{1}{4}$ and $\frac{1}{2}$ of the minimum national wage
- Vulnerable to poverty when PCI is between $\frac{1}{2}$ and 1 of the minimum national wage

Finally, in order to compare the distribution of these variables, their values are presented in reference to the quintiles of the SAP index. The statistical difference between the quintile means is tested by the nonparametric test of Kruskal-Wallis, coupled with a pairwise post-hoc analysis to evaluate which pairs of quintiles did not present significant difference.

5.3. Results and Discussion

5.3.1. Sensitivity analysis of the travel impedance models

The sensitivity analysis varying the threshold distances of the SAP index based on the KD model has shown that at the state-wise level the different threshold distances have not presented an intense impact upon the estimated accessibility poverty. This is a rather interesting outcome, showing the consistency and potential applicability of this index as an aid to support transport project prioritisations at a higher level. This result could perhaps be attributed to the fact that the maximum difference of threshold distances presented in Table 5.1 was only 240 km (between the Metropolis cut-offs of set 2 and 3), added to the rapid decay of influence within the thresholds caused by the KD function. Figure 5.4 presents the three different SAP indices plotted at the same colour scale to allow a visual comparison of the regional patterns.

As it can be expected, mostly regions along the shore (right and upper parts of the map), which have a higher concentration of urban centres (see Figure 5.1 in page 112), have presented lower levels of spatial accessibility poverty in the three trials. The two larger spots in blue colour that are common in the three maps represent the metropolitan area of Salvador (Bahia's state capital) and the conurbation of the metropolitan regions of Recife (Pernambuco's state capital) and João Pessoa (Paraíba's state capital). In contrast, the inner mainland areas are clearly the most affected by accessibility poverty in both cases, with an overall

remarkable low accessibility presented in Maranhão and Piauí states (the two states at the top left side).

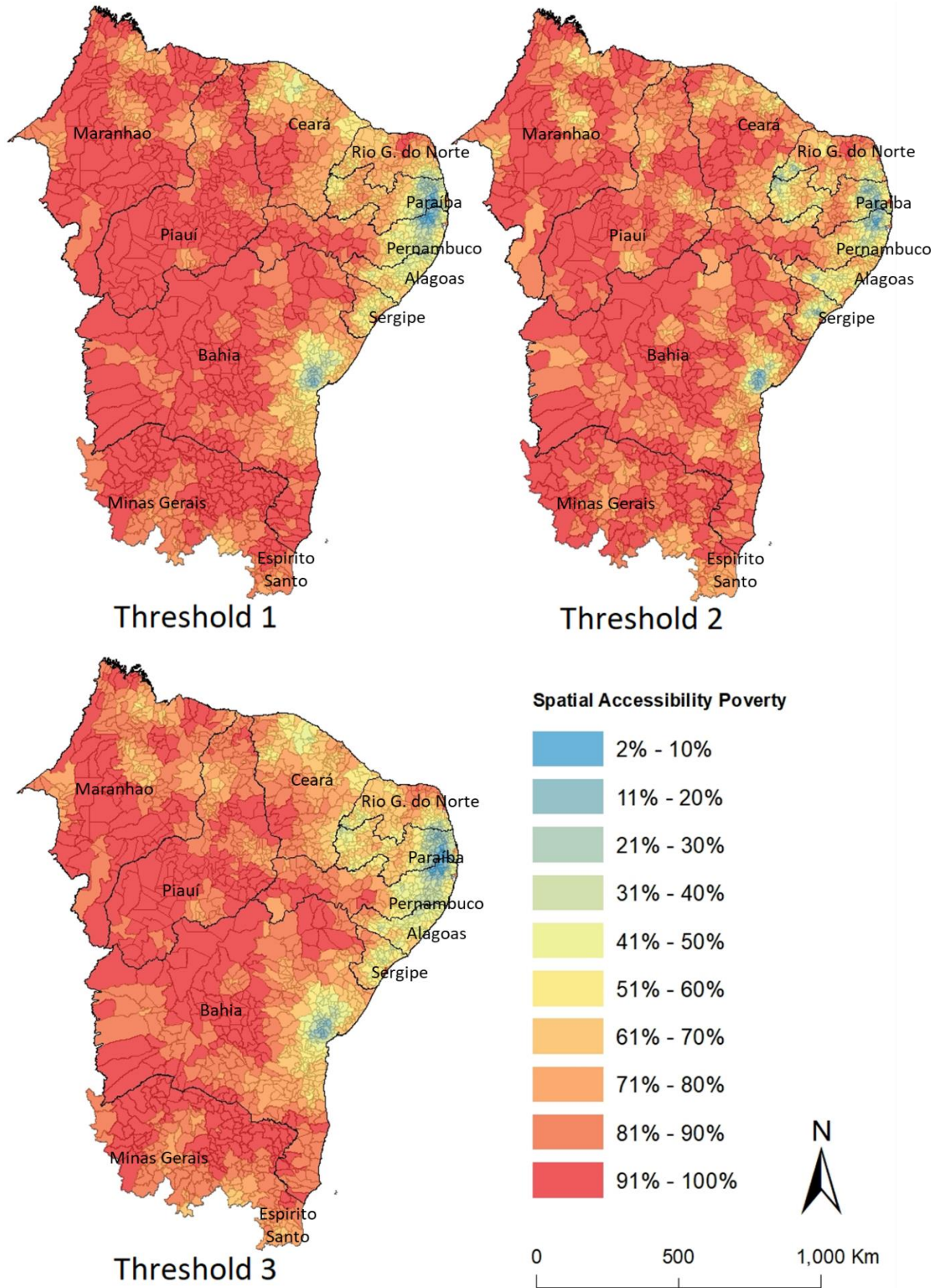


Figure 5.4: Spatial Accessibility Poverty by three different thresholds of Urban Influence

A relatively greater variation has been found when comparing the SAP indices computed with the two different travel impedance models (KD and FS). Figure 5.5 and Figure 5.6 presents a spatial comparison of these indices in a colour scale classified by quintiles and equal intervals, respectively. The SAP-KD used in this comparison (on the right in Figure 5.5) is based on the average of the three indices calculated above (shown in Figure 5.4). These results show that, even though the coastal area where there is higher concentration of urban areas present lower levels of SAP in both maps, a substantial variation can be observed depending on which travel impedance model is applied. Still, higher SAP rates are prevalent throughout the inner areas of the region in both maps, especially in Maranhão, Piauí, West of Bahia, West of Pernambuco, and North of Minas Gerais.

To further clarify the impacts of the travel impedance methods on the SAP indicator, Figure 5.7 presents a dispersion graph between the SAP indicators calculated with the FS and KD models. In this graph, each point represents a municipality from the case study area. The points highlighted in colours represent municipalities that were classified in the same quintile of both SAP indicators (FS and KD). For example, points highlighted in red are classified in the first quintile (accessibility richest) of the SAP-KD index as well as in the first quintile of the SAP-FS index. In total, 45% of the municipalities were found in coincident quintiles in both models. However, while the intermediate quintiles (second, middle and fourth) present higher variations in the municipality classification, the first and fifth quintiles present 66% and 51% of coincidence in quintile classification respectively.

These results show that municipalities in the extreme levels of SAP are less sensitive to variations on the travel impedance model than the other ones. Particularly in the fifth quintile (accessibility poorest), besides a greater coincidence in terms of quintile comparison, less variability can be also observed in Figure 5.5 to Figure 5.7 in terms of the absolute values. While in statistical terms this could be explained by a relatively smaller range of variation of the

accessibility poorest quintile (for both indices), in practical terms, this relates simply to the higher levels of remoteness experienced by the populations in these municipalities. In other words, regardless how these distances are measured, the travel impedance between these populations and the opportunities is still significantly above the average experienced by other municipalities.

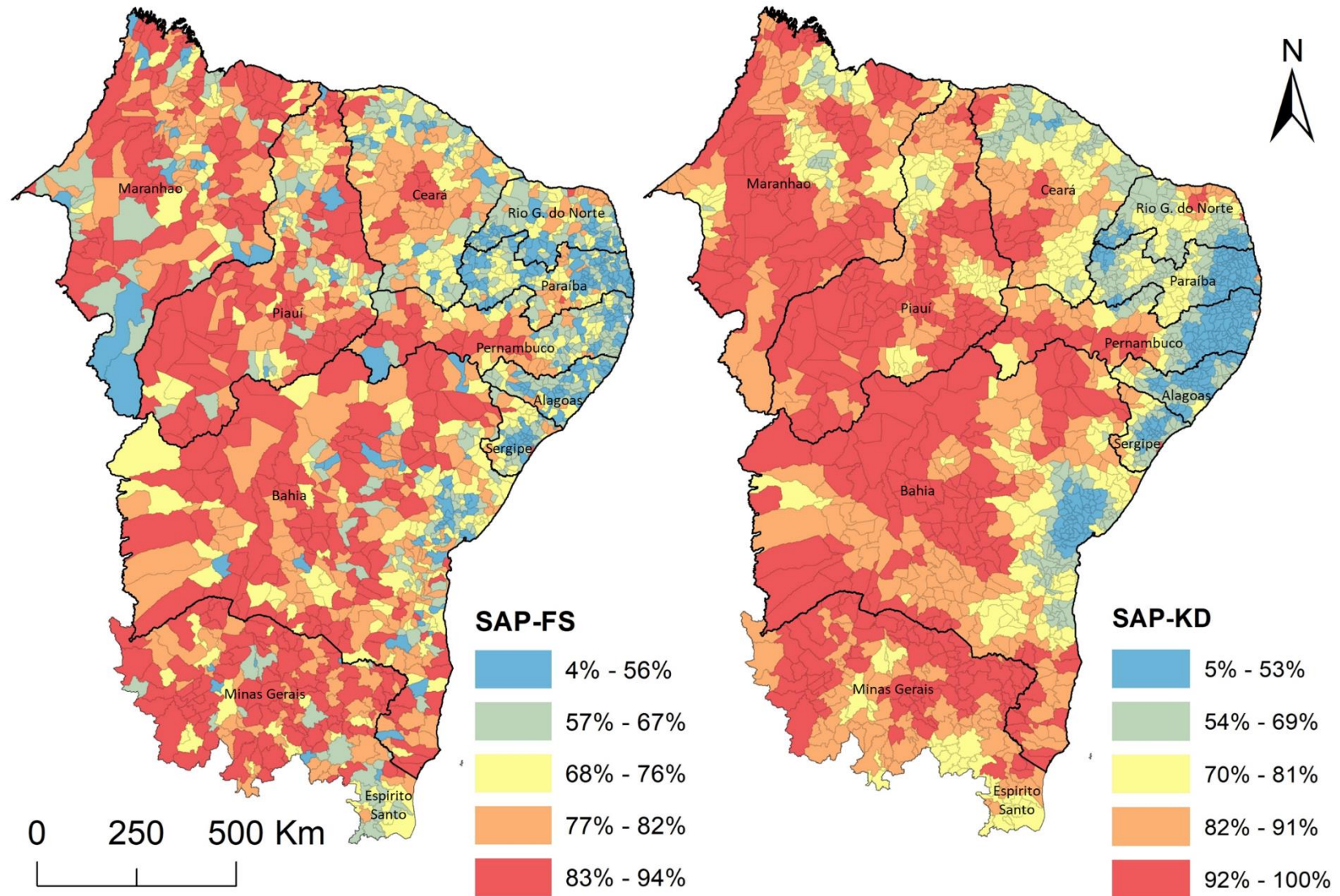


Figure 5.5: Spatial comparison of SAP indices by travel impedance model, with the colour scales classified by quintiles.

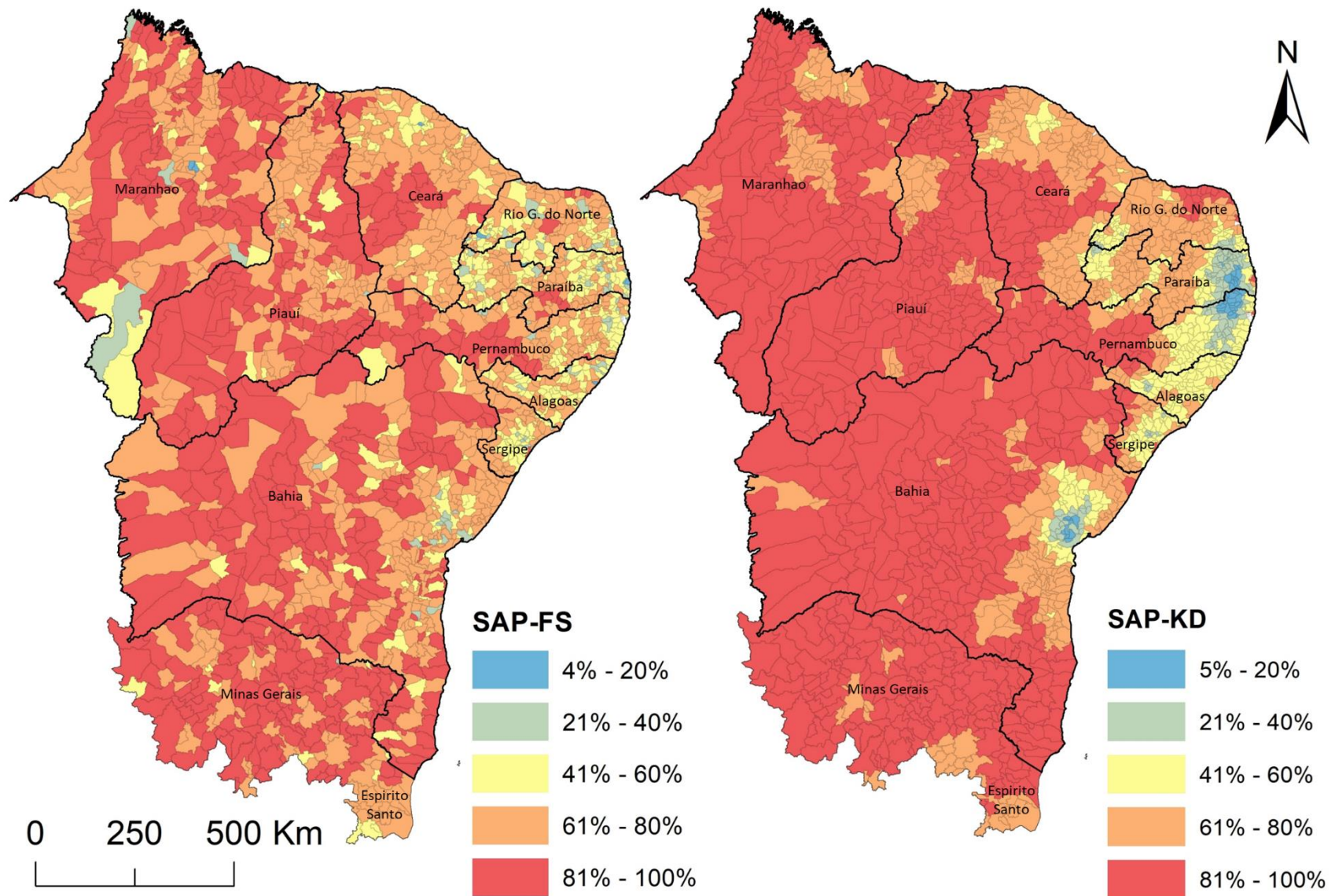


Figure 5.6: Spatial comparison of SAP indices by travel impedance model, with the colour scales classified by equal intervals

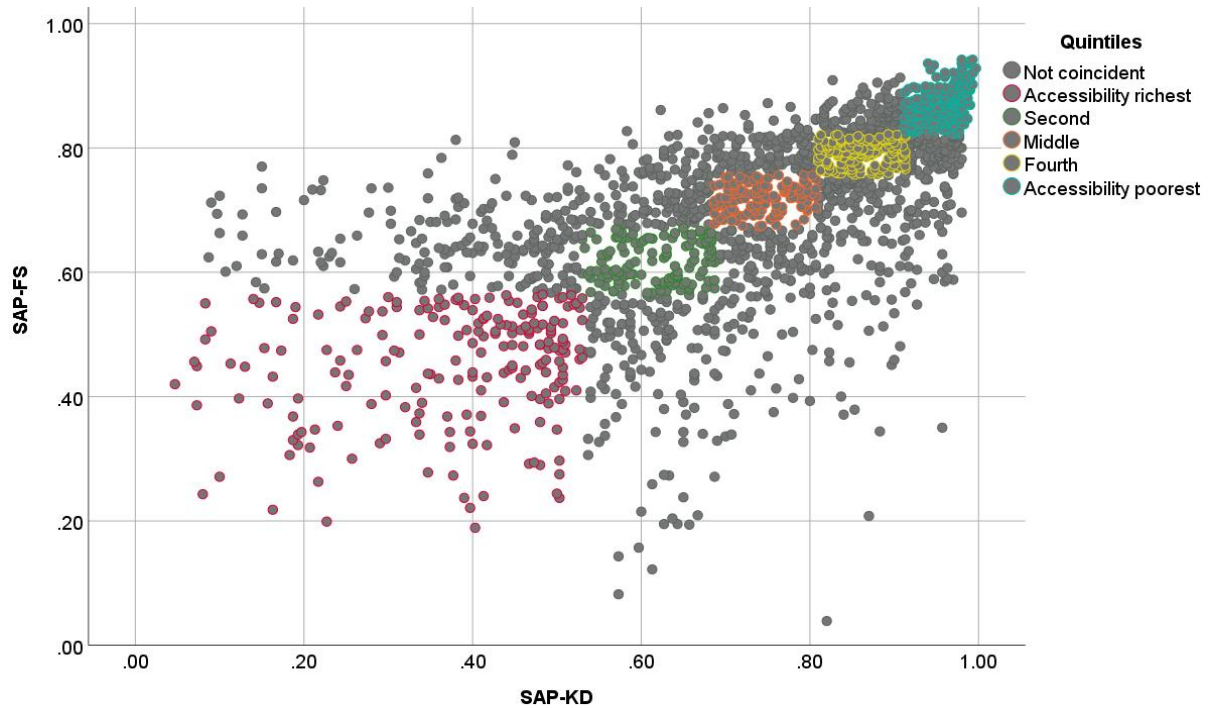


Figure 5.7: Graphical comparison of SAP index by different travel impedance models with coincident quintiles highlighted

These findings indicate that applications of the proposed models might be more appropriately performed by bands of SAP, rather than the precise values of each municipality. As shown in Figure 5.7, a more robust accessibility evaluation is likely to be achieved at a quintile level, than at value level. Further spatial applications at this macro level of analysis are performed, for example, by evaluating spatial autocorrelation and hotspots analysis in Chapter 6.

The comparison of these models makes a strong case for demonstrating the importance of sensitivity analysis when drawing transport policies based on accessibility indicators. Even though any reasonable threshold distance, or travel impedance model may promote more evidence-based decision making, in terms of prioritisation of transport interventions, the findings from the presented sensitivity analysis suggest that these SAP scores should not be taken separately from each other. Especially when appraising transport interventions at a smaller scale, where there is a higher fluctuation of scores, it is important to remark that local authorities should consider sensitivity analysis to evaluate the variation of the accessibility indices.

The appreciation of the advantages and limitations of each travel impedance model also represents an essential step when interpreting the outputs of this accessibility models. Especially in areas such as rural Northeast Brazil, where the majority of the transport network is based on non-paved roads and informal transport services that are not consistently mapped yet, the travel impedance model that is selected might focus the analysis on different aspects of the spatial accessibility. In this particular case, while the SAP-KD model is more effective in capturing the overlapping influences from urban centres of the same centrality level, the SAP-FS reflects a much better blueprint of the transport network, natural and political barriers (cliffs, rivers, borders, etc) in the travel impedance estimate. However, a major limitation in terms of accuracy of the SAP-FS is that, while people in poverty mostly live in a walking world, this model assumes travel speeds of motorised means of transport (up to 120km/h) in roads and motorways.

Moreover, although the SAP-FS index can express more directly the changes in the transport infrastructure, updates on this model will require changes in the Friction Surface data, which is not fully open access yet⁷⁰. On the other hand, while the SAP-KD express only indirect impacts of interventions on the transport infrastructure (i.e. by changes in population distribution and centrality level of urban centres⁷¹), these datasets are already periodically updated by the Brazilian government. Thus, transport interventions aiming at tackling SAP in this region should be carefully done considering these limitations.

Finally, the findings presented above show how data-poor contexts present a particularly complex environment to develop robust SAP measures. Perhaps due to this data limitation, the majority of the accessibility studies published so far have focused on either urban areas or economically developed regions where spatial datasets are far more accurate. Nevertheless, more methods like the ones that are proposed in this Chapter are needed if a socially inclusive transport development is a goal to be achieved.

⁷⁰ The transport network applied to calculate the final Friction Surface raster was not made publicly available by Weiss et al. (2018) by the time this thesis was written.

⁷¹ As land use and economic activity are primarily affected by transport infrastructure interventions (Wegener and Fürst, 2004), the population distribution grid and the centrality level of urban centres (both inputs of the SAP index) will also reflect indirectly the impacts of any transport intervention in this region.

5.3.2. *Factor analysis*

Instead of drawing causal relationships between the factors, the results of this factor analysis are intended to shed some light on the differences between municipalities with higher and lower accessibility levels, and to evaluate whether the newly defined SAP indicators generate reasonable results. Even though some patterns can be identified from this analysis, prescriptions of transport interventions based on it should be done carefully. As already highlighted in the previous sections of this Chapter, the lack of accurate, timely and spatialised data about some capabilities' domains, and the local transport patterns (including services and infrastructure) could lead to biased interpretations of the findings.

A summary of this factor analysis is presented in Table 5.3. In order to provide a statistic estimator of central tendency more robust to outliers than the mean, the median and mode of the variables have also been provided in the results. Moreover, as can be seen from coefficient of variability in Table 5.3, the quintiles of population, population density, GDP, percentage of rural households without electricity, road density, density of high schools, hospitals and basic care units present a high level of variability from the mean. However, only four out of the nineteen variables analysed (i.e. Density of Hospitals, Rural illiteracy, Total Population and Road density) did not present any statistical difference of means among the accessibility richest and poorest quintiles, as shown in Table 5.2. Moreover, the findings from the pairwise post-hoc analysis presented in Table 5.2 show that the variables of Population density, Municipality Area, Density of rural primary schools, and Rural households with no toilet present significant differences of means ($\text{sig} < 0.000$) between all quintiles.

It is clear from the findings presented in Table 5.3 that municipalities with higher spatial accessibility, despite not being statistically different in total population, they are more than ten times smaller in area. This fact clearly demonstrates an intense concentration of rural settlements, which is also indicated by the population density significantly (6.86 times) higher in municipalities better-off in spatial accessibility. In addition, the accessibility-richest municipalities present a

significantly higher GDP (132.4% higher on average) when compared to the municipalities from the last quantile (accessibility poorest). This indicator, as a rule, indicates less economic activity, fewer job opportunities and, *ceteris paribus*, less budget to invest in transport in these municipalities.

Under the Freedom of Movement domain, while Table 5.3 shows that there is no significant difference between the road density when comparing the first and fifth quintile, the statistic mode of the car ownership rates in rural areas is much lower (i.e. 0%) in the accessibility-poorest quintile compared to the richest one (i.e. 11%). These values suggest that the ease of movement in the municipalities from the 5th quintile is quite reduced as they are much larger in area and less people have access to private cars. Since road transport is predominantly the only available option⁷² for passengers in rural Northeast Brazil, longer distances and less motorised transport would inevitably exclude even more people in these regions.

Interestingly, the average and median of motorcycle ownership rate was below 30% only in municipalities with the best levels of SAP (first quintile). This fact supports the idea that home-grown solutions tackling accessibility poverty should not neglect the importance of this mode of transport in such a context. Being one of the most affordable and available modes of motorised transport, motorcycles either as a private transport or as motorcycle taxi have been argued to be an essential asset for low-income populations to overcome accessibility restrictions. Despite being often considered as an unsafe mode⁷³, several authors have reported the importance of motorcycles in the Global South context as a development tool to fight poverty and unemployment in hard-to-reach areas and where public transport is scarce (Bryceson et al, 2008; Kumar, 2011; Porter, 2014; Starkey and Hine, 2014; Jenkins and Peter, 2016, Evans et al, 2018).

In terms of access to education, the findings show that the density of rural schools (primary and high) are steadily lower in municipalities experiencing greater

⁷² With the exception of few communities along the Parnaíba and São Francisco basins, as well as by Carajás Railroad.

⁷³ Especially in countries of low standards of safety regulation and enforcement (Vasconcellos, 2008; Rodrigues et al, 2014).

accessibility poverty. Since the rural illiteracy rates are about the same (approximately 30%), these findings suggest that a less centralised allocation of schools may have compensated for the accessibility poverty impacts on education. Further investigations considering the number of rural school buses per municipality could bring more insights to the agenda of transport interventions that are more likely to be effective in tackling the deprivations of this domain.

In the Health dimension, the density of hospitals and primary healthcare units is also consistently lower as the SAP increases. This fact highlights the need for longer trips to reach medical services, especially of higher complexity, in rural settlements affected by SAP. These findings are in accordance with those presented in Chapter 3, showing that the SAP index can also capture low accessibility to healthcare.

The findings on the housing facilities domain show that municipalities which are accessibility deprived also experience less access to electricity and sanitation facilities (i.e. toilet and appropriate sewerage system). This outcome contrasts with the variations of income poverty by SAP quintiles. Whilst there is a clear increasing trend showing that housing conditions get worse as the SAP index increases, no straightforward pattern could be identified for the income poverty rates variations throughout the municipality groups. For a better visualisation of these outputs, Figure 5.8 and Figure 5.9 are presented showing the income poverty, and the housing conditions variations by SAP quintile, respectively. These findings reveal the underlying dynamic of multidimensional poverty that cannot be entirely captured by assessing income indicators alone. Figure 5.8 clearly shows that the lack of access to out-of-home basic services (e.g. education and healthcare) is often experienced in tandem with the lack of access to at-home services (e.g. sanitation and electricity).

Figure 5.9 shows that, perhaps contrary to what was expected, only minor differences when comparing the highest and lowest SAP quintiles in terms of income-poverty rates. Even though extreme income-poverty rates are 15.6% higher in the accessibility poorest municipalities, less severe levels of income-poverty do not present the same expected trend. This fact does not completely square with the intuition that higher access to essential services would lead to

less income poverty, but it calls attention once again to the multidimensional concept of poverty. As already discussed earlier in Chapters 1 and 2, various deprivations experienced by a person in poverty cannot be fully captured by income indicators alone. In that sense, more dimensions of poverty (such as housing conditions) should be taken into account before drawing any causal inference between accessibility levels and actual poverty reduction.

The lack of access to essential services and job opportunities is a transport-related exclusion dimension (Church et al., 2010) that plays a central role in the perpetuation of chronic poverty (Vakis et al., 2016). Benevenuto and Caulfield (2019) argue that improvements in accessibility to services and opportunities are instrumental in tackling the structures, processes and livelihood strategies that affect the inter-generational poverty transfer. Thus, the SAP indicators that are proposed can be used in complement to other poverty-related indicators to devise socially oriented transport interventions.

Table 5.2: Statistical difference among quintiles - Kruskal Wallis test

Variable	Sig.	Quintiles not significantly different in pairwise post-hoc comparison (Sig.>0.05)
SAP KD (average)	0.000	-
SAP FS	0.000	-
Area	0.000	-
Gross Domestic Product (GDP)	0.001	1-2 , 2-3 , 3-1 , 4-3 , 4-2 , 4-1 , 5-3 , 5-4
Total Population	0.067	All
Population density	0.000	-
Share of population in rural areas	0.000	1-2 , 2-3 , 3-4, 4-5
Road density	0.073	All
Car ownership in rural areas	0.002	2-1 , 2-3 , 3-1 , 3-4 , 4-2 , 5-2 , 5-3 , 5-4
Motorbike ownership in rural areas	0.000	2-5 , 2-4 , 2-3 , 4-3 , 5-4 , 5-3
Illiteracy in Rural population +10 of age	0.037	All
Rural households with no electricity	0.000	1-2
Rural households with no toilet	0.000	-
Rural households with no adequate sewage	0.000	1-2 , 2-3 , 3-4 , 4-5
%Rural families in extreme poverty	0.003	1-2 , 1-3 , 2-3 , 2-4 , 2-5 , 3-4 , 3-5 , 5-4
%Rural families in poverty	0.000	3-2 , 4-3 , 4-2 , 5-4 , 5-3 , 5-2
%Rural families vulnerable to Poverty	0.001	1-2 , 1-3 , 1-4 , 2-3 , 2-4 , 3-4 , 5-4
Density of rural primary schools	0.000	-
Density of rural high schools	0.000	1-2 , 1-4 , 1-3 , 2-3 , 2-4 , 3-4 , 3-5 , 4-5
Density of rural Primary healthcare centres	0.001	2-1 , 3-2 , 3-1 , 4-5 , 4-3 , 4-2 , 5-3 , 5-2
Density of rural Hospitals	0.299	All

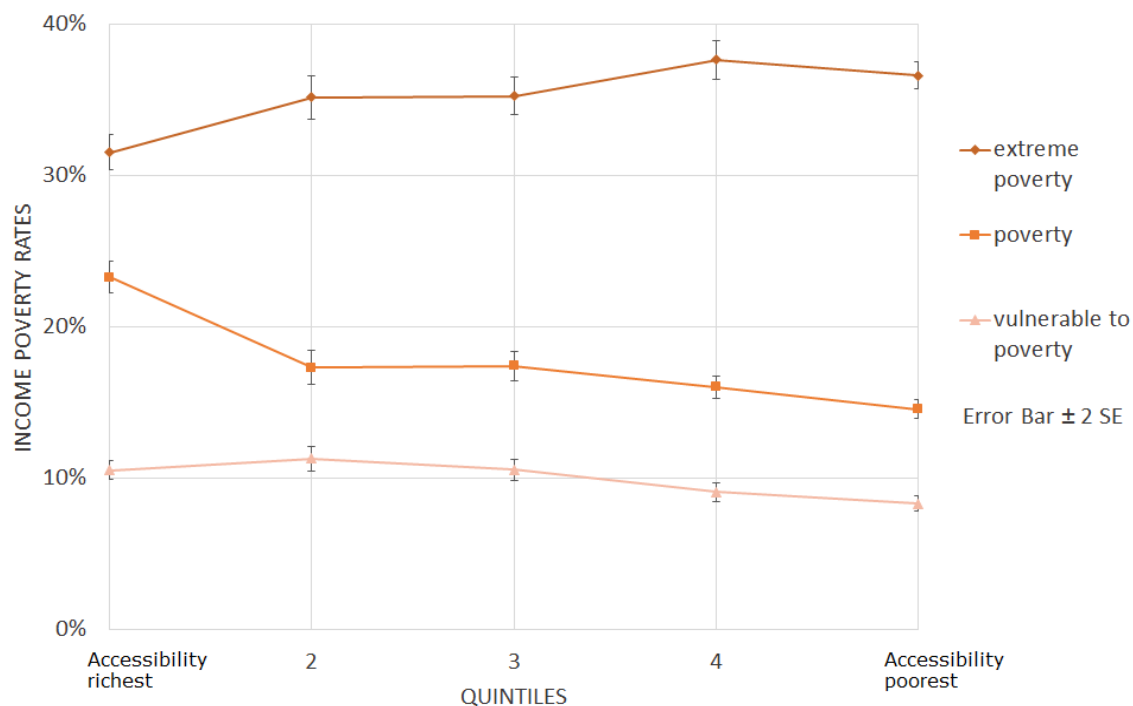


Figure 5.8: Income poverty rates by SAP quintile

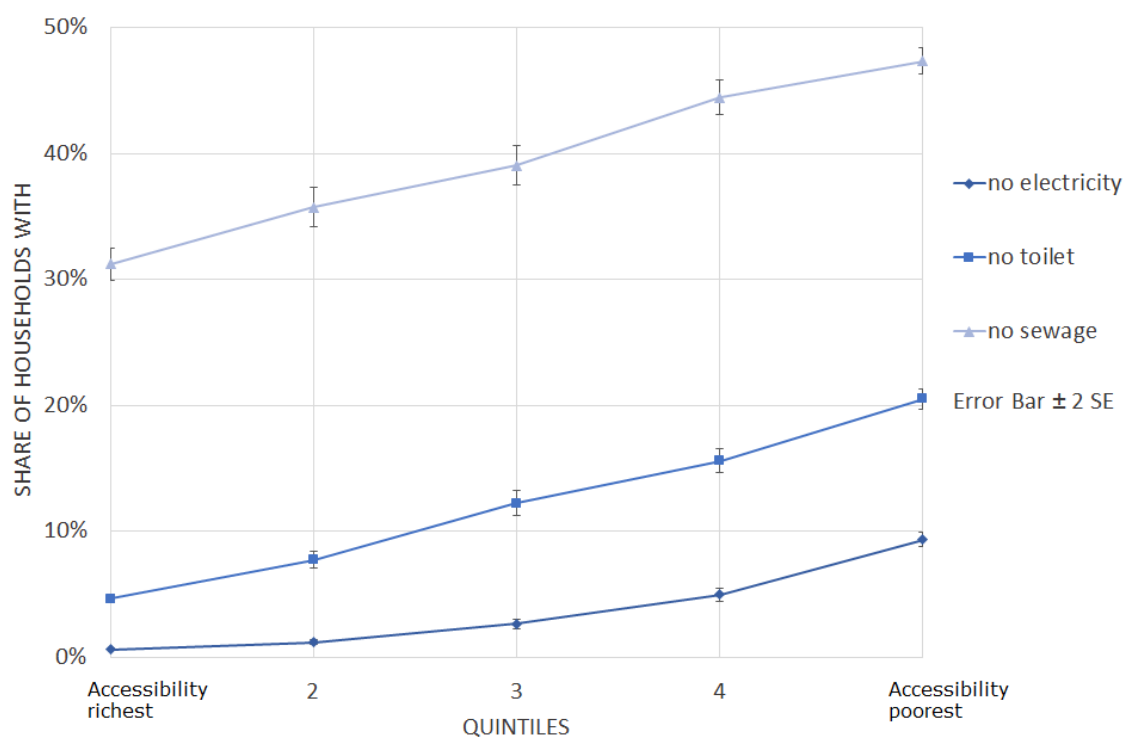


Figure 5.9: Basic Housing facilities by SAP quintile

Table 5.3: Factor analysis of the municipalities by SAP quintiles

Quintile	Statistics	SAP KD (average) %	SAP FS %	Area km ²	Total Population Inhab.	Population density Inhab./km ²	Share of population in rural areas %	Road density km/100km ²	Density of rural Hospitals 100/km ²	Density of rural Basic healthcare units 100/km ²	Density of rural Prim. Schools 100/km ²
Accessibility Richest	Mean	37%	45%	189.7	26801	138.7	37%	3.46	0.05	1.50	7.93
	Median	41%	47%	125.7	12508	98.6	36%	0.00	0.00	0.44	6.76
	Mode	50%	51%	26.0 ^a	1526 ^a	17.1 ^a	36%	0.00	0.00	0.00	0.00
	Std. Dev.	13%	9%	183.3	62798	254.5	19%	5.41	0.28	3.32	5.56
	Coef. of Var.	34%	20%	97%	234%	183%	52%	157%	600%	221%	70%
Second	Mean	62%	62%	380.5	22935	80.7	41%	2.93	0.05	0.71	4.11
	Median	63%	62%	277.4	12598	44.9	41%	0.98	0.00	0.31	3.64
	Mode	68%	59% ^a	39.7 ^a	1944 ^a	9.9 ^a	35% ^a	0.00	0.00	0.00	0.65 ^a
	Std. Dev.	5%	3%	329.0	31540	169.0	18%	3.50	0.26	1.05	2.83
	Coef. of Var.	7%	5%	86%	138%	210%	44%	120%	520%	148%	69%
Middle	Mean	74%	72%	716.8	25211	35.1	45%	2.44	0.01	0.40	2.69
	Median	74%	72%	499.3	12546	25.7	44%	1.97	0.00	0.16	2.15
	Mode	71%	72%	66.3 ^a	10454	3.3 ^a	40% ^a	0.00	0.00	0.00	1.19
	Std. Dev.	4%	2%	853.1	41012	42.7	19%	2.83	0.05	0.68	2.03
	Coef. of Var.	5%	3%	119%	163%	122%	42%	116%	407%	171%	75%
Fourth	Mean	86%	79%	1116.1	18831	18.8	50%	1.97	0.02	0.28	1.93
	Median	86%	79%	834.5	13418	15.5	52%	1.38	0.00	0.15	1.47
	Mode	86%	79% ^a	131.3 ^a	2368 ^a	1.6 ^a	52%	0.00	0.00	0.00	1.35 ^a
	Std. Dev.	3%	2%	875.1	20324	13.4	18%	2.20	0.12	0.40	1.58
	Coef. of Var.	4%	2%	78%	108%	72%	35%	112%	515%	147%	82%
Accessibility Poorest	Mean	96%	87%	1946.4	16452	20.2	52%	1.55	0.01	0.24	1.38
	Median	96%	87%	1369.7	10614	8.2	54%	1.03	0.00	0.13	0.92
	Mode	97%	84%	181.9 ^a	3532 ^a	1.0 ^a	69%	0.00	0.00	0.00	0.28 ^a
	Std. Dev.	2%	3%	1751.6	32818	171.0	18%	1.95	0.03	0.31	1.34
	Coef. of Var.	2%	3%	90%	199%	847%	34%	125%	380%	132%	97%

* Multiple modes exist. The smallest value is shown.

Table 5.3 (continued)

Quintile	Statistics	Car ownership in rural areas %	Motorbike ownership in rural areas %	Gross Domestic Product (GDP) R\$ 1000	Rural households with no electricity %	Rural households with no toilet %	Rural households with no adequate sewage %	Illiteracy in Rural population +10 of age %	%Rural families in extreme poverty %	%Rural families in poverty %	%Rural families vulnerable to Poverty %
Accessibility Richest	Mean	10%	26%	470731	1%	5%	31%	30%	32%	23%	11%
	Median	10%	24%	134917	1%	3%	31%	31%	32%	22%	10%
	Mode	11% ^a	19% ^a	14837 ^a	0%	1%	18%	32%	0%	0%	0%
	Std. Dev.	4%	13%	1459622	1%	5%	18%	6%	16%	15%	9%
	Coef. of Var.	44%	49%	310%	117%	101%	58%	20%	51%	64%	85%
Second	Mean	9%	32%	418468	1%	8%	36%	30%	35%	17%	11%
	Median	8%	30%	131511	1%	5%	36%	30%	35%	16%	11%
	Mode	0% ^a	2% ^a	20246 ^a	1%	1%	50%	28% ^a	27%	0%	0%
	Std. Dev.	4%	15%	1036494	2%	7%	18%	6%	16%	13%	9%
	Coef. of Var.	48%	47%	248%	168%	95%	49%	20%	46%	73%	84%
Middle	Mean	10%	37%	406532	3%	12%	39%	29%	35%	17%	11%
	Median	9%	36%	105659	1%	9%	37%	30%	37%	16%	10%
	Mode	6%	6% ^a	16222 ^a	1%	2%	36%	29% ^a	37%	13% ^a	0%
	Std. Dev.	6%	15%	1004401	4%	12%	19%	6%	15%	11%	8%
	Coef. of Var.	62%	42%	247%	167%	98%	48%	20%	42%	65%	78%
Fourth	Mean	9%	34%	196439	5%	16%	44%	30%	38%	16%	9%
	Median	8%	34%	109996	3%	14%	44%	31%	36%	16%	8%
	Mode	1% ^a	9% ^a	23153 ^a	1%	3% ^a	56%	33%	39%	0%	0%
	Std. Dev.	5%	12%	329646	6%	12%	17%	6%	16%	9%	8%
	Coef. of Var.	60%	36%	168%	129%	77%	39%	19%	43%	58%	86%
Accessibility Poorest	Mean	9%	33%	202517	9%	20%	47%	29%	37%	15%	8%
	Median	8%	32%	83493	6%	18%	48%	29%	36%	14%	7%
	Mode	0% ^a	3% ^a	35703	2%	11%	55%	24%	31% ^a	0%	0%
	Std. Dev.	5%	13%	972725	10%	14%	17%	6%	15%	10%	8%
	Coef. of Var.	62%	38%	480%	103%	67%	35%	22%	40%	67%	95%

* Multiple modes exist. The smallest value is shown.

5.4. Conclusion

Throughout this Chapter, two methods have been developed to estimate the overall access to basic services and opportunities in rural areas. The presented findings shed light particularly on municipalities of an understudied region of Brazil which is intensely affected by various social and accessibility issues. The proposed indicators are potentially replicable globally since they require a fairly basic spatial database to be processed, filling a significant research gap in the transport literature of the Global South.

In summary, the present Chapter has sought to contribute to the literature by covering four major limitations of previous works addressing this research gap. First, as an alternative to indices measuring rural accessibility only to the transport network (Roberts et al., 2006; Iimi et al., 2016), the SAP index evaluates the level of access from rural areas to key destinations proxied by the urban centres. Second, since the proposed indicators measure accessibility based on land use and geographic spatial data, they do not require sophisticated spatial databases (e.g. GTFS data) that are, as a rule, not consistently available yet in many rural areas of the global South. Third, instead of measuring the accessibility only to the nearest city (Weiss et al., 2018), it considers also the overlapping influences of the surrounding urban centres of different sizes and distances. Finally, since the SAP index is built on a prioritarian principle, it does not require the definition of an arbitrary accessibility poverty line for defining priority areas.

In this sense, this Chapter provides ready-to-use tools for assessing access to services and opportunities in rural and underdeveloped areas, where the majority of people in poverty still live (Iimi et al., 2016). The appreciation of this index is also intended to open the debate in the transport planning realm on where and for whom transport interventions ought to be mostly targeted. Arguably, including indicators such as the SAP indices in transport appraisal frameworks should provide a means to consider the social impact and equity in a much less biased and paternalistic fashion.

If taken together with other indicators, a comprehensive framework can be developed to screen the local needs and the transport-related exclusion dimensions (Church et al., 2000) in an objective way at a municipality level. The SAP indicators can be particularly useful as indicators for the transport-related exclusion dimension called 'exclusion from facilities' by Church et al. (2000). In this sense, it is suggested that SAP indicators can be applied, for example, as a weighting factor for criteria related to this dimension in multi-criteria decision analysis of transport projects, giving, thus, priority for projects that deliver greater improvements to regions in higher accessibility poverty.

When assessing the SAP index in the sensitivity analysis, the presented results have shown that the travel impedance models can significantly affect the outputs of accessibility indicators. Therefore, the interpretations and further applications of these indices in transport policies should be done also considering the limitations of each method. This fact once again suggests the importance of considering sensitivity analysis and complementary factor analysis when applying the SAP index for action prioritisation purposes.

Additionally, the factor analysis has presented five domains of capabilities deprivations that can be drawn from census indicators to investigate potential patterns of the municipalities most affected by accessibility poverty. Perhaps counter-intuitively, the findings point out that the high rates of income poverty are not always associated with spatial accessibility poverty. Instead, other factors like deprivation of housing facilities and low population density appear to be more associated with critical SAP levels.

For future studies, the disaggregation of the SAP index for each service and opportunity (education, health, jobs, etc) should be carried out as soon as the location of the services become available. More accurate results will be also possible when the transport network become consistently mapped and census data for the rural areas become disaggregated in smaller areas (i.e. by census tract, or neighbourhood). Meanwhile, the proposition of new transport interventions targeting poverty reduction should consider accessibility poverty indicators in addition to other socio-economic and transport-related indicators that could depict the specific needs and particularities of each region.

Finally, it is argued that poverty reduction policies are more likely to be effective in the long run if they also address the accessibility dimension of poverty in a systematic way as discussed throughout this Chapter. Since access to services and opportunities is a key difference between those who have escaped chronic poverty and those still trapped in it (Vakis et al., 2016), the SAP index and other indicators of transport-related exclusion are crucial to promoting a new standard of transport development strongly committed to eradicating poverty.

CHAPTER 6: A SCREENING FRAMEWORK OF TRANSPORT NEEDS

6.1. Introduction

Despite the increasing emphasis on the social aspects of transport externalities in the global agenda of public policies (UN, 2016), transport appraisals (ex-ante) are still strongly driven by economic and environmental analysis only (Geurs et al, 2009; Jones and Lucas, 2012b). In this context, the goals targeting poverty reduction and social well-being promotion become fundamentally undermined when the social impacts are overlooked in the decision-making process of transport development (Vasconcellos, 2003; World Bank, 2006; Jones and Lucas, 2012b, Jones et al, 2013).

Geurs et al. (2009) argue that traditional transport appraisal frameworks like Cost-Benefit Analysis (CBA) often underexpose the social dimension claiming an alleged lack of objectivity and a difficulty to precisely estimate the social effects of transport projects and policies. In terms of transport modelling, Vasconcellos (2003) argues that traditional models, such as the four-stage model⁷⁴, should not be enhanced, but rather fully replaced by novel social and political approaches that are able to carefully address issues relating transport, equity and poverty reduction. Furthermore, policy recommendations reported in the academic literature and by numerous international guidelines⁷⁵ have consistently

⁷⁴ The four-stage model is a classical transportation demand forecasting model that combines trip generation, trip distribution, mode choice and trip assignment into computational iterations that attempt to predict the equilibrium of a transportation system (Ortuzar and Willumsen, 2011).

⁷⁵ Especially from countries with a tradition in transport project evaluation like the Netherlands, Japan, Australia, Germany, UK, and Ireland.

emphasised the essential role of accessibility audits when appraising transport interventions in terms of distributional effects, equity and social exclusion (Thomopoulos et al, 2009; Mackie and Worsley, 2013; Manaugh et al, 2015, DTTAs, 2016, DfT, 2017; Pereira, 2019).

Nonetheless, since accessibility alone does not account for all the aspects in which transport impacts poverty and well-being, a more comprehensive socially driven framework is still needed. As concluded in Chapter 2, tackling the cycles of poverty through transport development requires strategies to address all the eight Transport-Related Exclusion (TRE) dimensions. Despite the importance of performing accessibility assessments (Chapters 3 and 5) in these contexts, other TRE dimensions also need to be evaluated. Thus, by clarifying what and where the priority transport-related needs are, the decision-making process can have the right inputs to be more objective and effective in reducing poverty.

As described in Chapter 1, the methodologies applied to screen regional transport needs and prioritise transport interventions in Brazil have persistently neglected fundamental aspects of poverty reduction and the social dimension of transport. Dabelm and Brandão (2010) report that the Brazilian federal guidelines for road transport appraisal are poorly detailed and are restricted to economic and environmental evaluations. Moreover, Paranaíba (2017) states that even for screening urban mobility needs, the Federal Guidelines fall short in defining clear criteria for the selection of potential transport projects.

Beyond the Brazilian case, several authors have asserted that poverty reduction and social issues are, in general, still superficially addressed in transport appraisals, and more interdisciplinary research is needed to develop tools and call attention to the social dimension in the decision-making process (Geurs et al 2009; Van Wee and Geurs, 2011; Jones and Lucas, 2012a). Overall, these studies also reinforce the latent need for an objective method of screening the transport needs at a municipal and regional that can objectively guide transport interventions to where and for whom they are most needed.

Allied to this, the spillover effects on economic growth and productivity often attributed to transport infrastructure investments (Cantos et al., 2005; Yu et al.,

2013) do not necessarily result in poverty alleviation and wellbeing improvements for the least advantaged population. As illustrated in Chapter 4, the population in extreme poverty have not benefitted in terms of per capita income improvements from the flagship project on the BR-232 motorway performed in Northeast Brazil. This evidence shows once again that socio-economic progress for the neediest is not an automatic outcome from large transport infrastructure investments.

Hence, in a context where the transport-related needs have been either disregarded, not fully captured, or addressed by subjective approaches, the proposition of an objective and well-grounded screening framework of transport needs can play a pivotal role in making transport planning more socially inclusive. This Chapter is dedicated to respond to this challenge answering the last research question of this thesis and building on theoretical frameworks and evidence raised in the first five chapters. The framework that is proposed applies the Analytic Hierarchy Process (AHP) and spatial autocorrelation techniques to provide tools and evidence-based guidelines that can guide transport interventions in Northeast Brazil to become more effective in reducing poverty. While the socially driven framework that is outlined here focuses on the transport needs of Northeast Brazil, it can also be replicated in other developing countries facing similar socio-economic and transport challenges.

This Chapter is divided into a brief review of the social impacts of transport interventions; the methodology describing the reasons for the selected data and techniques; the resulting maps and graphs along with a discussion and interpretation of the findings; and, finally, the conclusion reflecting on policy implications and guidelines devised from this study.

6.2. Social impacts of transport interventions

The definition by Geurs et al. (2009) for the social impact of transport is used in this Chapter as the positive/negative influence that transport-related interventions have on well-being, preferences, behaviour or perception of individuals, groups, social categories and society in general. It is worth mentioning that in order to

avoid the risk of neglecting important issues related to poverty reduction, this definition might occasionally overlap with economic and environmental impacts.

Table 6.1 summarises a substantial amount of research reported in academic literature (Vasconcellos, 2003; Geurs et al, 2009; Jones and Lucas, 2012b; Jones et al, 2013; Mackie and Worsley, 2013; Manaugh et al, 2015) as well as international guidelines (DNIT, 2006; World Bank, 2006; Eliasson, 2013; DfT, 2015; DTTAs, 2016, TaIC, 2016; DfT, 2017; Marcelo and House, 2018) applied in several countries to measure transport impacts on social exclusion, multi-dimensional poverty and equity. The table presents theoretical concepts that underpin the social effects of transport interventions.

For the sake of clarity, five categories and twenty-three subcategories are used based on the literature to classify all these dimensions of measurable social effects. Table 6.1 also presents some specific examples that have been applied in the literature to disaggregate and measure these subcategories. Additionally, a corresponding TRE dimension (Church et al, 2000; Benevenuto and Caulfield, 2019) is linked to each sub-category in order to exemplify how these dimensions can be measured by usual proxies. As discussed in Chapter 2, these eight TRE dimensions compose a comprehensive theoretical framework that can be used to distil the relationships of social exclusion, poverty, and transport in the Global South. Moreover, Chapter 2 has shown that the factors that promote the inter-generational poverty transfer can be reduced by developing strategies to tackle these eight dimensions when planning transport.

However, Lucas (2012) states that while these TRE dimensions provide an overall description of the nexus between social exclusion and transport, they fail in identifying where transport policy attention should be focused. The present Chapter covers this research gap by developing a framework that can evaluate where and which transport-related needs should receive higher attention in social appraisals of transport interventions. In the next Section, the methodological steps applied in this Chapter to develop such a socially driven framework for screening transport needs are further clarified.

Table 6.1: Summary of transport impacts on poverty

Category	Sub-category	Example of Disaggregation	Transport-related exclusion dimensions
Accessibility	To Education	Public/Private and Primary/Secondary/Training/Higher	From facilities
	To Healthcare	Public/Private and GP's/Clinics/Hospitals	From facilities
	To Employment, and social activities	Rural (to urban centres), Urban (jobs, gatherings, supermarkets)	From facilities
	To Transport network	Rural (all-season roads), Urban (public transport nodes)	Geographic
	At a meso-level	Between neighbourhoods (mostly for social trips)	Geographic
	At a micro-level	Facilities adapted to special needs (people with disabilities, elders, etc)	Physical
Economic	Land	Land use, land and rent price, densification, agglomeration	Economic
	Productivity	Employments changes estimates, increase in production	Economic
	Affordability	Public transport (fares) and Private transport (vehicle operating costs)	Economic
Social environment	Severance	By physical barriers or intense traffic during the construction of operation	Spatial
	Discrimination	Prevention of movement based on gender, race, ethnicity, etc	Social position-based
	Security	Crime prevention measures (CCTV, lighting, emergency call, etc)	Fear-based
	Forced Relocation	Uncertainty of being relocated and relocation itself	Fear-based, Geographic
Transit-related	Travel time	Time savings in all types of trips (business, leisure, educational, etc)	Time-based
	Reliability	Frequency, timetables, opening and closing times of public transport.	Time-based
	Comfort	Levels of crowdedness and stress during the trips	Physical
	Resilience	Disruption of service/infrastructure due to floods, landslide, accidents, etc	Indirectly related to all dimensions
Health-related	Water pollution	During operation (waterways) and construction (groundwater, rivers)	Idem
	Air quality	Increased risk of death/diseases due to high exposure to CO ₂ , NO _x , SO ₂ , particles	Idem
	Noise	During construction and operation (noise nuisance, sleep disturbance, etc)	Idem
	Vibration	Due to vehicles (operation) and machines (construction)	Idem
	Accidents	Fatal, serious, slight, damage only, or including dangerous cargo	Idem
	Physical fitness	Change in premature death by increasing the use of NMT	Idem

6.3. Methodology

The screening framework that is proposed converts open access data into maps showing where and what are the transport needs that should be prioritised by future transport interventions. Figure 6.1 presents a schematic overview of the steps taken throughout this process. Further rationale for each step is given in the next Section, describing the techniques and the input data that have been applied to each step.

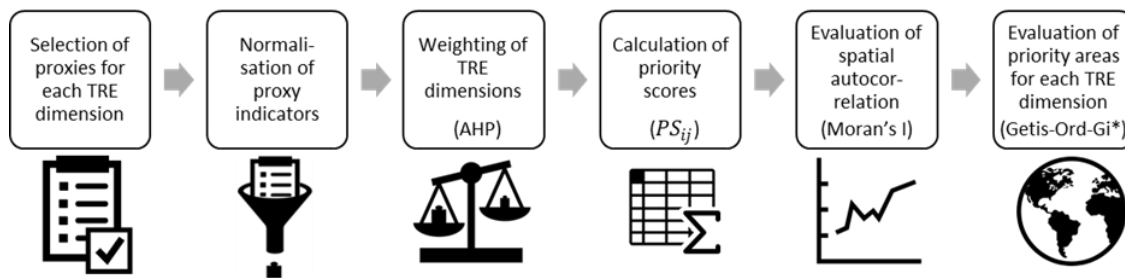


Figure 6.1: Overall methodology of the screening framework of transport needs

6.3.1. Selection and normalisation of proxies

Data availability is often a determinant factor of model sophistication in the realm of transport modelling (Dimitriou, 2013). To balance such a trade-off, and avoid simplistic analysis resulting in unenforceable policies, this study proposes one proxy to each of the eight transport-related exclusion dimensions. In that sense, the proposed screening framework is intended to cover at least partially all forms of exclusion emerging from transport issues that reinforce cycles of poverty.

This Section aims to show that even in regions where transport-related data is very limited and very aggregated, the transport needs can still be proxied by open access indicators available at a municipality level. These proxy indicators are either directly selected from governmental databases (e.g. % of elderly or people with disabilities) or indirectly calculated from publicly available datasets (e.g. the Spatial Accessibility Poverty index calculated in Chapter 5). The following list briefly describes the rationale for the selection of the indicator that is applied to proxy each TRE dimension in Northeast Brazil. However, the same framework

can still be replicated to other contexts using similar proxies that can capture the severity of each TRE dimension.

1. Physical: The demand for special transport facilities described by this dimension is measured by the share of the population of each municipality of over 65 years of age or with any disability⁷⁶ (including mental, mobility, visual or hearing disabilities). For visual and hearing disability, only people with severe and total levels of impairment were taken into account. The dataset was retrieved from the latest Brazilian demographic census (IBGE, 2010a).
2. Geographical: Since GTFS data is still very limited in the Global South (Pritchard et al, 2019; Pereira, 2019; Oloo, 2018; Evans et al, 2018) and informal mobilities are vital to billions living with poor road access (O'Brian and Evans, 2017), any attempt to measure the geographic exclusion dimension at a state or regional level built on the formal public transport network datasets would inevitably include too many areas with a coarse misrepresentation. Therefore, a simpler but rather consistent index is then applied to proxy this dimension. The Rural Accessibility Index (RAI) proposed by the World Bank studies (Roberts et al, 2006; Iimi et al, 2016) measures the share of people living farther than 2km from an all-season road.
3. From facilities: In a context where the facilities are not consistently mapped, and the majority of them are as a rule concentrated in the urban centres (Weiss et al., 2018; IBGE, 2008; Church et al, 2000), the Spatial Accessibility Poverty index (Chapter 5) offers a reasonable proxy for measuring the exclusion from facilities of a given municipality. This SAP index conjugates a factor of severity (how spatially excluded a person from the basic opportunities⁷⁷ is) and an extent factor (how many people are being affected by this accessibility poverty).

⁷⁶ This proxy can also be used to measure the need for healthcare, in cases where there is enough data to disaggregate the dimension *from facilities* by healthcare and other essential services.

⁷⁷ The SAP index, that has been further explained in Chapter 5, considers the urban centres as an aggregated proxy for basic opportunities such as schools, healthcare centres, and job opportunities.

4. Economic: To assess the severity of the economic needs preventing people from accessing desired destinations, this study applies a household per capita income indicator that measures the share of the population living with less than half of a minimum wage - which means R\$255.00 a month⁷⁸ in the purchasing power parity of 2010. The individuals below this income line are considered to be at least vulnerable to poverty by the UNDP (2010).
5. Time-based: The only travel-time indicator consistently available for all the municipalities in the Brazilian census (IBGE, 2010a) is the share of employed individuals who i) are vulnerable to poverty (same income strata mentioned above) and ii) spend more than two hours commuting every day.
6. Fear-based: The indicator utilised to proxy the fear-based dimension in the proposed framework is the ratio between the number of deaths per year per municipality caused by transport-related accidents (reported by the Brazilian Health Database – DATASUS, 2016a) and the number of vehicles registered in each municipality (reported by the National Transit Authority - DENATRAN, 2016) multiplied by 100,000. The number of deaths considered in this study was an average of the latest years of data available (from 2009 to 2016).
7. Spatial: This dimension evaluates the exclusion caused by spatial barriers (e.g. gated communities, traffic intense roads, etc) that mostly affect low-income people who live in a walking world. To create a spatial indicator that measures these barriers, an impractical and currently non-existent amount of spatial data would be needed at a regional level. In that sense, alternatively, this study applies the concept of motorcycle ownership as a proxy for this dimension. It is argued that municipalities with high motorcycle ownership would be less vulnerable to exclusion caused by spatial barriers since low-income population would have higher access to

⁷⁸ Or 139 EUR, or 184 USD applying the appropriate exchange rates according to OECD (2018).

low-cost motorised vehicles, either as their own private motorised transport or in the form of motorcycle taxis⁷⁹.

8. Social-position based: Since ethnicity-, race- and religion-based crimes in public space are as a rule not consistently measured across municipalities and over time, the selected proxy for this dimension had to be restricted to gender-based violence. Cases of verbal, physical and sexual violence against women perpetrated by strangers in public space (reported by the Brazilian Health Database - DATASUS, 2016b) were considered into this dimension as an average of the latest years of available data (from 2009 to 2016). The ratio between the number of these cases and the female population multiplied by 10,000 is then taken as the final proxy for this transport-related exclusion dimension.

Since the selected indicators do not have comparable scales, normalisation and outlier removal are required before the hierarchisation process that is described in the next Section. The extreme outliers have been identified⁸⁰ by means of SPSS software⁸¹ and converted to the closest neighbour value in order to have a smoother range of values, while also keeping the shape of the original frequency distribution. After this, the normalisation of all the eight selected indicators was carried out leaving the data prepared for the pairwise comparison presented in next step.

⁷⁹ Despite being considered as an unsafe mode of transport especially in countries of low standards of safety regulation and enforcement (Vasconcellos, 2008, Rodrigues et al, 2014), several studies have reported the importance of motorcycle taxis and motorcycle ownership in the Global South context as a development tool to fight poverty and unemployment in hard-to-reach areas and where public transport is scarce (Bryceson et al, 2008; Kumar, 2011; Porter, 2014; Starkey and Hine, 2014; Jenkins and Peter, 2016, Evans et al, 2018).

⁸⁰ Even for the most dispersed variable analysed only less than 1% of the sample (i.e. 19 municipalities) have been identified as extreme outliers.

⁸¹ IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

6.3.2. Weighting the transport-related exclusion dimensions

Once the proxies were selected as described in the previous Section, a weighting system is then proposed to evaluate the relevance of each dimension in comparison to the others within each municipality. This system is based on the Analytical Hierarchy Process established by Saaty (1980), which is still nowadays one of the most commonly used methods for multi-criteria decision analysis in transport projects (Macharis and Bernardini, 2015; Jones et al., 2013; Thomopoulos et al., 2009). For the purpose of this study, the Analytic Hierarchy Process (AHP) has only been applied to calculate the weights (also called the eigenvector) of the TRE dimensions. The following flow chart presents the steps taken based on the AHP method to estimate the relative importance (i.e. weights) of the TRE dimensions proxied by the indicators specified in Section 6.3.1.

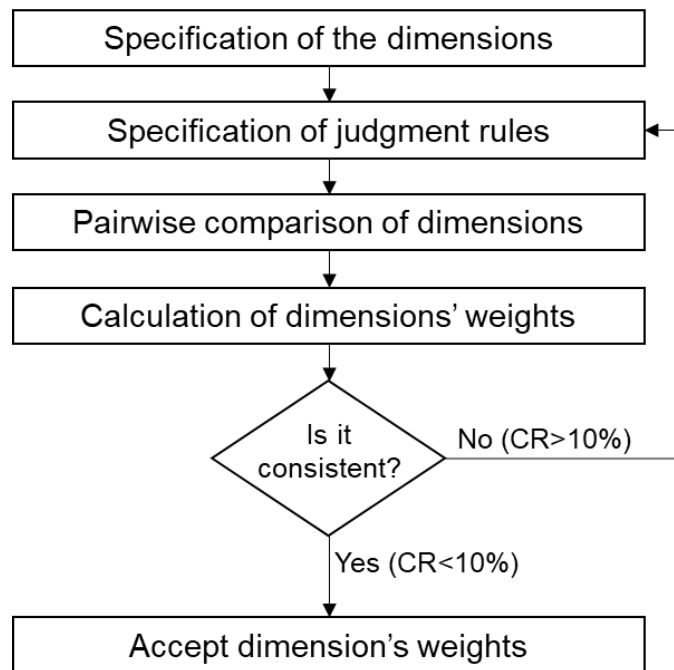


Figure 6.2: Steps of AHP method applied to calculate the TRE dimensions' weights

An important aspect of this research is that while traditional weight calculations using AHP rely on surveys or personal opinion judgment at the pair-wise comparison step, the approach that is proposed applies objective judgment rules based on numerical comparison of indicators. Therefore, the weights derived

from this process are less susceptible to manipulation or strong interference of private agendas of decision-makers.

The judgment rules applied to the pairwise comparisons of the normalised proxy indicators are presented in Table 6.2. In summary, when two given dimensions are compared by their normalised proxies, the higher is the first proxy is in comparison to the second, the higher is the score assigned to this pairwise comparison. For instance, if the normalised proxy indicators for the “time-based” and the “fear-based” exclusion dimensions are 0.60 and 0.20 respectively, the pairwise comparison following the judgment rules proposed in Table 6.2 result in a score of 9 (since the first dimension (i.e. D_i) is more than 100% greater than the second dimension (i.e. D_j)). Scores like this one are then used to populate the AHP matrix (exemplified by Table 6.3 and Table 6.4) in which the final dimensions’ weights are finally calculated. Since the indicators are compared only after the normalisation and outlier removal, differences of over 100% between a pair of indicators would represent a significant variation in absolute terms. Therefore, the maximum and minimum scores (i.e. 9 and 1/9) are given to variations of over 100% between the dimensions. The other seven intermediate scores are defined considering an even distribution of variation among these intermediate bands, as shown in Table 6.2 below.

Table 6.2: Judgment rules applied to each pair of transport-related exclusion dimensions

Pairwise comparison	Score
D_i is more than 100% greater than D_j	9
D_i is between 75% and 100% greater than D_j	7
D_i is between 50% and 75% greater than D_j	5
D_i is between 25% and 50% greater than D_j	3
D_i is between 25% lower and 25% greater than D_j	1
D_i is between 50% and 25% less than D_j	1/3
D_i is between 75% and 50% less than D_j	1/5
D_i is between 100% and 75% less than D_j	1/7
D_i is more than 100% lower than D_j	1/9

The matrices displayed in Table 6.3 and Table 6.4 show samples of the pairwise comparison of dimensions done by the AHP method. These are two cases out of the 1,990 municipalities analysed by the same framework. The weights shown at the last column of this matrix have been computed by the technique proposed by Kostlan (1991). This approximation method was selected since it is one of the most commonly used techniques that simplify the original calculation process proposed by Saaty (1980), reducing dramatically the computational power needed to solve 1,900 matrices simultaneously⁸², while also keeping only less than 10% of variation from the exact eigenvector (Vargas, 2010).

Table 6.3: Matrix showing a sample of the computed weights - Ipupiara, Bahia state

Dimensions	From facilities	Economic	Spatial	Geographic	Time-based	Physical	Fear-based	Social position-based	Weights
From facilities	1	7	9	9	9	5	9	9	39%
Economic	1/7	1	1	9	9	1/3	9	9	13%
Spatial	1/9	1	1	9	7	1/5	9	9	12%
Geographic	1/9	1/9	1/9	1	1/9	1/9	1/9	9	3%
Time-based	1/9	1/9	1/7	9	1	1/9	9	9	8%
Physical	1/5	3	5	9	9	1	9	9	19%
Fear-based	1/9	1/9	1/9	9	1/9	1/9	1	9	5%
Social position-based	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1%

⁸² One for each municipality.

Table 6.4: Matrix showing a sample of the computed weights – Bom Jesus das Selvas, Piauí state

Dimensions	From facilities	Economic	Spatial	Geographic	Time-based	Physical	Fear-based	Social position-based	Weights
From facilities	1	3	1	3	3	9	3	9	29%
Economic	1/3	1	1	1	1	9	1	7	14%
Spatial	1	1	1	1	1	9	1	7	16%
Geographic	1/3	1	1	1	1	9	1	5	13%
Time-based	1/3	1	1	1	1	1/5	7	1	12%
Physical	1/9	1/9	1/9	1/9	5	1	5	1/9	2%
Fear-based	1/3	1	1	1	1/7	1/5	1	1	12%
Social position-based	1/9	1/7	1/5	1/5	1	9	1	1	2%

After calculating the dimensions' weights, a consistency test was then performed following Equation 6.1 to evaluate whether the weights are appropriately reflecting the relative judgments (for example, if $D_1 > D_2$ and $D_2 > D_3$ it would not be consistent to have $D_1 < D_3$). This test is particularly important to check for consistency in cases where two or more dimensions present very low values (close to zero). Since the judgment rules are computed based on the result of a division of two dimensions⁸³, close-to-zero values in the denominator can compromise the pairwise comparisons. Therefore, the consistency test is applied following Equation 6.1 as proposed by Saaty and Vargas (2006). If the ratio between the Consistency Index (CI), and the Random Consistency Index (RI)⁸⁴ is below 10%, the weights are considered to be consistent (Saaty and Vargas, 2006). This ratio is also called as the Consistency Ratio (CR). Therefore, as

⁸³ For example, if D_1 divided by D_3 equals 1, then the pairwise comparison value is 1 following the judgment rules proposed in Table 6.2.

⁸⁴ The Random Consistency Index (RI) is a value defined by Saaty and Vargas (2006) that depends only on the number of dimensions being analysed by the AHP matrix.

described in the flowchart of Figure 6.2, if $CR < 10\%$ the calculated weights are accepted.

Equation 6.1

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Where:

CI is the consistency index

λ_{max} is the maximum eigenvalue

n is the number of dimensions

6.3.3. Prioritisation scores calculation

Finally, a prioritisation score is proposed taking the weights and the normalised proxies as inputs. This step is crucial to combine the priorities at a local and regional level into the same indicator. While the normalised proxies (Np_{ij}) indicate the severity of a TRE dimension in a given municipality in comparison to the region (regional priority), the weights (w_{ij}) shows the respective severity of this dimension when compared to the other dimensions of the same municipality (local priority). Hence, the prioritisation score (PS_{ij}) at a municipality level is proposed by Equation 6.2, combining these two factors - how important a given dimension is at a local level, and how severe the same dimension is in a municipality comparing with the regional figures.

Equation 6.2

$$PS_{ij} = w_{ij} * Np_{ij}$$

Where:

PS_{ij} is the priority score of the dimension i in municipality j

w_{ij} is the weight of the dimension i in municipality j

Np_{ij} is the normalised proxy of the dimension i in municipality j

6.3.4. Cluster analysis and evaluation of priority regions

Whilst the priority indicators proposed above in Section 6.3.3 can be applied for example to funding prioritisation of local transport investments (at the municipality level), a final step is still needed to identify where interventions at a regional level are most needed. Thus, a spatial cluster analysis is proposed for each of the eight transport-related exclusion dimensions measured by the prioritisation scores. By doing so, it becomes possible to spot patterns of transport-related exclusions at a regional level, showing priority areas where a given dimension is severe in both, absolute (Np_{ij}) and relative (w_{ij}) terms. The outputs of this analysis offer an objective answer at a regional level to the third research question, providing evidence-based guidance for transport policies aiming at poverty reduction. In summary this is possible by i) defining regions (clusters of municipalities) sharing a higher need for specific transport interventions, ii) evaluating the level of governance⁸⁵ at which these interventions are needed, and iii) identifying top-priority areas that accrue more overlapping clusters of transport-related exclusion dimensions.

Firstly, an incremental analysis was performed to check for global spatial autocorrelation of the prioritisation score at different distance bands. This analysis is an essential step to identify the size in which the clusters reach maximum spatial autocorrelation. That is, the number of neighbour municipalities that results in fewer chances of a given transport-related exclusion dimension being randomly distributed across the entire region. As this study has been developed using the ArcGIS platform, the recommended method for this in the literature is the Moran's I test of global spatial autocorrelation (Mitchell, 2005).

⁸⁵ For example: municipal, sub-regional, state, regional, or national.

In this analysis, the z-scores are plotted versus a series of increasing distances varying from 5 km up to 1,200 km in some cases. According to Mitchell (2005), z-scores reflect the intensity of spatial clustering (or randomness). Therefore, statistically significant peaks of z-scores are considered to be appropriate distance bands (distance radius parameters) for measuring also spatial clusters (hot spots). In other words, the distance bands that represent the maximal clustering pattern of each Priority Score can then serve as inputs to the final evaluation of regional hotspots that will show the areas that should be prioritised in future transport interventions for each TRE dimension.

Thus, after identifying the distance bands of each TRE dimension, a local cluster analysis could be then performed using the technique proposed by Getis and Ord (1992) by means of ArcGIS. In a more recent study, Getis and Ord (2010) argue that when Moran's I tests are used in conjunction with their G_i^* -statistics methods (Ord and Getis, 1995), local "pockets" of dependence may be identified giving rise to spatial associations. Finally, the location of these pockets of priority scores that proxy transport-related exclusion dimensions are suggested to be priority areas that are in most need for specific transport interventions at a municipal and regional level.

6.4. Results and Discussion

6.4.1. Weighting factors

The first test performed after calculating the weights of each dimension was the consistency test described by Equation 6.1. The maximum consistency ratio found among all the 1,990 cases was less than 6%. As this value is below the consistency ratio limit (10%), all the calculated weights can, therefore, be considered consistent. In other words, all the generated weights reflect appropriately the relative scale of priorities determined by the comparison judgments rules (presented in Table 6.2 on page 155).

The boxplots in Figure 6.3 describe statistically the weights of the transport-related exclusion dimensions obtained by the AHP matrices of the 1,990

municipalities included in this case study⁸⁶. Based on the averages presented on this graph, it is possible to observe that exclusion *from facilities* stands out as the highest priority in the region overall. This fact demonstrates that the most recurrent transport issue in Northeast Brazil is related to the lack of access to basic services and opportunities.

As described in Chapter 5, the SAP index (the proxy for this dimension) measures the remoteness from urban centres experienced by the rural population. By comparing this issue with the other seven dimensions through the AHP model, it is possible to conclude that this is the most pressing transport issue for the majority of municipalities in Northeast Brazil. Yet, the specific areas which demand particular transport interventions targeting this issue are further explored later by the results of the cluster analysis.

In addition, Figure 6.3 also points out to other two groups of dimensions with an overall second and third level of importance among the municipalities of this region. The first group is composed of the Spatial, Geographic, Economic and Physical dimensions. This group presents similar levels of relative priority, showing that, as a rule, there are only minor variations of the weights of these dimensions among the municipalities.

As can also be noted in Figure 6.3, the third level of relative priority is composed of the fear-based, time-based and social position-based dimensions. Since the distribution of the proxies of these dimensions is highly skewed (not normally distributed), a substantial number of outliers are displayed when evaluating their overall average. This fact denotes that, while most of municipalities are not much affected by these three transport-related exclusion dimensions, in a few specific municipalities (outliers) these dimensions do represent critical transport issues that require high priority. The variations of these indicators throughout the municipalities contrast particularly with the *Geographic* and *From Facilities* dimensions, which present a much more parametric distribution (i.e. less skewed and with fewer outliers). It is worth noting that these two dimensions are related

⁸⁶ The complete spreadsheet showing these weights is available at the following link <https://drive.google.com/file/d/19WZR9ZlpmtfZAyalp5oj3pjXK7YK373N/view?usp=sharing>

to the level of remoteness (from all-season-roads and town centres) in which the inhabitants of each municipality live. This fact highlights once again that the spatial burden separating people from opportunities in Northeast Brazil is a key priority to be addressed even when compared to the other TRE dimensions.

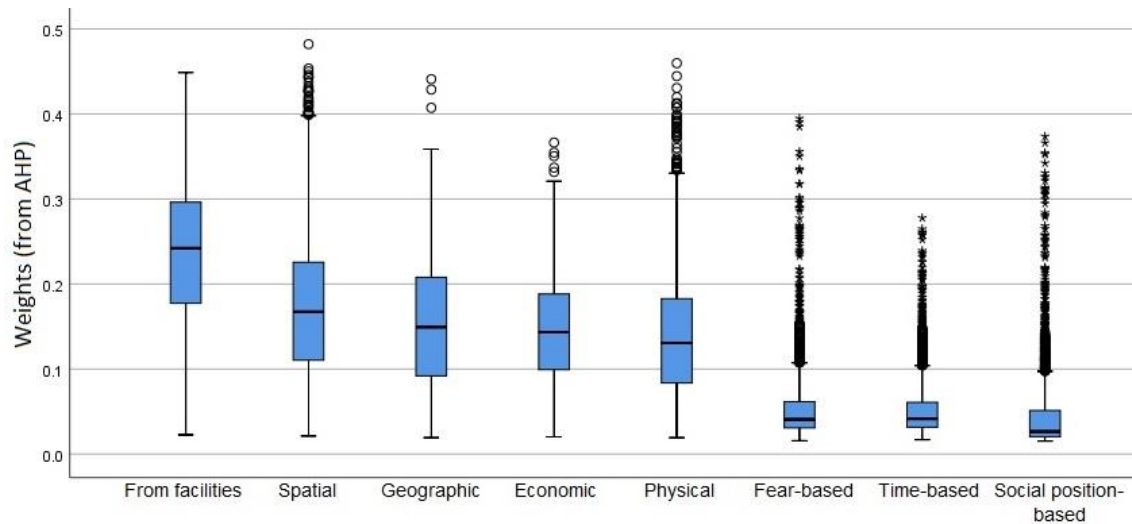


Figure 6.3: Distribution of weights estimated by AHP to each transport-related exclusion dimension

As can be expected, by following the objective judgment rules proposed in Table 6.2, the average weights and their frequency distribution tend to follow the same patterns of the original indicators (proxies) on which they are based. Therefore, it is worth mentioning that, even after the normalisation and the outlier removal, it is likely that the indicators with a negatively skewed frequency distribution would tend to have higher weights on the overall average. That is, the higher the normalized average of a proxy indicator, the higher its respective average *weight*.

Nevertheless, the skewness of the overall input data, in this case, should not be taken as a caveat in the model since it also represents the regional trends in terms of transport needs. Moreover, the distribution of the overall data does not affect the hierarchisation process at a local level since it is done considering only the relative importance of the local indicators.

Figure 6.4 shows that, despite having a clear relationship between the proxy indicator and its respective weight, a substantial variability can be also observed in the dispersion graphs. This fact reveals the relevance of the hierarchisation model. By assessing the relative importance of specific transport-related

exclusion dimensions in comparison to the others, it is possible to understand the nature of transport interventions that are primarily needed. In a context with several transport needs and limited budget, these results may help guide the prioritisation of transport investments to tackle poverty more effectively.

Even though this Chapter applies these weights mainly to screen the transport needs at a local and regional level, they can also serve as a valuable input for MCDA-based appraisals of potential transport projects targeting this region. This is a potential secondary application of the outputs of this Chapter. Since these weights represent an evidence-based ranking of social priorities, they can mitigate the risk of corruption and manipulation when defining the social criteria and their respective weights in MCDA frameworks. This contribution represents a significant step forward in the methods for prioritising transport projects that are crucially needed for planning a socially inclusive transport. Building upon these weights, performance indicators can then assess how a potential transport project will impact the most relevant local needs. In this way potential transport projects that deliver solutions of greater social impact to problems of greater importance (translated by the higher weights) will, therefore, receive greater prominence in the MCDA appraisal. To further illustrate this, some performance indicators are suggested in Appendix A showing how the social impact promoted by a potential project can be estimated in each transport-related exclusion dimension and, subsequently combined with other economic and environmental impact indicators.

Finally, this variability also shows that the same value of a proxy indicator may represent different priority levels depending on the municipality. For instance, if the exclusion *from facilities* was compared only based on the plain SAP indicators of the municipalities of *Santo Amaro do Maranhão* (Maranhão State) and *Mucugê* (Bahia state), the conclusion would be that this dimension should be equally prioritised in both municipalities since their SAP index is 98% for both. However, as they have different local weights, the final priority score (PS_{ij}) obtained for the same dimension (*from facilities*) is 2.35 times higher for the latter municipality when compared to the former. This example emphasises the importance of

having an evidence-based comparison of the local needs when establishing priority areas and priority lines of action for transport interventions.

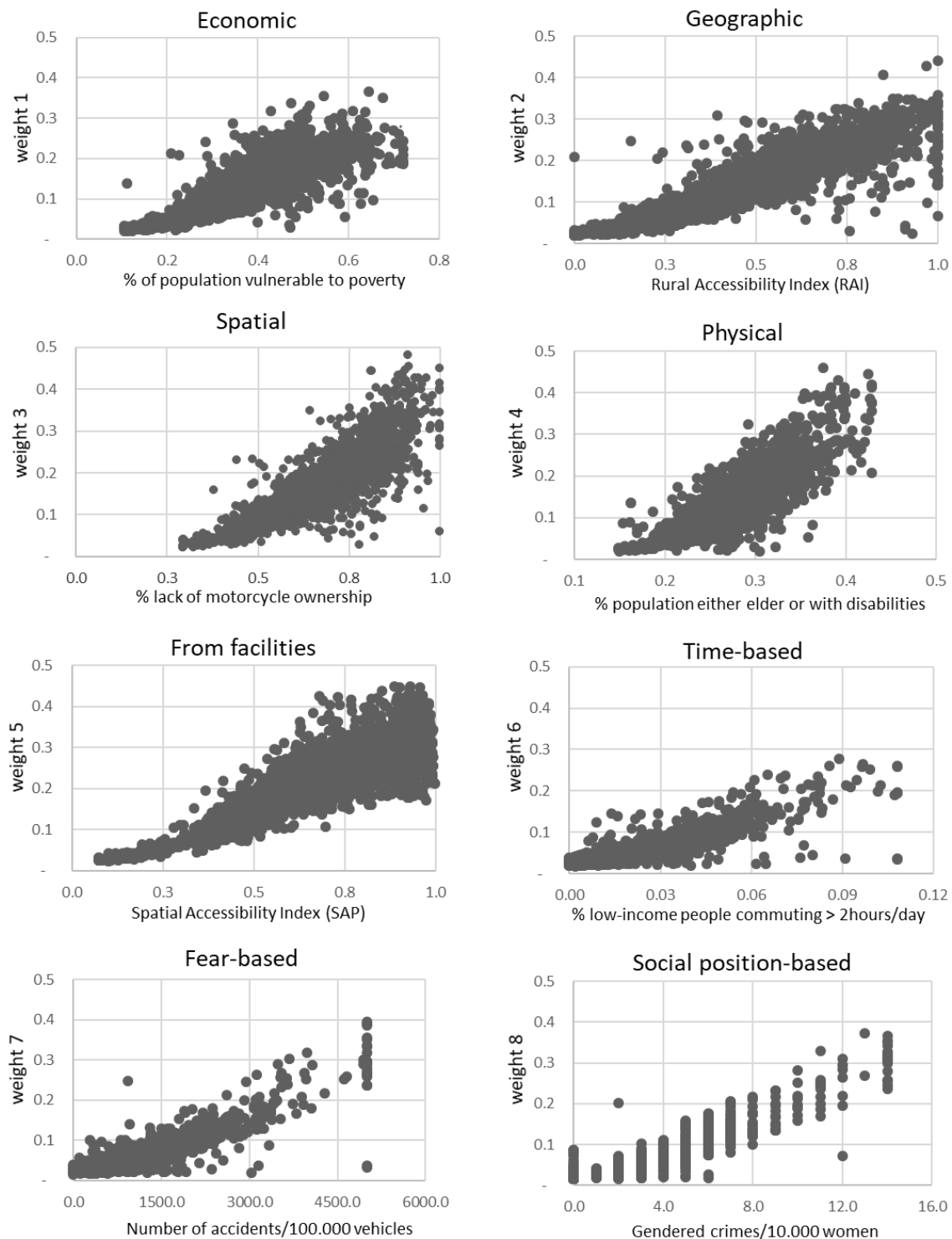


Figure 6.4: Distribution of weights derived from AHP by each indicator

6.4.2. Incremental spatial autocorrelation

The results obtained from the incremental spatial autocorrelation (ISA) analysis are summarised in Figure 6.5. Except for the first iteration ($D = 5$ km) of all the eight graphs, the following reported results are all statistically significant at a 99% confidence level (i.e. $p\text{-values} < 0.01$). This exception is due to the various sizes of the municipalities being sometimes too large to have a neighbour within the first 5 km of radius from its centre point. Nonetheless, as all the peak points of the eight graphs of Figure 6.5 (represented by the red dots) are far greater than 5 km, no further impacts are expected to be introduced in the incremental analysis by having the first iteration not statistically significant.

According to Mitchell (2005), the null hypothesis evaluated by Moran's I test is that the spatial data being analysed is randomly distributed among the study area. In that sense, if the p-value is statistically significant and the z-score is positive, the null hypothesis can be rejected, meaning that the spatial distribution of high and/or low values is probably too unusual to be a result of a random chance. Thus, since the results show z-scores greater than 2.58 (critical value according to Mitchell, 2005) and p-values lower than 0.01, it can be inferred that there is a clustering pattern in the spatial distribution of this data. In the context of this analysis, a statistically significant cluster points out to municipalities that are affected by the same transport-related exclusion dimension and, thus, can be targeted at a local and regional level with similar transport interventions.

The graphs of Figure 6.5 show that the intensity of the z-scores can reach one or more peaks as the incremental distance increases. These peaks indicate distances where spatial clustering is most pronounced (Mitchel, 2005). As already explained in Section 6.3.3, these peaks (often the first one) are appropriate values to use for tools with a distance band (e.g. Getis-Ord Gi* local cluster analysis, which are further discussed in Section 6.4.3). For cases such as the *Geographic*, *Fear-based* and *Social position-based* dimensions, where two peaks have been found by the ISA analysis (Figure 6.5), only the first peak was then considered as the chosen distance band. In other words, for these three

cases in which two significant distance bands were revealed by the ISA analysis, only the smallest one was taken into consideration for further hotspot analysis.

Moreover, the incremental analysis in Figure 6.5 demonstrates that spatial clusters formed by the prioritisation scores of the *social-position*, *fear*, and *time-based* dimensions are smaller than the other six dimensions ($D(\text{first peak}) < 100,000 \text{ m}$). With regards to the *spatial* dimension ($D(\text{first peak}) = 285,000 \text{ m}$), even though it refers to physical barriers of the local built environment, it is possible to conclude that a slightly wider group of neighbour municipalities also appear to share the same spatially excluding issues. Given this relatively low distance bands, these findings suggest that transport issues related to social exclusion based on these four dimensions tend to be much more concentrated than a regionally rooted problem in the evaluated area.

On the other hand, the dimensions related to *physical*, *geographic*, *from facilities*, and *economic* issues have their maximum intensity of spatial clustering at a wider range ($D(\text{first peak}) > 500,000 \text{ m}$). This fact suggests the transport interventions aiming at these dimensions, beyond targeting specific high ranked municipalities within the clusters, should also devise strategies to cope with these issues at a sub-regional or even state-wide level.

In summary, these results point out the scale of interventions that are needed for each of the transport-related exclusion dimensions in the case study region. The evidence has shown that while some dimensions are much more localised (e.g. social position and fear-based), others require transport interventions at a regional scale (e.g. geographic, economic, and physical). Further results are provided in the next Section showing where these interventions are mostly needed by providing the location of the hotspots of each dimension. This results finally emphasises how transport development can tackle multi-dimensional poverty in these regions.

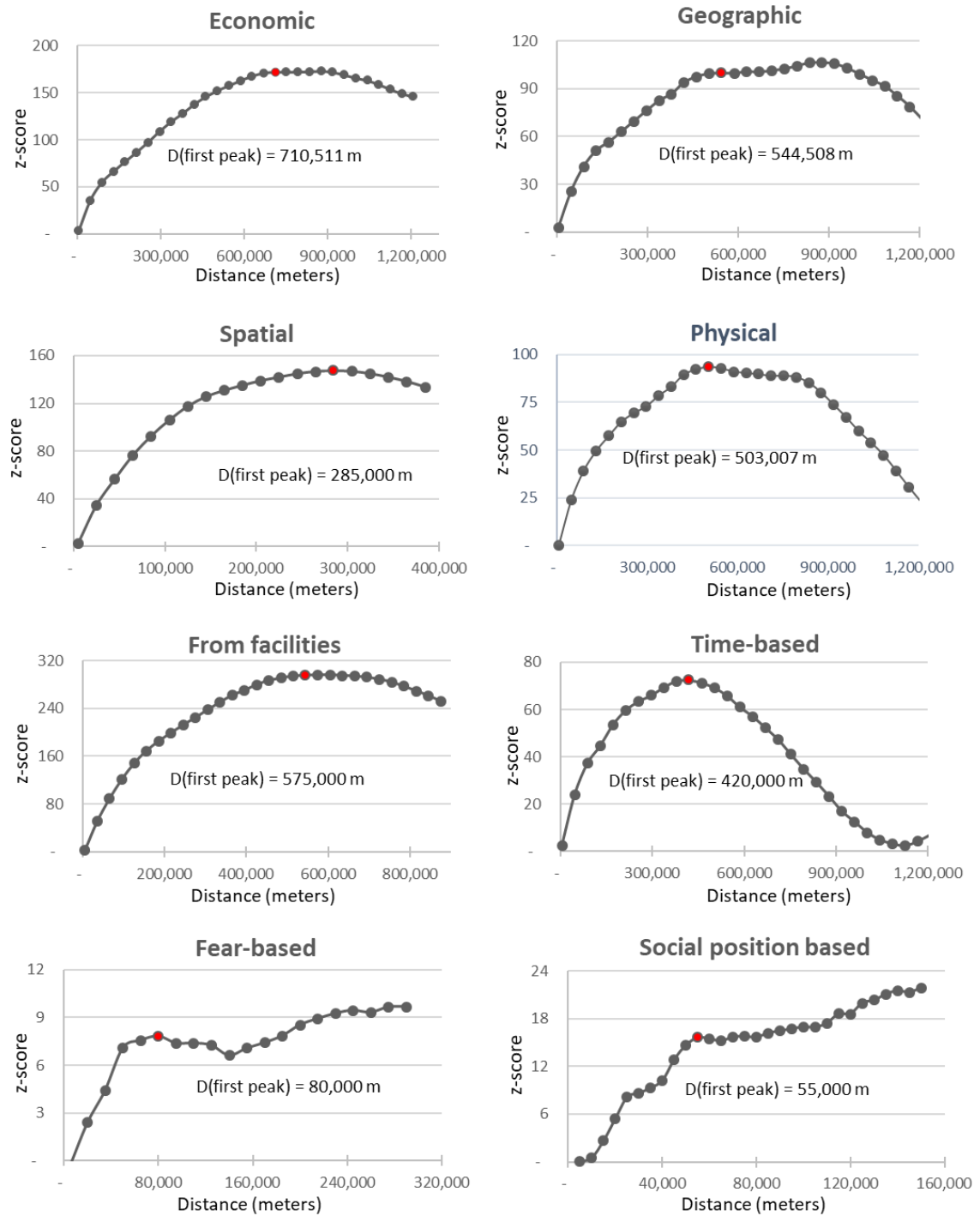


Figure 6.5: Incremental global spatial autocorrelation analysis (Moran's I) of the prioritisation scores of the transport-related exclusion proxies

6.4.3. Local spatial cluster analysis

The first z-score peak of each dimension, resulting from the incremental autocorrelation analysis, was then used as an input for the local spatial pattern association analysis, also referred as hot spot analysis (Ord and Getis, 1995). Figure 6.6 presents the maps that emerged from such an analysis. These results depict clusters of high positive z-scores (hot spots) as well as those with an intense negative z-score (cold spot). The level of confidence is also disaggregated into four confidence intervals (99%, 95%, 90% and not significant).

For a given dimension, an area considered to be a statistically significant hot spot (red) indicates that the municipalities within this area have high prioritising scores (PS_{ij}) surrounded by other municipalities with high values as well (Mitchel, 2005). In other words, the statistically significant hot spots depicted in Figure 6.6 point to areas where the municipalities are severely affected by a given transport-related exclusion dimension both from a local and regional point of view (see Equation 6.2). In this way, these maps offer supporting evidence for tailored specific interventions that can better address poverty through transport policies and investments.

Church et al (2000) highlight marginal improvements to physical accessibility in areas which already have high standards of this dimension may result in little difference to residents whose main barrier to movement is due to time-based or cost constraints. Applying this concept to the example of Ipupiara (shown at Table 6.3), the construction of new rural roads (i.e. *geographic* dimension which weight is 3%) is not expected to be as effective in reducing poverty as improvements in access to schools or healthcare (i.e. *from facilities* dimension, which weight is 39%), for example.

In response to this, the identification of these hot spots presents a crucial tool capable of identifying the priority areas in need of specific transport interventions, as well as the most pressing transport issue that is likely to be reinforcing the poverty trap in these areas. In fact, as can be seen in the maps of Figure 6.6, these eight dimensions are very often intertwined, and the same area falls within more than one hot spot, especially in areas under severe circumstances of

deprivation. Nevertheless, by separating out these maps it is possible not only to evaluate the interactions of these transport-related exclusion dimensions but also to draw regional strategies for a socially driven transport planning.

Finally, Figure 6.7 combines all the statistically significant hot spots at 99% confidence into the same map. This map depicts regions where there is overlapping of four transport-exclusion dimensions, bringing particular attention to the states of Maranhão (MA) and Piauí (PI), which are vastly covered by priority areas of 3 and 4 dimensions. Minor, yet still significant, spots of fourfold overlapping can be also spotted in Southeast of Bahia (BA), centre of Paraíba (PB) and Pernambuco (PE).

It can thus be concluded that, since these areas are affected by severe levels of multidimensional transport-related exclusion, that they might require higher priority than the others. Particularly the state of Maranhão (MA), which is entirely immersed in issues related to income poverty (*economic*), long commuting times (*time-based*), and low access to opportunities (*from facilities*), is an obvious concern clearly in need of urgent socially driven transport interventions. Taken together, these results suggest that transport planning in Northeast Brazil can and should be sensitive to social issues by including quantitative analysis, as is proposed in this study, into screening frameworks and appraisals of transport projects.

Overall, these findings elucidate a crucial step in the process of planning transport for poverty alleviation. By knowing the nature of the most critical transportation needs and the areas where they are most severe, targeted transport initiatives can be more effectively planned to break the factors that perpetuate the poverty cycle. In the next Chapter a further discussion is provided on successful cases that can be used as references for addressing these needs in Northeast Brazil and how these results can be input into the decision-making of transport policies.

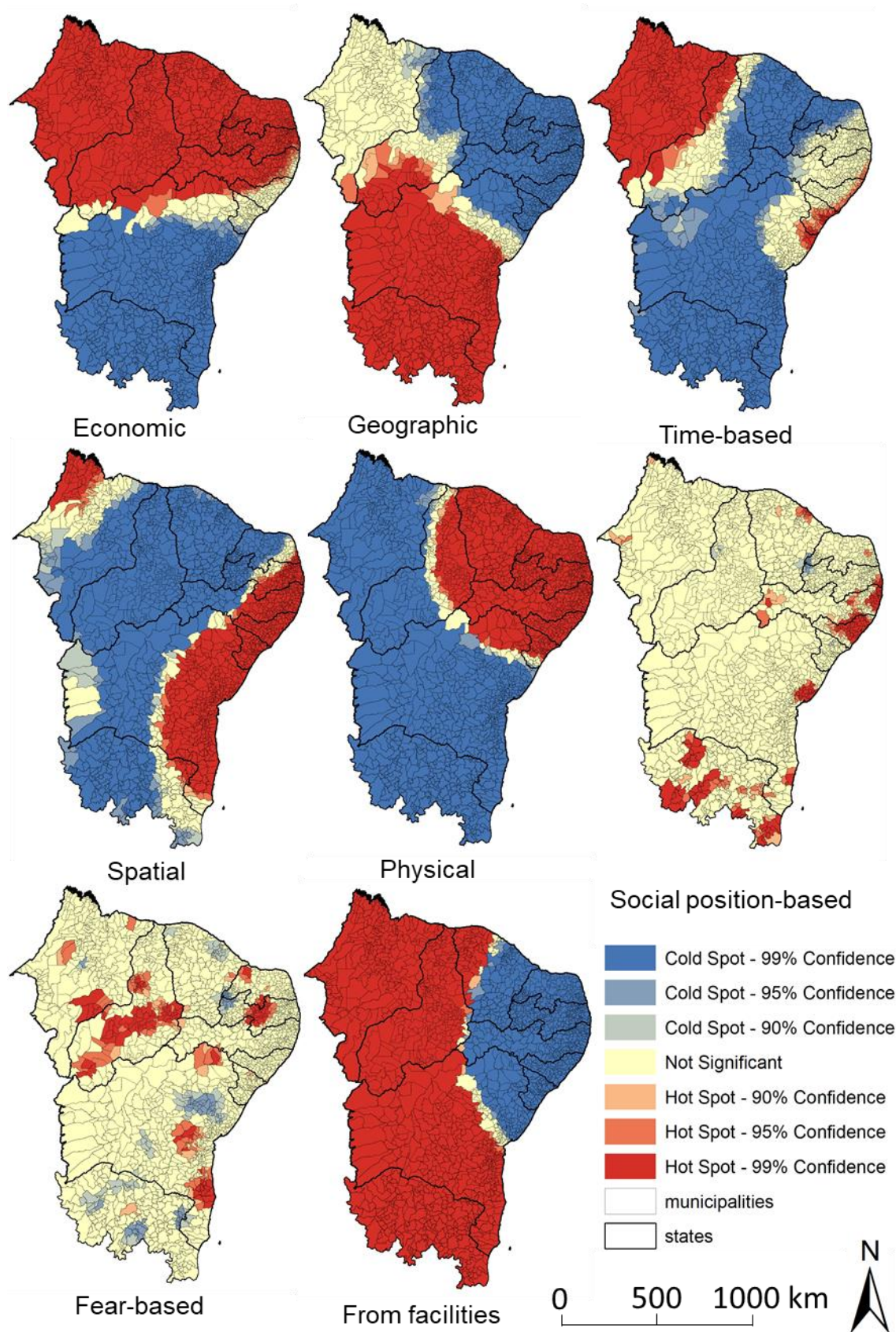


Figure 6.6: Local spatial cluster (Getis-Ord G_i^*) analysis of the prioritisation scores of the eight transport-related exclusion dimensions

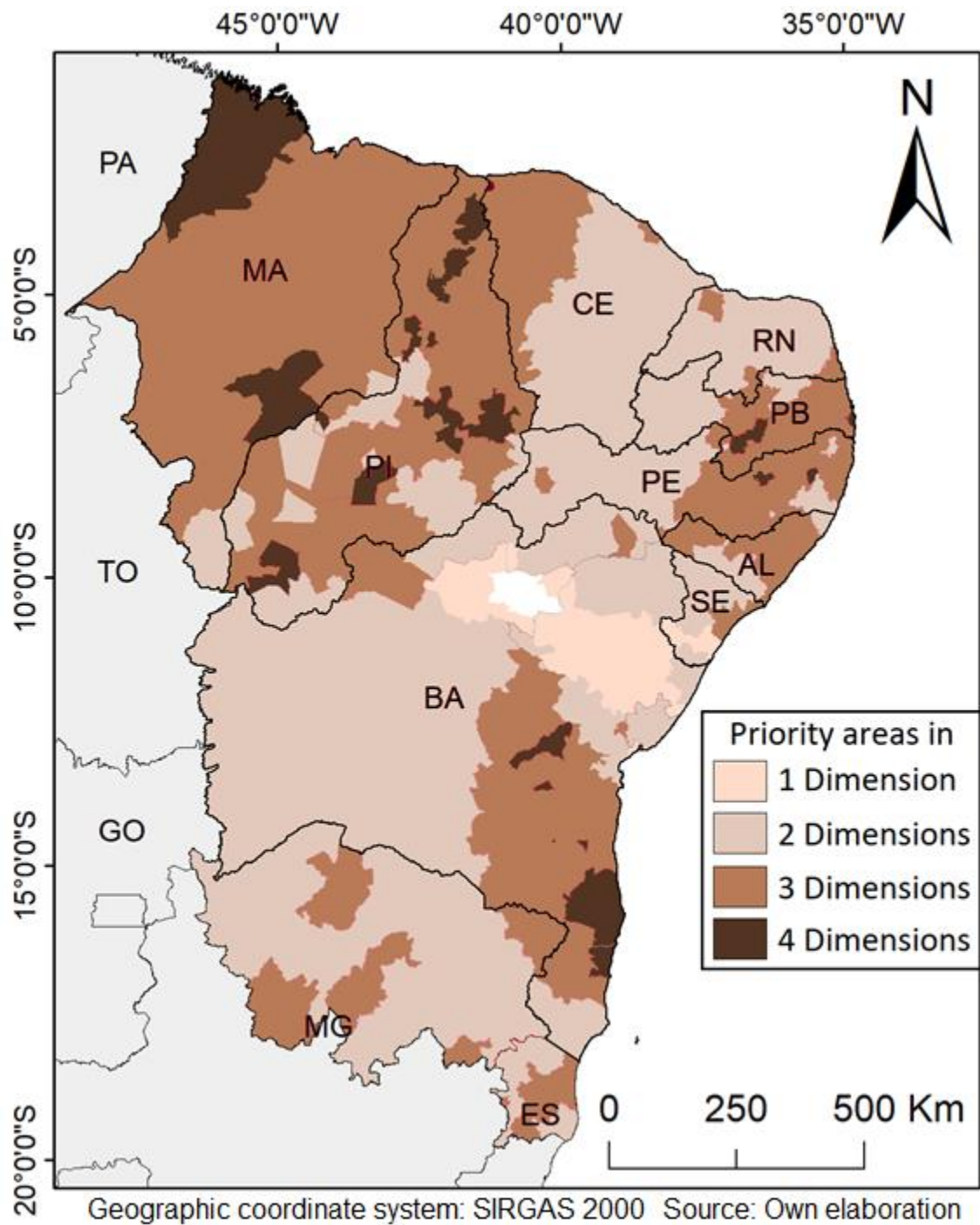


Figure 6.7: Priority areas at 99% of confidence based on the transport-related exclusion screening framework applied to Northeast Brazil

6.5. Conclusion

The framework proposed in this case study has sought to offer a screening framework that can support transport planning in Northeast Brazil by identifying transport issues that are likely to be reinforcing poverty traps both at the municipality and regional level. By applying publicly available data to well-established MCDA and spatial cluster analysis, the proposed methodology has been able to identify priority areas and priority lines of action to tackle poverty more effectively through transport development.

Previous research has documented the lack of tools for appraising social issues in transport planning (Geurs et al 2009; Van Wee and Geurs, 2011; Jones and Lucas, 2012a). On the other hand, the links between transport development, social exclusion, and poverty have been increasingly recognised in the literature (Church et al 2000; Lucas, 2012). In that sense, this Chapter contributes to the literature by proposing a framework capable of performing a transparent and objective analysis of the social dimension that can complement mainstream transport planning techniques. This framework is particularly tailored to the context of Northeast Brazil, where the poverty level is most severe in the Country and where the social dimension of transport has been continuously neglected at the planning stage.

As discussed in previous chapters, transport and accessibility are directly related to the structures, processes and livelihood strategies that affect the inter-generational transfer of poverty. The findings reported throughout this study reflect an effort to clarify which transport-related exclusion dimension should be mainly targeted at in each municipality and sub-regions in order to break the cycles of poverty.

The results have shown that municipalities within the Northeast region present different transport needs and suffer from a range of transport externalities. Therefore, the methodology of screening priorities at a sub-regional level (by clusters) and at a local level (by priority scores) can provide a systematic and evidence-based social analysis to guide transport policies.

Furthermore, the findings also highlight that whilst some areas are particularly affected by a single dimension (e.g. west of Bahia and east of Ceará states), others are overlapped by four dimensions (e.g. North of Maranhão and Center of Pernambuco states). This fact sheds light on specific sub-regions and municipalities that deserve higher priority and targeted transport interventions. Overall, it is also worth mentioning that only two out of 1990 municipalities of the entire case study region were not found in any statistically significant hot spot (considering 99% confidence). Revealing, thus, the relevance and the need for socially driven transport interventions in Northeast Brazil.

Future research is needed to integrate the weights generated by the presented framework into MCDA-based social appraisals of potential transport projects. Likewise, more detailed and comprehensive proxies should be further explored in future as soon as disaggregated poverty- and transport-related data becomes available for these municipalities. Nonetheless, for any region or municipality where this data is already available, this methodology can still be adapted to harness more transport-related exclusion indicators through this screening framework and reorient transport planning towards more effective poverty reduction strategies.

CHAPTER 7: DISCUSSION

This Chapter provides an overall discussion of the key findings presented throughout this thesis in order to clearly link them to the three research questions stated in Chapter 1.

7.1. Key findings and implications

The first research question investigated in this thesis was how transport development is linked to poverty reduction in the Global South context. As shown in the literature review (Chapter 2), the existing approaches that describe the transport-poverty nexus tend to focus on urbanised and economically developed countries and do not fully address the challenges experienced in less developed countries. This issue, occasionally suggested by previous studies (Rynning et al., 2017; Lucas et al. 2016a), has also emerged after the systematic analysis of 40 studies from developing countries through the lenses of the theoretical framework proposed by Church et al. (2000). As demonstrated with reference to the literature, the seven transport-related exclusion dimensions proposed by this seminal study in the British context must be adapted and complemented by an eighth dimension (related to the social position type of exclusion) in order to better explain the links between poverty and transport in the Global South. This theoretical update articulates a transport policy analysis framework that is compatible with the multidimensional concept of poverty against which to judge the channels that transport development can contribute to poverty reduction.

The findings from Chapter 2 also show that several factors can affect the intergeneration poverty transfer (Hulme et al., 2001). These are related to accessibility to jobs, education, social network, social capital, healthcare, and public transport. More recently, researchers have also shown that such a

phenomenon can be influenced even by the DNA since poverty leaves wide epigenetic marks in the genome⁸⁷ (McDade et al., 2019). Nonetheless, while genetic legacy and many other factors cannot be directly addressed by public policies, indirect solutions can be fostered by a more equitable and socially inclusive transport development. In this context, Chapter 2 brings to light a more nuanced understanding of how cycles of poverty can be broken by promoting specific strategies targeting the eight transport-related exclusion dimensions.

In the particular case of Northeast Brazil, Chapter 3 has shown that spatial accessibility limitations can present a major hurdle for rural low-income families when in need of basic services, such as healthcare. The results have shown that one every five people in extreme poverty is forced to travel 10 km at least, mostly by non-motorised transport, in the hottest and driest part of Brazil to reach the nearest healthcare centre. The findings also show that 53% of the rural low-income population travel over 5 km to the closest basic healthcare centre, and 60% of them are farther than 10 km from the nearest hospital. In other words, the intersectionality between income poverty and lack of access to basic services have clearly jeopardised the well-being and health outcomes of these rural low-income families. This fact has been also demonstrated by combining health-related data with the rurality and per-capita income levels from municipalities of Northeast Brazil. Whilst among more affluent municipalities the rurality level virtually does not affect the Life expectancy, among municipalities with the lowest per-capita income, the population from more urbanised municipalities are expected to live 3 years more than those living in more ruralised municipalities.

Global trends show that 90% of maternal deaths are concentrated in low- and middle-income countries, and the majority of them could have been prevented by appropriate access to healthcare (UN, 2019b). The global statistics presented in the latest Sustainable Development Goals report indicate that extreme poverty is concentrated in, and overwhelmingly affects, rural populations (UN, 2019b). This strongly supports the case that transport policies aiming at tackling extreme poverty should be concentrated on less urbanised municipalities where extreme

⁸⁷ Evidence has shown that people living in poverty have presented a particular DNA methylation process that leads to more susceptibility to developing health problems later in life.

poverty is most severe and is experienced in a number of different deprivations. Nevertheless, the proposition of public policies addressing rural transportation should be done carefully. Otherwise, even more negative externalities related to road crashes and air pollution can result as a consequence of rapid and debilitating development of motorised mobility (Jones et al., 2016; Jones et al., 2019).

From this, the next research question that has driven this thesis was how the social outcomes of transport interventions in Northeast Brazil can be measured, in order to learn from the past what has been successful in reducing poverty. The case study presented in Chapter 4 has shown two main findings on this matter that emerge by applying different-in-different matching (DIDM) techniques to publicly available socioeconomic datasets, such as those from the national census (IBGE, 2010a). First, the estimated social outcomes were shown to be substantially dependent on which method is used to analyse the data. The analysis of nearly 20% of the indicators (5 out of 26) resulted in opposing conclusions depending on whether the DIDM method was used, instead of a simple DID. This fact emphasises the potential misperceptions of a 'context-less' analysis that can lead to equivocate transport policies.

Secondly, the results demonstrated that while this large transport infrastructure investment (a crossing-state road widening project) improved the overall levels of poverty-related indicators, the impact on the average per-capita income of the population in extreme poverty was actually negative. In other words, the findings show that the population surviving in extreme poverty had their average per-capita income reduced by 8.2% after the completion of the project, while the equivalent control group presented opposite trends for the same indicator. This empirical case study serves as a cautionary tale about how large transport infrastructure investments are not enough to guarantee extreme poverty alleviation. Likewise, this fact underscores the necessity to evaluate the local needs and transport issues that mostly affect the least advantaged population when prioritising transport interventions.

Possibly, the persistent neglect of these needs assessment is not by lack of awareness nor by chance, but it has been driven by the efficient-equity trade-off

that is often mentioned in the academic literature (Gannon and Liu, 1997; Vasconcellos, 2003; Macharis et al, 2009; Haddad et al, 2011; Annema et al, 2015; Marcelo et al, 2016). In other words, decision-makers may tend to focus on transport investments that can produce higher impacts on productivity and gross domestic product growth (Haddad et al, 2011) rather than on improvements in the welfare of vulnerable people (Gannon and Liu, 1997). Mackie et al. (2014) also claim that with the global financial crisis, even decision-makers and politicians from countries⁸⁸ that usually include some social impact dimensions in traditional CBAs for transport projects are often more prone to focus on the economic impacts, rather than less tangible social benefits.

In this context, many researchers have consistently argued that CBAs or any other utilitarian approach are not enough for evaluating equity and social exclusion issues in transport appraisals since they tend to neglect specific transport needs of each region and of particular 'at risk' groups (Van Wee and Geurs, 2011; Lucas et al, 2016a; Di Ciommo and Shiftan, 2017; ITF, 2017b; Hickman and Dean, 2018). Martens and Di Ciommo (2017) conclude that even if accessibility gains are used instead of travel time savings in the traditional CBA, questions of justice and equity would still remain about the model. These authors argue that the real problem is that the utilitarian bias of a CBA framework would still prioritise the 'greatest good for the greatest population', regardless the distribution among different social categories and regions. Hickman and Dean (2018) also sustain that the nature of CBA is consequential, so it will favour projects that affect larger groups of populations in, as a rule, denser and economically more vibrant regions, rather than in socially deprived and more dispersed areas. Reinforcing, thus, the existing inequalities and poverty traps in the long run.

In response to that, over the past 15 years, researchers and planners have increasingly adopted and suggested the introduction of a second social appraisal method based on multi-criteria decision analysis (MCDA), as a complement or even a full substitute of the CBAs (Thomopoulos et al, 2009, Manaugh et al, 2015). Authors have argued that MCDA enhances the likelihood of policy success

⁸⁸ Such as New Zealand, Sweden, England, USA and Germany.

in the long run since it can be done even when data is scarce, and it is capable of reconciling conflicts among several interested and affected groups (Manaugh et al, 2015; Marcelo et al, 2016). For instance, Jones et al. (2013) have demonstrated that is possible to integrate indigenous and scientific knowledge in transport appraisals by using a MCDA framework. Likewise, Van Wee (2012) asserts that MCDA offers an alternative framework in order to include in social appraisals effects that are difficult to monetise (e.g. social and distributional effects) in traditional CBAs.

On the other hand, Lucas et al (2016b) maintain that MCDAs do not inherently clarify the distributional effects of a given project, and this needs to be carefully evaluated and embedded into the framework to ensure that priority is given to vulnerable groups. Eijgenraam et al. (2000) and Thomopoulos et al. (2009) also criticise MCDA for its subjectivity and for being susceptible to manipulation specially when assigning the weights to each criterion. In this sense, the expected benefit of a comprehensive social analysis given by MCDA frameworks could be substantially undermined by the risk of corruption and manipulation of this analysis. As a result, while MCDA frameworks have been proposed to address the limitations of traditional CBAs, they have also amplified a major flaw of subjectivity in the definition of their parameters.

This brief panorama on the limitations of the most commonly used social appraisals frameworks sheds light on the challenges that lie in the third research question of this thesis. In a context where the resources and data are scarce (UN, 2015b), and the decision-making process is dominated by politicised power (Benitez et al., 2010), the question of how to plan transport to tackle poverty requires better analytical methods that can help guide transport interventions to where and for whom they are mostly needed. Thus, the last two research Chapters (5 and 6) have sought to offer a two-fold answer to this research question: firstly, by proposing a key indicator compatible with the municipality governance level that could perform a comprehensive evaluation of the lack of access to basic services in Northeast Brazil; and, secondly, by developing a screening framework that not only addresses the current limitations of the abovementioned frameworks (CBA and MCDA), but also brings a clear

understanding on where each transport-related exclusion dimension requires higher priority of action.

By triangulating the Spatial Accessibility Poverty index against other socioeconomic indicators, Chapter 5 has shown that municipalities considered as the accessibility-poorest of Northeast Brazil have also other spatial and transport-related similarities when compared to the accessibility richest ones. The results have shown that municipalities facing higher accessibility-poverty are 6.8 times more sparsely populated (i.e. with lower population density), with 55.2% less motorways (i.e. with a lower motorway density) and have the motorcycle ownership rate 27% higher. These trends show that transport interventions targeting this municipalities are more likely to be successful in reducing poverty if they consider this decentralised demand for transport. Since investments in large infrastructure projects, such as the paradigmatic case of the widening of the BR-232 motorway assessed in Chapter 4, might not result in real improvements for the least advantaged population, it is argued that more decentralised transport interventions are needed in these municipalities in order to tackle poverty more effectively. The discussion on whether private or public transport solutions should take the lead in responding to these needs involves economic and operational issues that are out of the scope of this thesis. Yet, a few references to both scenarios can be found in the international literature.

Lessons from some European countries show that Demand Responsive Transport (DRT) can offer a high level of flexible and feasible public transport services for deprived and sparsely populated communities (Saroli, 2015; Leiren and Skollerud, 2015; Velaga et al., 2012; McDonagh, 2006). For instance, data from the Rural Transport Programme (RTP) launched in 2007 in Ireland shows an increasing popularity and effectiveness by connecting over 2 million passengers to essential services (i.e. hospitals, banks, post offices, retail centres) in 2018 (NTA, 2019). Nevertheless, concerns related to funding and affordability of these schemes in contexts of severe and multidimensional poverty might represent a significant issue to be addressed in further studies. Alternatively, when formal public transport services fail to meet the local demands for mobility,

small-scale operators of paratransit-type of services⁸⁹ come into play to fill these gaps. These informal services are often-times the only available transport alternative to carless, disadvantaged individuals to reach jobs, market, and access healthcare in areas devoid of formal public transport (Cervero and Golub, 2007). For these reasons, despite having concerns on safety, noise and air pollution, most researchers have advocated towards a middle ground between the extremes of acceptance and outright prohibition of informal flexible transport systems especially in peri-urban and rural contexts (Silcock, 1981; Cervero 2000, Kumar, 2011; Phun, 2016; Jenkins and Peters, 2016; Evans et al., 2018).

Although the latest official data (IBGE, 2019b) indicates that the current Brazilian population is mostly urban (84.7% of the total), it is important to highlight how the limitations of these definitions of 'urban' and 'rural' also result in unfavourable consequences in transport policy making. The current definition of rurality based essentially on the non-urban classification, which ignores intermediate rurality situations in thousands of small municipalities, results in a distorted picture for the transport policies aimed at this target area within the Brazilian territory. For example, using rural typification methodologies based on OECD international experiences, Bitoun et al. (2015) argue that the share of population residing in essentially and relatively rural municipalities actually corresponds to 37% of the Brazil's total population (2.5 times higher than the current official data). This fact illustrates how transport policies aiming only at urban mobility⁹⁰ could result in unfeasible transport service standards by defining the same level of service for these different so-called 'urban' contexts. Likewise, overestimating urban population can also lead to transport planning and policies to be incorrectly restrictively focused on urban mobility alone, which would result in the complete neglect of majority of people in extreme poverty who live in rural areas and are severely affected by transport-related exclusions.

The results of Chapter 5 have also shed some light on this topic, showing that income poverty is not necessarily associated with lack of accessibility. Rather,

⁸⁹ Such as minibuses, passenger-adapted trucks, vans, microvans, station wagons, three-wheelers, motorcycles taxis and pedicabs.

⁹⁰ Such as the Federal Law 12.587/2012 (Brasil, 2012) that are further discussed later.

other dimensions of poverty that are mostly present in less urbanised communities were found to be associated with high SAP levels. For example, the rural households of municipalities facing higher accessibility poverty have proportionally 9 times more households without electricity, 5 times less access to proper toilet facilities, and 1.5 times less access to adequate sewerage system than the accessibility richer ones. These findings show also how poverty cannot be fully captured by income indicators and that the local transport needs preventing social development might change even among income-poor regions. Also, this emphasises the fact that to overcome poverty, coordinated transport interventions in multiple sectors are needed (Gomide, 2004), rather than fragmented social policies. In this sense, Chapter 6 recalls the theoretical concept of the eight transport-related exclusion dimensions (Church et al., 2000) to promote a comprehensive understanding of the nature of the transport interventions that should be prioritised in each municipality and sub-region of Northeast Brazil.

As explained in Chapter 2, the factors that promote the inter-generational poverty transfer can be reduced by developing specific strategies to tackle these eight dimensions individually when planning transport. While the proposed priority scores proposed in Chapter 6 have revealed specific priorities within each municipality, the overall results of this Chapter have presented a high clustering pattern of these dimensions with a particularly high prevalence of the exclusion from facilities. The states of Piauí and Maranhão have shown the largest number of municipalities overlapped by 3 and 4 hotspots of transport exclusion simultaneously. These results make a strong evidence base to help guide future targeted transport interventions aiming at reducing the mechanisms that prevent people to escape poverty.

Additionally, the weights which resulted from the analysis in Chapter 6 can serve as a valuable input for social appraisals of transport projects using MCDA frameworks. Since these weights represent an evidence-based ranking of social priorities, they can mitigate the risk of corruption and manipulation when defining the social criteria and their respective weights in MCDA frameworks. This contribution represents a significant step forward in the methods for prioritising

transport projects that are crucially needed for planning a socially inclusive transport. Building upon these weights, performance indicators can then assess how a potential transport project will impact the most relevant local needs. In this way projects that deliver solutions of greater social impact to problems of greater importance (translated by the higher weights) will, therefore, receive greater prominence in the MCDA appraisal.

7.2. Policy recommendations

A number of theoretical insights, appraisal methods, and policy guidance have been proposed throughout this thesis based on the evidence raised in each chapter. Likewise, the recommendations consolidated in this Section are intended to support policy-makers, researchers and practitioners involved in transport planning and poverty reduction programmes in the Global South, particularly those from Northeast Brazil. The list of policy recommendations presented in this Section gives broad guidance in order to make public spending on transport development more effective in reducing poverty. To avoid the recurrent issue of seeing the government as a singular entity (Veeneman and Mulley, 2018), the recommendations provided in this Section are divided into the three levels of governance that are practiced in Brazil. In the absence of broader guiding legislation (for both rural and urban contexts) defining the roles of each government layer in this matter, the present Section draws policy recommendations based on the duties defined by the Federal Law 12.587/2012, also called Law of Urban Mobility (Brasil, 2012).

As shown in Chapter 3 and 5, the greatest challenges of transport that prevent people in extreme poverty to access essential services occur predominantly in remote and sparsely populated communities, where the nearest urban or healthcare centre are still very far for a non-motorised trip. Therefore, in order to improve accountability and effectiveness of public transport policies targeting these communities, it is firstly suggested a more objective definition of duties of each level of governance in the planning and provision of transport services and infrastructure for remote and sparsely populated regions. In other words, future federal transport policies should consider a transversal update on the concept of

passenger transportation, as being far greater than just urban mobility. In the same way, while the specific strategies that are devised below support the main assignments of each government level according to the Law of Urban Mobility (n. 12.587/2012), they also consider this broader concept of transport, including peri-urban, rural and remote rural mobility.

7.2.1. Federal level

Developing an urban mobility data system

Perhaps the most common issue consistently raised throughout this thesis was the lack of transport- and poverty-related data. Opensource, timely and spatially disaggregated data is a sine qua non condition for tackling poverty more effectively. For example, the location of low-income residents could be easily collected when they are registered in public social programmes such as P1MC, *Bolsa Familia*⁹¹, etc. Likewise, simple spatial databases containing the locations (latitude/longitude) of public schools, public transport stops, social security centres, police stations, and other basic public services could unchain a myriad of accessibility analysis that would result in a huge stride for an equitable development of transport, as well as other sectors. Despite rapid advances in technologies using artificial intelligence, for example, to map roads automatically from satellite images (e.g. Mapwith.ai), manual mapping efforts are likely to remain needed to generate and update GTFS databases at a national level. Therefore, it is vital to deepen this agenda within this Information System, mapping and gathering data not only in urban but also in rural areas. This is also a crucial step in informing independent researchers, advocacy groups (e.g. INFRA2038) and grassroots movements (e.g. ASA) that can increase the accountability on the social dimension of transport development and collaborate in developing new tools and studies to support decision-makers.

⁹¹ It is a well-established cash transfer programme that currently benefits over 14.1 million families living in poverty or extreme poverty Brazil (Brasil, 2019).

Giving technical and financial assistance to states and municipalities

As shown in Chapter 5, the municipalities facing better spatial accessibility also present a GDP 132.4% higher than those with worst accessibility levels. This fact indicates limitations that might occur not only related to the lack of qualified human resources to perform appropriate transport planning, but also to properly invest in essential transport projects at the local level. In that sense, considering the limited budget available to this end, Federal Agencies could benefit from the municipality rankings and hotspot maps developed in this thesis (Chapter 5 and 6) to support the prioritisation of municipalities where there is a higher need for financial and technical support from the Federal government.

Fostering medium and large-scale transport projects in urban agglomerations and metropolitan regions

Based on the findings of Chapter 4 on how the large-scale transport investment has impacted upon extreme poverty, it is recommended to complement technical, economic and environmental appraisals with social impact evaluations (ex-ante) to foster more socially inclusive transport projects. To do so, the framework proposed in Chapter 6 combined with the MCDA techniques further addressed in Appendix A are likely to bring transparency and objectivity to the planning stage of the transport infrastructure life cycle. Moreover, ex-post analysis, as developed in Chapter 4, of previous transport projects of this magnitude can also promote an important learning process to feedback future planning. In this way, a new standard of transport planning is expected to be achieved, reconciling the supply requirements (economic efficiency and technical feasibility) and the needs of people who have been mostly prevented from accessing essential services and life opportunities.

Supporting coordinated actions among municipalities and states in conurbations.

As pointed out in Chapter 6, there is a high clustering pattern on the distribution of all the eight transport-related exclusion dimensions, in which the clustering size varies from 42km (for the time-based dimension) to 710 km (for the economic dimension). These clusters of municipalities reveal where and which kind of targeted actions should be primarily coordinated by the Federal Government

among municipalities and states in policy instruments such as Regional Development Plans (SUDENE, 2019). The results from this thesis have shown that the states of Maranhão and Piauí should be given the top priority of these coordinated actions since their municipalities have the higher number of hotspots of transport-related exclusions.

7.2.2. State level

Providing public intercity public transport services

Studies measuring spatial accessibility, as presented in Chapter 5, are capable of revealing where the most profitable demands for intercity public transport services are (cold spots of this dimension), and conversely, the sub-regions presenting the most remote areas with very limited access to urban centres. By harnessing this kind of information, state governments might be able to design bidding contracts serving accessibility poor regions as a counterpart for winning profitable routes, combining economic efficiency with social sustainability. For the specific case of Northeast Brazil, while the higher demand for intercity services is likely to remain along the shore at the eastern side⁹², Chapter 5 also highlights that large areas in Piauí, Maranhão and West Bahia require further attention when planning intercity public transport to reduce the impacts of spatial accessibility poverty in these municipalities.

Proposing specific tax policy and incentives for the implementation of PNMU (i.e. National Plan of Urban Mobility)

Following the guiding principles of equity, social inclusion and universal access present in the PNMU (Brasil, 2013), evidence from Chapter 2 has shown some specific groups of people that should be given priority when designing equitable tax policies and specific incentives of transport. Therefore, it is essential to evaluate the distributional effects of any proposal of this nature, disaggregating the impacts by gender, age, ability, race, and income strata. As shown in Chapter 2, these social groups generally present specific travel behaviours, especially

⁹² In states such as Sergipe, Alagoas, Paraíba, Rio Grande do Norte, and East of Pernambuco

when there is intersectionality of more than one layer of social exclusion. Therefore, targeted incentives should consider these patterns, including social characteristics of the beneficiaries and their preferred mode of transport and routes, in order to better serve these critical groups.

7.2.3. Municipality level

Planning, executing and evaluating the Urban Mobility Policy;

A transport recommendation that can be drawn from this thesis is that Urban Mobility Plans and other transport policy instruments at municipality level (Barone, 2003) should be tailored according to the relative importance of the local transport needs. This is particularly illustrated in Chapter 6 by many examples of municipalities with similar figures of a given transport-related exclusion indicator that represent different levels of local priority. In this sense, it is argued that the local hierarchisation of transport-related exclusion dimensions might point out to transport interventions that will have a higher impact on improving the conditions of the most vulnerable population. As shown in Chapter 2, the intergenerational cycle of poverty is woven in a tangle of exclusions that can be mitigated by appropriate transport interventions. In this sense, instead of isolated and remedial poverty-reduction actions, a socially-inclusive transport planning is suggested to foster long-term and effective solutions to break these cycles.

Promoting regulation of urban transport services;

The main reason for the increase of informal transport services in Brazil is the lack of an appropriate regulatory framework, that usually causes shortcomings on the regular public transport such as inadequate itineraries, low frequencies, few service options, high tariffs, poor comfort, among others (Gomide, 2004). Moreover, as already discussed in the previous Section, the disruption of informal transport services can jeopardize even more the accessibility of the least advantaged population since this is often the only option available for them. Therefore, the results presented in this thesis, especially in Chapter 6, call on decision-makers to reflect on how regulation of transport services should be

structured taking into account the travel behaviour of the low-income population to promote a more inclusive and equitable transport system.

Providing directly, indirectly or by associated management, the essential urban collective public transport services;

Since the predominant transport-related exclusion dimension in the Northeast is lack of access to essential services and opportunities, it is argued that the heatmaps provided in Chapter 5 showing the spatial accessibility poverty can offer a transparent and less paternalistic evaluation of which areas deserve priority investments in this matter. But that is not enough. To plan an effective provision of essential transport services for people facing multidimensional poverty, it is important also to understand their accessibility restrictions as people and not only as inhabitants of a certain place. As low-income people in Northeast Brazil mostly travel by NMT (Cortez and Vaz, 2013; ANTP, 2018) and are primarily affected by land price variations, it is also essential to integrate any future transport investment with an ample strategy to improve NMT infrastructure (e.g. cycle lanes and footpaths) as well as land use and housing measures to avoid unexpected gentrification processes. Especially in Northeast Brazil where local governments face constant scarcity of resources and fiscal crisis, it is crucial to make transport investments more effective in addressing these needs.

CHAPTER 8: CONCLUSIONS

This Chapter outlines the main conclusions that can be drawn from this research, explaining how the five objectives proposed in Chapter 1 have been met throughout the thesis. This final Section also summarises the main contributions to the knowledge in the field of transport planning and policy, while also acknowledging its methodological and data limitations in a critical assessment. Finally, future directions for research relating poverty reduction and transport development are suggested, based on the topics that have not been fully captured by this project as well as on emerging issues that are likely to influence future academic research around this theme.

8.1. Thesis summary

The overarching goal of this research was to promote a new standard of transport development in Northeast Brazil strongly committed to poverty eradication. To this end, the first specific research objective was to develop a theoretical framework that could help guide transport policies to tackle the poverty trap more effectively in the Global South context. This objective has been achieved by adapting the seminal transport policy analysis framework published by Church et al. (2000) to meet the challenges reported by 40 recently published papers addressing the transport-poverty nexus in the Global South. It was concluded that targeted transport initiatives should take into account all the eight transport-related exclusion dimensions described in Chapter 2 in order to foster social development and mitigate the intergenerational poverty transfer.

The second objective was to evaluate the current level of access to basic services of people in extreme poverty in Northeast Brazil. By evaluating the location of nearly half-million cisterns given by the Federal Government to low-income

families, the spatial accessibility to healthcare and urban centres of remote low-income households in Northeast Brazil has been investigated. From the analysis in Chapter 3, it was possible to conclude that more than half of the low-income rural families in this region live more than 5 km from the nearest basic healthcare centre and over 10 km from the nearest urban centre, where most of the basic public services and job opportunities are located. These results emphasise that the majority of this rural low-income population, who mostly live in a walking world, experience a severe transport-related burden preventing them from accessing essential public services, which often translates into significant worsening in living and health conditions.

The third objective of this research was to develop an ex-post evaluation framework to assess the impacts of transport interventions upon low-income residents of Northeast Brazil, using publicly available data only. Chapter 4 has sought to meet this goal by structuring and testing such a framework in a case study involving a road-widening project in Pernambuco state. In the development process of this framework, it was possible to conclude that the estimated social outcomes are highly sensitive to the assessment method that is applied to interrogate the data (comparing DID and DIDM techniques). This shows how crucial it is to consider the context of these transport interventions to purge eventual confounding factors from the ex-post impact analysis. Moreover, the case study assessed by this framework has also shown that despite the overall socioeconomic progress brought about by this large transport investment, the least advantaged groups within the project catchment area have not benefitted from this project. This fact calls attention to the need for complementary actions targeting these groups to ensure an equitable and inclusive distribution of public investments.

The fourth objective of this thesis was to develop a spatial indicator that could measure the lack of access to basic services and opportunities at the municipality level for the entire region of Northeast Brazil. While the findings in Chapter 3 give an unprecedented statistical panorama on this issue, Chapter 5 was set out to explore this question from a spatial standpoint enabling, thus, more accurate and socially inclusive transport interventions. Although the results of these two

chapters are not directly comparable (i.e. statistical vs spatial), they complement each other to provide a comprehensive assessment of the exclusion from facilities in the Northeast Brazil.

Due to the scarcity of spatial data in this context, the indicator had to be developed with a fairly basic amount of spatial inputs, summarising for each municipality the overlapping influence of the surrounding urban centres on its rural localities. On the other hand, the relative simplicity of this model allows its replicability in other regions with similar widespread poverty and lack of spatial data, where few similar indicators have been applied. The analysis of the SAP index in Northeast Brazil has shown that high rates of income-poverty or rurality in a given municipality do not necessarily imply high levels of spatial accessibility poverty. Rather, low access to basic services was found to be much more associated with deprivations of housing facilities (such as sanitation and electricity), and low population density. Beyond showing that not all cases of income poverty are necessarily associated with accessibility poverty, this fact also highlights the concept of multi-dimensional poverty, reinforcing that income measurements should be complemented by other exclusion dimensions (such as accessibility) when planning for more socially sustainable transport development.

Finally, the fifth objective of this research was to combine the proposed theoretical concept (Chapter 2), the spatial accessibility indicator (Chapter 5), and other publicly available datasets into a screening framework of transport needs. In Chapter 6, this tool was developed to point out the lines of actions that should receive higher priority from the transport authorities at a local and regional level. Besides calculating the hierarchy of dimensions to be addressed for each municipality, this last research Chapter also called attention to the precise location of a number of different hotspots of high concentration of multiple transport-related deprivations. Hence, the final recommendations for future transport planning and policy discussed in Chapter 7 were founded upon the theoretical, quantitative and spatial evidence raised throughout this thesis.

8.2. Main contributions

Several gaps in the existing literature were identified in the literature review (Chapter 2), as well as in the introduction of each research chapter (Chapters 3-6). This thesis has sought to provide innovative methodologies and raise evidence to address these gaps and contributes to the state of the knowledge on transport planning and poverty reduction by:

- Conceiving a theoretical framework showing the nexus between transport planning and intergenerational poverty transfer in the context of the Global South
- Updating the traditional transport-related exclusions dimensions model proposed by Church et al. (2000) with an eighth dimension (based on the social position) that is particularly suitable for countries of the Global South
- Applying a cisterns location dataset to proxy for the low-income households in Northeast Brazil, which have allowed quantitative evaluations of the current level of access to basic services and opportunities of the least advantaged population in this understudied area, and have highlighted how transport issues can undermine public health and wellbeing in these contexts
- Structuring an ex-post analysis framework capable of evaluating the social outcomes of transport interventions in Northeast Brazil using publicly available datasets only, thus, unlocking a myriad of possibilities of case studies to assess from a social impact perspective, the transport interventions which occurred between previous censuses
- Assessing the project of widening the motorway BR-232 in Pernambuco state in terms of social impacts and distributional effects on different low-income groups in the municipalities along the project
- Developing an index to measure spatial accessibility to key destinations based on simple land-use patterns, as an alternative to data-intensive accessibility indicators that are not applicable where the transport network is not consistently mapped in the Global South. The SAP index is also built based on the prioritarian principle which does not require the definition of an arbitrary accessibility poverty line for defining priority areas

- Proposing a tailored transport screening framework capable of performing a transparent and objective analysis of the social dimension that can complement mainstream transport planning techniques in Northeast Brazil, and pointing out the lines of actions that are most needed at a local and regional level to target poverty through transport development more effectively

8.3. Critical assessment

While this research endeavour has sought to address as much as possible the central questions about the transport-poverty nexus in underexplored and data-scarce areas, some limitations of scope and methodology should be acknowledged to offer a clear understanding about which ways this work can be improved in future. Overall, the methods applied in this thesis are limited by the trade-off between model sophistication and data availability. For instance, while accessibility models of high accuracy are currently inapplicable in these areas as they require unavailable sets of spatial data to be processed, Chapters 3 and 5 had to use simpler models based on Geodesic distance and Friction Surface to cope with these data limitations. Similarly, the SAP index that applies the locations of urban centres to proxy essential services and opportunities, could be enhanced in an updated version considering the exact location of these points of interest, as soon as their locations become consistently available in Northeast Brazil.

With regards to the scope of the ex-post analysis, as already mentioned in Chapter 4, this research has not investigated the direct impacts of transport infrastructure investments on health outcomes. Moreover, despite being reasonable to assume that neighbour municipalities with similar characteristics (translated by a similar propensity score) tend to be homogeneous in terms of socioeconomic conditions, other sources of endogeneity that could affect social development such as private investments, and targeted public initiatives in healthcare, education, and welfare have not been considered in this study. Also, the distributional impacts within the municipalities could not be considered

beyond the rural/urban differences in this analysis since there was no further disaggregation of the publicly available datasets for these municipalities.

Finally, even though the social impact and accessibility evaluations of this study were mainly focused on rural areas where poverty is most severe, the negative effects of transport-related exclusions on urban residents did not go unnoticed. Although global trends show that the majority of people in extreme poverty still live in rural areas (UN, 2019b), a substantial number of poverty-stricken groups living in the fringes of post-colonial cities also face concerning transport issues. While this issue has garnered some attention in large cities from Southeast Brazil, like Sao Paulo (Pritchard et al., 2019) and Rio de Janeiro (Pereira, 2018), this thesis has not been able to cover the metropolis in the Northeast at the same level of detail.

8.4. Future research

The United Nations projects that, if trends are kept and no significant change in the current policies are made, extreme poverty will remain around 6% of the global population by 2030 (UN, 2019b), which in absolute terms will represent over a half billion people. In the realm of transportation, this projection shows the clear need to increase research on methods for a socially driven transport planning that can be translated into the universalisation of access to basic services and life opportunities, primarily for those trapped in chronic and multidimensional poverty.

A natural progression of this research field is to address the data limitations often referred to throughout this thesis. For example, as GTFS data, and transport-related data become consistently available and more disaggregated in the Global South, more accurate accessibility measurements will become also possible. Moreover, as artificial intelligence enables an increasingly accurate satellite imagery interpretation (e.g. mapwith.ai), spatially disaggregated data on the transport infrastructure will shortly not be a problem for accessibility measures even in remote areas anymore. Rather, the innovative methods to map socioeconomic and travel behaviour indicators in low-income regions might offer

a promising research avenue to move forward the debate on transport planning, poverty reduction, and social exclusion. Moreover, as the literature review chapter has shown, with more disaggregated data at hand, essential accessibility analysis will become possible, disaggregating evaluations by services (education, healthcare, public transport), by socio-economic features (e.g. income groups, gender, age), by transport modes (including informal and nonmotorized modes), by location (rural/urban, central/peripheral areas), and job opportunities (separating by job requirements and including informal jobs).

On the other hand, with the majority of people moving towards urban areas, and serious transport issues emerging from a debilitating and unconstrained urbanisation process (UN Environment, 2016), deprived and sparsely populated regions are less likely to attract as much transport research and investments as urban mobility issues. In this sense, if decision-makers and researchers are willing to deepen the agenda of '*leaving no one behind*' (UN, 2018), the trade-off between equity and efficiency might come to the fore in the academic and public debate. Thus, further research showing how to integrate the weights of the transport-related exclusion dimensions (presented in Chapter 6) into MCDA-based transport appraisals might be another interesting line for future research in this context. These are a few possible directions to extend the research on how transport development can be instrumental in achieving the first Sustainable Development Goal of eradicating poverty everywhere and in all its forms by 2030.

PUBLICATIONS

Journal Papers:

Benevenuto, R., Caulfield, B., Poverty and transport in the Global South: An Overview, *Transport Policy*, 79, 2019, p115 – 124. DOI: 10.1016/j.tranpol.2019.04.018

Benevenuto, R., Azevedo, I.C.C. and Caulfield, B., 2019. Assessing the spatial burden in health care accessibility of low-income families in rural Northeast Brazil. *Journal of Transport & Health*, 14, p.100595. DOI: 10.1016/j.jth.2019.100595

Benevenuto, R. and Caulfield, B., 2020. Measuring access to urban centres in rural Northeast Brazil: A spatial accessibility poverty index. *Journal of Transport Geography*, 82, p.102553. DOI: 10.1016/j.jtrangeo.2019.102553

Conference Proceedings:

Benevenuto, R., Fernandez, F., Caulfield, B., From rural poverty to urban amenities - Assessing the risk of accessibility poverty in Northeast Brazil. *46th European Transport Conference*, Dublin Castle, 2018. Available at: <https://bit.ly/30R9yIp>

Benevenuto, R., Fernandez, F., Caulfield, B., Assessing social outcomes of transport investments – A quasi-experimental study of Pernambuco, Brazil. *Civil Engineering Research Ireland (CERI) Conference*, Dublin, Ireland, 2018.

Benevenuto, R., Fernandez, F., Caulfield, B., Accessibility and extreme poverty in Rural Northeast Brazil. *The International Network for Transport and Accessibility in Low-Income Communities (INTALInC) Workshop*, University of Oxford 2018. Available at <http://doi.org/10.13140/RG.2.2.15585.15204>

Guimarães, T., Benevenuto, R. Assessing Urban Mobility Plans through the lenses of transport equity. Case study of four Brazilian cities. *NECTAR Cluster 7 Social and Health Issues international workshop*. University of Utrecht, 2018.

Benevenuto, R., Caulfield, B., Addressing poverty through transport development in the developing World, *Irish Transport Research Network Conference*, Dublin, Ireland, 2017. Available at: <https://bit.ly/31vixJv>

REFERENCES

- Adedini, S.A., Odimegwu, C., Bamiwuye, O., Fadeyibi, O. and Wet, N.D., 2014. Barriers to accessing health care in Nigeria: implications for child survival. *Global health action*, 7(1), p.23499.
- Adeel, M., Yeh, A.G.O. and Zhang, F., 2016. Transportation disadvantage and activity participation in the cities of Rawalpindi and Islamabad, Pakistan. *Transport Policy*, 47, pp.1-12. DOI:10.1016/j.tranpol.2015.12.001
- Agbenyo, F., Nunbogu, A.M. and Dongzagla, A., 2017. Accessibility mapping of health facilities in rural Ghana. *Journal of Transport & Health*, 6, pp.73-83. DOI:10.1016/j.jth.2017.04.010
- Albuquerque, M.V.D., Viana, A.L.D.Á., Lima, L.D.D., Ferreira, M.P., Fusaro, E.R. and Iozzi, F.L., 2017. Desigualdades regionais na saúde: mudanças observadas no Brasil de 2000 a 2016. *Ciência & Saúde Coletiva*, 22, pp.1055-1064.
- Alkire, S. and Foster, J. 2008. Counting and multidimensional poverty measurement. Oxford: Oxford Poverty & Human Development Initiative - OPHI, 33 p. (OPHI working papers, n. 7). Retrieved at 15/02/2019 from <<http://www.ophi.org.uk/wp-content/uploads/ophi-wp7.pdf>>. Acesso em: nov. 2017.
- Alkire, S. and Foster, J., 2011. Counting and multidimensional poverty measurement, *Journal of Public Economics* 95, 476-487. DOI:10.1016/j.jpubeco.2010.11.006
- Alkire, S. and Santos M. E., 2014. Measuring Accurate Poverty in the Developing World: Robustness and Scope of the Multidimensional Poverty Index. *World Development* Vol. 59, 251-274. DOI: 10.1016/j.worlddev. 2014.01.026
- Alkire, S. and Seth, S., 2015. Multidimensional poverty reduction in India between 1999 and 2006: Where and how? *World Development*, 72, pp.93-108. DOI: 10.1016/j.worlddev.2015.02.009

- Alkire, S., 2007. Choosing dimensions: The capability approach and multidimensional poverty. In *The many dimensions of poverty* (pp. 89-119). Palgrave Macmillan, London. DOI:10.1057/9780230592407_6
- Alkire, S., Chatterjee, M., Conconi, A., Seth, S., Vaz, A., 2014. Poverty in Rural and Urban Areas: Direct comparisons using the global MPI, The Oxford Poverty and Human Development Initiative (OPHI), Briefing 24.
- Amann, E., Baer, W., Trebat, T. and Lora, J.V., 2016. Infrastructure and its role in Brazil's development process. *The Quarterly Review of Economics and Finance*, 62, pp.66-73.
- Anand, A. and Tiwari, G., 2006. A gendered perspective of the shelter–transport–livelihood link: the case of poor women in Delhi. *Transport Reviews*, 26(1), pp.63-80. DOI:10.1080/01441640500175615
- Annema, J.A., Mouter, N. and Razaei, J., 2015. Cost-benefit analysis (CBA), or multi-criteria decision-making (MCDM) or both: politicians' perspective in transport policy appraisal. *Transportation Research Procedia*, 10, pp.788-797.
- ANTP (Associação Nacional de Transportes Público), 2018. Sistema de Informações da Mobilidade Urbana - Simob/ANTP. Relatório geral 2016. Available at <http://files.antp.org.br/simob/simob-2016-v6.pdf>
- Apparicio, P., Abdelmajid, M., Riva, M. and Shearmur, R., 2008. Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues. *International journal of health geographics*, 7(1), p.7.
- Armstrong-Wright, A., 1986. *Urban Transit Systems*, World Bank Technical paper number 52.
- Articulação do Semiárido Brasileiro (ASA), 2018. Programa 1 milhão de cisterna, retrieved from <http://www.asabrasil.org.br/acoes/p1mc>
- Asher, S. E.; Novosad, P. M., 2018. Rural roads and local economic development (English). Policy Research working paper; no. WPS 8466. Washington, D.C.:

World Bank Group. <http://documents.worldbank.org/curated/en/204301528246225577/Rural-roads-and-local-economic-development>

Asomani-Boateng, R., Fricano, R.J. and Adarkwa, F., 2015. Assessing the socio-economic impacts of rural road improvements in Ghana: a case study of Transport Sector Program Support (II). *Case studies on transport policy*, 3(4), pp.355-366. DOI:10.1016/j.cstp.2015.04.006

Assis, T. R. P., 2012. Sociedade civil e a construção de políticas públicas na região semiárida brasileira: o caso do programa um milhão de cisternas rurais (P1MC). *Revista de Políticas Públicas*, 16(1).

Austin, P.C., 2011. An introduction to propensity score methods for reducing the effects of confounding in observational studies. *Multivariate behavioral research*, 46(3), pp.399-424.

Babinard, J.; Hine, J.; Ellis, S.; Ishihara, S.. 2010. Mainstreaming gender in road transport : operational guidance for World Bank staff. Transport paper series ; no. TP-28. Washington, DC: World Bank.

Banister, D., 1994. Equity and acceptability in internalising the social costs of transport. *EMCT, Internalising the social costs of transport*, pp.153-175.

Barone, M. Pobreza, 2003. Pobreza, Transporte e Inclusão Social. 14º Congresso de Transportes e Trânsito em Vitória/ES ANTP. Available at http://files-server.antp.org.br/_5dotSystem/download/dcmDocument/2013/01/21/E16178C3-9D55-4F45-ABDE-02DD83888054.pdf

Barros, M.B.D.A., Francisco, P.M.S.B., Zanchetta, L.M. and César, C.L.G., 2011. Trends in social and demographic inequalities in the prevalence of chronic diseases in Brazil. *PNAD: 2003-2008. Ciencia & saude coletiva*, 16(9), pp.3755-3768.

Bell, S., Wilson, K., Shah, T.I., Gersher, S. and Elliott, T., 2012. Investigating impacts of positional error on potential health care accessibility. *Spatial and spatio-temporal epidemiology*, 3(1), pp.17-29.

- Benevenuto, R. and Caulfield, B., 2019. Poverty and transport in the global south: An overview. *Transport Policy*, 79, pp.115-124. DOI: 10.1016/j.tranpol.2019.04.018
- Benevenuto, R., Fernandez Jr., F. Caulfield, B., 2018. From rural poverty to urban amenities - Assessing the risk of accessibility poverty in rural Northeast Brazil. In *European Transport Conference papers 2018*, Dublin, Ireland. Association for European Transport (AET). Available at <https://aetransport.org/en-gb/past-etc-papers/conference-papers-2018?abstractId=5895&state=b>
- Benitez, D., Estache, A. and Søreide, T., 2010. Dealing with politics for money and power in infrastructure. The World Bank. DOI:10.1596/1813-9450-5455
- Beuran, M., Gachassin, M. and Raballand, G., 2015. Are There Myths on Road Impact and Transport in Sub-Saharan Africa?. *Development Policy Review*, 33(5), pp.673-700. DOI:10.1111/dpr.12125
- Bitoun, J., Miranda, L.I.B.D. and De Araújo, T.B., 2015. As ruralidades brasileiras e os desafios para o planejamento urbano e regional. XVI ENANPUR "Espaço, Planejamento e Insurgências.
- Blanco, J., Lucas, K., Schafran, A., Apaolaza, R. (2018). Contested mobilities in the Latin American context. *Journal of Transport Geography*, 67, 73–75. DOI:10.1016/j.jtrangeo.2018.01.006
- Blaschke, T., 2010. Object based image analysis for remote sensing. *ISPRS journal of photogrammetry and remote sensing*, 65(1), pp.2-16.
- Bocarejo, J.P., Portilla, I.J., Velásquez, J.M., Cruz, M.N., Peña, A. and Oviedo, D.R., 2014. An innovative transit system and its impact on low income users: the case of the Metrocable in Medellín. *Journal of Transport Geography*, 39, pp.49-61. DOI:10.1016/j.jtrangeo.2014.06.018
- Booth, D., L. Hanmer, and E. Lovell. 2000. Poverty and transport: a report prepared for the World Bank in collaboration with DFID Overseas Development Institute: London. Available at <https://www.odi.org/resources/docs/3554.pdf>

Brasil, 2012. Lei nº 12.587, de 3 de janeiro de 2012, que institui as diretrizes da Política nacional de mobilidade Urbana. Diário oficial da União, 4.

Brasil, 2013. Política Nacional de Mobilidade Urbana. Ministério das Cidades. Available at <http://www.portalfederativo.gov.br/noticias/destaques/municipios-devem-implantar-planos-locais-de-mobilidade-urbana/CartilhaLei12587site.pdf>

Brasil, 2019. Bolsa Família repassa R\$ 2,6 bilhões a beneficiários em abril. Secretaria Especial do Desenvolvimento Social – Ministério da Cidadania. Available at <http://mds.gov.br/area-de-imprensa/noticias/2019/abril/bolsa-familia-repassa-r-2-6-bilhoes-a-beneficiarios-em-abril>

Brookhart, M.A., Wyss, R., Layton, J.B. and Stürmer, T., 2013. Propensity score methods for confounding control in nonexperimental research. *Circulation: Cardiovascular Quality and Outcomes*, 6(5), pp.604-611.

Bryceson, D.F., Bradbury, A. and Bradbury, T., 2008. Roads to poverty reduction? Exploring rural roads' impact on mobility in Africa and Asia. *Development Policy Review*, 26(4), pp.459-482. DOI: 10.1111/j.1467-7679.2008.00418.x

Bryceson, D.F., Mbara, T.C. and Maunder, D., 2003. Livelihoods, daily mobility and poverty in sub-Saharan Africa. *Transport reviews*, 23(2), pp.177-196. DOI:10.1080/01441640309891

Calderón, C., Servén, L., 2004. The Effects of Infrastructure Development on Growth and Income Distribution. Policy Research Working Paper; No.3400. World Bank, Washington, D.C.. © World Bank. <https://openknowledge.worldbank.org/handle/10986/14136> License: CC BY 3.0 IGO.

Campolongo, F., Cariboni, J. and Saltelli, A., 2007. An effective screening design for sensitivity analysis of large models. *Environmental modelling & software*, 22(10), pp.1509-1518.

Cano, I., 2010. Racial bias in police use of lethal force in Brazil. *Police Practice and Research: An International Journal*, 11(1), pp.31-43.

- Cantos, P., Gumbau-Albert M., Maudos, J., 2005. Transport infrastructures, spillover effects and regional growth: evidence of the Spanish case, *Transport Reviews*, 25:1, 25-50, DOI: 10.1080/014416410001676852
- Cass, N., Shove, E. and Urry, J., 2005. Social exclusion, mobility and access 1. *The sociological review*, 53(3), pp.539-555. DOI:10.1111/j.1467-954X.2005.00565.x
- Cervero, R. and Golub, A., 2007. Informal transport: A global perspective. *Transport policy*, 14(6), pp.445-457.
- Cervero, R., 2000. Informal transport in the developing world. UN-HABITAT.
- Chagas, A.L.S., Toneto, R. and Azzoni, C.R., 2012. A spatial propensity score matching evaluation of the social impacts of sugarcane growing on municipalities in Brazil. *International Regional Science Review*, 35(1), pp.48-69.
- Chein, F., Pinto, C. C. de X., 2017. Roads, Urbanization and Development: some empirical evidences from Brazilian experience. *Seminário 52 IPEA*.
- Church, A., Frost, M. and Sullivan, K., 2000. Transport and social exclusion in London. *Transport Policy*, 7(3), pp.195-205. DOI: 10.1016/S0967-070X(00)00024-X
- Coirolo, L., Barbosa, T., 2002. Rural Development and Poverty Alleviation in Northeast Brazil. en breve; No. 11. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/10402> License: CC BY 3.0 IGO.
- Coirolo, L.; Lammert, J., 2008. Rural Poverty Reduction in Northeast Brazil: Achieving Results through Community-Driven Development. en breve; No. 125. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/10279> License: CC BY 3.0 IGO.
- Confederação Nacional dos Transportes (CNT)., 2018. Classificação do Estado Geral - Extensão Total Avaliada. Pesquisa CNT de Rodovias 2018. Available at: http://pesquisarodovias.cnt.org.br/Pagina/relatorio_por_unidade_federativa

Conselho Federal de Medicina (CFM), 2018. Considerações sobre o programa mais médicos. Available at https://portal.cfm.org.br/images/PDF/2018_pesquisa_maismedicos.pdf

Cook, C. C., Duncan, T., J., S., Sharma, A., Guobao, W., 2005. Assessing the Impact of Transport and Energy Infrastructure on Poverty Reduction. © Asian Development Bank. <<http://hdl.handle.net/11540/240>>.

Cook, T.D., Campbell, D.T. and Shadish, W., 2002. Experimental and quasi-experimental designs for generalized causal inference. Boston: Houghton Mifflin.

Cortez, F., Vaz, N. P., 2013. A bicicleta como alternativa de transporte e a possibilidade de inserção social em Maceió/AL. 19º Congresso Brasileiro de Transporte Trânsito. ANTP

Crenshaw, K., 1989. Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. U. Chi. Legal F., p.139.

Currie, G. and Delbosc, A., 2010. Modelling the social and psychological impacts of transport disadvantage. Transportation, 37(6), pp.953-966. DOI:10.1007/s11116-010-9280-2

Currie, G. and Senbergs, Z., 2007, September. Exploring forced car ownership in metropolitan Melbourne. In Australasian Transport Research Forum (Vol. 200).

Dai, D. and Wang, F., 2011. Geographic disparities in accessibility to food stores in southwest Mississippi. Environment and Planning B: Planning and Design, 38(4), pp.659-677. DOI: 10.1068/b36149

Dai, D., 2010. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. Health & place, 16(5), pp.1038-1052. DOI: 10.1016/j.healthplace.2010.06.012

Dalbem, M.C. and Brandão, L., 2010. Avaliação econômica de projetos de transporte: melhores práticas e recomendações para o Brasil. Revista de Administração Pública, 44(1), pp.87-117.

Danish International Development Agency (Danida), 2010. Impact evaluation of Danida support to rural transport infrastructure in Nicaragua. Prepared jointly by Orbicon A/S and Goss Gilroy. Copenhagen: Danish Ministry of Foreign Affairs, Denmark.

Datasus, 2010. Razao entre óbitos informados e estimados. Available at <http://tabnet.datasus.gov.br/cgi/idb2011/a1802b.htm>. Retrieved in 11/Dec/18.

Datasus, 2016a. Mortalidade causada por acidentes de transportes terrestres por municípios. Retrieved at 25/Mar/2019 from <http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sim/cnv/obt10br.def>.

Datasus, 2016b. Violência doméstica, sexual e outras violências - Brasil. Retrieved at 25/Mar/2019 from <http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sinannet/cnv/violebr.def>

De Luca, G.D., 2007. Roads, Development and Deforestation: a review. Development Research Group Paper. The World Bank. Available at http://siteresources.worldbank.org/INTKNOWLEDGEFORCHANGE/Resources/491519-1199818447826/roads_development_and_desorestation_a_review.pdf

de Souza, A.T., Peterson, K.E., Andrade, F.M.O., Gardner, J. and Ascherio, A., 2000. Circumstances of post-neonatal deaths in Ceara, Northeast Brazil: mothers' health care-seeking behaviors during their infants' fatal illness. *Social science & medicine*, 51(11), pp.1675-1693.

DENATRAN (Departamento Nacional de Trânsito (DENATRAN)),. 2016. Frota nacional de veículos - Dezembro de 2016. Retrieved at 25/Mar/2019 from <http://www.denatran.gov.br/estatistica/261-frota-2016>

Deng, H., Li, Y., Li, W. and Yu, Y., 2016. Urban transport social needs in China: Quantification with central government transit grant. *Transport Policy*, 51, pp.126-139. DOI:10.1016/j.tranpol.2016.07.005

Dercon, S., Gilligan, D.O., Hoddinott, J. and Woldehanna, T., 2009. The impact of agricultural extension and roads on poverty and consumption growth in fifteen

Ethiopian villages. *American Journal of Agricultural Economics*, 91(4), pp.1007-1021.

DER-SP (Departamento de Estradas de Rodagem do Estado de São Paulo (DER-SP)., 2014. Avaliação de impacto social e ambiental (AISA) - Complementar. Programa de Transporte, Logística e Meio Ambiente pp 233-235.

DfT (Department for Transport (DfT)., 2015. TAG UNIT A4.2 - Distributional Impact Appraisal. Transport Analysis Guidance. Available at <https://www.gov.uk/transport-analysis-guidance-webtag>

DfT (Department for Transport (DfT)., 2017. TAG UNIT A4.1 - Social Impact Appraisal. Transport Analysis Guidance. Available at <https://www.gov.uk/transport-analysis-guidance-webtag>

Di Ciommo, F. and Shiftan, Y., 2017. Transport equity analysis *Transport Rev.*, 37 (2) (2017), pp. 139-151

Di Ciommo, F., 2018. How the Inaccessibility Index Can Improve Transport Planning and Investment. *International Transport Forum - OECD*, Paris, France. Discussion Paper. Available at https://www.itf-oecd.org/sites/default/files/docs/inaccessibility-index-transport-planning-investment_0.pdf

Dillon, A., Sharma, M. and Zhang, X., 2011. Estimating the impact of rural investments in Nepal. *Food Policy*, 36(2), pp.250-258. DOI: 10.1016/j.foodpol.2010.11.022

Dimitriou, H.T. ed., 2013. *Transport Planning for Third World Cities* (Routledge Revivals). Routledge. pp 280-292.

DNIT (Departamento Nacional de Infraestrutura de Transportes (DNIT), 2006. Diretrizes básicas para elaboração de estudos e projetos rodoviários. Escopos básicos/Instruções de serviço. Ministério dos Transportes. Publicação IPR-726 pp 40-41.

DNIT (Departamento Nacional de Infraestrutura de Transportes), 2018. Road shapefiles. Retrieved from <http://www.dnit.gov.br/mapas-multimodais /shapefiles>

Dourado, A. de F., 1915. Transporte “informal” x “formal” verdadeira ou falsa questão? Revista dos Transportes Públicos – ANTP. Ano 17 1º trimestre. p81-92.

DTTAS (Department of Transport, Tourism and Sport (DTTAS), 2016. Guidelines on a Common Appraisal Framework for Transport Projects and Programmes. Strategic Research and Analysis Division (SRAD) pp 45-54 available at <http://www.dttas.ie/corporate/english/appraisal>

Economist. 2013. “Not Always with Us.” June 1–7. Retrieved at 22/05/2019 from <https://www.economist.com/briefing/2013/06/01/not-always-with-us>

Eijgenraam, C.J.J., Koopmans, C.C., Tang, P.J.G., Verster, A.C.P., 2000. Evaluation of Infrastructural Projects; Guide for cost-benefit analysis, Sections I and II, CPB, The Hague, NEI (Changed Name to ECORYS), Rotterdam.

Eliasson, J. 2013. International comparisons of transport appraisal practice: Annex 4 Sweden Country Report. Institute for Transport Studies, University of Leeds, Leeds.

Empresa Brasileira de Planejamento de Transportes (GEIPOT), 2000. Transportes em Pernambuco – Maio de 2000. O sistema de transportes. Available at <http://www.geipot.gov.br/cadernos/2000/pe-2000.htm# sub1>

Empresa de Planejamento e Logística S.A. (EPL), 2018. Plano Nacional de Logística – Relatório Executivo. Available at: <https://www.epl.gov.br/plano-nacional-de-logistica-pnl>

EPL (Empresa de Planejamento Logístico S.A.), 2019. Rede Georreferenciada – Cenário Rede Básica. Retrieved at 12/06/2019 from <https://www.epl.gov.br/rede-georeferenciada-pnl-2025>

Escobal, J. and Ponce, C., 2002. The benefits of rural roads: enhancing income opportunities for the rural poor.

ESRI. 2019. How Kernel Density Works - Default search radius (bandwidth) algorithm. ArcMap 10.3. Available at <http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-kernel-density-works.htm>

Evans, J., O., Brien, J. and Ch Ng, B., 2018. Towards a geography of informal transport: Mobility, infrastructure and urban sustainability from the back of a motorbike. *Transactions of the Institute of British Geographers*. DOI:10.1111/tran.12239

Fan, S. and Chan-Kang, C., 2008. Regional road development, rural and urban poverty: Evidence from China. *Transport Policy*, 15(5), pp.305-314. DOI: 10.1016/j.tranpol.2008.12.012

Fang, Y. and Zou, W., 2014. Neighborhood effects and regional poverty traps in rural China. *China & world economy*, 22(1), pp.83-102. DOI:10.1111/j.1749-124X.2014.12054.x

Farrington, J. H., & Farrington, C., 2005. Rural accessibility, social inclusion and social justice: towards conceptualisation. *Journal of Transport Geography*, 13(1), 1–12. DOI: 10.1016/j.jtrangeo.2004.10.002

Farrow, A., Larrea, C., Hyman, G. and Lema, G., 2005. Exploring the spatial variation of food poverty in Ecuador. *Food policy*, 30(5), pp.510-531. DOI:10.1016/j.foodpol.2005.09.005

Fluegge, K., Malone, L.L., Nsereko, M., Okware, B., Wejse, C., Kisingo, H., Mupere, E., Boom, W.H. and Stein, C.M., 2018. Impact of geographic distance on appraisal delay for active TB treatment seeking in Uganda: a network analysis of the Kawempe Community Health Cohort Study. *BMC public health*, 18(1), p.798.

Fontes, L.F.C., Conceição, O.C. and Jacinto, P.D.A., 2018. Evaluating the impact of physicians' provision on primary healthcare: Evidence from Brazil's More Doctors Program. *Health economics*.

- Fortney, J., Rost, K. and Warren, J., 2000. Comparing alternative methods of measuring geographic access to health services. *Health Services and Outcomes Research Methodology*, 1(2), pp.173-184.
- França, J.M.C. and Hue, S., 2014. *Piratas no Brasil: As incríveis histórias dos ladrões dos mares que pilharam nosso litoral*. Globo Livros.
- Francis, R.L., Lowe, T.J., Rayco, M.B. and Tamir, A., 2009. Aggregation error for location models: survey and analysis. *Annals of Operations Research*, 167(1), pp.171-208.
- Fuenmayor, G.J., Hunt, J.D. and Abraham, J.E., 2017. Impact of Transit Fare Increase in Caracas, Venezuela: Analysis Using PECAS Model (No. 17-01764).
- Gabrysch, S. and Campbell, O.M., 2009. Still too far to walk: literature review of the determinants of delivery service use. *BMC pregnancy and childbirth*, 9(1), p.34.
- Gachassin, M., Najman, B. and Raballand, G., 2010. *The Impact of Roads on Poverty Reduction: a case study of Cameroon*.
- Galeano, E.H., 1972. *Las venas abiertas de América Latina*. Departamento de Publicaciones, Universidad de la República. No. 338(8) p.91.
- Gannon, C.A. and Liu, Z., 1997. *Poverty and transport* (No. TWU-30). Washington, DC: World Bank. Available at: <http://siteresources.worldbank.org/INTURBANTRANSPORT/Resources/twu-30.pdf>
- Garcia-Subirats, I., Vargas, I., Mogollón-Pérez, A.S., De Paepe, P., da Silva, M.R.F., Unger, J.P. and Vázquez, M.L., 2014. Barriers in access to health care in countries with different health systems. A cross-sectional study in municipalities of central Colombia and north-eastern Brazil. *Social Science & Medicine*, 106, pp.204-213.
- Getis, A. and Ord, J.K. 1992. "The Analysis of Spatial Association by Use of Distance Statistics" in *Geographical Analysis* 24(3).

- Getis, A. and Ord, J.K., 2010. The analysis of spatial association by use of distance statistics. In *Perspectives on Spatial Data Analysis* (pp. 127-145). Springer, Berlin, Heidelberg.
- Geurs, K.T. and Van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport geography*, 12(2), pp.127-140. DOI: 10.1016/j.jtrangeo.2003.10.005
- Geurs, K.T., Boon, W. and Van Wee, B., 2009. Social impacts of transport: literature review and the state of the practice of transport appraisal in the Netherlands and the United Kingdom. *Transport reviews*, 29(1), pp.69-90. DOI: 10.1080/01441640802130490
- Gibson, J. and Olivia, S., 2010. The effect of infrastructure access and quality on non-farm enterprises in rural Indonesia. *World Development*, 38(5), pp.717-726.
- Gomide, A.D.Á., 2004. Transporte urbano e inclusão social: elementos para políticas públicas. *Revista dos Transportes Públicos - ANTP - Ano 26, 3º trimestre*
- Griesse, M.A., 2007. The geographic, political, and economic context for corporate social responsibility in Brazil. *Journal of Business Ethics*, 73(1), pp.21-37.
- Guagliardo, M.F., 2004. Spatial accessibility of primary care: concepts, methods and challenges. *International journal of health geographics*, 3(1), p.3. DOI: 10.1186/1476-072X-3-3
- Guasch, J.L., 2004. Granting and renegotiating infrastructure concessions: doing it right. World Bank Publications.
- Guzman, L.A., Oviedo, D. and Rivera, C., 2017a. Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography*, 58, pp.236-246. DOI:10.1016/j.jtrangeo.2016.12.016

- Guzman, L.A., Oviedo, D., Rivera, C., Rodriguez, C. and Peralta-Quiros, T., 2017b. Accessibility and Poverty: Assessing Public Transport Subsidies in Bogotá. TRB Conference No. 17-01180.
- Gwatkin, D. R., Rustein, S., Johnson, K., Pande, R. P., Wagstaff, A. 2000. Socio-economic differences in health, nutrition, and population in Brazil (English). World Bank publication. Country reports on HNP and poverty. Washington, DC. Report number 30553. Available at <http://documents.worldbank.org/curated/en/455461468015634905/Socio-economic-differences-in-health-nutrition-and-population-in-Brazil>
- Haddad, E.A., Perobelli, F.S., Domingues, E.P. and Aguiar, M., 2011. Assessing the ex ante economic impacts of transportation infrastructure policies in Brazil. *Journal of development effectiveness*, 3(1), pp.44-61.
- Hanmer, L., Booth, D. and Lovell, E., 2000. Poverty and Transport. A Report prepared for the World Bank in collaboration with DFID, Overseas Development Institute. DOI:10.2139/ssrn.1754546
- Hansen, H., Andersen, O.W. and White, H., 2011. Impact evaluation of infrastructure interventions. *Journal of Development Effectiveness*, 3(1), pp.1-8.
- Hansen, W.G., 1959. How accessibility shapes land use. *Journal of the American Institute of planners*, 25(2), pp.73-76. DOI:10.1080/01944365908978307
- Hanson, S., Hanson, P., 1980. Gender and urban activity patterns in Uppsala, Sweden. *Geogr. Rev.* 70, 291–299. DOI:10.2307/214257
- Harvey, D., 1980. A justiça social ea cidade. *Hucitec*. p. 116
- Haynes, R., Lovett, A. and Sünnerberg, G., 2003. Potential accessibility, travel time, and consumer choice: geographical variations in general medical practice registrations in Eastern England. *Environment and Planning A*, 35(10), pp.1733-1750.

Headey, D., Stifel, D., You, L. and Guo, Z., 2018. Remoteness, urbanization, and child nutrition in sub-Saharan Africa. *Agricultural Economics*, 49(6), pp.765-775. DOI: 10.1111/agec.12458

Hernandez, D., 2018. Uneven mobilities, uneven opportunities: Social distribution of public transport accessibility to jobs and education in Montevideo. *Journal of Transport Geography*, 67, pp.119-125. DOI:10.1016/j.jtrangeo.2017.08.017

Hernandez, D.O. and Titheridge, H., 2016. Mobilities of the periphery: informality, access and social exclusion in the urban fringe in Colombia. *Journal of transport geography*, 55, pp.152-164. DOI:10.1016/j.jtrangeo.2015.12.004

Hickman, R. and Dean, M., 2018. Incomplete cost–incomplete benefit analysis in transport appraisal. *Transport Reviews*, 38(6), pp.689-709.

Hine, J. and Mitchell, F., 2017. Transport disadvantage and social exclusion: exclusionary mechanisms in transport in urban Scotland. Routledge. DOI:10.4324/9781315235677

Hulme, D., Moore, K. and Shepherd, A., 2001. Chronic poverty: meanings and analytical frameworks. *Chronic Poverty Research Centre Working Paper*, (2).

IBGE (Instituto Brasileiro de Geografia e Estatística), 2008. Regiões de influência das cidades (REGIC). Retrieved at 06/06/2019 from <http://www.ibge.gov.br/home/geociencias/geografia/regic.shtm>.

IBGE (Instituto Brasileiro de Geografia e Estatística), 2010a. Censo Demográfico 2010 - Resultados da Amostra - Famílias e Domicílios. Retrieved at 06/06/2019 from <https://sidra.ibge.gov.br/>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2010b. Grade Estatística 2010. Retrieved at 13/6/2019 from <http://mapasinterativos.ibge.gov.br/grade/default.html>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2013. Projeção da população do Brasil por sexo e idade para o período 2000-2060; Projeção da população das Unidades da Federação por sexo e idade 2000-2030. Rio de

Janeiro Disponível em: <http://www.ibge.gov.br/home/estatistica/populacao/projecao_da_populacao/2013/default.shtm>.

IBGE (Instituto Brasileiro de Geografia e Estatística), 2014. Uso da terra do Brasil 1:5.000.000. Shape file retrieved at 06/06/2019 from http://www.geoservicos.ibge.gov.br/geoserver/wms?service=WFS&version=1.0.0&request=GetFeature&typeName=CREN:UsoTerraBrasil_5000&outputFormat=SHAPE-ZIP

IBGE (Instituto Brasileiro de Geografia e Estatística), 2016. Arranjos populacionais e concentrações urbanas no Brasil. Retrieved at 06/06/2019 from https://www.ibge.gov.br/apps/arranjos_populacionais/2015/pdf/publicacao.pdf

IBGE (Instituto Brasileiro de Geografia e Estatística), 2016. Produto Interno Bruto dos Municípios. Tabela 5938 – PIB a preços correntes. Retrieved at 22/05/2019 from <https://sidra.ibge.gov.br/tabela/5938>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2017a. Síntese de indicadores sociais: uma análise das condições de vida da população brasileira. Coordenação de População e Indicadores Sociais. - Rio de Janeiro. ISSN 1516-3296; n. 37

IBGE (Instituto Brasileiro de Geografia e Estatística), 2017b. Perfil dos municípios Brasileiros. Available at <https://biblioteca.ibge.gov.br/visualizacao/livros/liv101595.pdf>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2017c. Divisão regional do Brasil em regiões geográficas imediatas e regiões geográficas intermediárias: 2017. Available at <https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=2100600>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2018a. Pesquisa Nacional por Amostra de Domicílios Contínua Primeiro Trimestre de 2018. Retrieved at 22/05/2019 from: https://biblioteca.ibge.gov.br/visualizacao/periodicos/2421/pnact_2018_1tri.pdf.

IBGE (Instituto Brasileiro de Geografia e Estatística), 2018b. Síntese de indicadores sociais: uma análise das condições de vida da população brasileira: 2018. Coordenação de População e Indicadores Sociais. - Rio de Janeiro. 151 p. ISSN 1516-3296. Retrieved at 22/05/2019 from <https://biblioteca.ibge.gov.br/visualizacao/livros/liv101629.pdf>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2019a. Pesquisa Nacional por Amostra de Domicílios Contínua - Divulgação Trimestral - 1º trimestre 2019. Retrieved at 22/05/2019 from <https://sidra.ibge.gov.br/home/pnadct/nordeste>

IBGE (Instituto Brasileiro de Geografia e Estatística), 2019b. População Rural e Urbana. Available at <https://educa.ibge.gov.br/jovens/conheca-o-brasil/populacao/18313-populacao-rural-e-urbana.html>

limi, A., Ahmed, A.K.F., Anderson, E. C., Diehl, A. S., Maiyo, L.; Peralta-Quiros, T., Rao, K. S., 2016. New rural access index: main determinants and correlation to poverty (English). Policy Research working paper; no. WPS 7876. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/821621478094511356/New-rural-access-index-main-determinants-and-correlation-to-poverty>

limi, A., Lancelot, E. R., Manelici, I., Ogita, S., 2015. Evaluating the social and economic impacts of rural road improvements in the state of Tocantins, Brazil (English). Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/109021467992478157/Evaluating-the-social-and-economic-impacts-of-rural-road-improvements-in-the-state-of-Tocantins-Brazil>

Inchauste, G., Azevedo, J. P, Essama-Nssah, B., Olivieri, S., Nguyen, T. V., Saavedra-Chanduvi, J. and Winkler, R. 2014. Understanding changes in poverty (English). Directions in development; poverty. Washington, DC: World Bank Group. <http://documents.worldbank.org/curated/en/275271468336660502/Understanding-changes-in-poverty>

International Fund for Agricultural Development, 2011. Rural poverty report (2011), IFAD, Rome. Available at:

http://www.fao.org/fileadmin/user_upload/rome2007/docs/IFAD%20Rural%20Poverty%20Report%202011.pdf

ITF (International Transport Forum), 2017a. Income inequality, social inclusion and mobility. Roundtable report 164, 200p. Retrieved at 22/05/2019 from <https://www.itf-oecd.org/sites/default/files/docs/income-inequality-social-inclusion-mobility.pdf>

ITF (International Transport Forum), 2017b, Quantifying the Socio-economic Benefits of Transport, ITF Roundtable Reports, OECD. Publishing, Paris. DOI: 10.1787/9789282108093-en

Jenkins, J.T. and Peters, K., 2016. Rural connectivity in Africa: motorcycle track construction. In Proceedings of the Institution of Civil Engineers-Transport (Vol. 169, No. 6, pp. 378-386). Thomas Telford Ltd. DOI: 10.1680/jtran.15.00080

Jones, P. and Lucas, K., 2012a. Social impacts and equity issues in transport: an introduction. *Journal of Transport Geography*, 21.

Jones, P. and Lucas, K., 2012b. The social consequences of transport decision-making: clarifying concepts, synthesising knowledge and assessing implications. *Journal of transport geography*, 21, pp.4-16.

Jones, S. and Walsh, J., 2013. Defining a post-conflict role for rural transport in sub-Saharan Africa: A crosscutting literature review. *AFCAP GEN B*, 127.

Jones, S., Tefe, M. and Appiah-Opoku, S., 2013. Proposed framework for sustainability screening of urban transport projects in developing countries: A case study of Accra, Ghana. *Transportation Research Part A: Policy and Practice*, 49, pp.21-34.

Jones, S., Tefe, M., Zephaniah, S., Tedla, E., Appiah-Opoku, S. and Walsh, J., 2016. Public transport and health outcomes in rural sub-Saharan Africa—A synthesis of professional opinion. *Journal of Transport & Health*, 3(2), pp.211-219.

Jones, S., Lidbe, A. and Hainen, A., 2019. What can open access data from India tell us about road safety and sustainable development?. *Journal of Transport Geography*, 80, p.102503.

Jordan, H., Roderick, P., Martin, D. and Barnett, S., 2004. Distance, rurality and the need for care: access to health services in South West England. *International journal of health geographics*, 3(1), p.21.

Júnior, J.A.O. and Filho, M.A.A., 2002. The Brazilian Motorcycle Taxi Phenomenon. In *Traffic And Transportation Studies* (2002) (pp. 1566-1572).

Kabia, E., Mbau, R., Muraya, K.W., Morgan, R., Molyneux, S. and Barasa, E., 2018. How do gender and disability influence the ability of the poor to benefit from pro-poor health financing policies in Kenya? An intersectional analysis. *International journal for equity in health*, 17(1), p.149. DOI:10.1186/s12939-018-0853-6

Kenyon, S., Lyons, G. and Rafferty, J., 2002. Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility. *Journal of Transport Geography*, 10(3), pp.207-219. DOI:10.1016/S0966-6923(02)00012-1

Khan, S., Combaz, E. & McAslan Fraser, E. (2015). *Social exclusion: topic guide*. Revised edition. Birmingham, UK: GSDRC, University of Birmingham.

Khandker, S. R.; Koolwal, G. B., 2011. Estimating the Long-term Impacts of Rural Roads: A Dynamic Panel Approach. Policy Research working paper; no. WPS 5867. World Bank. © World Bank. <https://openknowledge.worldbank.org/handle/10986/3633> License: CC BY 3.0 IGO."

Khandker, S.R., Bakht, Z. and Koolwal, G.B., 2009. The poverty impact of rural roads: evidence from Bangladesh. *Economic Development and Cultural Change*, 57(4), pp.685-722. DOI:10.1086/598765

Kostlan, E. (1991). Statistical Complexity of Dominant Eigenvector Calculation. Hawaii: *Journal of Complexity* Volume 7, Issue 4, December 1991, Pages 371-379.

Krejcie, R.V. and Morgan, D.W., 1970. Determining sample size for research activities. *Educational and psychological measurement*, 30(3), pp.607-610.

Kumar, A. 2011. Understanding the Emerging Role of Motorcycles in African Cities: A Political Economy Perspective. Sub-Saharan Africa Transport Policy Program (SSATP) discussion paper; no. 13. World Bank publication, Washington, DC. Available at <http://hdl.handle.net/10986/17804> License: CC BY 3.0 IGO.”

Langford, M. and Higgs, G., 2006. Measuring potential access to primary healthcare services: the influence of alternative spatial representations of population. *The Professional Geographer*, 58(3), pp.294-306. DOI: 10.1111/j.1467-9272.2006.00569.x

Langford, M., Fry, R. and Higgs, G., 2012. Measuring transit system accessibility using a modified two-step floating catchment technique. *International Journal of Geographical Information Science*, 26(2), pp.193-214. DOI: 10.1080/13658816.2011.574140

Lau, J.C.Y., 2010. The influence of suburbanization on the access to employment of workers in the new towns: A case study of Tin Shui Wai, Hong Kong. *Habitat international*, 34(1), pp.38-45. DOI:10.1016/j.habitatint.2009.05.002

Lau, J.C.Y., 2013. Sustainable urban transport planning and the commuting patterns of poor workers in a historic inner city in Guangzhou, China. *Habitat International*, 39, pp.119-127. DOI: 10.1016/j.habitatint.2012.11.006

Lebo, J. and Schelling, D., 2001. Design and appraisal of rural transport infrastructure: ensuring basic access for rural communities (Vol. 23). World Bank Publications.

Lefebvre, H., 1974. La production de l'espace. *L'Homme et la société*, 31(1), pp.15-32.

Leiren, M. D. and Skollerud, K., 2015. Passenger transport in rural and sparsely populated areas in Norway. *International Transport Forum Discussion Paper* 2015-08. OCDE.

Levy, C. and Dávila, J.D., 2017. Planning for Mobility and Socio-Environmental Justice: The Case of Medellín, Colombia. In *Environmental Justice and Urban Resilience in the Global South* (pp. 37-55). Palgrave Macmillan, New York.

Levy, C., 2013. Travel choice reframed: “deep distribution” and gender in urban transport. *Environment and Urbanization*, 25(1), pp.47-63. DOI:10.1177/0956247813477810

Li, Y. and DaCosta, M.N., 2013. Transportation and income inequality in China: 1978–2007. *Transportation Research Part A: Policy and Practice*, 55, pp.56-71. DOI:10.1016/j.tra.2013.08.006

Lillesand, T., Kiefer, R.W. and Chipman, J., 2014. *Remote sensing and image interpretation*. John Wiley & Sons.

Lionjanga, N. and Venter, C., 2018. Does public transport accessibility enhance subjective well-being? A study of the City of Johannesburg. *Research in Transportation Economics*, 69, pp.523-535. DOI:10.1016/j.retrec.2018.07.011

Litman, T., 2003. *Measuring transportation: Traffic, mobility and accessibility*. Institute of Transportation Engineers. *ITE Journal*, 73(10), p.28.

Lofgren, H., Robinson, S. and Thurlow, J., 2004. *Prospects for growth and poverty reduction in Zambia, 2001-2015*.

Lokshin, M. and Yemtsov, R., 2005. Has rural infrastructure rehabilitation in Georgia helped the poor?. *The World Bank Economic Review*, 19(2), pp.311-333.

Lucas, K., 2011. Making the connections between transport disadvantage and the social exclusion of low income populations in the Tshwane Region of South Africa. *Journal of Transport Geography*, 19, 1320-1334. DOI:10.1016/j.jtrangeo.2011.02.007

Lucas, K., 2012. Transport and social exclusion: Where are we now?. *Transport policy*, 20, pp.105-113.

Lucas, K., Mattioli, G., Verlinghieri, E. and Guzman, A., 2016a. Transport poverty and its adverse social consequences. In *Proceedings of the institution of civil*

engineers-transport (Vol. 169, No. 6, pp. 353-365). Thomas Telford (ICE Publishing). DOI:10.1680/jtran.15.00073

Lucas, K., Tyler, S. and Christodoulou, G., 2009. Assessing the 'value' of new transport initiatives in deprived neighbourhoods in the UK. *Transport Policy*, 16(3), pp.115-122.

Lucas, K., Van Wee, B. and Maat, K., 2016b. A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. *Transportation*, 43(3), pp.473-490.

Luo, J., Tian, L., Luo, L., Yi, H. and Wang, F., 2017. Two-step optimization for spatial accessibility improvement: a case study of health care planning in rural China. *BioMed research international*, Volume 2017 (p.12). DOI: 10.1155/2017/2094654

Luo, W. and Wang, F., 2003. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design*, 30(6), pp.865-884.

Luo, W. and Wang, F., 2003. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design*, 30(6), pp.865-884. DOI: 10.1068/b29120

Macharis, C. and Bernardini, A., 2015. Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach. *Transport policy*, 37, pp.177-186.

Macharis, C., De Witte, A. and Ampe, J., 2009. The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice. *Journal of Advanced transportation*, 43(2), pp.183-202.

Macinko, J., de Souza, M.D.F.M., Guanais, F.C. and da Silva Simoes, C.C., 2007. Going to scale with community-based primary care: an analysis of the family health program and infant mortality in Brazil, 1999–2004. *Social science & medicine*, 65(10), pp.2070-2080.

Mackie, P. and Worsley, T., 2013. International comparisons of transport appraisal practice: overview report. Institute for Transport Studies, University of Leeds, Leeds.

Mackie, P., Worsley, T. and Eliasson, J., 2014. Transport appraisal revisited. *Research in Transportation Economics*, 47, pp.3-18.

Maia, M.L., Lucas, K., Marinho, G., Santos, E. and de Lima, J.H., 2016. Access to the Brazilian City—From the perspectives of low-income residents in Recife. *Journal of Transport Geography*, 55, pp.132-141. DOI: 10.1016/j.jtrangeo.2016.01.001

Manaugh, K., Badami, M.G. and El-Geneidy, A.M., 2015. Integrating social equity into urban transportation planning: A critical evaluation of equity objectives and measures in transportation plans in North America. *Transport policy*, 37, pp.167-176.

Marcelo, D. G.; House, A. S. R. 2018. Prioritizing Infrastructure Investments: A Comparative Review of Applications in Chile (English). Policy Research working paper; no. WPS 8602. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/959221538675961651/Prioritizing-Infrastructure-Investments-A-Comparative-Review-of-Applications-in-Chile>

Marcelo, D., Mandri-Perrott, C., House, S., Schwartz, J. 2016. Prioritizing Infrastructure Investment : A Framework for Government Decision Making. Policy Research Working Paper; No. 7674. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/24511> License: CC BY 3.0 IGO.

Martens, K. and Bastiaanssen, J., 2014. An index to measure accessibility poverty risk. In Paper presented at Colloquium Vervoersplanologisch Speurwerk. Eindhoven, the Netherlands (Vol. 32, p. 33). Available at: https://www.academia.edu/7908819/An_index_to_measure_accessibility_poverty_risk

Martens, K. and Di Ciommo, F., 2017. Travel time savings, accessibility gains and equity effects in cost–benefit analysis. *Transport reviews*, 37(2), pp.152-169.

- Martens, K., 2016. Transport justice: Designing fair transportation systems. Routledge. p. 158. DOI: 10.4324/9781315746852
- Martens, K., Di Ciommo, F. and Papanikolaou, A., 2014. Incorporating equity into transport planning: utility, priority and sufficiency approaches. In: "XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística. PANAM 2014", 11/06/2014 – 13/06/2014, Santander, España. pp. 1-16. Available at <http://oa.upm.es/36984/>
- McCulloch, N., Weisbrod, J., Timmer, C. P., 2007. Pathways Out of Poverty During an Economic Crisis: An Empirical Assessment of Rural Indonesia. Policy Research Working Paper; No. 4173. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/7217> License: CC BY 3.0 IGO."
- McDade, T.W., Ryan, C.P., Jones, M.J., Hoke, M.K., Borja, J., Miller, G.E., Kuzawa, C.W. and Kobor, M.S., 2019. Genome-wide analysis of DNA methylation in relation to socioeconomic status during development and early adulthood. American journal of physical anthropology, 169(1), pp.3-11.
- McDonagh, J., 2006. Transport policy instruments and transport-related social exclusion in rural Republic of Ireland, Journal of Transport Geography, Vol. 14, pp. 355-366.
- McGrail, M.R. and Humphreys, J.S., 2009. Measuring spatial accessibility to primary care in rural areas: improving the effectiveness of the two-step floating catchment area method. Applied Geography, 29(4), pp.533-541. DOI: 10.1016/j.apgeog.2008.12.003
- Ministério da Saúde, 2018. UPA e UBS. Sabe o que significam essas siglas? Retrieved from <http://www.blog.saude.gov.br/servicos/33620-upa-e-ubs-sabe-o-que-significam-essas-siglas.html>
- Ministério das Cidades, 2017. Instrução Normativa nº 17, de 11 de Julho de 2017. Regulamenta a reformulação do Programa de Infraestrutura de Transporte e da Mobilidade Urbana - Pró-Transporte. Available at <http://www.cidades.gov.br/>

images/stories/ArquivosCidades/ArquivosPDF/IN27-80140.000 291.2017-27eegulamentaareformulacaodoprotransporte-CONSOLIDADA.pdf

Ministério das Cidades, 2017. Instrução Normativa nº 27, de 11 de Julho de 2017. Regulamenta a reformulação do Programa de Infraestrutura de Transporte e da Mobilidade Urbana - Pró-Transporte. Retrieved at 22/05/2019 from http://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/19170407/do1-2017-07-12-instrucao-normativa-n-27-de-11-de-julho-de-2017-19170212

Ministério das Cidades, 2018. Instrução Normativa nº 28, de 20 de Novembro de 2018. Regulamenta o Programa de Desenvolvimento Urbano (Pró-Transporte). Retrieved at 22/05/2019 from http://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/51058894Cidades

Ministério das Cidades, 2018. Instrução Normativa nº 28, de 20 de Novembro de 2018. Regulamenta o Programa de Desenvolvimento Urbano (Pró-Transporte). Retrieved at 22/05/2019 from http://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/51058894Cidades

Ministério das Cidades. 2015. Caderno de Referência para Elaboração de plano de mobilidade urbana. Secretaria nacional de transporte e da mobilidade urbana – SeMob. Retrieved at 22/05/2019 from <http://www.cidades.gov.br/images/stories/ArquivosSE/planmob.pdf>

Mitchell, A., 2005. The ESRI Guide to GIS Analysis: Volume 2: Spatial Measurements & Statistics (Vol. 2). Redlands, CA: ESRI press.

Motte-Baumvol, B. and Nassi, C.D., 2012. Immobility in Rio de Janeiro, beyond poverty. *Journal of Transport geography*, 24, pp.67-76. DOI:10.1016/j.jtrangeo.2012.06.012

MTPA (Ministério dos Transportes, Portos e Aviação Civil). 2018. Anuário Estatístico de Transportes 2010-2017. Brasília, Brasil. Segunda edição. Available at https://www.infraestrutura.gov.br/anu%C3%A1rio_estatistico.html

Mu, R. and Van de Walle, D., 2007. Rural Roads and Local Market Development in Vietnam. Policy Research Working Paper; No. 4340. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/6878> License: CC BY 3.0 IGO.”

Naimanye, A.G. and Whiteing, T., 2016, October. Poverty-centred rural road funds sharing in sub-Saharan Africa. In Proceedings of the Institution of Civil Engineers-Transport (Vol. 169, No. 6, pp. 387-396). Thomas Telford Ltd. DOI:10.1680/jtran.15.00071

Narayan, D., Patel, R., Schafft, K., Rademacher, A., Koch-Schulte, S., 2000. Voices of the poor Can anyone hear us? New York. Oxford University Press for the World Bank. Available at: <http://documents.worldbank.org/curated/en/131441468779067441/Voices-of-the-poor-can-anyone-hear-us>

Nash, J.C., 2008. Re-thinking intersectionality. Feminist review, 89(1), pp.1-15. DOI:10.1057/fr.2008.4

Nelson, A., 2008. Travel time to major cities: a global map of accessibility. Global Environment Monitoring Unit, Joint Research Centre of the European Commission. Available at: <http://forobs.jrc.ec.europa.eu/products/gam/>

Nesbitt, R.C., Gabrysch, S., Laub, A., Soremekun, S., Manu, A., Kirkwood, B.R., Amenga-Etego, S., Wiru, K., Höfle, B. and Grundy, C., 2014. Methods to measure potential spatial access to delivery care in low-and middle-income countries: a case study in rural Ghana. International journal of health geographics, 13(1), p.25. DOI: 10.1186/1476-072X-13-25

Neutens, T., 2015. Accessibility, equity and health care: review and research directions for transport geographers. Journal of Transport Geography, 43, pp.14-27. DOI: 10.1016/j.jtrangeo.2014.12.006

Nigriello, A., 1992. O Impacto do Sistema de Transporte sobre o Espaço Urbano e seu Controle. Pós. Revista do Programa de Pós-Graduação em Arquitetura e Urbanismo da FAUUSP, 1(2), pp.47-54.

Nogueira, P.T.A., Bezerra, A.F.B., Leite, A.F.B., Carvalho, I.M.D.S., Gonçalves, R.F. and Brito-Silva, K.S.D., 2016. Características da distribuição de profissionais do Programa Mais Médicos nos estados do Nordeste, Brasil. *Ciência & Saúde Coletiva*, 21, pp.2889-2898.

Noor, A. M., Zurovac, D., Hay, S. I., Ochola, S. A., & Snow, R. W., 2003. Defining equity in physical access to clinical services using geographical information systems as part of malaria planning and monitoring in Kenya. *Tropical Medicine and International Health*, 8(10), 917–926. doi:10.1046/j.1365-3156.2003.01112.x

Noor, A.M., Alegana, V.A., Gething, P.W., Tatem, A.J. and Snow, R.W., 2008. Using remotely sensed night-time light as a proxy for poverty in Africa. *Population Health Metrics*, 6(1), p.5.

NTA (National Transport Authority), 2019. Rural Transport Programme: Growth in Passenger Journeys. Retrieved from <https://www.nationaltransport.ie/public-transport-services/rural-transport-programme/>

O'Brian, J.E., Evans J., 2017. Informal mobilities and elusive subjects: researching urban transport in the global South. *Urban Mobilities in the Global South*. Routledge, pp. 98-114. DOI: 10.4324/9781315265094

OECD (Organisation for Economic Co-operation and Development), 2018. Purchasing power parities (PPP), Retrieved at 12/06/2019 from <https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm#indicator-chart>

Oliveira, F.C. and Andrade, M.O., 2016. Mobility difficulties to low income people living in peripheral hill areas in Recife Brazil. The 14th World Conference in Transport Research, Shanghai. *Transport Research Proceedings*

Oloo, F., 2018. Mapping Rural Road Networks from Global Positioning System (GPS) Trajectories of Motorcycle Taxis in Sigomre Area, Siaya County, Kenya. *ISPRS International Journal of Geo-Information*, 7(8), p.309. DOI:10.3390/ijgi7080309

- Ord, J.K. and Getis, A., 1995. Local spatial autocorrelation statistics: distributional issues and an application. *Geographical analysis*, 27(4), pp.286-306.
- Ormerod, M., Newton, R., Phillips, J., Musselwhite, C., McGee, S. and Russell, R., 2015. How can transport provision and associated built environment infrastructure be enhanced and developed to support the mobility needs of individuals as they age. *Future of an ageing population: evidence review* Foresight, Government Office for Science, London, UK.
- Ornati, O.A., Whittaker, J.W. and Solomon, R., 1969. *Transportation needs of the poor: A case study of New York City*. Praeger.
- Ortega E, Otero I, Mancebo S., 2014. TITIM GIS-tool: A GIS-based decision support system for measuring the territorial impact of transport infrastructures. *Expert Systems with Applications*. Nov 15;41(16):7641-52.
- Ortuzar, J., Willumsen, L.G., 2011. *Modelling Transport*, 4th edition John Wiley & Son Ltd., Chichester, United Kingdom.
- Osorio, R.G., Servo, L.M.S. and Piola, S.F., 2011. Necessidade de saúde insatisfeita no Brasil: uma investigação sobre a não procura de atendimento. *Ciência & Saúde Coletiva*, 16, pp.3741-3754.
- Oviedo, D., Levy, C. and D'avila, J, 2017. Constructing wellbeing, deconstructing urban (im)mobilities in Abuja, Nigeria. In *Urban Mobilities in the Global South* (pp. 193-214). Routledge)
- Özkazanç, S. and Sönmez, F.N.Ö., 2017. Spatial analysis of social exclusion from a transportation perspective: A case study of Ankara metropolitan area. *Cities*, 67, pp.74-84. DOI:10.1016/j.cities.2017.04.013
- Paranaíba, A. C., 2017. *Metodologia Para Priorização de Projetos de Infraestrutura em Mobilidade Urbana com Base na Configuração Urbana e no Escalonamento Multidimensional*. Dissertação de Mestrado, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Brasília, DF, 135p.

Partnership on Sustainable, Low Carbon Transport (SLoCaT), 2019. Transport Targets of Sustainable Development Goals. Available at <http://www.slocat.net/sdg-targets>

Pawson, R., Greenhalgh, T., Harvey, G. and Walshe, K., 2005. Realist review-a new method of systematic review designed for complex policy interventions. *Journal of health services research & policy*, 10(1_suppl), pp.21-34. DOI:10.1258/1355819054308530

Pereira, R. H. M., 2018. Ex-Ante Evaluation of the Accessibility Impacts of Transport Policy Scenarios: Equity and Sensitivity to Travel Time Thresholds for Bus Rapid Transit Expansion in Rio De Janeiro. Available at SSRN: <https://ssrn.com/abstract=3147748> or <http://dx.doi.org/10.2139/ssrn.3147748>

Pereira, R.H., 2019. Future accessibility impacts of transport policy scenarios: equity and sensitivity to travel time thresholds for Bus Rapid Transit expansion in Rio de Janeiro. *Journal of Transport Geography*, 74, pp.321-332. DOI:10.1016/j.jtrangeo.2018.12.005

Pereira, R.H., Schwanen, T. and Banister, D., 2017. Distributive justice and equity in transportation. *Transport Reviews*, 37(2), pp.170-191. DOI: 10.1080/01441647.2016.1257660

Phun, V.K. and Yai, T., 2016. State of the art of paratransit literatures in Asian developing countries. *Asian Transport Studies*, 4(1), pp.57-77.

Polzin, P., Borges, J. and Coelho, A., 2014. An extended kernel density two-step floating catchment area method to analyze access to health care. *Environment and Planning B: Planning and Design*, 41(4), pp.717-735. DOI: 10.1068/b120050p

Porter, G., 2014. Transport services and their impact on poverty and growth in rural Sub-Saharan Africa: A review of recent research and future research needs. *Transport Reviews*, 34, 25–45.

Porter, G., 2002. Living in a walking world: rural mobility and social equity issues in sub-Saharan Africa. *World development*, 30(2), 285-300. DOI:10.1016/S0305-750X(01)00106-1

Porter, G., 2007, March. Transport, (Im)Mobility, and Spatial Poverty Traps: Issues for Rural Women and Girl Children in Sub-Saharan Africa. In *Understanding and addressing spatial poverty traps: An international workshop*, Spier Estate, Stellenbosch, South Africa. <http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3536.pdf>

Porter, G., Blaufuss, K. and Acheampong, F.O., 2007. Youth, mobility and rural livelihoods in sub-Saharan Africa: Perspectives from Ghana and Nigeria: Poverty, development and livelihoods. *Africa insight*, 37(3), pp.420-431. DOI:10.4314/ai.v37i3.22500

Porter, G., Hampshire, K., Abane, A., Munthali, A., Robson, E., Mashiri, M. and Tanle, A., 2012. Youth, mobility and mobile phones in Africa: findings from a three-country study. *Information Technology for Development*, 18(2), pp.145-162 DOI:10.1080/02681102.2011.643210

Porter, G., Tewodros, A., Bifandimu, F., Gorman, M., Heslop, A., Sibale, E., Awadh, A. and Kiswaga, L., 2013. Transport and mobility constraints in an aging population: health and livelihood implications in rural Tanzania. *Journal of Transport Geography*, 30, pp.161-169. DOI:10.1016/j.jtrangeo.2013.05.001

Pritchard, J.P., Tomasiello, D.B., Giannotti, M. and Geurs, K., 2019. Potential impacts of bike-and-ride on job accessibility and spatial equity in São Paulo, Brazil. *Transportation Research Part A: Policy and Practice*, 121, pp.386-400. DOI:10.1016/j.tra.2019.01.022

Qin, Y. and Zhang, X., 2016. The road to specialization in agricultural production: Evidence from rural China. *World Development*, 77, pp.1-16. DOI:10.1016/j.worlddev.2015.08.007

Raballand, G., Thornton, R.L., Yang, D., Goldberg, J., Keleher, N.C. and Müller, A., 2011. Are rural road investments alone sufficient to generate transport flows? Lessons from a randomized experiment in rural Malawi and policy implications.

- Radke, J. and Mu, L., 2000. Spatial decompositions, modeling and mapping service regions to predict access to social programs. *Geographic Information Sciences*, 6(2), pp.105-112. DOI: 10.1080/10824000009480538
- Rajkhan, S., 2014. Women in Saudi Arabia: Status, rights, and limitations. A paper submitted to the faculty of the University of Washington Bothell in candidacy for the degree of Master of Arts in Policy Studies.
- Ramos, S., & Musumeci, L., 2005. *Elemento suspeito: Abordagem policial e discriminação na cidade do Rio de Janeiro*. Rio de Janeiro: Civilização Brasileira.
- Rand, J., 2011. Evaluating the employment-generating impact of rural roads in Nicaragua. *Journal of development effectiveness*, 3(1), pp.28-43.
- Rasella, D., Aquino, R. and Barreto, M.L., 2013. Impact of income inequality on life expectancy in a highly unequal developing country: the case of Brazil. *J Epidemiol Community Health*, pp.jech-2012.
- Rauniyar, G., Orbeta, A. and Sugiyarto, G., 2011. Impact of water supply and sanitation assistance on human welfare in rural Pakistan. *Journal of development effectiveness*, 3 (1), 62–102.
- Ravallion, M., 1998. Poverty lines in theory and practice. The World Bank. DOI: 10.1596/0-8213-4226-6
- Ravallion, M., 2007. Evaluating anti-poverty programs. *Handbook of development economics*, 4, pp.3787-3846. DOI:10.1016/S1573-4471(07)04059-4
- Roberts, P., KC, S., Rastogi, C., 2006. Rural Access Index: A Key Development Indicator. Transport paper series; no. TP-10. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/17414> License: CC BY 3.0 IGO.
- Rodrigues, E.M., Villaveces, A., Sanhueza, A. and Escamilla-Cejudo, J.A., 2014. Trends in fatal motorcycle injuries in the Americas, 1998–2010. *International*

journal of injury control and safety promotion, 21(2), pp.170-180. DOI: 10.1080/17457300.2013.792289

Rodríguez, C., Gallego, J.M., Martinez, D., Montoya, S. and Peralta-Quiros, T., 2016. Examining Implementation and Labor Market Outcomes of Targeted Transit Subsidies: Subsidy by Sistema Nacional de Selección de Beneficiarios for Urban Poor in Bogotá, Colombia. Transportation Research Record: Journal of the Transportation Research Board, (2581), pp.9-17. DOI:10.3141/2581-02

Rosenbaum, P.R. and Rubin, D.B., 1983. The central role of the propensity score in observational studies for causal effects. Biometrika, 70(1), pp.41-55.

Rynning, M. K., Uteng, T.P. and Lucas, K., 2017. Epilogue: Creating planning knowledge through dialogues between research and practice. Urban mobilities in the global south. Routledge.

Saaty, T.L. and Vargas, L.G., 2006. Decision making with the analytic network process (Vol. 282). Springer Science+ Business Media, LLC.

Saaty, T.L., 1980. The analytic hierarchy process, McGrawHill, New York

Sachs, J., 2008. The end of poverty: economic possibilities for our time. European Journal of Dental Education, 12, pp.17-21. DOI:10.1111/j.1600-0579.2007.00476.x

Sadhu, S.S. and Tiwari, G., 2016. An activity pattern–destination land use choice model of low income households of informal settlements–Case study of Delhi. Transportation Research Part A: Policy and Practice, 85, pp.265-275. DOI:10.1016/j.tra.2016.01.017

Salon, D. and Gulyani, S., 2010. Mobility, poverty, and gender: travel ‘choices’ of slum residents in Nairobi, Kenya. Transport Reviews, 30(5), 641-657. DOI:10.1080/01441640903298998

Sanchez, T.W., 2008. Poverty, policy, and public transportation. Transportation Research Part A: Policy and Practice, 42(5), 833-841. DOI:10.1016/j.tra.2008.01.011

- Silva, J.B., Guerra, L.D., Ioris, A.A. and Gomes, R.A., 2015. Conflitos sociopolíticos, recursos hídricos e programa um milhão de cisternas na região semiárida da Paraíba. *Novos Cadernos NAEA*, 18(2).
- Santos, L. M. P., Oliveira, A., Trindade, J.S., Barreto, I.C., Palmeira, P.A., Comes, Y., Santos, F.O., Santos, W., Oliveira, J.P.A., Pessoa, V.M. and Shimizu, H.E., 2017. Implementation research: towards universal health coverage with more doctors in Brazil. *Bulletin of the World Health Organization*, 95(2), p.103.
- Santos, M., 2009. *Pobreza urbana*. São Paulo. Editora EDUSP.
- Sarkar, A.K. and Ghosh, D., 2008. Integrated Rural Accessibility Planning (IRAP) an application in three panchayats in Rajasthan, India. *Progress in Development Studies*, 8(3), pp.241-259. DOI: 10.1177/146499340800800303
- Saroli, C, 2015. Passenger transport in rural and sparsely populated areas in France. *International Transport Forum Discussion Paper 2015-09*. OCDE.
- Scheffer, M., Cassenote, A., Guilloux, A. G. A., Biancarelli, A., Miotto, B. A., & Mainardi, G. M., 2018. *Demografia médica no Brasil 2018*. Demografia Médica no Brasil 2018. São Paulo, SP: FMUSP, CFM, Cremesp, 2018. 286 p. ISBN: 978-85-87077-55-4.
- Schuurman, N., Berube, M. and Crooks, V.A., 2010. Measuring potential spatial access to primary health care physicians using a modified gravity model. *The Canadian Geographer/Le Geographe Canadien*, 54(1), pp.29-45. DOI: 10.1111/j.1541-0064.2009.00301.x
- Seekings, J., 2008. The continuing salience of race: Discrimination and diversity in South Africa. *Journal of contemporary African studies*, 26(1), pp.1-25.
- Seiler, C., 2007. The significance of race to transport history. *The Journal of Transport History*, 28(2), pp.307-311.
- Sen, A., 1982. *Poverty and famines: an essay on entitlement and deprivation*. Oxford university press.

- Serajuddin, U., Uematsu, H., Wieser, C., Yoshida, N. and Dabalen, A., 2015. Data deprivation: another deprivation to end. The World Bank. Policy Research working paper; no. WPS 7252. Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/700611468172787967/Data-deprivation-another-deprivation-to-end>
- Setboonsarng, S. 2006. Transport Infrastructure and Poverty Reduction. Asian Development Bank. Research Policy Brief No. 21. Available at <http://hdl.handle.net/11540/4064>
- Shannon, G.W., Bashshur, R.L. and Metzner, C.A., 1969. The concept of distance as a factor in accessibility and utilization of health care. *Medical Care Review*, 26(2), pp.143-161.
- Shaw, S. and Sahoo, H., 2019. Accessibility to Primary Health Centre in a Tribal District of Gujarat, India: application of two step floating catchment area model. *GeoJournal*, pp.1-10. DOI: 10.1007/s10708-019-09977-1
- Silcock, D.T., 1981. Urban paratransit in the developing world. *Transport Reviews*, 1(2), pp.151-168.
- Silva, E.N.D., Ramos, M.C., Santos, W., Rasella, D., Oliveira, A. and Santos, L.M.P., 2018. Cost of providing doctors in remote and vulnerable areas: Programa Mais Médicos in Brazil. *Revista Panamericana de Salud Pública*, 42, p.e11.
- Silverman, B. W., 1986. *Density Estimation for Statistics and Data Analysis*. New York: Chapman and Hall. 175pp. DOI: 10.1002/bimj.4710300745
- Social Exclusion Unit, 2003. *Making the Connections: Final report on Transport and Social Exclusion*. Office of the Deputy Prime Minister, London.
- Spencer, J. and Angeles, G., 2007. Kernel density estimation as a technique for assessing availability of health services in Nicaragua. *Health Services and Outcomes Research Methodology*, 7(3-4), pp.145-157.

Spicker, P., 2007. Definitions of poverty: twelve clusters of meaning. *Poverty: An international glossary*, pp.229-243.

Starkey, P.; Hine, J. Poverty and sustainable transport: how transport affects poor people with policy implications for poverty reduction. ODI, London, UK (2014) pp. 72 .

Starkey, P., Njenga, P., Kemtsop, G., Willilo, S., Opiyo, R. and Hine, J., 2013, September. Rural transport service indicators. In Final Report. International Forum for Rural Transport and Development (IFRTD), for African Community Access Programme.

Stifel, D. and Minten, B., 2017. Market access, well-being, and nutrition: evidence from Ethiopia. *World Development*, 90, pp.229-241. DOI:10.1016/j.worlddev.2016.09.009

Stifel, D., Minten, B. and Koru, B., 2016. Economic Benefits of Rural Feeder Roads: Evidence from Ethiopia. *The Journal of Development Studies*, 52(9), pp.1335-1356. DOI: 10.1080/00220388.2016.1175555

Stock, R., 1983. Distance and the utilization of health facilities in rural Nigeria. *Social science & medicine*, 17(9), pp.563-570.

SUDENE (Superintendencia de Desenvolvimento do Nordeste), 2019. Plano Regional de Desenvolvimento do Nordeste – PRDNE. Recife. Available at <http://www.sudene.gov.br/images/arquivos/planejamento/PRDNE/PRDNE-27052019.pdf>

Szwarcwald, C.L., de Souza Júnior, P.R.B., Marques, A.P., de Almeida, W.D.S. and Montilla, D.E.R., 2016. Inequalities in healthy life expectancy by Brazilian geographic regions: findings from the National Health Survey, 2013. *International journal for equity in health*, 15(1), p.141.

TaIC, 2016. ATAP Guidelines: T5 Distributional (Equity) Effects. Retrieved from https://atap.gov.au/tools-techniques/distributional-effects/files/t5_distributional_equity_effects.pdf

- Tanser, F., Gijsbertsen, B., & Herbst, K., 2006. Modelling and understanding primary health care accessibility and utilization in rural South Africa: An exploration using a geographical information system. *Social Science & Medicine*, 63(3), 691–705. doi:10.1016/j.socscimed.2006.01.015
- Tanser, F., Hosegood, V., Benzler, J., & Solarsh, G., 2001. New approaches to spatially analyse primary health care usage patterns in rural South Africa. *Tropical Medicine and International Health*, 6(10), 826–838. doi:10.1046/j.1365-3156.2001.00794.x
- Thaddeus, S. and Maine, D., 1994. Too far to walk: maternal mortality in context. *Social science & medicine*, 38(8), pp.1091-1110.
- Thomopoulos, N., Grant-Muller, S. and Tight, M.R., 2009. Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology. *Evaluation and program planning*, 32(4), pp.351-359.
- Titheridge, H., Mackett, R.L., Christie, N., Oviedo Hernández, D. and Ye, R., 2014. Transport and poverty: a review of the evidence.
- Travassos, C., de Oliveira, E.X. and Viacava, F., 2006. Desigualdades geográficas e sociais no acesso aos serviços de saúde no Brasil: 1998 e 2003. *Ciência & Saúde Coletiva*, 11, pp.975-986.
- UN Environment, 2016. Global Outlook on Walking and Cycling. UN Environment, Nairobi.
- UN (United Nations), 1995. The Copenhagen declaration and programme of action: World summit for social development 6-12 March 1995, New York: United Nations Department of Publications
- UN (United Nations), 2004. Forging a Global South – United Nations Development Programme. Available at: <https://www.undp.org/content/dam/china/docs/Publications/UNDP-CH-PR-Publications-UNDay-for-South-South-Cooperation.pdf>

UN (United Nations), 2015a. Resolution adopted by the General Assembly on 25 September 2015 - Transforming our world: the 2030 Agenda for Sustainable Development. Available at https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

UN (United Nations), 2015b. The Millennium Development Goals Report.

UN (United Nations), 2016, Global Sustainable Development Report 2016, Department of Economic and Social Affairs, New York, July.

UN (United Nations), 2017. The Sustainable Development Goals (SDG). New York: United Nations, 2017. 60 p. Retrieved at 22/05/2019 from <https://unstats.un.org/sdgs/files/report/2017/TheSustainableDevelopmentGoalsReport2017.pdf>

UN (United Nations), 2018. Leaving no one behind - Committee for Development Policy. Available at: https://sustainabledevelopment.un.org/content/documents/2754713_July_PM_2._Leaving_no_one_behind_Summary_from_UN_Committee_for_Development_Policy.pdf

UN (United Nations), 2019a. Sustainable Development Goals. Goal 1: No poverty. Facts and figures. Retrieved at 15/02/2019 from <https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-1-no-poverty.html>

UN (United Nations), 2019b. The Sustainable Development Goals Report 2019. Available at <https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf>

UN (United Nations), 2019c. Sustainable Development Goals - Knowledge platform. Sustainable Transport. Available at <https://sustainabledevelopment.un.org/topics/sustainabletransport>

UNDP (United Nations Development Programme), Fundação João Pinheiro e Instituto de Pesquisas Econômica Aplicada. 2010 Atlas do desenvolvimento humano no Brasil. Available at <http://www.atlasbrasil.org.br/2013/pt/consulta/>

- UNDP (United Nations Development Programme), 2016. Desenvolvimento humano nas macrorregiões brasileiras: 2016. – Brasília. PNUD, IPEA, 55 p. Retrieved at 22/05/2019 from <https://www.undp.org/content/dam/brazil/docs/IDH/undp-br-macrorregioes-brasileiras-2016.pdf>
- UNDP (United Nations Development Programme), 2019. Table 1. Human Development Index and its components. Retrieved at 22/05/2019 from <http://hdr.undp.org/en/composite/HDI>
- Vajjhala, S.P. and Walker, W.M., 2010. Roads to participatory planning: Integrating cognitive Mapping and GIS for transport prioritization in rural Lesotho. *Journal of Maps*, 6(1), pp.488-504. DOI:10.4113/jom.2010.1086
- Vakis, R., Rigolini, J., Lucchetti, L., 2016. Left Behind: Chronic Poverty in Latin America and the Caribbean. World Bank publication. Washington, DC. Available at: <http://hdl.handle.net/10986/21552>
- Valor. 2018. Extrema pobreza avança e é recorde em 9 estados. Retrieved at 22/05/2019 from <https://www.valor.com.br/brasil/5912587/extrema-pobreza-avanca-e-e-recorde-em-9-estados>
- Van de Walle, D., 2009. Impact evaluation of rural road projects. *Journal of development effectiveness*, 1(1), pp.15-36.
- Van Wee, B. and Geurs, K., 2011. Discussing equity and social exclusion in accessibility evaluations. *European journal of transport and infrastructure research*, 11(4).
- Van Wee, B., 2012. How suitable is CBA for the ex-ante evaluation of transport projects and policies? A discussion from the perspective of ethics. *Transport Policy*, 19(1), pp.1-7.
- Vargas, R. V., 2010. Using the analytic hierarchy process (AHP) to select and prioritize projects in a portfolio. In *PMI global congress* (pp. 1-22). Available at: <https://ricardo-vargas.com/downloads/download-file/6888/12430>

Vasconcellos, E., 2001. Urban Transport: Environment and Equity: The Case for Developing Countries, Earthscan, London and Sterling VA, 333 pages.

Vasconcellos, E.A., 2003. Inclusion of social benefits in road transport planning. Think piece paper for the Framework for the Inclusion of Social Benefits in Transport Planning, United Kingdom Department for International Development. Available at: <https://www.gov.uk/dfid-research-outputs/inclusion-of-social-benefits-in-road-transport-planning-a-think-piece-paper>

Vasconcellos, E.A., 2005. Urban change, mobility and transport in São Paulo: three decades, three cities. Transport Policy, 12(2), pp.91-104. DOI:10.1016/j.tranpol.2004.12.001

Vasconcellos, E.A., 2008. O custo social da motocicleta no Brasil. Revista dos Transportes Públicos–ANTP, ano, 30, p.31. Available at <http://www.emdec.com.br/moto2012/downloads/artigo.pdf>

Vasconcellos, E.A., 2008. O custo social da motocicleta no Brasil. Revista dos Transportes Públicos–ANTP, ano, 30, p.31.

Vasconcellos, E.A., 2011. 12 Equity evaluation of urban transport. Urban transport in the developing world: a handbook of policy and practice, p.332.

Vasconcellos, E.A., 2018. Urban transport policies in Brazil: The creation of a discriminatory mobility system. Journal of transport geography, 67. DOI:10.1016/j.jtrangeo.2017.08.014

Veeneman, W. and Mulley, C., 2018. Multi-level governance in public transport: Governmental layering and its influence on public transport service solutions. Research in Transportation Economics, 69, pp.430-437.

Velaga, N. R., Beecroft, M., Nelson, J. D., Corsar, D., & Edwards, P. (2012). Transport poverty meets the digital divide: accessibility and connectivity in rural communities. Journal of Transport Geography, 21, 102-112. DOI: 10.1016/j.jtrangeo.2011.12.005

- Venter, C., 2011. Transport expenditure and affordability: The cost of being mobile. *Development Southern Africa*, 28(1), pp.121-140. DOI:10.1080/0376835X.2011.545174
- Vermeiren, K., Verachtert, E., Kasaija, P., Loopmans, M., Poesen, J. and Van Rompaey, A., 2015. Who could benefit from a bus rapid transit system in cities from developing countries? A case study from Kampala, Uganda. *Journal of Transport Geography*, 47, pp.13-22. DOI:10.1016/j.jtrangeo.2015.07.006
- Victora, C.G., Aquino, E.M., do Carmo Leal, M., Monteiro, C.A., Barros, F.C. and Szwarcwald, C.L., 2011. Maternal and child health in Brazil: progress and challenges. *The Lancet*, 377(9780), pp.1863-1876.
- Vyas, S. and Kumaranayake, L., 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health policy and planning*, 21(6), pp.459-468. DOI: 10.1093/heapol/czl029
- Wachs, M. and Kumagai, T.G., 1973. Physical accessibility as a social indicator. *Socio-Economic Planning Sciences*, 7(5), 437-456. DOI: 10.1016/0038-0121(73)90041-4
- Walker, N., Yenokyan, G., Friberg, I.K. and Bryce, J., 2013. Patterns in coverage of maternal, newborn, and child health interventions: projections of neonatal and under-5 mortality to 2035. *The Lancet*, 382(9897), pp.1029-1038.
- Walks, A., 2018. Driving the poor into debt? Automobile loans, transport disadvantage, and automobile dependence. *Transport policy*, 65, pp.137-149.
- Wang, F., 2012. Measurement, optimization, and impact of health care accessibility: a methodological review. *Annals of the Association of American Geographers*, 102(5), pp.1104-1112. DOI: 10.1080/00045608.2012.657146
- Warr, P., 2005. Road development and poverty reduction: The case of Lao PDR (No. 64). ADBI Research Paper Series.
- Wee, B.V. and Banister, D., 2016. How to write a literature review paper?. *Transport Reviews*, 36(2), pp.278-288. DOI:10.1080/01441647.2015.1065456

Weiss, D.J., Nelson, A., Gibson, H.S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N. and Mappin, B., 2018. A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature*, 553(7688), p.333. DOI: 10.1038/nature25181

Wegener, M. and Fürst, F., 2004. Land-use transport interaction: state of the art. Available at SSRN 1434678.

William, M. K., 2006. The regression-discontinuity design. <http://socialresearchmethods.net/kb/quasird.htm>.

Wixey, S., Jones, P., Lucas, K. and Aldridge, M., 2005. Measuring accessibility as experienced by different socially disadvantaged groups. London, Transit Studies Group, University of Westminster.

World Bank, 2002. Brazil: Growth and Poverty Reduction in Pernambuco. Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/15444> License: CC BY 3.0 IGO.

World Bank, 2006. Social analysis in transport projects: guidelines for incorporating social dimensions into Bank-supported projects (English). Social Analysis Sector Guidance Note Series. Washington, DC: World Bank. <http://documents.worldbank.org/curated/en/688971468136802153/Social-analysis-in-transport-projects-guidelines-for-incorporating-social-dimensions-into-Bank-supported-projects>

World Bank, 2017. Monitoring Global Poverty: Report of the Commission on Global Poverty. Washington, DC: World Bank. <<https://openknowledge.worldbank.org/handle/10986/25141>>.

World Bank, 2019a. Country and Lending Groups. Retrieved at 22/05/2019 from <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>

World Bank, 2019b. GDP (current US\$). Retrieved at 22/05/2019 from https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true&year_high_desc=true

World Bank, 2019c. GINI index (World Bank estimate). Retrieved at 22/05/2019 from <https://data.worldbank.org/indicator/si.pov.gini>

WHO (World Health Organization), 2015. MDG 4: Reduce child mortality. Available at https://www.who.int/topics/millennium_development_goals/child_mortality/en/

Yang, D.H., Goerge, R. and Mullner, R., 2006. Comparing GIS-based methods of measuring spatial accessibility to health services. *Journal of medical systems*, 30(1), pp.23-32. DOI: 10.1007/s10916-006-7400-5

Yu, N., De Jong, M., Storm, S., & Mi, J., 2013. Spatial spillover effects of transport infrastructure: evidence from Chinese regions. *Journal of Transport Geography*, 28, 56-66.

Zou, W., Zhang, F., Zhuang, Z. and Song, H., 2008. Transport Infrastructure, Growth, and Poverty Alleviation: Empirical Analysis of China. *Annals of Economics & Finance*, 9(2).

APPENDIX A: Performance indicators for MCDAs

The following list of indicators describes how the theoretical framework of transport-related exclusion dimension could be further applied to MCDAs. As it can be noted, all the following indicators that are suggested are presented as a relative value, that is, *expected change for every euro invested*, or also, *affected population over the total population*. This type of indicator is mainly suggested since it allows the total social impact to be accounted for the sum of these values multiplied by the weights calculated in Chapter 6. It is also worth mentioning that these indicators can be further simplified into discrete values (e.g. zero for 'no impact', -1 for 'worsening' or +1 for 'improvement') if the planning agency cannot afford more detailed performance estimates.

- From facilities: Increase or decrease of the overall level of accessible public services (e.g. education, health) in a given threshold time for every euro invested. Whenever possible, also disaggregating the analysis by social groups (e.g. income strata, gender, race, etc.), sub-region (e.g. neighbourhoods, census tracts) and mode of transport (e.g. walking, cycling, public transport, private car, cycle & ride, etc)
- Geographic: Increase or decrease of the of socially vulnerable population covered by transport network (e.g. public transport terminals, shared bicycle stations, on-demand rural transport lines, all-season roads) and displaced after project completion for every euro invested
- Economic: Percentage of population in income poverty positively or negatively affected by changes in direct or indirect costs caused by the new intervention (e.g. changes in fares, inclusion of tolls, changes in land use costs around new stations, increase in productivity and job creation around the project, etc)
- Fear-based: Increase or decrease in the expected number of accidents for every euro invested, or also, from a fear of crime standpoint, the percentage of the population benefited by improvements in the public space security (e.g. CCTV installation, security guards, lighting on public roads, etc)

- Physical: Number of the elderly or disabled population benefiting from micro accessibility enhancements (e.g. sidewalk accessibility ramps, sound, visual and tactile signalling at intersections, etc.) for every euro invested
- Time-based: Increase or decrease on the average travel time between neighbourhoods / municipalities for every euro invested. Whenever possible, also disaggregating analysis by social group (e.g. income bracket, gender, race), subregion (e.g. census tracts) and mode by transport (e.g. public transport, car, cycle & ride, etc)
- Spatial: Number of people benefiting from the reduction of spatial barriers (e.g. pedestrian crosswalks, inclusion of cycle lanes and crosswalks in tunnels and bridges, etc) for every euro invested
- Based on social position: Percentage of the population of a particularly excluded social groups (evidenced by prior analysis) that will be impacted (positively or negatively) by a project, or also, the total number of this population that will be impacted for every euro invested. Thus, urban infrastructure projects that aim, for example, at improving security in these high-crime regions should be given priority in this regard

At last, based on models similarly applied by the World Bank (Marcelo et al., 2018; and Marcelo et al., 2016), the social impact calculated these MCDAs can be plotted against other environmental and economic assessments (e.g. Net Present Value, or Internal Rate of Return) to provide a comprehensive appraisal of potential transport interventions. By doing so, a more socially inclusive transport planning can be achieved, delivering feasible and objective transport contributions to the poverty eradication process.