BALANCING ECONOMIC, SOCIAL AND ENVIRONMENTAL VALUE IN TRANSPORT INFRASTRUCTURE BUSINESS MODELS

by

NIKOLAOS KALYVIOTIS

Dipl.-Ing., MSc, MSPM, MBA

A thesis submitted to the University of Birmingham for the degree of
DOCTOR OF PHILOSOPHY
IN CIVIL ENGINEERING

Department of Civil Engineering
School of Engineering
College of Engineering and Physical Sciences
University of Birmingham

November 2021

ABSTRACT

There is ongoing debate about the value of the benefits of infrastructure systems (specifically those of energy, water and wastewater, transport, waste, and communications) and how to prioritize infrastructure investments to encompass considerations of social, economic and environmental wellbeing. The use of the term '*infrastructure system*' is related to interdependencies. Infrastructure systems operating in different countries and cities are interrelated in different ways, but all have a strong relationship to '*transport*' – there is a cost and a utility associated with movement. Infrastructure systems are ultimately created to serve individuals, who place a value on them. In order to explore all forms of value realisation – the foundation for what are commonly termed business models – the relationship between an individual and the transport system needs to be established. The hypothesis being tested in this thesis is that it is possible to identify both the full range of value and interdependencies required, and hence to establish robust alternative business models, for transport infrastructure interdependencies management that incorporate considerations of social, economic and environmental wellbeing, noting that the interdependencies lie with the other four national infrastructure sectors in the UK (see above).

Different research methods were used for each type of value. Economic value was studied using the research methodology of '*networks and cohorts*' on input-output tables and applying linear analysis to the data. Social value was studied by collecting data with a structured interview process and analysing this with the appropriate statistical methods. Environmental value was taken from previous studies which linked it with the economic value (demand) of the input-output tables. Economic and environmental value interdependencies were analysed through Pearson's correlation coefficient of secondary data, while social value interdependencies were analysed through statistical analysis of primary data.

The new business model captures a wide range of the values of social, economic and environmental considerations on infrastructure systems. The new business model permits better understanding of how the overall system works by policy makers and hence better decisions on which type of infrastructure to focus on if they want to add value to society.

Keywords: *Infrastructure Business Models; Infrastructure; Infrastructure Management; Infrastructure Interdependencies; Economic Value; Social Value; Environmental Value*

To my family

ACKNOWLEDGEMENTS

Acknowledgements and thanks are given to all those who contributed directly or indirectly to the completion of this thesis. Special acknowledgements and thanks should be given for consulting as well as providing help in choosing and finalizing the contents of this research to my supervisors at University of Birmingham (2015-2018), at University of Illinois at Urbana-Champaign (2017-2018) and at University of Melbourne (2018):

- **Professor Christopher D.F. Rogers**, Professor of Geotechnical Engineering at University of Birmingham and Director of the UKCRIC National Buried Infrastructure Facility, UK
- **Professor Miles R. Tight**, Professor of Transport, Energy and Environment at University of Birmingham, UK
- **Professor Geoffrey J.D. Hewings**, Professor of Urban and Regional Planning, of Economics, and of Geography and Regional Science at University of Illinois at Urbana-Champaign and Director of the Regional Economics and Applications Laboratory, USA
- **Professor Hemanta Doloi**, Professor of Property and Construction Management and Technology at University of Melbourne, Australia

and to the examiners for their constructive feedback:

- **Professor Thomas L. Theis**, Professor of Civil and Materials Engineering and Director of the Institute for Environmental Science and Policy at the University of Illinois at Chicago, USA
- **Andrew Quinn**, Reader in Atmospheric Science and Engineering at the University of Birmingham, UK

The author is also grateful to **Professor Shoshanna Saxe**, Assistant Professor in Sustainable Infrastructure, for letting him work on the final details of his PhD thesis along with his postdoctoral fellowship and his course instructorship at University of Toronto, Canada (2018-2020).

This thesis and its outcomes would not be achieved without the help, the support and the provision of needed material and data from the aforementioned people. The author gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under grant numbers EP/K012398 (iBUILD: Infrastructure BUsiness models, valuation and Innovation for Local Delivery), EP/J017698 (Transforming the Engineering of Cities to Deliver Societal and Planetary Wellbeing, known as Liveable Cities) and EP/P013635 and EP/R017727 (UKCRIC: UK Collaboratorium for Research on Infrastructure and Cities) and of the Universitas21 for supporting this thesis by awarding the author the Universitas21 PhD Scholarship. Finally, the author would like to thank the staff of the University of Birmingham, the University of Illinois at Urbana-Champaign and the University of Melbourne.

I want to thank my parents, Asterios and Evangellia, and my brother, Konstantinos, for standing next to me during this journey.

I would like to thank my partner and my best friend, Maria Katsiperi, for the support that provided me and for accompanying me across Canada, the US and the UK. Without Maria the completion of this journey would be so much harder.

Finally, I also would like to thank all my friends. First my friends in Greece, Ilias Eleftheriou and Ifigenia Dosi, who gave me constant support during my studies despite the physical distance and whom I consider family.

Second, I would like to thank Kostas Konstantinidis and Marina Mavridou for their support during my first days in Birmingham and for our discussions during the lunch breaks at Costa Coffee.

This journey would not be the same without Evita Papazikou, Stella Despoudi, José Carlos Nogueira Filho, Argyris Anagnostopoulos, Stylianos Providakis, Konstantina Simou and our after-office drinks at Staff House, at Goose, at Actress and Bishop and all around Birmingham.

A huge thanks to the Greek community of UIUC and especially to Dimitris Skarlatos, Dimitris Fytanidis and Soteris Demetriou for our nights at Legends and at Murphy's, and for our weekend BBQs. You made me feel like home!

In addition, I would like to thank the REAL “Mafia” and especially Andre Fernandes Tomon Avelino, Yizhou Zhang, Alfredo Cartone, Orsa Kekezi, Raissa Carvalho Bragança, Raquel Langarita, Nora Schindler, Fernando Bermejo Patón and Fernando Rubiera Morollón for our academic discussions during the Friday Seminar Series and for the great time we spent together in Urbana-Champaign, in Chicago, in Vancouver and in Morgantown.

Last but certainly not least, I would like to thank my friends in Toronto, Georgios Kolliopoulos, Stathis Maneas, Gina Kalogerakis, Anthi Kostopoulou, Georgios Giotis, Marianna Kosta and Victor Kariofillis for all the coffee breaks at the University, our nights at Logo Bar and the road trips around Canada. I was fortunate to meet you.

Thank you! Ευχαριστώ! Nikos Kalyviotis

TABLE OF CONTENTS

LIST OF PEER-REVIEWED PUBLICATIONS

The author of this thesis, Nikolaos Kalyviotis, was the lead author and essentially wrote all the following papers and the other authors (Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H.) provided comment and guidance, as part of their supervision duties.

(See the list of publications here: https://gtr.ukri.org/projects?ref=EP%2FP013635%2F1)

JOURNAL PUBLICATIONS:

[1] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2018a) **"Defining the Social Value of Transport Infrastructure"**, *Proceedings of the Institution of Civil Engineers journal Infrastructure Asset Management, Issue: Themed issue on Understanding the value of infrastructure systems* (DOI: 10.1680/jinam.18.00005)

[2] **Kalyviotis N**., Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2018b) "**Infrastructure Management: Development of a Business Model for Transport Infrastructure Interdependencies Management**", *RELAND: International Journal of Real Estate & Land Planning* (https://ejournals.lib.auth.gr/reland/article/view/6479)

[3] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2018c) "**The Environmental Value of Sustainable Transport Infrastructure**", *RELAND: International Journal of Real Estate & Land Planning* (https://ejournals.lib.auth.gr/reland/article/view/6457)

INTERNATIONAL CONFERENCES PUBLICATIONS:

[1] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2018d) **"Transport Infrastructure Environmental Evaluation in the United Kingdom"**, *11th annual Midwest Graduate Student Summit on Applied Economics, Regional, and Urban Studies (AERUS)*, 7–8 April, West Virginia University, West Virginia, United States of America (https://sites.google.com/view/aerus2018/program)

[2] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2017a) **"Transport infrastructure interdependencies with energy, water, waste and communication infrastructure in the United Kingdom"**, *64th Annual North American Meetings of the Regional Science Association International*, 8–11 November, Vancouver, Canada (http://s3.amazonaws.com/narsc-uploads/newsite/wp-content/uploads/2009/03/24043536/Final-Program2.pdf)

[3] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2017b) **"Next Generation Infrastructure Interdependencies: An economic deterministic model of transport interdependencies in the United Kingdom"**, *International Symposium for Next Generation Infrastructure*, 11–13 September, London, United Kingdom (http://isngi.org/wp-content/uploads/2017/10/ISNGI-Kalyviotis-Next-Generation-Infrastructure-Interdependencies.pdf)

[4] **Kalyviotis N.**, Rogers C.D.F., Tight M.R., Hewings G.J.D. & Doloi H. (2017c) **"The individual as the key-stakeholder of Next Generation Infrastructure projects: Defining the social value of transport infrastructure in the United Kingdom"**, *International Symposium for Next Generation Infrastructure*, 11–13 September, London, United Kingdom (http://isngi.org/wp-content/uploads/2017/10/ISNGI-Kalyviotis-The-individual-as-the-key-stakeholder-of-Next-Generation-Infrastructure.pdf)

[5] **Kalyviotis N.**, Rogers C.D.F. & Tight M.R. (2017d) "**Valuing Transport Infrastructure: A quantitative study of the factors defining the social value of transport infrastructure in the United Kingdom**", *Valuing Infrastructure Conference: Valuing the Infrastructure of Cities, Regions and Nations*, 26 – 27 April, Leeds, United Kingdom (http://conferences.leeds.ac.uk/valuing-infrastructure/wp-content/uploads/sites/14/2017/01/VTI.pdf)

[6] **Kalyviotis N.**, Rogers C.D.F. & Tight M.R. (2017e) **"Infrastructure Interdependencies: Transport sector economic dependency with other critical infrastructure sectors in the United Kingdom"**, *Valuing Infrastructure Conference: Valuing the Infrastructure of Cities, Regions and Nations*, 26 – 27 April, Leeds, United Kingdom (http://conferences.leeds.ac.uk/valuing-infrastructure/wp-content/uploads/sites/14/2017/01/Infrastructure-Interdependencies.pdf)

LIST OF TABLES AND FIGURES

GLOSSARY AND ACRONYMS

Here are presented useful terms, explanations and acronyms that reader meets in the thesis.

As
Arsenic

CBA
Cost-benefit analysis

Cd
Cadmium

CH_4
Methane

CO
Carbon monoxide

CO_2
Carbon dioxide

COPERT
Calculation of Emissions from Road Transport

Cr
Chromium

CSR
Corporate Social Responsibility

Cu
Copper

GVA
Gross Value Added

Hg
Mercury

iBUILD
Infrastructure BUsiness models, valuation and Innovation for Local Delivery

IOGs
Input-Output Groups

N_2O
Nitrous oxide

NH_3
Ammonia

Ni
Nickel

NMVOC
Non-methane volatile organic compound

NO_x
Nitrogen oxide

ONS
UK's Office for National Statistics

PM_{10}
Particulate Matter (PM10): Inhalable particles, with diameters that are generally 10 micrometres and smaller.

$PM_{2.5}$
Particulate Matter (PM2.5): Inhalable particles, with diameters that are generally 2.5 micrometres and smaller.

PCDD_F
Dioxins (PCDD-F) are a group of polychlorobenzodioxins (PCDDs) and polychlorodibenzofurans (PCDFs)

Pb
Lead

Se
Selenium

SO_x
Sulfur oxide

TSP
Triple superphosphate

Zn
Zinc

Chapter 1 Introduction

1.1 Background

This doctorate is most closely linked with the Liveable Cities (Liveable Cities, 2015) and iBUILD (iBUILD, 2017) programmes, both of which have a specific focus within the area of infrastructure and urban engineering. While this research draws on ideas from several different disciplines, the application area relates most strongly to Civil Engineering and the thesis has been written with this perspective in mind. This research aimed to develop a new approach to business model formulation to improve the delivery of value from transport infrastructure systems in the United Kingdom More specifically, it has concentrated on the creation of new business models that take account of economic value, environmental value and social value (which are necessarily dependent on each other), and infrastructure interdependencies in urban areas. Material from this thesis has been published by the author in international journals (Kalyviotis et al., 2018a,b,c) and conferences (Kalyviotis et al., 2017a,b,c).

1.1.1 Infrastructure business models and interdependencies management

There is an ongoing debate about the value of the non-economic benefits of infrastructures and how to prioritize infrastructure investments in the United Kingdom considering environmental and social value (iBUILD, 2017). Environmental and social value "*are sufficiently difficult to observe or measure quantitatively, much less capture in economic transactions, and the benefits may be diffuse and sufficiently small in magnitude to escape the attention of individual beneficiaries*" (Frischmann, 2012, p.6). Infrastructure is generally defined as "*a large-scale physical resource made by humans for public consumption*" (Frischmann, 2012, p.3). Infrastructure is related to economic interdependencies. Starting from the general interdependency theory, economists call interdependencies synergies (Steinmueller, 1996) and engineers call them interconnections (Hall et al., 2016). The different names used for dependencies and interdependencies by the social sciences and engineering show the need for interdisciplinary research between the two fields. 'Interdependencies' will be used here after to mean both dependencies and interdependencies. Searching for a better understanding of the impact of infrastructure interdependencies on transport infrastructure system performance led to the consideration of a new infrastructure business model including economic, social and environmental value, and including the value deriving from these interdependencies.

The literature mostly focuses on economic value and interdependencies (Hall et al., 2016). The economic interdependencies can be mapped using data from the economic input-output tables of different sectors. Additionally, the environmental impact of different infrastructure/sectors, for example in terms of pollutant production, can easily be found from previous research (Stadler et al., 2018) and this can be incorporated as one thread of environmental value consideration. This is an example of how it is possible to study the connections between different infrastructure systems and environmental consequences (i.e. pollutants) and to create a model with them. Social value is more difficult to discern by such means, but can be investigated by associating it with the needs of society and then asking society itself to define it (e.g. via interviews and surveys).

1.1.2 The business models concept

Business models by definition focus on value creation (hence value identification) and value capture for the key stakeholder or the final user (Magretta, 2002; Casadesus-Masanell & Ricart, 2010). However, this immediately points to the fact that there are many stakeholders to whom value will derive (in this case from transport infrastructure systems). The forces of evolution of business models are innovation (Markides & Geroski, 2005), globality (Craig & Douglas, 2000), public policy (Harrington & Estes, 2004) and corporate social responsibility (European Commission, 2011).

Internal value creation is achieved with value chain analysis and externally from the value network (Porter, 1985). External value is achieved by deconstructing the value chain to map the elements which support the business model (Christensen, 1997). Marketing imperative can be divided into three value propositions: low cost leader (Bordalo et al, 2016), mass customization (Pine, 1993) and solutions (Miller et al., 2002), the latter being the most common in the innovation industry. When a traditional market (e.g. transport infrastructure) needs an innovative solution, the marketing imperative may be a combination of mass customization and solution. The growth engine shows how firms grow, in other words shows the relationship between the inputs and the outputs of a business model under a specific market opportunity / target (Manda et al., 2015). The aforementioned elements of the business model should be considered during the development of any new business model.

1.1.3 Co-creation with stakeholders

Co-creation has recently attracted the attention of academics in an effort to understand the effects of stakeholders' needs and wants – their interdependencies in relation to the system under consideration – on value creation and capture. Value co-creation identifies where and when customers are ready to do business without economic constraints. Co-creation may enhance the performance of infrastructure systems by influencing the delivery of their outcomes due to the combination of knowledge capital and resources from different stakeholders. The co-creation approach requires alternative organizational structures which encourage creativity and help to control outcomes in the dynamic environment created from interactions (Roser et al., 2013, p.24-25). This required structure is based on "*incentives rooted in the supply and demand for interaction and transactions for which prices or explicit market based value may be determined*" (Roser et al., 2013, p.28). But how can this structure be designed to capture the determined value? Analysis of the empirical data in the research of George & Bock (2011, p.91-94), regarding business models, defined a business model as the design of the organizational structure for capturing value, something they called "*value structure*" (2011, p.107). In the framework of the adaptive organizational structure required by the co-creation concept, it is obvious that the business model is the key element to design this "*value structure*". Co-creation can be investigated in this framework without a separate analysis. The required alternative structure consists of relational structures too (Roser et al., 2013, p.28), which reflect the interdependencies inherent in the systemic analysis that underpins this thesis.

1.1.4 Establishing the research question

Infrastructure business models and infrastructure interdependencies define the under-researched landscape, and research gap, that led to the selection of the topic, the formulation of the research question, and the purpose and structure of the study. While there are numerous studies that focus on critical infrastructure interdependencies in the literature, most of them are focused also on times of crisis. Studies that focus on routine infrastructure interdependencies on a daily basis are very sparse.

Regarding infrastructure, Steinmueller (1996, p.117) observed: "*Both traditional and modern uses of the term infrastructure are related to "synergies", what economists call positive externalities that are incompletely appropriated by the suppliers of goods and services within an economic system.*" The traditional idea of infrastructure was derived from the observation that the private gains from the construction and extension of transportation and communication networks, while very large, were also accompanied by additional large social gains. Hall et al. (2016, p.6) defined the infrastructure as "*the collection and interconnection of all physical facilities and human systems that are operated in a coordinated way to provide* (a service)". For the purposes of this research, interdependencies refer to the synergies, which Steinmueller (1996) described, or to the interconnections, which Hall et al. described, as they both meant the same thing. The dominant value model of infrastructure interdependencies today is the economic value model's perspective of each infrastructure without considering the infrastructure interdependencies; i.e., siloed thinking. An alternative approach would involve energy, water, communication and waste infrastructures being analysed and incorporated into the appraisal of transport infrastructure systems' performance. This would complete the picture of the attractiveness of transport and allow recommendations for potential investments to be developed. This doctoral study aims to point out the findings that are relevant to economic value interdependencies of transport infrastructure.

Additionally, "*Infrastructure investment has always been considered key for economic growth*" (Rodríguez-Pose, 2015, p.2). The final users in the context of urban development are the individuals living in the specific urban area and affected by its economic growth. Furthermore, "*the development of transport infrastructure is* *most economic*" in the context of urban development (Dick & Rimmer, 2009, p.275). The individuals living in the specific urban area may be considered as a "*key stakeholder*", since their needs (and wants) define the government's responsibilities; moreover, previous studies have shown that "*infrastructure investment alone is not significantly linked with regional GDP change*", but transport infrastructure investment "*is more strongly linked to economic growth in regions with better government quality*" (Rodríguez-Pose, 2015, p.30). This "*strong and highly significant connection with regional economic performance*", when transport infrastructure investment "*is interacted with government quality*" (Rodríguez-Pose, 2015, p.32), highlights the importance of the individuals who elect or define the government. For the above reasons this study will focus on the economic value through growth, which affects (i.e., there is social value) and is affected by the citizens, who are the key-stakeholders.

The system of infrastructure networks (energy, water, transport, waste, communication) addressed by the iBUILD research project has been studied around the world (Hall et al., 2016, p.5; Dick & Rimmer, 2009, p. 273), as they are important not only for their economic value. The dominant value model of infrastructure interdependencies today is the economic value model's perspective of each infrastructure, without considering the infrastructure interdependencies and the necessary requirements of sustainability, resilience and liveability (Rogers, 2018). The process of identifying the research gap, or 'gap spotting', which will be used is, neglect spotting (Sandberg & Alvesson, 2011, p.30). This is spotting a research gap in under-researched areas in existing literature (Sandberg & Alvesson, 2011, p.30). This study aims to fill the aforementioned research gap and highlight the findings that are relevant to economic value interdependencies of transport infrastructure in developed countries.

In their turn, interactions create interdependencies, which should be investigated by the new business model. Therefore, the business model requires the involvement of the end users, "*key-stakeholders*", as value co-creators.

This thesis aims to fill this research-gap and points out the findings that are relevant to infrastructure business models and infrastructure interdependencies management. The theoretical contribution of this research will be in the fields of civil engineering and infrastructure management, and especially in the area of infrastructure business model theory.

1.2 Hypothesis, Research Question and Objectives

The above arguments logically result in the following hypothesis:

"Current methods of defining the value of transport systems are too narrowly defined, failing to account for not only the complete range of value that transportation systems offer but also the independencies with other urban systems (including infrastructure systems). The business models constructed from these narrower definitions of value therefore fail to realise their full potential."

This hypothesis will be tested against the literature and, assuming it to be correct, the aim of this research will be to develop a new way of constructing a business model. The aim will be met by striving to answer the following research question:

"How can infrastructure business models enable key infrastructure stakeholders to understand better the way that transport infrastructure is valued by those who use it and make better informed decisions about infrastructure interdependencies management, and thereby enable infrastructure systems and the services they deliver to flourish and infrastructure performance to be enhanced?"

This research question assumes there to be two primary interdependencies: the interdependencies between the key-stakeholders and the transport infrastructure systems, and the interdependencies between the transport infrastructure systems and the other four 'economic infrastructures (water, waste, energy and ICT). The main objectives for this doctoral research, which establish the scope of this research, are:

- **Objective 1**: Redefine infrastructure value in terms of the three pillars of sustainability and enable it to escape from its mainstream economic concept. To do so, a new approach should be introduced by identifying and exploiting the social and environmental characteristics of value.
- **Objective 2**: To explore exemplar infrastructure (inter)dependencies when creating and capturing value.
- **Objective 3**: To develop a suite of alternative new value-optimized infrastructure business models focusing on the value judgements of the users of transport infrastructure, and the impacts on transport infrastructure systems' value by other four 'economic infrastructures', by considering them as key stakeholders.

1.3 Philosophical Stance and Definition of Terms

The philosophical stance taken in this thesis should be discussed in terms of ontology and epistemology. Ontology is *"the nature of reality"*; what is what (Hudson & Ozanne, 1988, p.508) and epistemology is *"the theory of knowledge"*; how we can know (Pollock & Cruz, 1999, p.11). The ontological argument will be based on literature review. The epistemological analysis will be based on research methodology and on iBUILD (iBUILD, 2017) and Liveable Cities (Liveable Cities, 2017) outcomes, which have been obtained from the complementary research programmes. (More details about the two research programmes can be found at https://research.ncl.ac.uk/ibuild/ and at http://liveablecities.org.uk/). Broadly speaking, the scientific ideals can be described with three representative examples (Wainwright & Forbes, 2000, p.260): positivism, interpretivism and (critical) realism. "*The positivist approach is about constructing 'objective' realities or prototypes based on observable phenomena"* (Wainwright & Forbes, 2000, p. 261). The new value model constructs a new reality for capturing value by tracking the interdependencies. On the other hand, interpretivism focuses on ranking of *"subjective meanings and socio-political as well as symbolic action in the process through which humans construct and reconstruct their reality"* (Orlikowski & Baroudi, 1991, p. 13). Finally, the aim of critical realism is *"…not simply to collect observations on the social world, but to explain these within theoretical frameworks which examine the underlying mechanisms that inform people's actions and prevent their choices from reaching fruition"* (May, 2011, p.12).

The research strategy is: *"Within this context, the needs of cities and their citizens in the far future constitute the brief for today's visionary engineering, while to deliver on this brief requires engineers to work seamlessly and effectively across multiple disciplines"* (Liveable Cities, 2015). In other words, the new model should be able to engage seamlessly and effectively across technology, the socioeconomic context and the natural environment. Mainstream natural sciences use only objectivism and purely positivism, but in the sphere of social sciences, the philosophical stance is more flexible as it can use all scientific ideals. So the combination of social science (types of value) with natural science (transport interdependencies) is achieved with positivism. Additionally, interpretivism is not the proper scientific ideal as it separates social and natural sciences. Furthermore, (critical) realism focuses mostly on the *"social situation"* and *"requires a deep understanding"* of it, *"beyond the observable and investigating the mechanisms behind any event"* (Lyubimov, 2015). Realism opposes the scope of this study, which is to develop *"new models to improve the delivery of infrastructure systems and the services they provide"* (iBUILD, 2017), a new reality through technocratic and economic approaches, and not to capture human relationships by understanding why this situation exists sociologically. Someone may claim that realism may be more appropriate for this study of value and infrastructure interdependencies, as ontologically it is considered to be more unrestrictive regarding the accommodation of insights (Bhaskar & Danermark, 2006, p. 295). However, it should be mentioned that this study constructs objective realities, based on observed phenomena (empirical data), in accordance with the positive scientific ideal (Wainwright & Forbes, 2000) and not based on insights. On the other hand, it is worth noting that positivism misses social complexity and content, does not capture human relationships, and analysis is not value free (Wainwright & Forbes, 2000). This study aims to address the problems of positivism by focusing on socioeconomic aspects.

1.4 Structure of thesis

This thesis generally used the typical flow chart methodology starting with the formulation of a Hypothesis, Research Question(s), Aim and Objectives and the theoretical frame of reference, development of a practical methodology and finally presentation of the empirical data, analysis, discussion and conclusions. However there were some differentiations due to the nature of the research. As mentioned above, this research studies infrastructure interdependencies using different values: economic value, environmental value and social value. Each type of value should clearly be defined to avoid overlapping of definitions. Additionally, different databases, data and research methodologies were used for each type of value. Accordingly, the different types of value are discussed and studied independently (Chapter 3) as three different studies with their own introduction, hypothesis, theory, methodology, findings and conclusions. The practical methodology, the empirical findings and the conclusions of each type of value are then integrated in a discussion of the final empirical findings, their use in developing a new approach to business model formulation, recommendations and conclusions (Chapters 4 & 5).

Figure 1.1 presents a methodology flow chart which shows how the different elements fit together. The green dashed lines separate the research that is primarily focused on value from that on business model development. However noting that the work on value progressively feeds into the business models, the solid red arrows show the general connection between value and business models. The red dashed arrows show which elements are specifically used for formatting each part of the study.

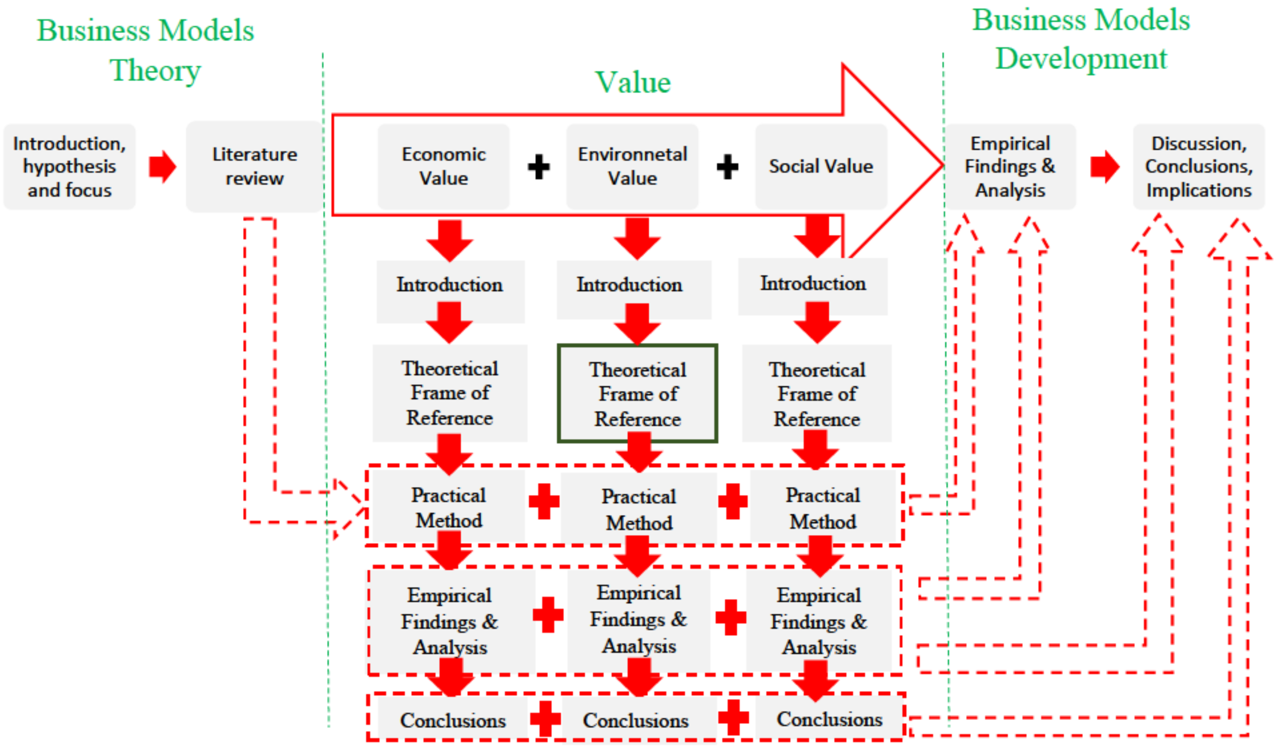


Figure 1.1 Methodology flow chart

For 'value', it is helpful to categorise the forms of value using a triple-bottom-line approach of economic, social and environmental value; to accommodate the alternative we have been using in the Liveable Cities programme of economic, social, environmental and governance, then governance should sit inside the social envelope.

It is recognised that several of the terms used in this thesis has specific meanings in different contexts, and thus it is important to define their meanings here. These include ‘infrastructure’, ‘business models’, and ‘value’, and ‘stakeholders’. All these concepts are deriving as a result of a critical literature review These terms are introduced in relation to the traditional, alternative meanings in the next chapters – those used by other authors – and how and they have been used, or interpreted, by different stakeholders:

- “***Infrastructure*** *generally conjures up the notion of a large-scale physical resource made by humans for public consumption*” (Frischmann, 2012, p.3). Additionally, “***Infrastructures*** *are capital goods that are not directly consumed and serve as support to the functions of a society (individuals, institutions and corporations)*” (Rodrigue, 2017, Chapter 7).

- **Business models** are how the business is organised and managed to deliver value to a chosen set of stakeholders and to deliver established value propositions.

The common elements of all definitions of business models are “*value*” and the “*final user*” (key-stakeholder).

- **Economic value** in infrastructure systems can be defined as the increase in economic prosperity through an infrastructure investment either for improving existing infrastructure or for building new ones (Kessides, 1993).

- Andersen (2007) studied **Environmental Value** in relation to human activity and categorized environmental value into the following primary types: amenity value, natural resource base, a sink for residual economic activity and a fundamental life support system (Andersen, 2007). Environmental amenity value is the inherent value that individuals receive from the environment without any additional interference (Anderson, 2007). Environmental amenity value is highly subjective and depends on individual experiences and preferences, and cultural factors (Gkargkavouzi, Paraskevopoulos and Matsiori, 2018).

- **Social Value**: This thesis studies business models and within the implementation of the business models, a value proposition articulates the essence of a business, defining how products and services are assembled and delivered to final users in order to meet their needs (Kambil et al., 1996)

- **Key-Stakeholders** or **Stakeholders** are those to whom the value is realised and should not be confused with the project management definition of stakeholders (Kalyviotis et al, 2010; 2013; 2015)

Chapter 2 Literature review

To test the hypothesis against the literature, this research has adopted the deductive approach (general to specific), as it is properly used in the framework of the scientific ideal of positivism (Wainwright & Forbes, 2000, p. 261-262). The deductive approach is cross-fertilized with induction at some points, since some of the findings are generalized. The main reason for using this model as part of this study is to draw conclusions through logical reasoning (deduction) and subsequently to draw some general conclusions from empirical observations (induction) (Bryman & Bell, 2011). Regarding value, the limitations in scope emerged from the way it was approached and the drive to develop a delimited theory. According to Huang and Gao (2015, p.156-157), the delimited theories should be examined in terms of validity using the empirical data in "*an unending process"*. They referred to the *"paradigm revolution"* method used for the dual nature of the light by Einstein (Huang and Gao 2015, p.152-154). As mentioned before, value can be either purely economic (technocratic approach) or also consider social and environmental factors (sustainability approach). Since value has a dual nature too, the author will approach it with the methodology of the *"paradigm revolution"*. This way, if the author is right, the term *"value"* will reassert itself. It is worth noting that the methodology of *"paradigm revolution"* indicates the methodology which Bryman and Bell describe in their book as *"weaving back and forth between data and theory"* (2011, p. 14). Although the two methods are slightly different, they both focus on developing powerful insights, first by testing theory (deduction) and then looking for the proper theory based on the observations (induction). To conclude, different research propositions (hypotheses) will be developed (deduction) and an explanation will be given to the results that is indirectly related with the hypothesis (induction).

Finally, the research overall is exploratory as it is not fully known the extent of the findings that will be finally mapped and described (David & Sutton, 2011, p. 11). The scope of exploratory studies is the optimization of the opportunities arising from the exploration of new phenomena (Robson, 2002, p. 59). The scope of this research is to exploit the social, environmental and economic opportunities emerging from the new value-optimized business model. Therefore, this research is mainly focused on achieving the exploratory research purpose.

2.1 Business models

Business models aim to understand how value is generated, what costs are likely to be faced and how involved stakeholders capture value. Business models help to understand the sustainability of a business. At the beginning of this thesis, business models and their core elements will be defined and discussed. This chapter will present what is a business model and how a business model achieves its aims. Material relating to Chapter 2 has been published by the author in international journals (Kalyviotis et al., 2018b) and conferences (Kalyviotis et al., 2017a,b).

2.1.1 The nature of business models

Business models have their roots in value. In addition to that, a universally accepted definition of business model does not exist. Osterwalder (2004, p.15) claims that a business model is "*an abstract conceptual model that represents the business and money earning logic of a company*". Afuah and Tucci (2001) define it as the core logic of the organization for creating value. Since the organizations compete for customers and resources, a business model should highlight what is different about a particular organization: "*how it wins customers, woos investors, and earns profits*" (Linder, 2004, p.84). Magretta (2002a, p.43) defines a business model as "*a set of assumptions about how an organization will perform by creating value for all the players on which it depends*". Furthermore, Magretta (2002a, p.43-44) claims that management starts "*from a theory of the business, from a model as to how the whole system will work to create value*". For better understanding of how Magretta thinks, she provided an analysis of the definition of a business model (2002b, p.3-8) and she described it as the reflection of the systems thinking, that is central to management. Business models have to tell a "*good story*", and have to be simple and understood by all stakeholders (Magretta, 2002b, p.3-8). Regarding its role, the role of the business model is to target specific outputs by entering certain inputs. Therefore it can be treated as a model. The term "*model*" is only the standard expression of the experience of the researcher, regarding the nature and the expressions of a phenomenon (Giannopoulos, 2002). A model represents, simplifies and shows relations (Ghauri & Grönhaug, 2010) and describes our understanding or theory regarding how a phenomenon functions (Ruist, 1990).

In the mainstream business and economics environment, business models have technical inputs and economic outputs, meaning they create and capture the capital value using technical elements (e.g. infrastructure). This approach is adapted from Casadesus-Masanell & Ricart (2010, p.197), who support that business model is "*how an organization earns money*" by creating and capturing value for final users. A definitive definition which includes all the previous discussion is: "*A business model describes the rationale of how an organization creates, delivers, and captures value – economic, social, or other forms of value*" (Aho, 2015, p.287). The common elements of all definitions are "*value*" and the "*final user*". The logic behind their approach is that each kind of value can be transformed to capital (economic) value, a logic which allows the assumption of the existence of other types of value. This research considers this assumption and accepts the different type of value. Nowadays, a better definition of value is required. The multi-value effectiveness should consider both socioeconomic and environmental factors. There should be a balance between these factors (economic, social, environmental). This balance is a political decision dependent on the needs and the abilities of each society. Additionally, it is challenging to separate the economic, social and environmental factors since they are interrelated. This research, based on its scope (delimitations), stands in favour of sustainability without ignoring the neo-classical economic model.

Since a business model is a model, it assumes limited environmental knowledge, as it is only the understanding regarding how a phenomenon functions under established rules. These established rules are coming either from assumptions (e.g. generalization of the sample with filters) or they can be either limitations (e.g. no access to required data) or delimitations (e.g. the scope may focus only on capital value). To conclude, business models, by definition, focus on value creation and how value is captured. This research defines business models as follows: *Business models are how the business is organised and managed to deliver value to a chosen set of stakeholders and to deliver established value propositions.*

The value proposition should create value, but how is value created within the business model? Amit & Zott (2001, p.493) support that, the way business models are constructed is crucial to its value creation. Develop a value framework to create understanding of the business and determine its success (2001, p.500). Within this context, Amit & Zott (2001; 2010) discuss four potential sources of value creation:

- *Efficiency*, meaning value is created by better processes (2001, p.503-504 & 2010, p.221-222)
- *Complementarities*, meaning increase value by leveraging products with complementary products from other firms (2001, p.504-505 & 2010, p.221)
- *Lock-in*, meaning create stickiness, increase switching costs (2001, p.505-507 & 2010, p.221)
- *Novelty* (2001, p.508-509 & 2010, p.221)

These four potential sources are suggested by Amit & Zott (2010, p.222) to be used as business model design themes.

Table 2.1 Business models in the literature

	Marketing imperative	**Internal value creation**	**External value creation**	**Growth engine**	**Linked to each other**
Afuah & Tucci (2001)	scope, implementation			revenue, capabilities, sustainability	Yes
Amit & Zott (2001)	transaction content & structure	efficiency, lock-in, novelty, complementarities	transaction governance		Yes
Linder (2004)	how it wins customers	how it earns profits		how it woos investors	Yes
Bryson (2017)		Government guarantee schemes & charges of actors		finance development	Yes
		inputs, activities and outcomes that aim to create and capture economic, social and environmental values over the whole infrastructure life cycle			
This thesis	Evaluation and use by the key-stakeholders/ final users (social value)	Economic value (Demand) Social & Environmental value creation (welling, emission reduction)		Growth by optimization of value	Yes

The core elements of the business model differ slightly in the literature (see Table 2.1). The starting point of this research was the conceptual framework of alternative infrastructure models that was developed by Bryson (2017). He presented a design of infrastructure business models, which aligns with the design themes and elements developed by Amit & Zott (2010). The choice of model should depend upon specific criteria. In the literature review, many authors agree that value arises from transaction benefits. Value is created either by reorganising activities to reduce transaction costs (Amit & Zott, 2010, p.222), by winning customers (Linder, 2004) or through a targeted implementation (Afuah & Tucci, 2001). Bryson et al. (2017) presented a design of infrastructure business models, which aligns with the design themes and elements introduced by Amit & Zott (2010). The value flow, allows selecting and combining financing sources. The choice of model should depend upon specific criteria. In the literature review, many authors agree that value arises from the choice of the right business model.

Infrastructure business models are defined by iBUILD (2017) as "*the system of physical artefacts, agents, inputs, activities and outcomes that aim to create, deliver and capture economic, social and environmental values over the whole infrastructure life cycle*". Instead of transaction costs the environmental and the social cost should be considered. "*Consumers benefit from the use of the finished product*" (Casadesus-Masanell & Heilbron, 2015, p.3) and "*business itself is chaotic human activity*" (Casadesus-Masanell & Heilbron, 2015, p.8), meaning that the key-stakeholder who benefits by the product is the final user. Additionally, not all the literature explicitly acknowledges the economic foundations of the business model and by "*adopting a different model of value capture, then, is a significant step in understanding the strategic benefits of business models*" (Casadesus-Masanell & Heilbron, 2015, p.12). In other words, by transforming the business model from an economic-oriented to a benefit- oriented model, coverage of non-economic need is achieved (non-economic value capture).

2.1.2 The marketing imperative of business models

Marketing is an imperative component of business models. The final user of the service or product faces aspects of the business model, as the role of marketing is to generate transaction. Value arises from transaction; therefore the role of marketing in business models is crucial and it directly relates to value creation (Vaccaro & Cohn, 2004, p.53). Business models demonstrate potential value and generate resource using marketing (Vaccaro & Cohn, 2004, p.47-49). In addition to that, marketing has to convey the message of the value proposition and so the final user will understand what is valuable about the service or product (Payne & Frow, 2014, p.215-216). The value proposition targets users for whom the organization is creating value (Payne & Frow, 2014, p.215-216). Broadly speaking, the most common value proposition can be divided into three types based on the relation of the price the user pays with the value gained: low cost leader, mass customisation, solutions (Figure 2.1).

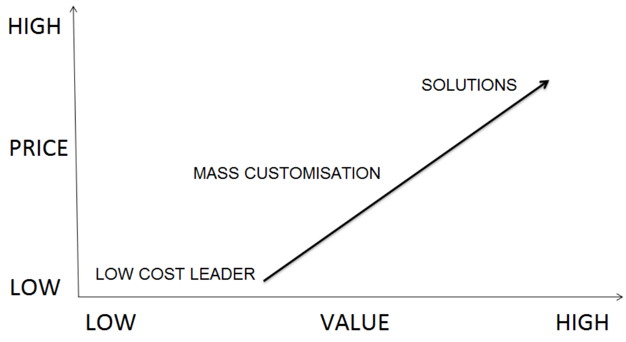


Figure 2.1 Value propositions

The value proposition of a low cost leader is commonly met when value is in cost sensitivity. Low cost leader proposition is accompanied with commoditisation of the service/product, due to the non-differentiation ("*undifferentiation*") of it (Bordalo et al, 2016, p.502-503). The service/product is readily interchangeable and can only be differentiated via price. This means that a low cost leader proposition requires the exploitation of economies of scale. "*Economies of scale refer to the decreasing unit costs when more of the same product is produced or when an identical service is provided more frequently or to more clients*" (Cruijssen et al., 2007, p.29). The alignment is obvious as the "*undifferentiation*" of the service/product, which accompanies the low cost leader proposition, in economies of scale is met as "*the same product*" or as "*identical service*". In this case, external value creation is strong either through outsourcing/offshoring or even with globality of sourcing.

Mass customisation is "*developing, producing, marketing and delivering affordable goods and services with enough variety and customisation that nearly everyone can find exactly what they want*" (Pine, 1993, p.44). A similar definition for mass customization is presented from Mooney et al., who claim that mass customization is the provision of "*variety and customisation through flexibility and quick responsiveness*" (2000, p.504). After studying the relevant literature, it can be seen that mass customisation value proposition is sought to give final users exactly what they want, at the price they want, and at the time they want it (Pine, 1993, p.44; Mooney et al., 2000, p.504; Duray & Milligan, 1999, p.61) and to "*provide sufficient variety in products and services so that virtually every final user is able to purchase a customised product for a mass produced price*" (Duray & Milligan, 1999, p.61). It is worth noting that customisation means the procedure of uniquely producing the service/product for each individual not the service/product variety; therefore, final users should be faced as a stakeholder of the business model, since they are involved in the process.

Gilmore & Pine (1997, p.91-101) identify four types of mass customisation related with the change or not of service/product and representation (Figure 2.2):

- Transparent customisation uses standard packaging with unique services/products targeting the final user, but without letting him/her know about the customisation itself (Gilmore & Pine, 1997, p.93-94; Pepper & Rogers, 2004, p.258).
- Collaborative customisation involves directly the final user in articulating covered needs and making customised services/products (Gilmore & Pine, 1997, p.92; Pepper & Rogers, 2004, p.258).
- Adaptive customisation offers a standard, but customizable service/product that is designed so that final users can alter it (Gilmore & Pine, 1997, p.92-93; Pepper & Rogers, 2004, p.258).
- Cosmetic customization presents a standard service/product to each final user, but it provides individually supporting services (Gilmore & Pine, 1997, p.93; Pepper & Rogers, 2004, p.258).

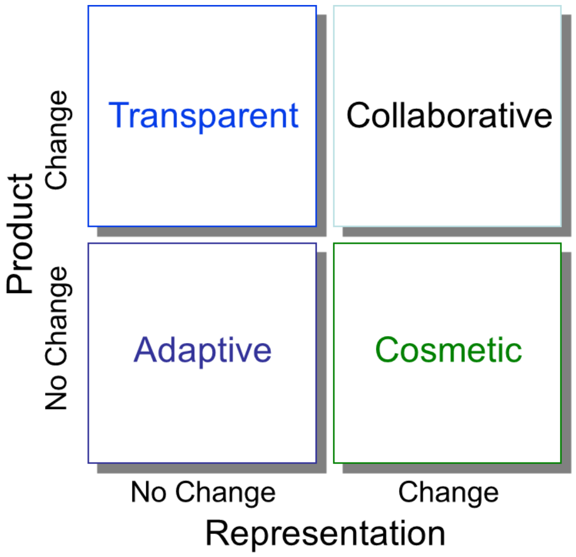


Figure 2.2 The four faces of mass customization (Gilmore & Pine, 1997, p.95)

The benefits of mass customisation are many as the customised service/product fits with the unique needs of the final user (Blecker & Friedrich, 2007, p.66; Berman, 2002, p.53). The lower inventory levels allows the process to be efficient throughout the distribution channel (Blecker & Friedrich, 2007, p.66-67; Berman, 2002, p.53). Furthermore, a good service/product, which attracts the final user due to its uniqueness, can have its price justifiably increased (Blecker & Friedrich, 2007, p.67; Berman, 2002, p.53). Finally, opportunities rise due to the continuous friction, in a good way, with the customer, since the market needs can be seen (Blecker & Friedrich, 2007, p.67-68; Berman, 2002, p.53). As can be seen, mass customisation requires a new business model paradigm. The challenges of mass customisation can be met as a result of operational changes, labour issues or even because of the supply chain, but the critical challenge is, will it appeal to final users?

The last value proposition type is the solutions, which creates exceptional value for the final user. This type of proposition presupposes the creation of mutually supporting value networks and intimate relations between the service/product provider and the final user. According to Miller et al. (2002, p.3), solutions are "*integrated combinations of products and/or services that are unusually tailored to create outcomes desired by specific clients or types of clients*". The service/product should fill a specific or unique need of the final user and face a precise challenge, in other words it should provide a solution to a specific problem (Miller et al., 2002, p.3; Ceci & Prencipe, 2008, p.278). The collaboration between the provider and the user for adding value is negotiable and it may involve third parties (Miller et al., 2002, p.11; Ceci & Prencipe, 2008, p.295). The research proposition of this research is between mass customisation and solution, because transport infrastructure should cover the needs of all users (mass customization), but at the same time the final user is a key-stakeholder who has specific problems and has a say in it (solutions).

2.1.3 Value creation and the value network

Value creation can be separated as two types: internal and external value creation. Internal value creation is achieved within the boundaries of the organization and it is linked with the structure of the organization and the business context (Porter, 1985). The key element of the internal value creation is the value chain.

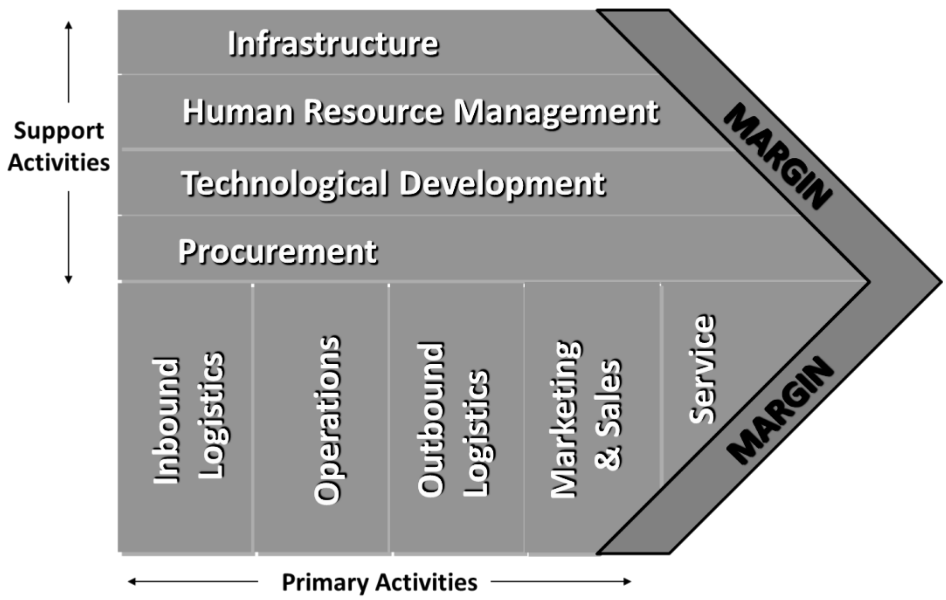


Figure 2.3 Michael Porter's value chain (Porter, 1985, p.37)

The value chain (Figure 2.3) creates a list of questions regarding where the core value lies, where core value creating competences/activities are, which channels should be chosen and who controls these channels (Porter, 1985). This means that the core relationships, including customer relationships, and value structure, including cost structure, should get defined.

External value is achieved by deconstructing the value chain, through value erosion from integration and the collection of upstream suppliers, downstream channels to market, and ancillary providers that support the business model (Christensen, 1997). The value propositions in a value network can be virtual, integrated or in between (hybrid) based on the involvement of third parties. The virtual value proposition happens when the total value created by the third parties and provided to the customer through the firm (e.g. Uber Technologies). Integrated value propositions are very rare or even not possible nowadays and happen when the total created and provided is by the same firm. Hybrid value propositions are the most common with the involvement of one or more third parties. Typical hybrid value propositions are co-creation (firm customer relations to create value), outsourcing (third party service provision), off shoring (third party manufacturing), etc.

Based on the theory a definition of the total value (both internal and external) and its proposition is required. The co-creation is the most proper value proposition for the new infrastructure business model since it considers the final user as a key stakeholder.

Business models, as discussed, have their roots in value. The common elements of all definitions of business models are "*value*" and the "*final user*" (key-stakeholder). The concept of value is used to determine the importance, worth or usefulness of the phenomenon under investigation. The challenge of valuing something arises when there are different types of values within the phenomenon. The comparison is achieved through the exchange. The exchange generates a quantitative sense of value, while the perceptions of value are qualitative.

Historically, the concept of value is linked with money (economic value). Adam Smith in his book The Wealth of Nations (1776, p.48) claims that "*the real price of everything, what everything costs to the man who wants to acquire it, is the toil and trouble of acquiring it. What everything is really worth to the man who has acquired it, and who want to dispose of it or exchange it for something else, is the toil and trouble which it can save to himself, and which it can impose upon other people.*" Additionally, Adam Smith knew that the price (money) of anything does not represent its real value, but a nominal one. This nominal value was mostly affected from the exchange process without deeper understanding of the real value. John Stuart Mill, in his book Principles of Political Economy (1848), focussed more on the factors affecting the value and he rejected Smith's approach. He concluded that value is distinguished from economic value which is worth estimating in monetary terms, while value is worth estimating in goods in general. These goods may have a non-measurable value (qualitative) that cannot be defined through money. Mill's conclusion was closer to the truth, as this non-measurable value was described as an environmentalist and anti-consumerist value.

The first to rigorously discuss environmental value was the Club of Rome (late 70's to early 80's) (Meadows et al., 1972). They point out, correctly, that air-pollution, deforestation etc. are not included in the economic value, but they suggested, wrongly, the transformation of this type of value to economic value. This transformation is dangerous as it allows people to believe that they can destroy the environment if they pay the right price (exchange value theory). There are limits to this exchange that should be defined considering the destruction of the humanity. The previous discussion has generated a new discussion between the neo-classical economic model and the strong sustainability model. The main assumptions of the neo-classical economic model coming from mainstream business and economics theory are: individuals create value via rational economic exchange and control (Tversky & Kahneman, 1991). The main assumptions of strong sustainability are: human dependence on ecosystem services (Schumacher, 1973) and the assessment of the coupled human-environment systems based on a vulnerability framework (Clark et al, 1990). It can be seen that, the value perceptions of business and economics oppose the social and environmental value perceptions of sustainability. The problem is due to the different ethics of each discipline.

Bonnedahl and Eriksson (2011) did a detailed analysis of alternative discourses on economic organization in their research. Their starting point is that the business and economics approach looks mainly to the interests of shareholder wealth followed by short term viability. The sustainability approach focuses on resilience followed by long term viability (all living, now and in the future). So, according to Bonnedahl and Eriksson (2011, p.168), in an economic organization the mainstream business and economic approach targets profit, consumption and growth and it focuses on the efficiency of its activities. On the other hand a strong sustainable organization targets stakeholder satisfaction and focuses on multi-value effectiveness via intra- and intergenerational justice (Bonnedahl & Eriksson, 2011, p.168). This definition accepts the multiple nature of value. Nowadays, a better definition of value is required. The multi-value effectiveness should consider both socioeconomic and environmental factors. There should be a balance between these factors (economic, social, environmental). This balance is a political decision depending on the needs and the abilities of each society.

So how can we calculate the value of an infrastructure, and for whom is it beneficial? Infrastructure is a shared-resource system collectively owned by its individual users. The individual users act independently in this system, according to their own needs. Sometimes, this action opposes the common good of all users, since the individual users do not consider the rest of society. This phenomenon can be described as "*The Tragedy of the Commons*" economic problem. The tragedy of the commons argument states that if the individual user tries to maximize possible value from a non-excludable and rival resource then this resource will be depleted (Hardin, 1968). The tragedy of the commons can be considered in relation to the value of infrastructure, especially regarding sustainability. The commons dilemma stands as a model for a great variety of infrastructure problems in society today, either directly as water, energy or indirectly through externalities of infrastructures such as waste. The water supply infrastructure is affected directly from the water resources deficit from water pollution, over-extraction of groundwater and waste water due to irrigation (Shiklomanov, 2000). Energy sources, and more specifically non-renewable energy sources, pollute the environment mostly, but not only, through their combustion (FAO, 2018). Common externalities of transport infrastructure are pollution, carbon emissions, and traffic accidents (Dubner & Levitt, 2008). Communications have many negative externalities; these include radio frequency and microwave radiation which affects human health (Szmigielski, 1996). Waste infrastructure is an externality by definition, as exposure to various waste is highly associated to health risks (Turley et al., 2013). These problems and externalities should be considered when an infrastructure interdependencies network is designed. To proceed, the tragedy of the commons argues that individuals will use the communal infrastructures to excess for getting all the benefits with little cost. The infrastructure is communally owed, but some of its elements (e.g. houses, cars, RF antennas etc.) are privately owned. The solutions provided by Hardin (1968) were: privatization of the commons and/or government regulation. By privatization of the commons, it is meant that the ownership of the infrastructure will be transferred to individual users, assuming that they will behave rationally focusing on the long-term sustainability of the infrastructure. The assumption of an individual's rational behaviour is very common in business research, but when it comes to mass society is not widely accepted. By government regulation it is meant the creation of limitations on the usage of each infrastructure. It is obvious that these solutions are not applicable for critical infrastructures (e.g. water, transport, communications), as it is hard to restrict access to them. Furthermore, by isolating critical infrastructures, the society is driven to the risk of losing access to them. Since the problem of infrastructure cannot be solved by privatizing everything and restrictions, we ought to solve it by making all critical infrastructure and its elements communal. The challenge of the collective behaviour can be sorted out by considering the individual user as a rational key-stakeholder and not as the final user (e.g. infrastructure sharing, value co-creation). To do so, it should create an environment /context/business model that will allow the individual user to act as a key-stakeholder, but at the same time there should be tools to control the rationality of the decisions of the individual. In transport infrastructure management the core value lies on the environmental, social and economic and the core relationships of the business model can be represented in an illustration with e.g. lines/connections.

2.1.4 The growth engine

Infrastructure managers are looking for growth entities. Value creation generates resources and the sustainability of the business model depends on resource generation (Manda et al, 2015). Business models are shaped by and executed within an external environment, meaning the resources are generated by the external interface between business and environment. By identifying where resources can be generated it can be seen that a part of the value generated does not come from direct resources, but comes, indirectly, from the infrastructure interdependencies. To conclude the key target of the business model is to generate or access resources through its value creation from all possible sources.

In this research the transport infrastructure value creation is not purely economic. So the growth engine should focus on sources (e.g. investors, partnerships, etc.) of resources who are interested in the social and environmental value too and in the indirect value creation. The stakeholders were taken from the literature (Bryson, 2017) and they were divided based on their interest in environmental and social value or not (see Table 2.2):

- Public Sector, Public-Private Partnership and Third Sector (Voluntary) have major interest in the environmental and social value, apart from the economic.
- Private Sector, Trust and Co-operative/Community Ownership were considered have major interest in the economic value. Co-operative/Community Ownership might have interests in social value as well as economic, but the creation of such bodies is to create profit. Also, private owners might claim that they have interests in social value, but still they target to be profitable. In other words, it is not discernible whether actions, such as corporate social responsibility, are because they are interested in social value or these actions are part of an economic policy, e.g. marketing. Additionally, in this case, actions targeting on social value are at the discretion of the stakeholder, meaning that the stakeholders may take no action for societal value to satisfy their members or shareholders, etc. On the other hand, public stakeholders will naturally seek to satisfy society’s needs and wants, meaning to increase the social value. The same approach is used for the environmental value since it is not clear if the stakeholders, in this case, were interested in it for economic reasons (e.g. fines) or not.

Table 2.2 Infrastructure business models ownership typology (Bryson, 2017)

Name	Description	Forms of Stakeholders	Type of value interests them:
Public-Private Partnership	Service **funded and operated** through a partnership between government and private business	• Public subsidy to private-led management • Publicly owned asset - SPV management • Public/private development and management of new asset • Private Finance Initiative • Public subsidy, private ownership and management • Performance based partnership • Public Special Purpose Vehicle	Environmental Social Economic
Public	Public **finance and management** of asset/service	• Publicly managed and owned infrastructure (tax) • Public management of community purchase • Funds of funds leverage • National subsidy • User pays charge • Collective management • Fiscal decentralisation • Social equity bonds	Environmental Social Economic
Private	Privately **financed and operated** asset/ service	• Toll • Service rental and usage fee • Privately operated with public subsidy	Economic
Co-operative/ Community Ownership	Organisation **owned and managed** by its members. Profits shared with members	• Community share scheme • Community ownership • Community asset transfer	Economic
Third Sector	Third sector **ownership** of asset	• Voluntary • Public-third sector partnership • Third sector asset managed by public sector	Economic
Trust	**Independent** local group of statutes (no ownership or shareholders) and surplus **revenues reinvested** in the trust	• Trust ports	Economic

2.1.5 Forces of evolution of business models

The previous sections (2.1.1-2.1.4) described the elements of the business models. The business models change due to external forces. The forces which evolve the business model are:

- Innovation: Innovation is the application of new knowledge to existing products, processes, marketing and/or organisational form (Markides & Geroski, 2005) and can be radical or incremental (Markides & Geroski, 2005, p.4-5). The new knowledge may be a new business model which will partly change the organisational form or processes for an existing product (e.g. transport).
- Global reach: The global markets create an environment where, apart from the geographic scope of the business models, other factors may create an advantage or disadvantage for the organisations (Craig & Douglas, 2000). It is obvious that if in a specific case study the spatial factors are defined by the study (e.g. transportation in the United Kingdom) then global reach may affect only some elements of the business models such as the assets, capabilities and resources and not the business model itself (the interlinkages).
- Public Policy: Public policy is a "*course of action adopted and pursued by a government*" (Subcommittee on Health and Environment, 1976, p.124) or a public agency and emerges as a response to a perceived problem (The Public Policy Cycle Web Site, 2001). Harrington & Estes (2004, p.5-6), after analysing the definition of policy, concluded that policy is strongly linked to citizenship. Since the individual is the key stakeholder in this research, it is assumed that the public policy is a result of the behaviour of the individual.
- Corporate social responsibility (CSR): European Commission (2011 cited in Martínez et al., 2016, p.13) defines the CSR "*as the process of integration in the organizational activities of social, environmental, ethical and human concerns from their interest groups, with two objectives: (1) to maximize value creation for these parts, and (2) to identify, prevent and mitigate the adverse effects of organizational actions on the environment.*".

Finally, this research focuses only on the development of a new model describing the infrastructure interdependencies in a specific environment without any major change to the forces of evolutions besides the aforementioned descriptions.

2.1.6 Business model design

Based on the aforementioned discussion the elements of the business models are connected/ linked as value flows around the business (see Table 2.1). Value creation is a result of the growth engine and marketing (see Figure 2.4).

Figure 2.4 Business model components

The value creation may be either internal or external (see Figure 2.5).

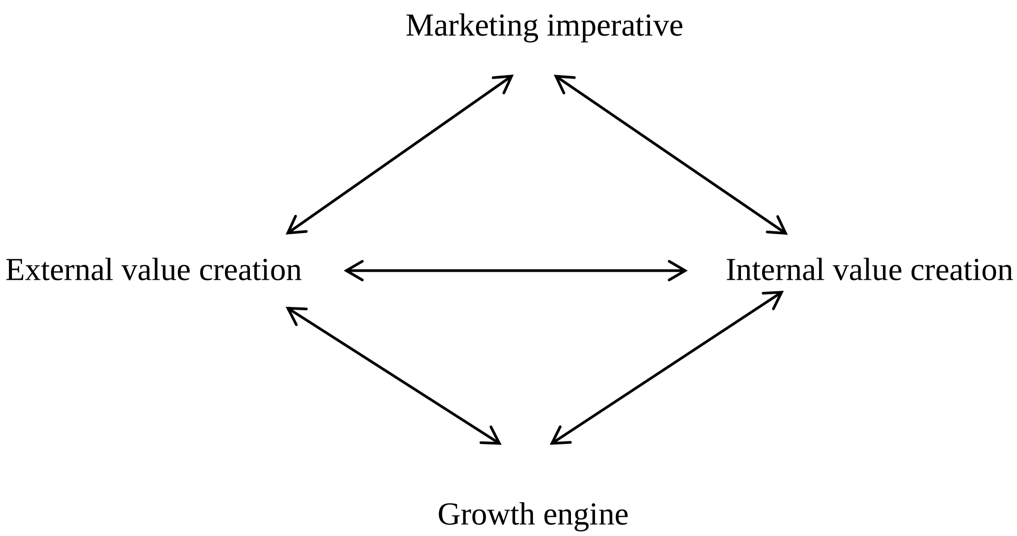


Figure 2.5 Business model components and relations

When it comes to the transport sector value creation may be internal to the transport itself or external through other sectors (waste, water, energy, communication or other sectors). The investors/ stakeholders (growth engine) combined with the successful achievement of the numbers (capacity) of the users of the transport through marketing are the reasons of the value creation too.

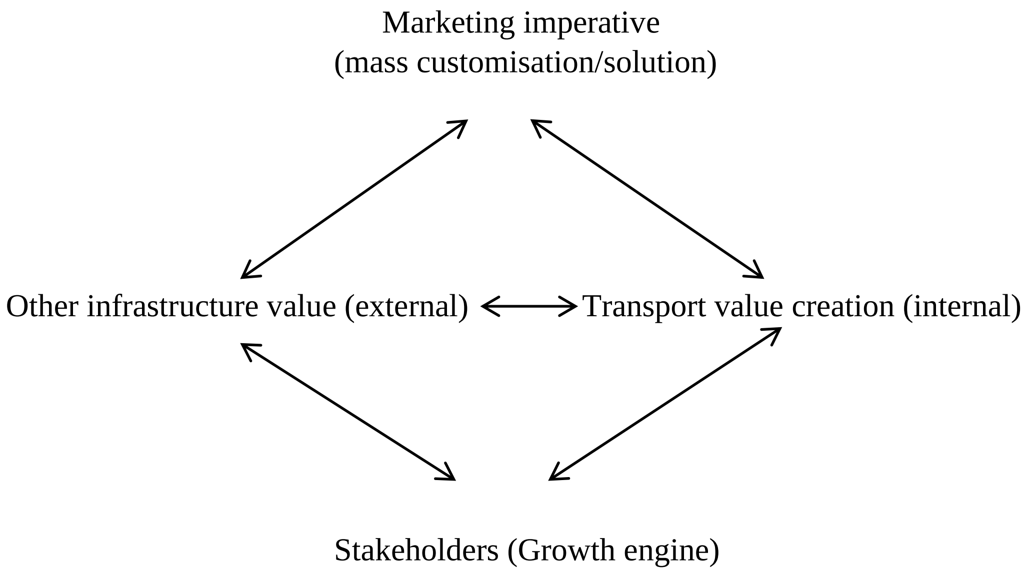


Figure 2.6 Transport Infrastructure business model components

The main challenge is how to track down the dependencies and represent them as "*lines*" in the final model. A business model is something qualitative and value is something quantitative, so they were linked by conceptualising the value interdependencies as functions with different value variables. The individuals were considered as key-stakeholders and not as end users. The model was separated in three parts based on the type of value - economic, social and environmental. These values were studied individually and then different research methodologies used to study their interactions and create mathematical equations. The dependency was studied inductively by looking at the correlation between each type of value of the different types of infrastructures. Correlation between two variables does not necessarily imply causality (Field, 2009, p. 619-620). The two variables can certainly be related with causality, but may not be. For example, both may be affected by a third variable. Therefore, it is obvious that a rough or superficial interpretation and use of the correlation may lead to wrong conclusions. Since the correlations do not imply dependency (Field, 2009, p. 619-620) this was confirmed by the theory. In any other case, a causal relationship (interdependence) between two correlated variables was verified with a rational assumption. Pearson correlation coefficient was used for this study (Field, 2009):

$$r = \frac{s_{xy}}{s_x \cdot s_y} = \frac{\sum_{i=1}^{v}\left(x_i - \overline{x}\right)\cdot\left(y_i - \overline{y}\right)}{\sqrt{\sum_{i=1}^{v}\left(x_i - \overline{x}\right)^2} \cdot \sqrt{\sum_{i=1}^{v}\left(y_i - \overline{y}\right)^2}}$$

Where:

- If $-0.3 < r < 0.3$ there is no linear correlation
- If $-0.5 < r \leq -0.3$ or $0.3 \leq r < 0.5$ there is a weak linear correlation
- If $-0.7 < r \leq -0.5$ or $0.5 \leq r < 0.7$ there is a medium linear correlation
- If $-0.8 < r \leq -0.7$ or $0.7 \leq r < 0.8$ there is a strong linear correlation
- If $-1 < r \leq -0.8$ or $0.8 \leq r < 1$ there is a very strong linear correlation
- If $r = \pm 1$ there is a perfect linear correlation

Of interest of this study is the existence of linear correlation, meaning r equals more than 0.3 or less than -0.3, and the size of the correlation (weak, medium, strong or very strong). The correlation shows the existence of the dependency/connection between the different transport infrastructure business model components and the size of the correlation explains how strong this dependency is. It is required to define the components of transport infrastructure and how they were used.

2.2 Transport infrastructure

Many different modes of transport interconnect to form an incredibly complex, global meta-network. "*Local, regional, national, and international transport occurs on land, over water, and in the air*" (Frischmann, 2012, p.189). This chapter is an introductory presentation of the general infrastructure typologies related to transport. There is no deep analysis of the construction methodologies and the required materials, as this is not the scope of this research. Nevertheless, this introductory presentation will allow the reader to come to understand the infrastructure interdependencies and the value creation better.

2.2.1 Defining infrastructure

"*Infrastructure generally conjures up the notion of a large-scale physical resource made by humans for public consumption*" (Frischmann, 2012, p.3). Additionally, "*Infrastructures are capital goods that are not directly consumed and serve as support to the functions of a society (individuals, institutions and corporations)*" (Rodrigue, 2017, Chapter 7).

Infrastructure is generally defined as "a large-scale physical resource made by humans for public consumption" (Frischmann, 2012). The large-scale physical resources are, among others, transport, communication, water, waste and energy systems needed for the operation of any society. The definition of infrastructure has changed over the years (see Table 2.3), based on the evolution of the society.

Table 2.3 Civil infrastructure definitions

Author	Definition
Jessen (1984)	Infrastructure as "public works" including "roads, bridges, dams, mass transit systems, and sewage and water systems" (Jessen, 1984)
Martini and Lee (1996)	Infrastructure provides "basic services to industry and household" (Martini and Lee, 1996)
Sussman et al. (2009)	"Complex, large-scale, interconnected, open, sociotechnical systems" (Sussman et al., 2009, p. 4)
Frischmann (2012)	Infrastructure is a "large-scale physical resource made by humans for public consumption" (Frischmann, 2012, p. 3)
Pearlstein (2014)	Infrastructure is a "large capital intensive natural monopolies such as highways, other transportation facilities, water and sewer lines, communication systems often publicly owned" or "the tangible capital stock owned by the public sector"
National Science Foundation (2017)	"Infrastructures are defined as networks of systems and processes that function cooperatively and synergistically to produce and distribute a continuous flow of essential goods and services" (National Science Foundation, 2017, p. 14)
Oughton et al. (2018)	"Infrastructure is an enabling system that provides a range of different services to intermediate and end users" (Oughton et al., 2018, p. 2).
Allenby and Chester (2018)	"The planet as infrastructure" (Allenby and Chester, 2018)

The different definitions highlight that infrastructures provide network services and public goods (Jessen, 1984; Martini and Lee, 1996; Grimsey and Lewis, 2002; Pearlstein, 2014; National Science Foundation, 2017), interact and interrelates with the socioeconomic system (Sussman et al., 2009; Allenby and Chester, 2018; Oughton et al., 2018) and influence the social value in terms of how the individuals see and understand the value of each infrastructure (Oughton et al., 2018). Allenby and Chester's definition is different to the others and less obvious in its meaning, as it implies that infrastructure is not just a human construct. Allenby and Chester's definition is a result of an academic discussion from an environmental prospective, as this definition tries to include in a system (planet system) both infrastructure built by humans and the environment/resources in this system (planet earth). In other words, infrastructure was defined based on its physical components at the beginning, then the socioeconomic value was included in infrastructure's definition and nowadays it considers the environmental value.

This thesis adopts the definition by Frischmann (2012), since this thesis discusses economic, social and environmental value dependencies of infrastructure systems both in terms of engineering and economics. The other definitions either focuses on infrastructure projects (Jessen, 1984; Martini and Lee, 1996) or on economic and policy elements (Sussman et al., 2009; Pearlstein, 2014; National Science Foundation, 2017) or describe new economic environments and approaches (Oughton et al., 2018; Allenby and Chester, 2018). The services/sectors of interest to this study are transport, waste, water, energy and communication (Hall et al., 2016, p.10; iBUILD, 2017; Liveable Cities, 2017; National Infrastructure Plan, 2013). The associated infrastructures of the services are as follows (Rodrigue, 2017, Chapter 7; Prud'homme, 2005, p. 153-181):

- Transportation: roads, bridges, tunnels, rail tracks, ports, harbours, airports, distribution centres etc.
- Water:
    - Water supply: dams, reservoirs, pipes, treatment plants etc.
    - Irrigation: dams, reservoirs, canals, sprinkling systems etc.
- Waste:
    - Water disposal: sewers, used water treatment plants etc.
    - Garbage disposal: landfills, incinerators, recycling facilities, compost units etc.
- Communications (Telecommunications): telephone exchanges, telephone lines, oceanic cables, cellular towers, fiber optic cables, web servers etc.
- Energy (Power): power plants, transmissions and distribution lines etc.

It can be noticed that, broadly speaking, every infrastructure system has a network (lines, roads, canals etc.), some terminals (web servers, airports, treatment plants etc.) and modes of transfer (cables, pipelines, vehicles etc.).

Transport, energy, water, waste, communications and housing are "*basic infrastructure services*" (Menéndez, 1991). The author is aware that there are other critical types of infrastructure systems, such as human health, education, common defence, parks etc., which have significant economic implications and intersect with transport systems. The thesis focuses on the "*basic infrastructure services"* since they have far-reaching effects to the other type of infrastructure sectors. For example, a bad water infrastructure or energy shortage or lack of transport modes can affect human health (Menéndez, 1991). According to Julie Kim (2015), who was the P3 FLIPS Program Developer at the Stanford Global Projects Center and was working to develop sustainable business models for public-private partnerships (P3) in the U.S. market, "clean water, sewage, roads, electricity, telecommunications" are the basic infrastructure services to support livelihood of their citizens "*Basic infrastructure services are services that allow the urban poor to live under conditions that facilitate their income- generating activities so they can maintain a good nutritional level and participate in the normal activities of society*" (Menéndez, 1991). New infrastructure develops over time to cover more or new needs arising from socio-economic developments during the operation period (Bakker et al., 2017), but the initial infrastructure needed for this development is that needed to deliver the "*basic infrastructure services*". Usually, governments do not provide housing, but they "provide the infrastructure – or just the basic infrastructure such as water, sanitation and electricity – to facilitate the construction of housing by the nongovernmental sector" (Menéndez, 1991).

2.2.2 Transport infrastructure and types of transport infrastructure

In general, a transport system consists of "*a number of fixed assets (infrastructure) and a number of mobile units (vehicles)*" (Enoch, 2012, p.5) and more specifically a network, vehicles and terminals. The vehicles transport either individuals or goods. The vehicles are moving in the network, which consists of routes and nodes. The terminals may be parking areas, boarding or goods stations etc. In traditional civil engineering, infrastructure is connected with major construction projects and more specifically in transport engineering it is connected with roads and highways, railroads, ports, airports, pipelines, canals, some owned by public entities and some owned by private corporations.

There are three types of transport: land transport, water transport and air transport.

According to Frantzeskakis & Giannopoulos (2005, p.63-65), all the transport systems have three key elements: vehicles, networks and terminals. Vehicles transfer either individuals or goods (Frantzeskakis & Giannopoulos, 2005, p.63). Network is where the vehicles travel and/or the circumstancies the vehicles travel (Frantzeskakis & Giannopoulos, 2005, p.63). Terminals are the places where the vehicles park, embark, disembark or transfer the individuals or the goods (Frantzeskakis & Giannopoulos, 2005, p.63).

Land transport can be done either with bicycle, walk, skateboard car, taxi or bus through a road network or through rail supporting each of them with specific terminal infastructure (Frantzeskakis & Giannopoulos (2005, p.63-65). Additionally, the transport modes are divided into public or private. An example of a typical land transport system can be found in Figure 2.7.

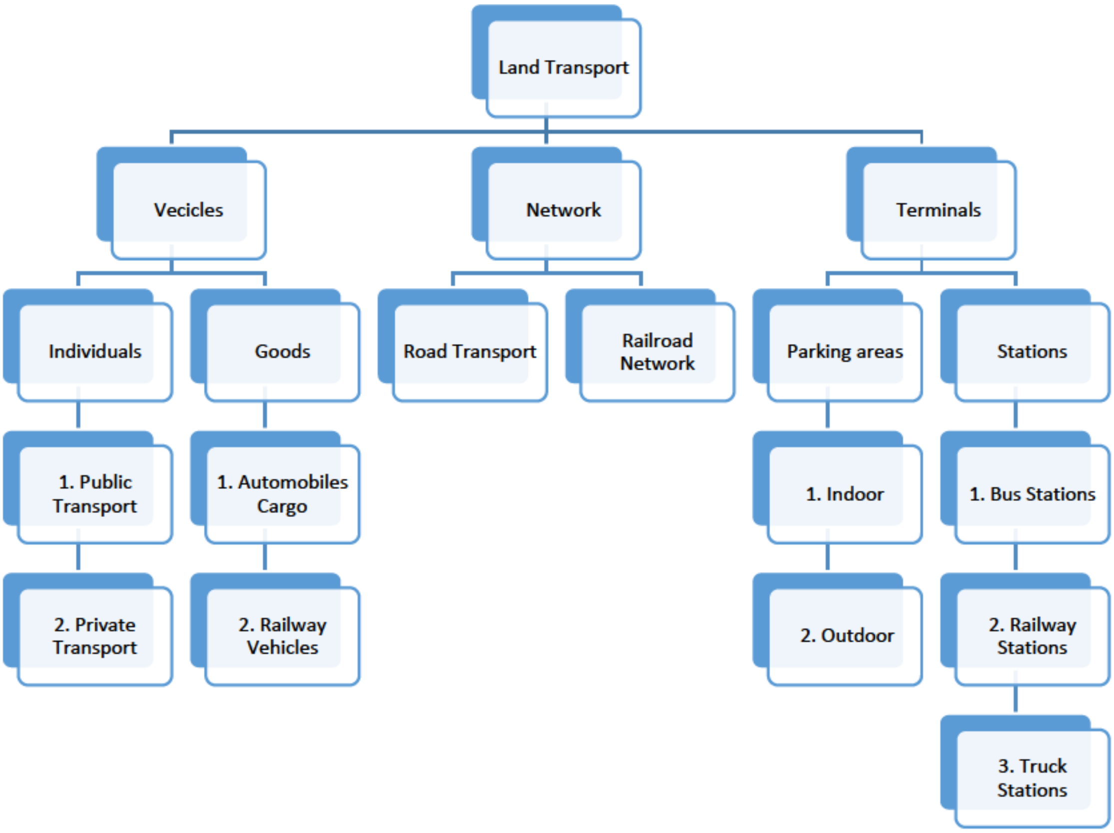


Figure 2.7 Land transport (Frantzeskakis & Giannopoulos, 2005, p.64)

According to Koutitas (1994, p.121-131), there are specific typologies of water transport infrastructure. The water infrastructure is divided into two categories based on the way they are structured: longitudinal and transverse structures and into two categories based on the service they provide: sea and coastal transport and inland water transport. Longitudinal structures are the breakwaters, the revetment and the quay walls, whereas transverse structures are the jetties, the causeways, the bridges and the loading arms. The water transport infrastructure, based on the service, can be divided to coastal and to river/canal infrastructure for the United Kingdom (see Figure 2.8).

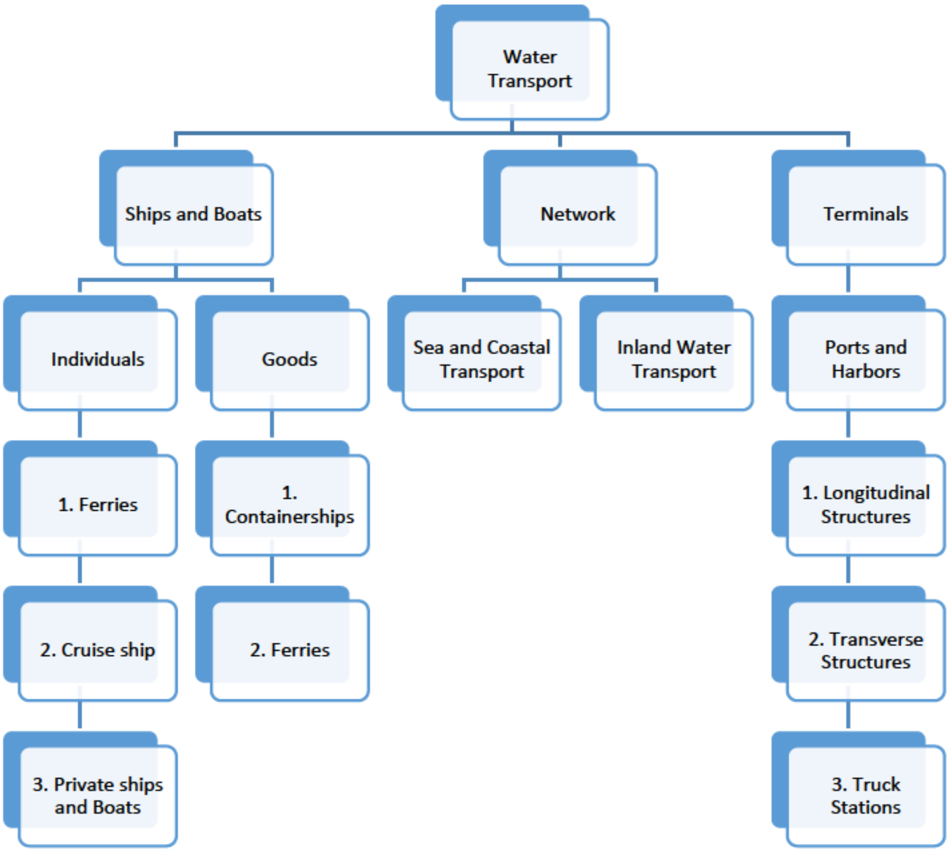


Figure 2.8 Water transport

Finally, an air transport system can be mapped more easily than water and land transport. Air transport happens with airplanes or sometimes with helicopters which move in the sky and the terminals are the airports (Nikolaidis, 2000, p.v-vi). There are a lot of regulations regarding the design of airports, airplane characteristics etc. since there are limitations on how an airplane takes off, lands or travels, but it is not part of this study (Nikolaidis, 2000). Based on these regulations the flights (network) are divided to domestic and long-/short-haul flights (Nikolaidis, 2000, p.6). Figure 2.9 represents a typical air transport system.

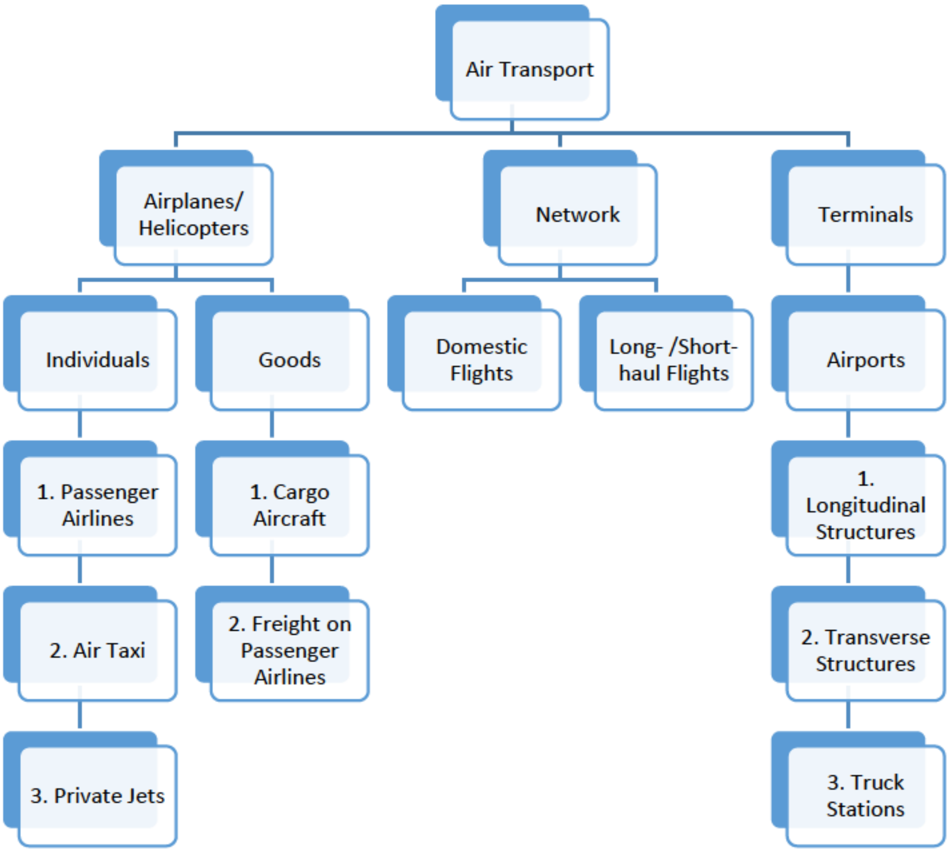


Figure 2.9 Air transport

The aforementioned civil engineering analysis (Figures 2.7-2.9) of the transport modes will be used as guidelines for choosing the proper data when transport infrastructure is investigated, meaning that vehicles, networks and terminals will be taken into consideration for this study and not only the transport as a service (economic approach).

The investigation of how the components of transport infrastructure create economic, social and environmental value for the society requires a better understanding of the concept of value and the explicit separation of the three subcategories: economic, social and environmental; meaning the requirement of explicit definitions and analysis of each subcategory individually.

To capture the full range of the values and benefits of social, economic and environmental considerations on infrastructure systems, first infrastructure, economic and environmental value, shareholder and stakeholder capitalism, and linear and circular economies should be defined. In defining these terms, comparisons between the differing theories are drawn. More specifically, linear and circular economies are two different types of economies with different assumptions, limitations and theories. Similarly, shareholder and stakeholder capitalisms focus on delivering value to different actors. The target audience of the thesis is political actors. The thesis asserts how political actors could encompass economic, social and environmental value if there is a transition from the current shareholder linear system (focusing on GDP creation) to a stakeholder circular system (including environmental and social value too). The comparison process based on this literature review will be used to explain why the economic value will be taken by the linear economy theory (input-output tables), why environmental value will be taken by circular economy theory (EXIOBASE 3) and how the involvement of the society (questionnaire) will help the transaction to a stakeholder circular system.

2.3 Shareholder Capitalism

The mainstream economic environment and approach of the 20th century is shareholder capitalism. Shareholder capitalism has changed forms over the years and still influences the political and economic system.

Shareholder capitalism is based on the presumption that corporations belong to and are controlled by their shareholders. Regarding civil and transport infrastructure, corporations were chartered for public purposes. In the 19th century, legal protection was provided to the shareholders through laws which defended the rights of shareholders and set the legislative framework for the ownership of each corporation (McCann & Berry, 2017). The political, legal and economic system, which was developed by the public authorities, was targeting on the encouragement and protection of the function of corporations chartered for public purposes (Pearlstein, 2014). In return, the corporations chartered for public purposes were expected to provide value to the society (Pearlstein, 2014). In addition, in the early 20th century, a shareholder-centric model started to appear in the Western world aiming at giving the control of the corporation to the shareholder by redistributing power away from managers and towards “the people institution, and his primary responsibility is to them” (Friedman, 1970). Shareholder capitalism requires alignment of managerial incentives with shareholder interests. The shareholder interests targeted to the maximization of the output growth in the shortest possible time (short-term share price movements) above all other considerations.

In the late 1900s, three factors accelerated the transition from managerial capitalism to profit-focused shareholder capitalism: globalization, deregulation, and rapid technological change (Pearlstein, 2014). Gradually, corporations began to focus on stakeholders (such as the final user and the employees) instead of shareholders, but the profitability was limited. The limited profitability led to a situation where corporates with weak shareholder support were acquired through hostile takeovers. This situation resulted corporate prioritization on short-term profits and focus on share prices without considering any negative externalities (Zingales, 2012). The negative externalities were economic, social and environmental. Negative externalities such as, wage and benefit cuts, closure of industrial plants, movement of production abroad, usage of cheap energy sources with high environmental impact, appeared in all the countries which adopted this behaviour, but mainly appeared in the US.

How the value of infrastructure was considered was affected by the shareholder capitalism framework. At the same time with shareholder capitalism, the emergence of private-sector participation in civil infrastructure led to the underlying view of maximizing economic profit. As infrastructure investments were historically undertaken by the private sector, the view of the maximization of the economic profit prevailed until the 20th century. In the 20th century, governments started to get involved with the infrastructure sector (McKibbin & Henckel, 2017). However, the appearance of performance issues in public infrastructure led to the private sector involvement again, who were focusing on profit maximization (McKibbin & Henckel, 2017).

The reason that shareholder capitalism was so attractive, was the fact that it resulted in higher economic value in terms of economic returns at a low perceived risk by maximizing share price (Gompers et al. 2003). Gompers et al. (2003) found that corporates with stronger shareholder rights had higher firm value, profit, sales growth, and lower capital expenditures and acquisitions. By the 2000s, shareholder capitalism was viewed as innovative and productive, with efficient capital markets, flexible and meritocratic labour markets, open and competitive product markets, and regulatory regimes most accommodating to economic growth (Pearlstein, 2014). However, the ignored negative economic, environmental, and social externalities, that impacted the stakeholders, started to raise concerns to the societies. Infrastructure developments now have to balance economic value against social value, such as increasing environmental and social value and minimizing negative externalities.

Shareholder capitalism relies on “competition, limited resources, and a winner-take-all mentality” for economic growth (Freeman, Martin, & Parmar, 2007). Shareholder capitalism focuses on the economic activity, has increased economic inequality, causes environmental degradation and leads to a situation that the owners of capital accumulate wealth more quickly than others (Freeman, Martin, & Parmar, 2007). This situation would continue to worsen if left unchecked and a shift towards stakeholder capitalism would not be advocated by policy makers.

2.4 Stakeholder Capitalism

In an ideal world, all infrastructures and their systems of operation would be funded by the government on behalf of society and therefore an infrastructure asset management model should deliver stakeholder value. The situation is blurred when a private provider is introduced, since this provider will have a responsibility to make money for its shareholders – an operating profit which not all goes back into service provision.

Stakeholder capitalism is the model/ideology aiming to "maximize the well-being of all stakeholders" affected by an action or decision or investment or business (Ingerson et al., 2015). Stakeholder capitalism considers as stakeholders every individual affected by an action or decision or situation, including the shareholders (Ingerson et al., 2015). Ideologically, stakeholder capitalism is morally more just compared with shareholder capitalism, as employees, final users, the society and the environment are taken into consideration. Successful implementation of stakeholder capitalism requires the coverage of the long-term needs of all stakeholders rather than short-term economic profits for one stakeholder (Freeman, Martin, & Parmar, 2007). Therefore, stakeholder capitalism relies on social and environmental values, rather than simply economic value (Freeman, Martin, & Parmar, 2007). Theoretically, there is a point of balance within stakeholder capitalism, where the maximization of profits for shareholders at the expense of other stakeholders (social value) or the environment (environmental value) stops. The coverage of the needs of all stakeholders is imperative for long term success of an in an action or decision or investment or business (Freeman, Martin, & Parmar, 2007).

The stakeholder capitalism model is suitable for civil infrastructure. Infrastructure must serve all the stakeholders it interacts with, since by definition "society as a whole benefits from infrastructure" (Frischmann, 2012). The discussion presented by Frischmann (2012), in his book titled 'Infrastructure: The Social Value of Shared Resources", aligns with the stakeholder capitalism ideology. Infrastructure interacts and affects a wide range of stakeholders, that in some cases include the entire society. Therefore, society views infrastructure as a public good. In democratic societies, public goods are managed by the elected governments. The elected representatives of all constituents, typically, aim to satisfy as many needs and wants of as many stakeholders as possible. Stakeholder capitalism is an appropriate model for action and decisions related with infrastructure, since infrastructure investments affect so many stakeholders (Freeman, Martin, & Parmar, 2007). Balancing the needs and wants between different sectors (transport, water, energy, communication, waste) of the public, the environment, the legal entities (corporations etc.), the final users and industry is challenging and requires a new approach.

Infrastructures, such as transport, water, waste, energy and communication, serve the long-term needs of society. Water and waste infrastructures cover basic needs and are essential to support human life. Transport, energy and communication infrastructures have become fundamental for society to function. Given the long-term nature of infrastructure investments, long-term operation and maintenance are required. Transport, water, waste, energy and communication infrastructure are essential in providing economic, environmental and social value to society (Hay, 2016). Most organizations and industries rely on these five types of infrastructures for operating. This reliance on civil infrastructure is only increasing (Hay, 2016). Economic value of civil infrastructures is either directly or indirectly distributed in different ways in society. Social and environmental value is indirectly attributed to civil infrastructure. Water and waste treatment protect waters (underground waters, lakes, rivers and sea) from pollution, transportation networks support the socialization of the people and leisure travels,

All the aforementioned ways and many others for adding value to the society should be taken into consideration by the policy makers. The stakeholders should be involved in the decision-making process of infrastructure investments, as each stakeholder has different long-term needs and wants that are covered by civil infrastructure and therefore, the stakeholder capitalism approach should be applied on studying infrastructures.

2.5 Linear vs Circular Economy

The discussion on the sustainable infrastructure investment environment is not only limited to a comparison between shareholder and stakeholder capitalism, but it goes deeper than that. The common model of the capitalist economy has a unidirectional linear frame: goods are produced, purchased, then discarded (Stahel & MacArthur, 2019). The concept of linear economy relies on the idea that creating new products is better for the economy than reusing or recycling or repurposing existing ones (Stahel & MacArthur, 2019). The flow of material or product through a process in a linear economy has an end point. Private corporations consider the end point until they deliver it to the society (from cradle to gate), rather than take responsibility until the end-of-life (from cradle to grave). Corporates claim that this responsibility has been transferred to the final user with product ownership (Stahel & MacArthur, 2019). Linear economy targets on creating economic value, ensuring flows of extracted raw materials, and producing goods (Stahel & MacArthur, 2019), without considering any social or environmental externalities.

In the mid-20th century, strong views between capitalism and socialism in the western world bolstered the view that a linear economy was essential to maintaining influence during a tense geopolitical period (Sariatli, 2017). Linear economy was giving the opportunity to developing nations to grow into developed nations (Sariatli, 2017). This is particularly true when considering the aggressive expansions of civil infrastructure in the mid-20th century within western countries and made linear economy popular (Sariatli, 2017). The success of the linear economy is based on the fact that only economic factors are taken into account by the Organisation for Economic Co-operation and Development (OECD) to determine whether a country is developing or developed. It should be taken into consideration that the linear economy aims to extract limitless economic value without consideration for sustainability (Bonciu, 2014). Linear economy results an over-consumption of the environment's raw materials and resources and production of more pollutants and waste to the environment (Bonciu, 2014).

As discussed above, from the 1970s to 1990s, three factors accelerated the transition from managerial capitalism to profit-focused shareholder capitalism: globalization, deregulation, and rapid technological change. These factors gave rise to a situation where the maximization of profit within a linear economy was the main goal and incentivizes the accelerated consumption of natural resources to continue economic growth. Infinite economic growth is just not possible in a world with finite resources. Furthermore, since the private sector claims that the responsibility of a product until the end-of-life is transferred to a stakeholder, the final user, then the final user should be involved in the decision-making process.

The limited recourses combined with increased environmental pollution require a new economic model. In 1973, Schumacher introduced the concept of circular economy (CE) in his book Small is Beautiful. Schumacher (1973) asserted that the linear economy treats natural resources like expendable income instead of non-renewable capital. CE uses the unidirectional linear flows described above but instead of discarding resources at the end of their life span, they are directed back into the inward flow creating a “circle”. Circular economy may not deal with the involvement of the final user in the decision-making process (social value), but takes into consideration the environmental value.

When it comes to civil infrastructure, economic groups such as the World Economic Forum highlight the need for measuring and monitoring infrastructure's performance in terms of social and environmental value (Schwab, 2019). This responsibility should be allocated to stakeholders with the means and the ability to evaluate infrastructure, businesses and governments (Schwab, 2019). In return, the environmental and economic value generated by businesses and governments will be increased (Schwab, 2019). In addition, the involvement of the government will indirectly involve final users. Stahel (2015) echoes these ideas by suggesting a CE system that will increase the lifespan of infrastructure by involving the different stakeholder throughout the life of the infrastructure (in line with stakeholder capitalism). This circular system will create an environment of sharing and mutual accountability and reward the different stakeholders (final users, infrastructure developers, businesses, etc.) using different monitoring and tracking mechanisms (Stahel, 2015).

In terms of economic value, CE sees infrastructures as infrastructure stocks (Schiller, Müller & Ortlepp, 2017). Infrastructure stocks are the companies that own and operate infrastructure assets (Schiller, Müller & Ortlepp, 2017) and not the engineering and construction companies. The "infrastructure stock" idea is not new, but many governments and business stakeholders do not have a standardized system for valuing these stocks. The lack of a standardized system for valuing these stocks means that regional and national economies cannot easily be integrated into the circular pattern. Schiller, Müller and Ortlepp (2017) described a simple process of valuing the infrastructure stock by tracking the input and the output of materials. During this input-output material process, one or more stakeholders should monitor any material added or taken. The process requires collaboration of the stakeholders and increases accountability. The implementation of the input-output material process described by Schiller, Müller and Ortlepp (2017) to regional and national sectors requires sector-by-sector input-output tables. There are such input-output tables for economic and environmental value, but not for social value. Using these tables, it is possible to propose a transition from a linear to a circular economy with focus on long term environmental and economic sustainability.

In all of the above, there is no specific mention of "who pays and who benefits?" As it was mentioned before, in an ideal world, all infrastructures and their systems of operation would be funded by the government on behalf of society and therefore an infrastructure asset management model should deliver stakeholder value. If stakeholders pay (via taxes) then they should benefit; if shareholders pay, then they require a benefit (via dividends). If governments outsource service provision, then they do so because they want to use taxes for something else or they believe that the sum of private service provision plus dividend payments to stakeholders would be cheaper than state provision (i.e. the power of the market and competition). If this is the case, then customers (tax payers) should be satisfied. In other words, the question this thesis tries to answer is where does the provision of 'wider value' fit into this picture?

The long-term nature of transport infrastructure investments requires relevant methods. Typically, cost-benefit analysis (CBA) or methods based on the CBA are used (Korytárová & Vaňková, 2017) for evaluating infrastructure projects. However, the emphasis on flows, met both in linear and circular economies, aligns with the ubiquitous economic metric, GDP. Flyvbjerg (2007) presented an analysis of a large-scale infrastructure project and concluded that environmental and social values of large-scale infrastructure projects are sometimes ignored or miscalculated (Flyvbjerg, 2007). Evidence shows that many infrastructure projects lack public involvement

(Flyvbjerg, 2007). The public involvement is one of the issues that this thesis aims to highlight and address.

Based on the literature findings, shareholder linear systems should transition into stakeholder circular systems, to encompass economic, social and environmental well-being of infrastructure systems. The literature review emphasizes that the negative externalities of a linear economy are detrimental to society and the environment. The private sector focuses mostly on the economic value resulting in the imposition of linear economy. Research has already shown that a stakeholder circular system will create business opportunities for the private sector due to product life extension and new recycle and reuse methods (Stehl, 2015). This thesis has as a starting point to study the linear economic value (GDP metric from the input-output tables) and gradually add the environmental and social values to the linear existing system. This way it would be easier for the reader to see the value added by stakeholder circular systems compared to shareholder linear systems. Infrastructure would benefit from adoption of circular economy principles, especially considering long-term sustainability. Studies have shown that a stakeholder circular system can encompass social, environmental and economic values. For example, stakeholder circular systems improve sanitation (environmental value) and increase water access to society and therefore the social value (Schroeder, Anggraeni, and Weber, 2018).

2.6 The involvement of public sector and the final user as a key-stakeholder (social value)

A stronger and faster transition from a shareholder linear economy to a stakeholder circular economy requires the involvement of the public sector and society (final users). This transition cannot immediately happen, since the shareholder linear practices are long-standing. Research, such as that reported in this thesis, is required to determine the best way for circular economy theories to be implemented. In the infrastructure industry, concepts such as circular economy and stakeholder capitalism have already been researched and proven effective if implemented correctly. This thesis combines existing theories and presents an innovative step-by-step method to consider economic, social and environmental value dependencies on transport infrastructure business models. Policy makers could use this research to intervene to increase the uptake of CE practices with regulations.

At this point it should be highlighted that, in some cases, the immediate implementation of the outcomes of this research would be debilitating and/or detrimental. For example, in the communication infrastructure sector, rare earth elements and custom-made metal alloys are used in minute quantities to create each communication device, such as smartphones (Stahel & MacArthur, 2019). The technology or processes required to separate and therefore enable the reuse these metals and elements do not currently exist. Nevertheless, the questions should be asked in every situation, even if the answers will sometimes be negative, and this thesis facilitates the asking of these questions.

This thesis suggests that a transition from linear to circular economy principles by considering the environmental value (EXIOBASE database) is preferred. For example, policy makers could implement an incentive programme to stimulate final users to incorporate aspects of sustainability into their travel behaviours on environmental grounds (that includes environmental and social value) that comes with long-term sustainability.

Another positive of this thesis approach is that by mapping social and environmental benefits into linear economy systems (e.g. input-output tables), values from all stakeholders are presented in the language that shareholder-focused systems already use.

Finally, since the private sector is mostly shareholder focused, it will be more focused on short-term economic value than long-term stakeholder value (Freeman, Martin & Parmar, 2007). The level of private sector involvement for most major public transport infrastructure projects will vary across jurisdictions, types of infrastructure, and over time, reflecting changing political and society preferences. The United Kingdom has created industry regulators so the government is sure that their priorities are being met, while still benefiting from the increased efficiency in cost and time that private-sector partners bring (Canada's Public Policy Forum, 2014). Therefore, policy makers can impose a degree of stakeholder capitalism on all corporates by incentivizing them to reduce their GHG emissions. The numerical limitations of GHG emissions for the reducing GHG emissions policies can be taken from the findings of this thesis.

2.7 The disciplinary context

This chapter presents the disciplinary context from which the parts of the interdisciplinary study have arisen.

2.7.1 Economic value of infrastructure

With infrastructure, economic value pertains to many of the same concepts as linear economy and shareholder capitalism. Economic value in infrastructure systems can be defined as the increase in economic prosperity through an infrastructure investment either for improving existing infrastructure or for building new ones (Kessides, 1993). More specifically, transport infrastructure contributes to society's economic growth by developing networks for trade between societies (Vickerman, 2007). Transport infrastructure investments, which are long-lived, have a long lead time and consume high capital costs, deliver their benefits in the long run (Vickerman, 2007). As identified within shareholder capitalism and the linear economy, short-term profitability is prioritized over long-term success and there is little incentive for infrastructure to be valuable for a long period of time. On the other hand, CE captures the long-term sustainable benefits of infrastructure. Additionally, stakeholder capitalism's societal goals, such as resilience, align with the long-term nature of infrastructure.

2.7.2 Environmental value of infrastructure

The environment should support human life. Environmental value can be defined as the importance and wellness of nature (Reser and Bentrupperbäumer, 2005). Some actions, such as the construction and the maintenance of infrastructure, will have environmental costs and will affect the wellness of nature, but in return, these actions will cover human needs. Applying the concept of environmental value to infrastructure requires one to consider that infrastructures are built to cover human needs and to support the quality of life.

Andersen (2007) studied environmental value in relation to human activity and categorized environmental value into the following primary types: amenity value, natural resource base, a sink for residual economic activity and a fundamental life support system (Andersen, 2007). Environmental amenity value is the inherent value that individuals receive from the environment without any additional interference (Anderson, 2007). Environmental amenity value is highly subjective and depends on individual experiences and preferences, and cultural factors (Gkargkavouzi, Paraskevopoulos and Matsiori, 2018). Anderson (2007) connected the environmental amenity value with emotions, perspective and other non-quantitative concepts (Anderson, 2007). Environmental amenity value will be studied as part of the social value in this thesis.

The next two categories of environmental value view environment as an economic source; either as a resource base for the economy or a sink for residual flows. These concepts were discussed when the different types of economic flows were set. As was presented before, in terms of economies, the environment is a source of renewable and non-renewable inputs into economic production and has the capacity to absorb waste from human economic activity (Andersen, 2007). These two categories of environmental value align with the Schiller, Müller and Ortlepp's (2017) input-output

CE model. As such, the two categories can be studied by using environmental input-output tools, such as the EXIOBASE database.

Finally, the last category of environmental value views environment as a life support system (Andersen, 2007). Andersen' approach (2007) is considered, but not adopted as it is in this thesis, since it is a purely economic approach. The author took Andersen' approach (2007) into consideration when dividing economic, social and environmental values of infrastructure systems, but as the reader will see in the following paragraphs it is not a sustainable approach as it is.

Infrastructure projects effect ecosystems by altering or even destroying a species' ecosystem (Lederman and Wachs, 2014). This type of effect is typically addressed on a project-to-project basis using tools such as the Habitat Conservation Plan (Lederman and Wachs, 2014). Habitat conservation plans are developed during the planning period of an infrastructure project focusing on the effect of the construction project (Lederman and Wachs, 2014) and not on the effect of the infrastructure as a system. At a systemic scale, the new infrastructure may interact with other infrastructures or environments, something that will increase the effect of the new infrastructure on the environment. Environmental amenity value is highly subjective and depends on individual experiences and preferences, and cultural factors (Gkargkavouzi, Paraskevopoulos and Matsiori, 2018).

Natural resources are required to construct and operate infrastructure systems. Most of the natural resource have a two-way relationship with infrastructure, since to extract most of the natural resources requires significant infrastructures (Weng et al., 2013). Economists study natural resource scarcity as a factor that dramatically influences economic growth (Ragnarsdóttir, Sverdrup and Koca, 2012). In addition, when analysing natural resource consumption, economists consider the influence on the development, such as low-density sprawling regional development requires the consumption of more natural resources per capita and per linear metre than dense urban development (Ewing et al., 2008; Blais, 2010). It is obvious that shareholder linear economy is deeply rooted in the thinking of economists. This is even more obvious considering that economists see the environment as a 'sink' for economic residuals, where waste or emissions are a type of economic residual (Andersen, 2007). Economists see human-built infrastructure as a way of helping to metabolize anthropogenic pollution that exceeds the environment's natural capacity for absorption. The dominant way of economic thinking, once again, is influenced by shareholder linear economy. This economic approach becomes even more unclear since the environmental limits of absorbing economic residuals is not defined. Global climate change is a clear example of this problem. There is mounting scientific evidence that the environmental capacity to absorb carbon is reaching a limit and there is no clear path to change the way society generates emissions. Furthermore, it is not clear how the emissions generated by each sector interact with emissions generated by other sectors. This thesis analyses the interaction between the emissions generated by each sector. There is no existing technology to expand the environment's capacity, so this thesis is looking at a way to limit the residuals of individuals by changes in individuals' habits. The environmental limits of absorbing emissions lie outside the scope of this study, but the findings of this study can be used to study the interactions between sectors and how human behaviour influences any environmental limits. The last type of environmental value an infrastructure should have is the basic life support. Infrastructure expands this function of the environment by providing access to water, energy and shelter (Moll et al., 2007). The accumulation of pollution impacts the final form of environmental value. If an infrastructure fails to support or adversely impacts human life, it creates, apart from the environmental issues, economic issues too (Moll et al., 2007). The discussion above shows how difficult it is to disconnect environmental value from the economic value in the existing socio-political environment.

2.7.3 Social value of infrastructure

The discussion of infrastructure and environmental value highlights an important pattern that creates a link to themes in social sciences. Policy and decision makers are affected by tangible short-term economic gains and political factors as the environmental value becomes less certain (Flyvbjerg, 2007). This thesis studies business models and within the implementation of the business models, a value proposition articulates the essence of a business, defining how products and services are assembled and delivered to final users in order to meet their needs (Kambil et al., 1996). Looking in the literature of social sciences for the coverage of human needs there are three main approaches: The theory of human needs (Doyal and Gough, 1984, 1991), the capability approach (Nussbaum, 1988; Sen, 1993) and Maslow's hierarchy of needs (Maslow, 1954). Both the theories of human needs (Doyal and Gough, 1984, 1991) and the capability approach (Nussbaum, 1988; Sen, 1993) see needs as non-hierarchical and non-substitutable. Theory of human needs' arguments have been highly abstract and are not appropriate for tactical and pragmatic questions (engineering). The capability approach ignores the needs of the most vulnerable people. This thesis tries to answer a tactical and pragmatic question which is the development of a new business model without ignoring the needs of the most vulnerable people. Maslow's hierarchy of needs is therefore the best tool for determining the value of infrastructure projects. The value in Maslow's hierarchy of needs is linked with the satisfaction of the individual and not an individual's productivity or income. This thesis covers the productivity/income gap by analyzing the collected data not only with Maslow's hierarchy of needs, but with a theory based on income, the expected utility theory. The key challenge of Maslow's approach is to determine quantitatively and qualitatively the satisfaction of a need.

Maslow's hierarchy accepts that the value is subjective, but does not show the impact of a decision of an individual if the scope of the decision impacts a diverse range of stakeholders or even stakeholders from different time (e.g. future generations) or spatial scales (e.g. stakeholders in different areas). An infrastructure may be extremely valuable to some people and meaningless to others (Gkargkavouzi, Paraskevopoulos and Matsiori, 2018). So it is not clear how to achieve an optimal level of social value, because different stakeholders have different needs (Lawer, 2019). The second source of ambiguity is the spatial scale of the infrastructure decision. If the infrastructure decision has a broad scale and affects stakeholders with different priorities in their hierarchy of needs, then there is less clarity about the genuine value of the project (Lawer, 2019). Stakeholder theory defines a stakeholder broadly as anyone who can affect or be affected by a decision (Freeman, Martin and Parmar, 2007). Conflicts on values between stakeholder and value uncertainty are increased as the number of stakeholders increases (Lawer, 2019). Additionally, when more subjective stakeholder needs are impacted, the likelihood of stakeholder conflict increases (Lawer, 2019). In these circumstances it is challenging to determine the true environmental or economic value of an infrastructure using Maslow's hierarchy of needs. This means that the environmental and economic values should be studied independently from the social value, as this thesis does. To deal with the conflict issues the author will generalize the results using statistical tools based on the vast majority of the stakeholders.

A clear and consistent narrative throughout the sections to underpin the assumptions and methods used demonstrating that these are sufficiently consistent to justify the conclusions.

2.8 Methods and assumptions of Economic Value

The feasibility of an infrastructure project is determined by assessing the economic value of the infrastructure investment. The definition of the "economic value of infrastructure" can vary according to the scale of the analysis. The analysis adapted by this thesis is a large scale (strategic) analysis aligning with the latest definitions of infrastructure (Sussman et al., 2009; Frischmann, 2012; Pearlstein, 2014; National Science Foundation, 2017; Oughton, 2018; Allenby and Chester, 2018) and not with the earliest which see infrastructure mainly as projects (Jessen, 1984; Martini and Lee, 1996).

As discussed before, the mainstream economic approach of the 20th century largely influences the existing political and economic systems today, which is dominated by the concept of a linear economy. Humans create economic value through economic exchange and through flows of extraction of raw materials and the production and consumption of goods and services (Stahel & MacArthur, 2019). The economic appraisal of an infrastructure project by a private entity (shareholder capitalism) focuses on the shareholder's economic value. The appraisal of an infrastructure project from a stakeholder viewpoint (stakeholder capitalism) focuses on the society's economic, social and environmental value. Cost-Benefit Analysis (CBA) and Input-output tables are two different methods widely used to assess the economic value of infrastructure projects.

CBA leans on the extensive available data gathered from previous projects of similar nature (Hoogmartens et al., 2014). Theoretically, the information associated with the project is readily available (Van Wee, 2007). CBA evaluates the economic performance of infrastructure in monetary units using different monetary criteria and methods (Vickerman, 2007). CBA attempts to capture the social and environmental value by estimating positive and negative externalities over the lifetime of the project (Atkins, Davies and Bishop, 2017). CBA employs a "circular economy" approach, since it attempts to capture the social and environmental value (Sariatli, 2017). Nevertheless, according to CBA, the project with the highest estimated monetary (economic) value will be selected. On the other hand, input-output tables employ a "linear economy" approach (Sariatli, 2017) and externalities, either social or environmental, can be estimated independently by combing the input-output tables with other databases (e.g. Exiobase). According to input-output tables, the infrastructure decisions are taken for maximizing the GDP growth (Ploszaj et al., 2015).

Both techniques are useful for analyzing the economic value of infrastructure, but CBA and input-output tables differ. Their differences highlight circumstances when one of the tools should be used over the other. CBA relies on expert evaluation of the specific impacts of a project by a multidisciplinary team (European Commission, 2014). The multidisciplinary team of experts estimates the construction, economic, environmental, and social value over the life time of the infrastructure project (European Commission, 2014). Conversely, input-output tables model the flow of economic value through an economy. The input-output table shows the effect of a new infrastructure on every sector of the economy and reveals dependencies between sectors. The inputs and outputs are generated by pre-determined equations, meaning that input-output analysis is less biased than the experts' approach used by CBA. New infrastructure impacts the variables that feed into the pre-determined input-output equations. In other words, the benefit of a new infrastructure is modelled by how it impacts the economic value across all sectors and it is possible to study the infrastructure dependencies, which is the scope of this thesis.

CBA and input-output tables provide analysis from opposite perspectives. CBA employs a bottom-up perspective in which it aggregates individual impacts of the infrastructure into a singular economic value. Input-output analysis employs a top-down perspective. It attributes anticipated changes throughout the entire economic system to a shock from changes in infrastructure. To combine and study the singular economic values of different infrastructure projects estimated by the CBA, requires that the starting points (bottom of the analysis) of the analysis are similar e.g. same assumptions, same costs and benefits etc. On the other hand, the holistic equations used by the input-output tables are fixed meaning that the starting point (top of the analysis) of the analysis is the same. To conclude input-output tables are more useful than CBA when someone studies the infrastructure as a whole, as this thesis does, because it compares similar and less biased data. CBA works better for smaller infrastructure projects when specific impacts can be assessed.

This thesis analyses the economic impact of infrastructure using economic input-output tables and the following discussion explain why. The main reason is that, regional economic input-output tables are used to measure the impact of infrastructure investment on the overall economy, when CBA focuses on specific infrastructure projects. Gross Domestic Product ("GDP") is viewed as a measure of economic progress, which is "the value of the goods and services produced by the nation's economy less the value of the goods and services used up in production" (Dynan, 2018).

2.8.1 Critical Summary of Cost Benefit Analysis

The Cost-Benefit Analysis (CBA) was first developed in the mid-19th century, and substantially evolved to its current form (Saad and Hegazy, 2015). CBA assigns a unit of monetary value to every impact of infrastructure (Vickerman, 2007). According to Hayashi and Morisugi (2000), CBA is the most commonly used economical value assessment methodology for infrastructure projects. In simple terms, cost-benefit analysis is a summary of all the benefits and costs of a project (Mouter, 2014). According to Couture et al. (2016), CBA have project-specific applications and varies in the types of costs and benefits measured, quantification method, time period considered, and discount factors used. The key features are:

- Benefit: Benefit is a gain in utility and is measured by how much an individual is willing to pay or willing to accept in compensation, meaning the demand (Couture et al., 2016). Benefits typically are assessed using the additional productivity provided by the project (Vickerman, 2007)
- Cost: Cost is a loss in well-being, which is measured by how much an individual is willing to accept to tolerate loss, or willing to pay to prevent loss (Couture et al., 2016).
- Time period (Couture et al., 2016; Van Wee 2007): Costs and benefits occur in different time intervals within the timeline of a CBA. Future costs and benefits

are discounted to define the present value of money (NPV). The present value of benefits and costs are then used to determine net-present value of projects, which also allow for comparison. Discount rate cannot get easily estimated and usually it is based on historical data.

- Sensitivity (Couture et al., 2016): The sensitivity analysis is used to estimate the uncertainty of project parameters such as discount rate, volume of consumption, etc. that are used in the CBA analysis. The sensitivity models are error-free if they do not reveal large unexpected changes in NPV. Sensitivity analysis is challenging as the number of projects increases, since the number of assumptions increases too. This means that using CBA is challenging when you are studying the infrastructure system as a whole, like this thesis does.

All the benefits and costs considered as part of the CBA are assigned to a monetary value. CBA levels all factors by reducing them to a single metric: Net Present Value (NPV) or the Benefit Cost Ratio (BCR) (Vickerman, 2007; Mouter, 2014). According to CBA, an infrastructure project is deemed efficient if "the total 'willingness to pay' for the beneficiaries is higher than the total 'willingness to accept compensation' of those who are disadvantaged by the project" (Branigan and Ramezani, 2018).

<u>Analysis of costs and benefits:</u>

Part of the audience of this thesis may have an engineering background and an explanatory analysis with cost and benefit curves is required for the audience to understand CBA. In addition the explanatory analysis will show the difference between private and public good and will highlight why it is difficult to use CBA analysis when you are considering both private and public stakeholder, as this thesis does.

The benefit or demand curve presents the amount of goods the buyer is willing to buy at any given price. Figure 2.10 presents a linear example of a demand curve. Based on the Figure 2.10, the equation connecting the price of a product with its demand is the following: $P = 120 - 2Q$ or $Q = -1/2P + 60$ (P: Price and Q: Quantity).

Demand	
Q	Price (CAD)
0	120
10	100
15	90
20	80
30	60
40	40
50	20
55	10
60	0

Figure 2.10 Demand curve example

Assuming that the price of the good is 60 CAD, the buyer will ask 30 units (quantity) of the good. The overall benefit is the area (geometric) under the demand curve (trapezoid area + triangle), meaning 30*60 + ½ 30*(120-60) = 1800 + 900 = 2700 CAD. Buyer's surplus is the overall benefit deducting consumer costs (triangle) meaning 2700 - 1800 = 900 CAD.

Total demand is the sum of the demand curves of each individual consumer. How to aggregate demand curves depends on the nature of the good (public or private). The demand curve differentiates based on whether the good is public or private. Public goods, such as infrastructure, should not exclude buyers and are not divided (indivisibility) (see Figure 2.11).

A		B		Sum	
Q	Price	Q	Price	Q	Price
0	**120**	0	90	0	**210**
10	**100**	10	80	10	**180**
20	**80**	20	70	20	**150**
30	**60**	30	60	30	**120**
40	**40**	40	50	40	**90**
50	**20**	50	40	50	**60**
60	**0**	60	30	60	**30**
		70	20	70	**20**
		80	10	80	**10**
		90	0	90	**0**

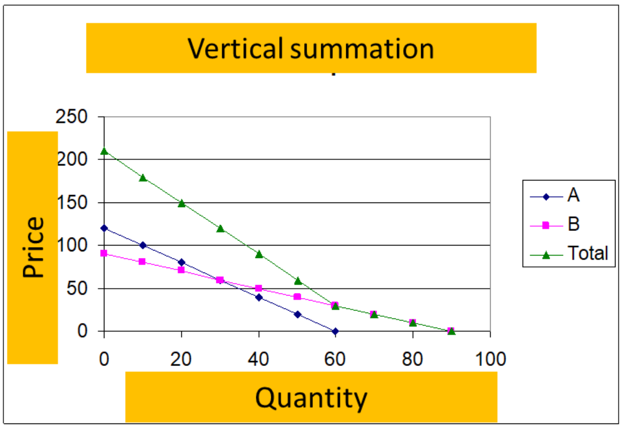


Figure 2.11 Demand curve example of a public good

A		B		Sum	
Q	Price	**Q**	Price	**Q**	Price
0	120			**0**	120
10	100	**0**	100	**10**	100
15	90	**0**	90	**15**	90
20	80	**10**	80	**30**	80
30	60	**30**	60	**60**	60
40	40	**50**	40	**90**	40
50	20	**70**	20	**120**	20
55	10	**80**	10	**135**	10
60	0	**90**	0	**150**	0

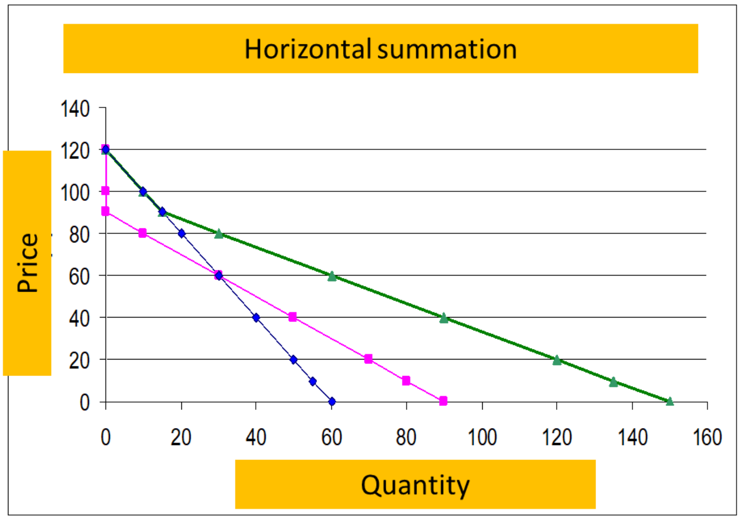


Figure 2.12 Demand curve example of a private good

Private goods and services exclude buyers and their price is defined by the free market (see Figure 2.12). The difference on studying private and public goods highlights the challenge of using CBA for studying infrastructure. There are economic elements on studying infrastructure that are either private or public or both (private-public-partnerships).

The cost or supply curve is estimated in a similar manner. The supply curve meets with the demand curve at the equilibrium point. This point represents the optimum solution based on cost-benefit analysis (see Figure 2.13)

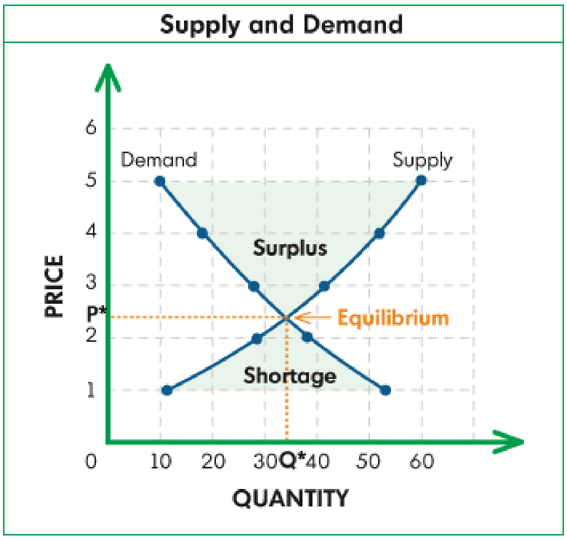


Figure 2.13 Equilibrium point of CBA

The equilibrium point "moves" based on which factors were taken into consideration and the type of market such as competitive market, monopoly etc. A typical differentiation is that the private sector does not take into consideration external costs affecting society (social costs) or external demand by society (external demand) (see Figure 2.14).

By using as a single metric the monetary value for all the factors (social and environmental), CBA takes into consideration the monetary power of a group of individuals, rather than the number of individuals who are affected by the project e.g. private vs social (see Figure 2.14). The social and environmental values are estimated using available data about consumer preferences (Ackerman and Heinzerling, 2002). It is challenging to aggregate the value of many social and environmental variables, because different stakeholder can value them in completely different ways (Gkargkavouzi, Paraskevopoulos and Matsiori, 2018). This problem is exacerbated when the scale of the infrastructure project expands due to the incensement of the number of stakeholders and the number of variables (Lawer, 2019), as more stakeholders and more variables means more connections-relations-equations in a non-linear way. Infrastructure as a whole impacts many stakeholders and its' environmental and social values are not easily quantifiable. Therefore, there is high uncertainty when studying infrastructure as a whole using CBA. That is because infrastructure impacts a broader range of stakeholders, whose values are unclear or contradicting (Lawer, 2019) and it is possible to impact stakeholders in the future, whose needs and preferences are not currently known.

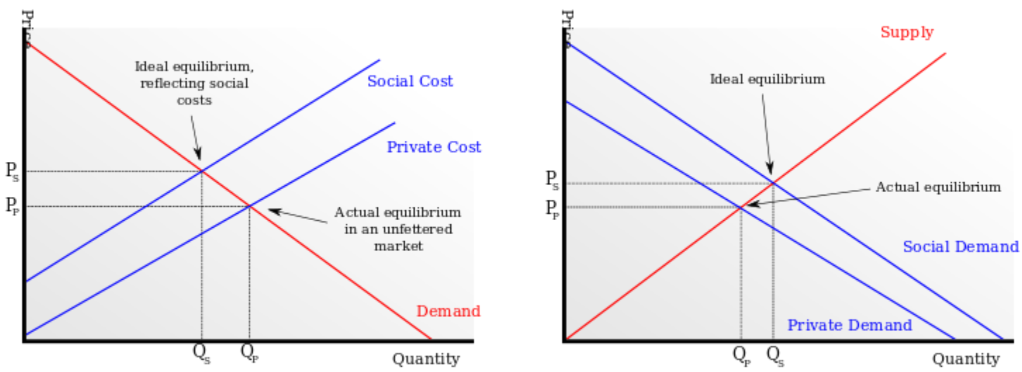


Figure 2.14 Ideal vs actual equilibrium in an unfettered market

Advantages and disadvantages of Cost-Benefit Analysis

CBA can incorporate a wide range of infrastructure cost and benefits, as long as there is adequate information about them (Hoogmartens et al., 2014). As mentioned before, environmental impacts often have concrete economic values and can be expressed as a monetary value (Andersen, 2007), but it is not a sustainable way. Similarly, social value can be expressed in terms of monetary value, when stakeholder preferences are strongly understood (Coase, 1960), but there can be no strong understanding of preferences when the number of stakeholders is big. The "dependency" of CBA on complete information is the method's primary weakness. When values do not have a monetary (market) price, CBA attempts to assign a monetary value (Ackerman and Heinzerling, 2002). The standardized CBA methods for estimating monetary value are based on survey data and secondary data (e.g. 'equivalent' consumer preferences) (Atkins, Davies and Bishop, 2017). The challenge, once again, is that many environmental and social values are entirely subjective (Ackerman and Heinzerling, 2002) and the uncertainty of CBA increases.

The lack of certainty also makes CBA more susceptible to bias (e.g. political bias) in order to create support for an infrastructure project (Van Wee, 2007; Ryu, J., 2019). According to Flyvbjerg (2007), many large-infrastructure projects that are supported by CBA are later found to have greater than expected costs, and lower than expected benefits (Flyvbjerg, 2007). A thorough CBA analysis, by a multidisciplinary team, should be employed to determine whether there is enough information to genuinely quantify the impacts of the project (European Commission, 2014; Zhuang et al., 2007).

On the other hand, CBA is less exposed to the subjectivity of factor weights, since it compares different options for the same infrastructure project under the same scheme (Van Wee, 2007). CBA ensures that the same criteria are used when assessing cost and benefits of different options of the same infrastructure and reduce bias due to "information asymmetry" (Branigan and Ramezani, 2018).

CBA often omits the environmental and social value of infrastructure, since CBA transforms them to economic value. CBA methodologies are usually performed for individual projects, and ultimately omit the "external costs to nonusers" (Vickerman, 2007). The stakeholder approach, used in this thesis, takes into consideration the non-users too. Additionally,

Moreover, CBA carries a significant amount of assumptions, which are deemed acceptable and negligible at small scales (Vickerman, 2007). However, when considering large infrastructure projects, these assumptions gain amplitude and affect the assessment further (Vickerman, 2007). Once again it becomes obvious that CBA cannot easily be used for studying large infrastructure systems. As portrayed by Vickerman, the assumptions include predicted and static demand (even when taking into account income rises and technology advancements), fixed dependencies between infrastructures (meaning that new infrastructure is evenly used with the existing one) and perfect competition among infrastructure providers (Vickerman, 2007; Wang, 2010). These assumptions increase the uncertainty of the CBA process and contradict the social value of infrastructure which accepts that the demand differentiated based on specific factors (e.g. new infrastructure provide better quality of services).

CBA is sensitive to changes in discount rates and to the time period considered (Wang, 2010; Flyvberg, Holm, Buhl, 2005). The discount rates are estimated based on historical data and their interpretation by the analyst, meaning that the discount rates are affected by potential biases (Wang, 2010; Flyvberg, Holm, Buhl, 2005). Wang (2010) noticed that analysts tend to favour infrastructure with short term benefits (aligning with shareholder capitalism) without considering the latest definitions of infrastructure, where infrastructure is a long-term resource (aligning with stakeholder capitalism).

Finally, a study of Saad and Hegazy (2015) concluded that CBA does not support multi-level decisions, such as the allocation of value between different infrastructure systems. This position (Saad and Hegazy, 2015) aligns with Wang's position that CBA do not take "wide economic impacts into consideration" (Wang, 2010).

The following table (Table 2.4) presents the advantages and the disadvantages of the cost-benefit analysis.

Table 2.4 Advantages and disadvantages of the cost-benefit analysis

Cost-Benefit Analysis	
Advantages	**Disadvantages**
Previous historical data to infer from Costs and benefits are already theoretically known in infrastructure projects (Van Wee, 2007)	Cost-benefit analysis tends to omit environmental and social benefits of projects (Van Wee, 2007)
Cost-benefit analysis is neutral when compared with other multi-criteria analysis (Van Wee, 2007)	Requires lots of assumptions: Risk of errors for large scale additions (Vickerman, 2007)
Provides direct comparison between alternatives. Cost-benefit analysis allows easy comparison of different options for same project, reducting bias and improving clarity (Vickerman, 2007)	Often subjected to optimism bias (Flyvbjerg, Skamris Holm and Buhl, 2005)
Incorporates specific elements of projects, including non-economic externalities	Does not support multi-level decisions (Saad and Hegazy, 2015)
	Many project impacts are difficult to quantify (European Commission, 2014; Zhuang et al., 2007)
	Cost, time and expertise to conduct a rigorous CBA can be extensive. As such, this should be scaled to the size of the civil infrastructure. Less effective as the project gets bigger.
	The value of time or some other non-quantifiable aspects used to evaluate the cost and benefit could lead to a biased result if manipulated wrongly (Wee, 2007)
	Data constraints and uncertainty with large projects with long-term horizons: CBA may not be able to account for inflation, interest rates, changes to cash flow and the present value of money. In addition, uncertainty in the forecasts for future revenue or sales, expected costs and cash flows, or event the impacts of climate change may limit the actual performance of the CBA;
	Also, wrongly determining the discount rate will lead to a skewed results
	Variations in scope, lack of consistency of CBA based on regional guidelines. This can lead to different outcomes that ultimately impact the evaluation of a decision (Gwee, Currie, & Stanley, 2011; Olsson et al., 2012)
	Equity is not considered CBA since benefits or costs for one stakeholder is not given greater value than others.

2.8.2 Critical Summary of Input-Output Tables

Input-output tables by using a pre-existing system of equations avoid some of the bias, such as the political bias, that CBA is susceptible to. That is because the input-output tables are developed in a similar manner all over the world. The input-output tables show the flow of value through an economy, by relating the demand in economic sectors to the required inputs from other sectors. This way it is possible to study dependencies between sectors.

Input-output tables were first developed in the 17th century, and later formalized by Wassily Leontief in 1974 (Scott, 2020). The input-output tables are n x n matrixes including all the economic sectors of an economy and the flow of the economic value between these sectors. The rows of the input-output tables show the output of each economic sector and the columns show the input to each sector. Each cell of the input-output table is the output of a specific sector to another sector (input). Input-output tables aim to "model linkages between the productive sectors of an economy" (Avelino and Dall'erba, 2018), which intrinsically focus on large scale and large impact economic events (e.g. infrastructure).

Input-Output tables are comprehensive tables that provide the inter-industry transaction statistics of a particular region or an economy (Scott, 2020; Jun, et al., 2018; Avelino and Dall'erba, 2018). They provide the total demand and supply of each economic sector and a way to assess the magnitude of correlation between various economic sectors (Jun et al., 2018), which is the main scope of this thesis.

<u>Advantages and disadvantages of Input-Output Tables</u>

The information used in input-output tables is usually provided by government agencies in collaboration with international financial institutes, and therefore the transparency is ensured and guaranteed (Wang, 2010). Theoretically, this means that the information used in input-output tables as a methodology is ideologically neutral, as it does not allow for "specific behavioural conditions for the individual, companies, or indeed, the state" (Wang, 2010). The input-output tables include quantitative data which can be challenging to get (Henry,).

When considering the advantages of input-output tables, their main advantage is that they explain the impact of entire sectors on others, and therefore represent "interconnectedness of economic processes" (Scott, 2020; Wang, 2010). Using input-output tables, it is possible to assess the economic impact, caused by changes in any sector, to the overall economy of an area (Jun et al., 2018). Changes to the infrastructure system (e.g. recessions, expansions, or emergencies etc.) are considered a shock in input-output analysis (Zhao and Kockelman, 2004). Shocks are changes that impact the input-output system of equations that model a sector's production and demand for resources (Yu, 2018; Dietzenbacher et al., 2013). Although the input-output analysis focuses on shocks/changes, on the other hand the input-output tables can be used to describe the current situation of a system, as this thesis does. Each sector or change in a sector (e.g. infrastructure systems) has direct and indirect economic effects to the other sectors. The direct effect is the direct output of this sector and the indirect is how this sector induces production factors to increase economic value to other sectors. Input-output tables have low data requirements for estimating the economic value of a sector (Avelino and Dall'erba, 2018) and are graphic and easy to use, while being readily accessible (Wang 2010). The accessibility of the data makes input-output tables a cost effective methodology (Grady, 1988).

The target of this thesis is to model infrastructure dependencies during typical situations, and not for emerging situations. A well calibrated input-output model can reveal systematic economic benefits that might not be clear to experts conducting a CBA (Thakur and Alvayay, 2012). This would especially be true for a critical infrastructure linkage that impacts a wide range of economic sectors (Setola, De Porcellinis and Sforna, 2009). Considering the above discussion (Thakur and Alvayay, 2012; Setola, De Porcellinis and Sforna, 2009), this thesis develops a new model to capture the dependencies of critical infrastructure. Once the underlying assumptions of the tables are understood, it is simple to explain the results of input-output tables to decision makers (Ploszaj et al., 2015), who are the audience of this thesis.

The simplicity of the input-output tables, that is the reason that decision makers can understand them, is the reason for their main disadvantage. Input-output tables only model the economic value of infrastructure on interconnected economic sectors (Ploszaj et al., 2015) and do not attempt to account for environmental and social value. A piece of infrastructure may have a similar effect on GDP, but dramatically different social and environmental values. In this thesis other data is used to cover this gap, the EXIOBASE database for the environmental value and surveys of the social value.

The second weakness of the input-output tables is that they cannot be easily used for individual infrastructure projects (Bess 2011; Taks, 2011). To develop an input-output table and their economic dynamics requires extensive economic data and validation (Yu, 2018). A lot of organizations (e.g. private sector, local governments) or even national governments do not have the capacity to develop input-output tables, especially when infrastructure projects have a broad impact on the economy (Duncombe and Wong, 1998). This thesis focuses on the infrastructure as a whole and not on individual infrastructure projects. Furthermore, the input-output tables were already provided by the World Input-Output Database for the United Kingdom. To conclude, there is no effect of this disadvantage on the analysis in this thesis.

The most crucial assumption of traditional input-output tables is that the economy is demand-driven (Van Wee, 2007) without taken into consideration technological changes, price changes, and international trade pattern changes (e.g. COVID-19 pandemic). Prices are constant without subject to change (Van Wee, 2007), making the input-output tables a fixed price model. The static nature of input-output tables is a result of the over-generalization of this methodology (Onat, Kucukvar, and Tatri, 2014). This concept is exemplified by the lack of account of "long term economic, industrial, and demographic changes" (Bess, 2011). Therefore, input-output tables should be updated periodically over time. The United Kingdom published a limited number of input-output tables which forced the author to look to other sources.

The last important shortcoming is that industries belonging to the same economic sector produce one homogenous product. For example, if a construction company (construction sector) has and maintains (manufacturing sector) its own truck fleet to provide a transportation service, such as transporting precast structures (transport sector), then the economic value is accounted for under the construction sector. This thesis focuses on infrastructure so it makes clear the boundaries of which parts of economic sectors are considered as infrastructure.

The following table (Table 2.5) presents the advantages and the disadvantages of the input-output tables.

Table 2.5 Advantages and disadvantages of the input-output tables

Input-Output Tables	
Advantages	**Disadvantages**
Allows user to understand impact of certain industries on others, and shows "interconnectedness of economic processes" (Scott, 2020; Wang, 2010)	Large uncertainties due to generalization (Onat, Kucukvar and Tatari, 2014) • Uncertainty of results • Lack of consensus on a preferred model leads to a decrease in its credibility (Avelino and Dall'erba, 2018)
When compared to other methodologies; lower data requirements, increased ease of use, good transparency (Ploszaj et al., 2015). Easy to explain results to decision makers	This is a static model (Wang, 2010)
Allows user to take into account factors that are not easily quantifiable (Henry, 2013)	No specialized methodologies to validate the data used in I-O tables (Zhao, 2017).
More cost effective (Grady, 1988)	Input-output models do not consider any productive constrains of the economy (AECOM, 2012).
	Does not attempt to model externalities
Measure the economic impact of infrastructure on the overall economy (Jun et al., 2018).	It is difficult to develop accurate underlying assumptions and equations, so it should be kept simple.

2.8.3 Comparison and Conclusion

Cost Benefit Analysis and Input-Output tables employ different tools and different perspectives when analyzing the economic impact of infrastructure. The first criterion, taken into consideration by the author, was the comprehensiveness. CBA can be applied when the infrastructure investment creates social and/or environmental value that can be quantified. Input-output tables are a useful tool for analyzing the relationship between different sectors of the economy. Input-output tables provide a more comprehensive and insightful view of an infrastructure's economic impacts, that a bottom-up CBA approach would not. Hence, to evaluate the full range of the value of the infrastructure systems to encompass the considerations of economic, social and environmental wellbeing, input-output tables should be combined with other databases.

Another criterion is the capability of the methods to compare scenarios or options. Both approaches have unique advantages for analysing different scenarios. However, input-output tables allow interpretations when infrastructure triggers economic growth on different sectors of the economy. On the other hand, an adequate CBA values infrastructure in terms of monetary units (Vickerman, 2007) with ambiguity regarding how the economy is affected by infrastructure.

The specific differences discussed above point to advantages that input-output tables (top-down approach) have over the CBA (bottom-up approach) when infrastructure dependencies are studied. However, it should be highlighted that input-output tables and CBA are not mutually exclusive, but when there are gaps in knowledge about the impacts of infrastructure, each method can be used to complement the other. Both techniques can be used to analyse infrastructure decisions under certain circumstances. CBA works best when there is adequate information to calculate a monetary value for all economic, social and environmental values of an individual infrastructure project (Grady, 1988). Input-output tables are most effective when the environmental and the social values of infrastructure are well separated by the economic value. That way the value created in the input-output tables due to infrastructure is a genuine representation of the infrastructure's aggregate economic value (Wang, 2010; Ward, 2017). Input-output tables work better than CBA when the economic impacts of infrastructure are dispersed across many economic sectors or other infrastructure. CBA is inadequate to assess the economic impact of a piece of infrastructure on the overall economy.

The following table (Table 2.6) presents a detailed comparison of CBA and input-output tables and makes clear why input-output tables are used in this thesis.

Table 2.6 CBA VS input-output tables

When to use which method?	
Input-Output Tables	**Cost-Benefit Analysis**
When you are studying "interconnectedness of economic processes" (Scott, 2020; Wang, 2010)	When empirical data is available (Van Wee, 2007)
(a) regional, national and interregional economic growth decomposition analysis; (b) linkage analysis for an area or between regions (key sector analysis); (c) impact analysis of events such as natural disasters, which may cause shortage and shock on the supply side (Oosterhaven, 2019).	Assessing economic value of single project (or multiple options for 1 specific project objective) (Van Wee, 2007)
When assessing impact of projects at a regional scale (Grady, 1988) or national accounts. It assesses macro-economic impacts (Wang, 2010; Ward, 2017)	
Allows user to take into account factors that are not easily quantifiable (Henry, 2013)	
Cost effective (Grady, 1988)	
Effective communication (Wang, 2010)	
Easy to use as data is normally provided by government agencies (large scale) (Wang, 2010)	

2.9 Methods and assumptions of Environmental Value

Society, today, depends on civil infrastructure. As it was highlighted in the previous chapter, the economic activity facilitated by energy, water, waste, transportation and communication infrastructure is what enables societies to prosper. The environment is invaluable in supporting not only these infrastructures that are critical for prosperity, but also human life. Therefore, environmental matters should be given the highest priority by governments and decision-makers. It is important for decision-makers to understand here are many views on what environmental value means, and therefore decisions should not focus on only one definition or metric for measurement of benefits. Another parameter that should be taken into consideration by the decision-makers is the context that the assessment of the environmental value takes place. The right definition of the appropriate context will help the decision-makers to understand the benefits and limitations of the different environmental value analysis methods. This thesis addresses both issues and aims to expand the context in which environmental decisions are made. First, environmental value as it relates to civil infrastructure is defined. Then, the thesis investigates which is the most appropriate method for assessing the environmental impacts in the economic context defined in the previous chapters by comparing two traditional assessment methods: process-based Life Cycle Assessments (LCAs) and Environmentally Extended Multiregional Input Output (EE MRIO) Tables, such as EXIOBASE 3. Upon analyzing both methods, it is argued that EXIOBASE 3 is a more useful tool in the context of environmental infrastructure and policy decision making, especially when the decisions are taken into a higher level and a top-down analysis is followed (e.g. focusing on the civil infrastructure of a society ,as a total, rather than specific infrastructure projects). However, each method is valuable for different applications, and the benefits and limitations of each will be discussed in detail herein.

Infrastructure is defined as the “large-scale physical resource made by humans for public consumption” (Frischmann, 2012, p. 3) necessary for supplying the needs of people and the functionality of the economy.

2.9.1 Environmental Value

Based on the literature review performed in this theis, literature surrounding environmental value discusses primarily the utility of nature. In the late 1990s, an interesting perspective on environmental value is that environmental value is not appreciated until it is disrupted or lost (Daily, 1997). The importance of forests in the hydrological cycle of an ecosystem was not apparent until deforestation led to flash flooding, significant erosion and other negative effects (Daily, 1997). These negative effects impact human, animal and plant life within an ecosystem. This literature presents the value in utility, but also the environmental value lost when ecosystems are degraded due to human activity. More recent conversations concluded that environmental value is the human’s ability to kindly and rightly use the nature to contribute equitably to the quality of life of the present and future generations, through a cross-disciplinary collaboration between societies and human activities (Reser & Bentrupperbäumer, 2005).

Nowadays, environmental value includes a debate on what exactly is the environmental value and whether it should focus on the natural systems (e.g. nature, ecosystems, animals etc) or on the benefits from the natural systems that support growth and human life (Chan et al., 2016). These ideas relate to the tension between strong and weak sustainability practices in business and government; strong sustainability applies the theory that humans are a part of nature, incorporating a partnership-style relationship, whereas weak sustainability applies the theory that humans control nature and implies a relationship of human dominance over the environment (Landrum, 2018).

Although both strong and weak sustainability theories claim that target to reduce negative impacts on the environment, decision-makers will exert a strong influence on the sustainability measures being adopted. How environmental values are viewed, understood and incorporated into decision-making are impacted by the society and how the society views, understand and incorporate the natural systems. Chan et al. (2016) argue that the environment has three dimensions of value: intrinsic, instrumental and relational. Intrinsic value is the type of value that the natural system has for the rest of the ecosystem excluding people ("independent of people") (Chan et al., 2016). Instrumental value is the type of value that "brings pleasure or satisfaction" to people (Chan et al., 2016). The relational value of the environment exists in the personal and social relationships that humans have with nature (Chan et al., 2016). The relational value is more complicated, as it is partly a part of the social value, at least in terms of how the social value is defined in this thesis (e.g. human needs). See Figure 2.15 for a depiction of these values.

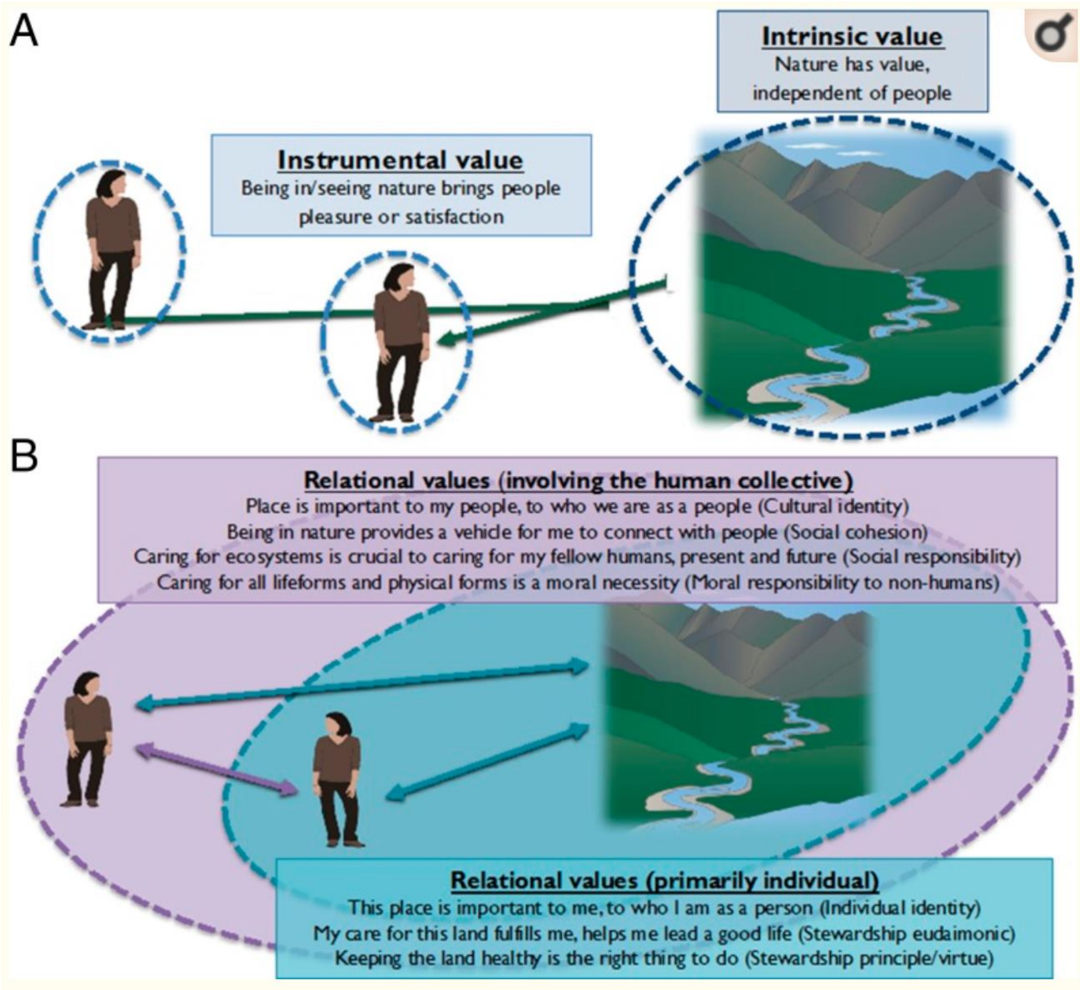


Figure 2.15 Different forms of environmental value (Chan et al., 2016)

Both strong and weak sustainability theories engage with the instrumental value of natural systems (Landrum, 2018). Weak sustainability model seeks to extract materials and resources from nature to a degree that minimizes harm to the environment (Landrum, 2018). Strong sustainability model extracts, recycles and replenishes materials, resources and energy in nature (Landrum, 2018). The challenge with the sustainability theories is that they do not engage directly with the intrinsic and relational values of nature. The environment/nature has inherent value that should be protected and is separated from human interaction or need, (Gómez-Baggethun, Ruiz-Pérez, 2011). Human needs with nature in the non-physical sense are also important (social value).Culturally, spiritually, socially and mentally, humans can extract significant value from the environment in ways that it is very challenging to be quantified (Chan et al., 2016). Herein lies an important difference between economic and environmental value; economic value can be transferred and replaced, but the intrinsic, instrumental and relational value in the environment cannot (Chan et al., 2016). When studying interdependencies, as this thesis does, economic value in one sector (e.g. infrastructure) can be transferred in another sector/industry, but environmental loss of value in one sector/industry cannot be rectified with environmental improvements in another sector/industry. Damage to an ecosystem by infrastructure systems is often permanent and will have rippling effects in the surrounding environment and therefore to society.

In the aforementioned context, civil infrastructure including transport infrastructure delivers instrumental value by manipulating and harnessing natural materials; processes that damage the environment (Frischmann, 2012). The environmental value has a direct relationship to civil infrastructure, which supports the environment's ability to provide human life through its resources, and provides conditions for the economy production. Additionally, processes that reduce environmental damage (e.g. renewable sources, collection and distribution of water, grow and distribution of food) require civil infrastructure (Frischmann, 2012). In other words, civil infrastructure has a two-way relationship with the environmental value, as civil infrastructure relies on the environment for materials, energy and water, but the same time civil infrastructure is needed for protecting the environment. Water treatment facilities, containment of harmful substances, the creation of parks and protected lands all exist to protect the environment. To benefit the environment, infrastructure, policy and operations should be designed to safeguard its environmental value (Gómez-Baggethun, Ruiz-Pérez, 2011). At this point, it should be noted that someone can claim that by not building any infrastructure, we would not have any environmental damage, but the initial assumption of this thesis is that infrastructure is required for human survival and coverage of human needs (see the economic chapter of this thesis).

2.9.2 Methods of Assessing Environmental Value

To protect environmental value, industrial and economic activity must be monitored. The environmental impacts being evaluated can include emissions, pollutants, resource use, effects on biodiversity, and more (Beylot, Corrado & Sala, 2019).

The four major stages within the analysis are: "(1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) life cycle interpretation" (ISO, 1997, p. 2). These stages are certified and supported by the requirements established in the standards of the International Organization for Standardization (ISO), which contribute to earning the acceptance of the international community and other stakeholders (ISO, 1997; Rebitzer et al., 2004). Table 2.7 illustrates the standards mentioned above, while Figure 2.16 bellow presents the LCA framework created in 1997 through ISO 14040 (ISO, 1997; Rebitzer et al., 2004).

Table 2.7 Standards of the International Organization for Standardization (ISO)

Standard	Description
ISO 14040	Summarizes the principles and context of LCA (ISO, 1997)
ISO 14041	Establishes the rules to define the goal and scope (boundaries and functional unit), and inventory analysis (Ekvall & Finnveden, 2001).
ISO 14042	Outlines the requirements of impact assessment data collection for inventory items analysis (ISO, 1997)
ISO 14043	Guides in the interpretation and conclusion formulation (ISO, 1997)
ISO 14044	Illustrates the requirements and guidelines management of LCA in overall context (Finkbeiner et al., 2006)

Based on another research by the author of this thesis (Olugbenga et al., 2019a):

Process-based LCA is a bottom-up methodology performed by mapping and characterizing 'all processes associated with all life cycle phases of the project' (Jones et al., 2017). Hybrid LCA method incorporates both top down economic input-output analysis-based (sector-by-sector wider analysis) and process-based LCA (Chester and Horvath, 2010) in an effort to recover the lack of data when data were available only for a part of the whole process or to expand the boundaries of analysis (Jones et al., 2017). Pseudo LCA method is based on a mix of primary data and data from literature to calculate the GHG emissions. Where system data were not readily available, simplified and parametric LCA approaches were adopted (Westin and Kågeson, 2012; Bueno et al., 2017). Simplified LCA was carried out by comparing the environmental impact of the rail infrastructure and no rail infrastructure condition within a given area (Bueno et al., 2017). In parametric LCA, specific system parameters were statistically modelled to calculate emissions associated with the system.

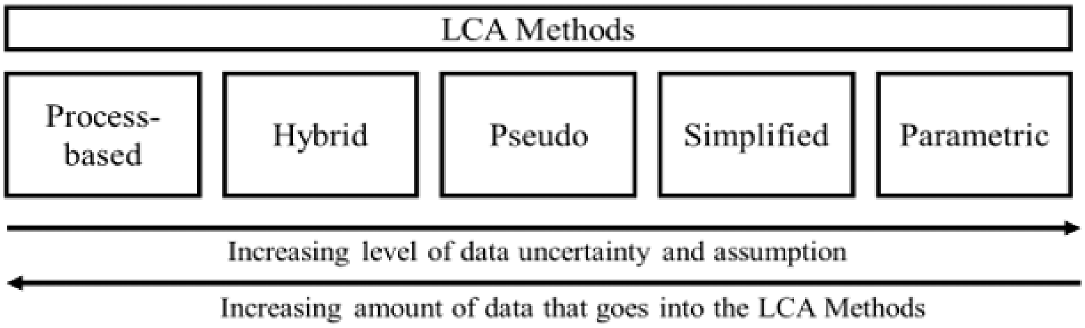


Figure 2.16 LCA Methods ranking based on data requirements and uncertainty

The analysis of the economic part of this thesis was done using input-output tables. Input-output tables can be combined with Environmentally Extended Multiregional Input Output Tables, a hybrid method. From the five methods mentioned above only the process-based Life Cycle Assessment method has less uncertainty than the hybrid. The two methods with the smallest uncertainty of assessing environmental impacts will be discussed in the following section: process-based Life Cycle Assessments and a hybrid LCA tool, Environmentally Extended Multiregional Input Output Tables.

2.9.3 Process-Based Life Cycle Assessments

A process-based Life Cycle Assessment (LCA) is a method of quantifying the environmental impacts of all the processes associated with an existing or potential product or service through each stage of its life (Jones et al., 2017; Finkbeiner, Wiedemann & Saur,1998). The process-based LCA method is the initial approach to addressing a life cycle evaluation of a good, service or system, focusing on a scientific analysis of the inputs (material and energy balance), and outputs (emissions and wastes) (Finkbeiner, Inaba, Tan, Christiansen, & Klüppel, 2006). The process-based LCA process is a detailed methodology for assessing the environmental impacts of a specific infrastructure system (Ayres, 1995; Trunzo, Moretti, & D'Andrea, 2019). This process-based LCA method is considered as a "powerful tool" to evaluate the environmental effects based on natural science models (Poudelet, Chayer, Margni, Pellerin, & Samson, 2012, p. 1). The process-based LCA is as a "bottom-up" method because it quantifies the environmental impacts for each process in all life cycle phases of a project (Olugbenga, Kalyviotis & Saxe, 2019a;b). The "bottom-up" nature of this method makes it challenging to be used on evaluating the infrastructure as a total. To evaluate the total civil infrastructure of a society, LCA should be applied to single infrastructure projects, single products, and services, and then scaled up to the level of interest. Therefore, detailed information is required on all materials and energy used, their supply chains, and the operation, maintenance and use of every piece of infrastructure being analyzed. More specifically, to perform a process-based

LCA in the level of interest of this thesis, it requires a huge amount of information on the extraction, transportation and assembly of every material used on each site, as well as the recycling or disposal of every single infrastructure project at the end of its life.

This method allows reaching a high level of environmental detail if the analysis focuses on single products such as specific material, project, or civil infrastructure (Beylot, Corrado, & Sala, 2019). However, many obstacles arise during its application that can restrict the evaluation of impacts. First, owing to the circular economy adopted in the quest of the environmental value, this method requires many assumptions and decisions to define the goal and scope of the analysis, which can create limitations on the number of components (materials, processes or flows), and sub emissions (Ayres, 1995; Beylot et al., 2019). This makes process-based LCA a very complicated and time-consuming process (Beylot et al., 2019).

Second, this method requires extensive primary data from each component within the civil infrastructure. Therefore, if there is not enough or credible data, all the input and output elements increase the level of complexity and uncertainty, making the method to lose its utility (Ayres, 1995; Beylot et al., 2019; Trunzo et al., 2019). The data required for this method comes from both public databases and customers. The former provides the inventory information of specific materials, energy, and processes (Finkbeiner et al., 2006; Lee & Inaba, 2004). Meanwhile, the customer data is collected from surveys and manufacture's assumptions that provide insight into a specific product (Finkbeiner et al., 2006; Lee & Inaba, 2004). Because this data comes from customer's assumptions, it is often "proprietary, unpublished or confidential", and therefore unable to be verified with other credible databases (Ayres, 1995, p. 8). The bigger the system analysis, the more data comes from multiple sources, making the result prone to overstatement (Ayres, 1995). Third, the process-based LCA ignores real human behaviour, and as a consequence, the economic market and activities related to global commerce (Gutowski, 2018). This thesis is trying to reduce the uncertainty related with the human behaviour, by studying the "customers" individually as part of the social value.

Based on the above, the process-based LCA method is appropriate for detail analysis of specific, single and small-scale infrastructure projects where socio-economic factors are not required to be evaluated. The results and evaluation obtained from this method are intended for engineer's and client's analysis purposes. Table 2.8 depicts real-world infrastructure projects which applied process-based LCA method and supports this hypothesis.

Table 2.8 Process-based LCA examples

Case	Description	Effectiveness
“Railway Bridge, Banafjäl Bridge case.” (Du, 2012)	• The process-based LCA is a comprehensive tool for quantifying environmental impacts. • Lack of data of specific materials. Although there are commercial databases available, is always preferable industries’ data rather than average estimation. • Based on the results, designers should avoid choosing structural components that need more maintenance.	The process-based LCA is useful in this type of civil infrastructure. Its results validate that this method can evaluate the ecological effects and provide valuable insight for engineers (as decision making) for future project considerations. However, to retain its credibility, it is necessary accurate data of each material.
“Road Construction and Use” (Trunzo et al., 2019)	The analysis was applied in an Italian provincial road. However, social and economic criteria were not considered to obtain a comprehensive sustainability evaluation.	The scope of this evaluation includes the assessment of road usage, which can consist of how many people use it, and the purpose of using it (connections and economy). In other words, economic activities information is required to estimate the ecological effects of road usage, and unfortunately, process-based LCA cannot provide this information.
“Warm Mix Asphalt (WMA) and Hot Mix Asphalt (HMA) Pavement. (Ma, Zhang, Zhao, & Wu, 2019)	This case was developed in China, where asphalt data was getting from different sources, estimating with higher uncertainty	The process-based LCA is not appropriate if precise information of raw materials is missing, and its reliability can be compromised if information comes from different open data sources.
“Green Infrastructure Practices” (Flynn & Traver, 2011)	• The method supports decision making • They were evaluated separately to get a high effect approach. However, the analysis should be expanded with a socio-economic evaluation to estimate the impacts in the implementation of these infrastructures	Process-based LCA encourages decision making but is not suitable to be applied in green infrastructure practices in the overall context. Individual evaluation of each technology is required to provide a better assessment. Further, socio-economic information is needed to evaluate the impacts related to its implementation.
“Testing whole Building.” (Simonen, 2015)	• The evaluation of a specific building can provide a better approach. • The effectiveness of the method will increase by using quality data in the assessment.	The process-based LCA method is suitable for isolate building assessment, and its performance will increase if quality data is used.

Decision-makers should perform environmental assessments on their existing infrastructure and ahead of the design of new infrastructure when evaluating alternatives to benefit the society. The decision-makers should be informed on the environmental impacts of an investment in a particular type of infrastructure or in a specified sector/industry. To address a scope of such scale, process-base LCA requires significant time and information resources. Detailed information regarding all processes involved in each life cycle of the operation in question is needed, and often this would not be available consistently over an entire region, industry or infrastructure type (Beylot, Corrado & Sala, 2019). This challenge was one of the main reasons that process-based method was not used in this thesis, since the scope of the thesis is to estimate the environmental impact of an entire region (United Kingdom) and infrastructure type/sector (Transport, Energy, Water, Waste and Communication). Due to the level of detail required, process-based LCAs have less uncertainty than other types of environmental impact assessment methods. Therefore, process-based LCA is interesting and reliable sources of information for appropriately scaled infrastructure development and policy making, and comparison of alternatives (Finkbeiner, Wiedemann & Saur, 1998). However, when looking at civil infrastructure on a national scale, as this thesis does, a process-based LCA becomes a difficult tool to use. Process-based assessment cannot be used in this thesis for similar reasons that cost-benefit analysis cannot be used (see previous chapter).

2.9.4 EXIOBASE Input Output Tables

Environmentally Extended Multiregional Input Output (EE MRIO) tables are tools for analyzing the environmental impact of economic activities, including infrastructure, and their interdependencies across multiple sectors (Stadler et al., 2018), as this thesis does. The EXIOBASE 3 is an EE MRIO database that combines estimates of the amount of products supplied and used within different sectors of the economy (Input – Output Tables) with estimates for aggregated emissions to the environment. EXIOBASE is a "global multi-regional input−output database" with a high level of sector disaggregation and founded in the economy (Wood et al., 2015, p. 2). It offers new clarity on the links between international commerce, environmental impact, and consumption with historical data from economic operations to determine the addition or removal of value along a given supply chain (Dennehy, 2018). This database has been developed in three different versions through specific projects, EXIOPOL project developed EXIOBASE1 (2000), CREEA project created EXIOBASE2 (2007), while DESIRE project built the last version EXIOBASE3 (1995-2011) (Tukker, Giljum, & Wood, 2018; Wood et al., 2015). EXIOBASE combines two forms analysis: monetary (euros) and supply-use (tonnes, terajoules, among others) by using a range of statistical models (Merciai & Schmidt, 2017; Wood et al., 2015). EE MRIO tables method combines elements of the hybrid LCA with parametric LCA methods, since it is based on economic factors and a range of statistical models. An EE MRIO table requires the corresponding input-output table for estimating environmental impacts related to the consumption of products (van Roekel, Walker, & Graveland, 2017; Tukker et al., 2018; Wood et al., 2015).

EXIOBASE 3 describes the environmental impacts of the complex global and cross-sectoral relationships, and can therefore inform policy-makers regarding the use of resources and the discharge of emissions to the environment (Stadler et al., 2018). EXIOBASE 3 captures both material and service exchanges between sectors (e.g. infrastructure). This tool is important for national and regional decision-makers due its high level of aggregation and environmental impacts. Therefore, EXIOBASE 3 allows decision-makers to take system-wide decisions on large scale.

EXIOBASE is structured analytically from different up to date databases that are necessary for macro-level policy (Merciai & Schmidt, 2017; Stadler et al., 2018; Thorpe, 2019). Some of these databases come from the industries' technologies, product sales assumptions, national input-output tables and statistics (Merciai & Schmidt, 2017; Stadler et al., 2018; Thorpe, 2019; Walker, Zult, Hoekstra, van der Berg, & Dingena, n.d.; Wood et al., 2015). Further, these databases are related to indicators that are monitoring progress under Sustainable Development Goals (SDG) and allow the modelling of consumer behaviour in different scenarios (Thorpe, 2019). EXIOBASE is appropriate to track the overall impact of the entire construction industry, and it is suitable for governments, policymakers and international agencies which let them lead strategies that address the socio-economic and ecological effects of civil infrastructure projects.

EXIOBASE expresses a high consistency level of the macroeconomic sector and international data sources by allowing the estimation of emissions factors associated with specific consumption activities within and outside of any particular country (Stadler et al., 2018; Tukker et al., 2018; Wood et al., 2015). This method considers several socio-economic variables which facilitate the footprint estimations towards a circular economy analysis of a specific sector within globalisation and international commerce perspective (Tukker et al., 2018; Walker et al., n.d.). One advantage of this approach is the detailed "environmental extensions" or "stressors" such as carbon emissions and other non-economic effects within the economic activities (Walker et al., n.d., p. 14). However, this does not mean that EXIOBASE provides more accurate results than process-based LCA, as it also has limitations (Perkins & Suh, 2019; Yang, Heijungs, & Brandão, 2017).

First, the last version of this technique proposes to cover global data, but only detailed information from 43 countries of 195 in total are included, grouping the rest of the countries in five world regions making the method run the risk of overestimation (Wood et al., 2015; Yang et al., 2017). Second, its time series is built for 1995–2011, thus opening up several analytical options, including time series analysis and structural decompositions restricted between these years (Wood et al., 2015). Third, the classification of emissions requires assumptions in which several elementary flows are not reported in the environmental extensions (Beylot et al., 2019). This prevents quantifying the entirety of ecological impacts for several impact categories and makes clear that this method manages a low level of detail or rough sector resolution (Beylot et al., 2019; Suh & Nakamura, 2007). This condition may influence the assessment results and demand a sensitivity analysis (Beylot et al., 2019). Table 2.9 presents the case of infrastructure projects that applied EXIOBASE method and supports hypotheses II.

Table 2.9 EXIOBASE examples

Case	Description	Effectiveness
"Environmental impacts of household consumption in Europe." (Castellani, Beylot, & Sala, 2019)	• EXIOBASE limits the analysis of the product's role and elementary flows. • Occasionally, the vocabulary used in the database does not allow for a clear distinction between production activities and product-related services.	EXIOBASE is not appropriate to assess individual civil infrastructure project because of its macro-scale data resolution, limiting the specific components' analysis.
"Corporate and product environmental footprints." (Kjaer et al., 2015)	• Economic data is easy to use and encourage decision making within acceptable time and cost. • Support policymaker's investment decisions. • This method disaggregates relevant sectors and hybridising with process-based LCA data can get more significant results.	This method could be applied to a specific material if the up to date process-based LCA data is integrated with EXIOBASE. Also, it is suitable to provide easier and faster results for government and policymakers, in the development of more sustainable infrastructures.
"Impacts on land use embodied in trade." (Bjelle et al., 2020)	• Asia and Africa's regions are not represented in detail (Bjelle et al., 2020). • Higher sectoral disaggregation is required for covering the socio-economic and environmental extensions (Bjelle et al., 2020).	Even though EXIOBASE includes a significance resolution and granularity information; there are many countries and region information that is not detail-covered, making it not applicable to the assessment.

As it was discussed in the previous chapter, the economic value of national civil infrastructure, such as transport, water, waste, energy and communication infrastructure facilitates economic activity and is embedded in the foundation of all sectors of the UK's or any county's economy. Combing the environmental impact information provided in EXIOBASE 3 tables with the corresponding input-output tables, decision-makers can choose to invest in civil infrastructure that supports positive environmental outcomes, or adapt infrastructure to facilitate environmental compliance in a sector that is causing negative externalities (Beylot, Corrado & Sala, 2019). Therefore, EXIOBASE 3 is a very powerful tool for decision-makers looking to maximize environmental value. However, EXIOBASE 3 cannot provide decision-makers with a level of detail that can determine whether one single infrastructure project is better than another in terms of environmental value. If someone wants to estimate the environmental value of a single infrastructure project using the EXIOBASE 3, he/she should do a very difficult top-down analysis.

2.9.5 Tools for Assessing the Environmental Value of Transport infrastructure

The aim of this section is to present and evaluate the emissions measuring tools for infrastructure projects. The tools presented are focusing on transportation infrastructure. First principal tools, such as SimaPro software, GaBi software, Brightway2 LCA framework, OpenLCA tool and Umberto software are not summarized here. These tools allow for LCA assessment of any product or process and require first principal life cycle analysis expertise and more extensive data collection. The tools focusing on transport infrastructure are tailored to transportation infrastructure assessment and the use by transportation engineers/planners. The direct application of first principal tools to transport sector is challenging, since their usage requires a detailed knowledge and understanding of the engineering design of transport infrastructure. Even if the user has the detailed design knowledge required, the usage of these tools requires a lot of time to calculate the embodied emissions, as the user would have to deconstruct the design process to fundamental processes. Transportation LCA tools are specialized tools developed by applied scientists and engineers.

Transportation LCA tools are designed to practically calculate practically the embodied emissions of transit and transport infrastructure, and include built in assumptions based on the experience and training datasets of the developers.

Table 2.10 provides a summary of the tools discussed and lists the locations that the tools were developed and the entry format of each tool. Most of the tools are developed in North America and Europe. Most of the tools are spreadsheets that use environmental indicators (e.g. GHG indicators) to calculate the emissions of infrastructures based on energy consumption of materials, equipment, services and design. Another reason that spreadsheets are common as an entry format is that the analysis is mainly based on linear algebra, meaning that there are not any complicated equations that cannot be represented in spreadsheets.

The background database used by each tool is often tool-specific. For example, both RSSB Rail Carbon Tool and Atkins' Carbon Critical Knowledgebase use the tool-specific database developed by Atkins. At this point it should be noted that the UK tools were cross-developed using elements and databases of existing tools and databases. Databases, such as the Bath Inventory of Carbon and Energy, the AggRegain Carbon Dioxide (CO2) Emissions, the database of the British Department for Environment, the database of the Food and Rural Affairs (Defra), the database of the British Cement Association etc. were individually developed by different organization, but all used by new tools. This way the development of these new tools was cheaper as they were able to rely on existing background databased.

Table 2.10 Transportation LCA tools location, entry format and database

Name of Tool	Location	Entry format	Background Databases
APTA Transit Emissions Quantifier Tool	USA	Spreadsheet	National Transit Database and Emissions & Generation Resource Integrated Database (eGRID)
asPECT (Asphalt Pavement Embodied Carbon Tool)	UK	Spreadsheet	asPECT's database (developed for the tool)
Athena's Eco Calculator	North America	Spreadsheet	Athena Sustainable Materials Institute database and the US Life Cycle Inventory Database
Atkins' Carbon Critical Knowledgebase	Worldwide	Web-based tool	Includes an extensive library of version-controlled operational and embodied GHG factor information developed by Atkins
'ERIC' Carbon Planning Tool	UK	Spreadsheet	Bath Inventory of Carbon and Energy, AggRegain Carbon Dioxide (CO2) Emissions, British Department for Environment, Food and Rural Affairs (Defra), British Cement Association
FHWA Infrastructure Carbon Estimator	USA	Spreadsheet	Life-cycle Environmental Inventory of Passenger Transportation in the United States (Chester, 2008) Office of Highway Policy Information. Highway Statistics (2012)
GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model	USA	Spreadsheet	U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy database
Highways England Carbon Tool	UK	Spreadsheet	Similar with Carbon Planning Tool's database by Environmental Agency (UK)
Klimatkalkyl Tool (Geokalkyl Tool for optimization)	Sweden	3D GIS Tool using Spreadsheet	Swedish Transport Administration's measurement database for environmental impact (TMO)
LIFE HUELLAS	Spain	Spreadsheet	EPA- TRACI (Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts)
RSSB Rail Carbon Tool	UK	Web-based tool	Includes an extensive library of version-controlled operational and embodied GHG factor information developed by Atkins
SULTAN (**SU**stainab**L**e **T**r**AN**sport) Illustrative Scenarios Tool	EU	Spreadsheet	SimaPro inventories and Inventory of GHG and energy database (Bath University)
Transportation LCA	USA	Web-based tool	transportation LCA database (tLCAdb) by Mikhail Chester, Arpad Horvath, and colleagues.
VICE 2.0: Vehicle and Infrastructure Cash-Flow Evaluation Model	USA	Spreadsheet	Database of State Incentives for Renewables & Efficiency (DSIRE) and data by original equipment manufacturers

Of the fourteen summarized tools, nine consider cradle to grave life cycle stages (this includes, material extraction, construction, operation, maintenance and end of life). Four focus on cradle to construction. The tools estimating emissions up to the construction stage were either developed by the private sector or by organization interested in construction. Finally, SULTAN Illustrative Scenarios Tool estimates the emissions of specific transport sectors in a country or an area, it was developed as part of a research project focused on possible impacts of policy on transport in the EU.

Eleven of the tools consider the embodied emissions of transport infrastructure. The three transportation LCA tools which do not consider the embodied emissions of transport infrastructure are focusing on operational emissions produced by the vehicles, since they were developed by agents interested in transport operation rather in transport infrastructure construction. Only two tools calculate the emissions for both vehicles and infrastructure, but both tools use data with high uncertainty. Transportation LCA is based on academic data focused on California and VICE 2.0 uses broad empirical data.

Ten tools estimate the emissions for both bus and rail modes. The two tools estimating only the emission of rail and the two tools estimating only the emission of bus, were developed to be used by rail or automotive sectors, respectively. To conclude there are only 14 tools estimating the emissions of transport infrastructure, and only one, the SULTAN Illustrative Scenarios Tool, that studies the emissions of transport infrastructure in total (as a sector). This highlights the need to develop more tools for analysing infrastructure as sectors, as this thesis do.

2.9.6 Critical Analysis of Methodologies and Tools

Both LCA and EXIOBASE tables captures the environmental value of civil infrastructure in different ways. Based on the definition of environmental value by Chan, environmental value is defined as the intrinsic, instrumental and relational value found within nature (Chan et al., 2016). In other words, environmental value is a multifaceted concept, and there is benefit in analyzing the strengths and weaknesses of both LCA and EXIOBASE tables for each facet - instrumental, intrinsic and relational- of environmental value individually to gain a better picture of the overall results, as they relate to civil infrastructure.

At first the environmental value will be analysed by using the environmental value definition of Chan nature (Chan et al., 2016), but this analysis is limited as it remains confined to the three environmental value types that are described above. Since there are other ways of capturing environmental value, there will be further analysis below based on other environmental value definitions in an attempt to cover different types of environmental value of civil infrastructure.

Neither method can be said to be better at capturing nature's intrinsic value (Chan et al., 2016), because it depends on the goals and the scale of environmental interventions. The intrinsic value of nature can be harmed by climate change, terrestrial, marine and freshwater eutrophication, land use, biodiversity, minerals, metals and fossil resource use and water depletion, which can all be modeled using either process-based LCA or EXIOBASE 3 (Beylot, Corrado & Sala, 2019). To make the biggest impact, emission reduction measures could be modeled in EXIOBASE 3 to inform national or sectoral policy. Smaller, but still important, impacts can be made by designing a civil infrastructure project to reduce embodied emissions over its life cycle using an LCA (Olugbenga, Kalyviotis & Saxe, 2019a). Therefore, the broad scope of EE MRIO tables captures the environmental value as defined in this thesis better than process-based LCA, because the scale of nature's intrinsic value is similarly extensive.

Most of the environmental impacts assessed by EXIOBASE 3 and LCA are related to the instrumental value of the environment. LCAs are useful in identifying whether investment in a specific project or product will affect any of the current uses of ecosystem goods (Daily, 1997). However, when assessed in isolation, an infrastructure project may not cause substantial environmental impact, but several similar projects in aggregate could result in larger consequences. For this reason, EE MRIO tables are more important in the protection of the environment's instrumental value. Governments need to control the shared resources amongst their citizens and industries to ensure that people are served fairly by civil infrastructure, industry is supported economically, and the environmental value of the area is protected (Gómez-Baggethun, Ruiz-Pérez, 2011). These types of decisions can be made with support from EXIOBASE 3.

Neither process-based LCA or EXIOBASE 3 captures the relational value of the environment. People, cultures and societies have different relationships with many aspects of nature (Chan et al., 2016). These are all things that it is challenging to be quantified, and cannot be measured by either process-based LCAs or EXIOBASE 3. Civil infrastructure can either contribute or detract from these relationships. Placed in an inappropriate location, infrastructure can permanently scar culturally significant land or damage political relationships (Dona & Singh, 2017). To capture the relational value the author of this thesis developed a quantitative survey to ask people their opinion.

Apart from Chan's approach, the process-based LCA and EXIOBASE are both methods used to quantify environmental footprints with standard mathematical functions (Crawford et al., 2018). Nevertheless, the emphasis of both will vary depending on the goal, assumptions, interest, and components such as resolution granularity, and unit measurement (Beylot et al., 2019; Castellani et al., 2019). Table 2.11 shows the most remarkable differences between both approaches.

Table 2.11 Process-based LCA VS EXIOBASE

Process-based LCA	EXIOBASE
Simple methodology (Ayres, 1995)	High level of sector disaggregation (Wood et al., 2015, p. 2)
Time and effort-consume, but a high level of environmental detail of single products (Beylot et al., 2019)	Environment accounts, micro and macro-scale scenarios (Merciai & Schmidt, 2017).
Limited to the areas of consumption and materials (Castellani et al., 2019)	Many products and consumption areas are included in the same database (EXIOBASE Consortium, 2015).
• Open database source (Finkbeiner et al., 2006) • Private sources from industries (sometimes confidential) (Finkbeiner et al., 2006) • No socio-economic data (Gutowski, 2018)	• Input-Output Table (MR-IOT); monetary (Beylot et al., 2019; Tukker et al., 2018) • Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT); supply-use (Beylot et al., 2019; Tukker et al., 2018) • Process-based LCA data; Coefficients and statistics(Beylot et al., 2019; Tukker et al., 2018)

Based on the results of the literature review analysed before, the author of this thesis considers that process-based LCA is appropriate for those small-scale physical civil infrastructures without its functionality analysis, and within a limit and restricted boundaries. Further, this process is appropriate if time and effort are invested in finding the real and proper data (not average) of each element within the system, including the information provided by the industry manufacturers to guarantee the accurate result of the environmental assessment of infrastructure. This method is oriented for engineers and decision-makers at mid-level. Regarding EXIOBASE, the author of this thesis considers it suitable for macro-scale civil infrastructure assessment in an overall context, including physical characteristics, components, and social and economic activities within and outside of the infrastructure geographical location. EXIOBASE is oriented for government authorities and international agencies whose make decisions at high-level. However, both methods should be combined if there is the case where small-scale civil infrastructure or specific material must be evaluated to estimate environmental impacts with socio-economic elements. The combination of both will capture missing areas of consumption and provide better and understandable results.

2.9.7 Conclusion

Environmental value is a complex matter that affects all countries, industries and economic activities. It encapsulates the intrinsic, instrumental and relational value of nature. Both process-based LCA and EE MRIO tables are useful tools in evaluating environmental impacts at different scales. Process-based LCA is a useful tool when making specific decisions about products or projects. However, environmental issues require large scale interventions, and therefore EXIOBASE 3 is a better resource for policy makers to make important changes and preserve environmental value in their home countries and in the countries with whom they are trading.

Neither method of analysis captures the irreversible change to the environment that is made when civil infrastructure is built. Civil infrastructure development encourages further development and therefore current decisions impact future decisions, which is not possible to accurately model (Saxe et al., 2020). The impacts on society, humans, non-human life, and resources in the near and farther future should be better captured in infrastructure and environmental decision-making. Social considerations have been added to EXIOBASE 3, but the adequacy of this feature in addressing social issues is yet to be seen (Stadler et al., 2018). This thesis covers partly this gap. Everyone has a responsibility to make environmentally conscious decisions. This includes the final users when choosing products, engineers when designing civil infrastructure, asset owners when choosing what and where to build, and most importantly governments. Policy makers should understand and use EE MRIOs to inform large scale environmental decisions that will protect the natural ecosystems in which we live, and society itself. The rest of the stakeholders should be asked to contribute to this process.

2.10 Summing up the disciplinary context

There is ongoing debate about the value of the benefits of infrastructure systems (specifically those of energy, water and wastewater, transport, waste, and communications) and how to prioritize infrastructure investments to encompass considerations of social, economic and environmental wellbeing. The use of the term ‘infrastructure system’ is related to interdependencies. Infrastructure systems operating in different countries and cities are interrelated in different ways, but all have a strong relationship to ‘transport’ – there is a cost and a utility associated with movement. Infrastructure systems are ultimately created to serve individuals, who place a value on them. In order to explore all forms of value realisation – what is commonly termed a business model – the relationship between an individual and the transport system needs to be established. The hypothesis being tested in this thesis is that it is possible to identify the full range of value for transport infrastructure, including social, economic and environmental wellbeing, and to establish the interdependencies with the other four infrastructure sectors in the UK, and hence to establish robust alternative business models for transport infrastructure interdependencies management.

Based on the literature of the business model, the three main components of them are: [1] marketing imperative, [2] internal and external value creation and [3] growth engine. The three main components of the business model are combined and modelled in a business model with one or more of the following: pricing model, revenue model, channel model (e.g. clicks and mortar – a type of business model that has both online and offline operations), commerce process model (method of transaction), market segment (targeting of customers, etc.), value chain structure (the firm's operations, etc.), organisational form, value proposition (e.g. whether to compete on quality or price) as source of differentiation, position in value network (identification of competitors, complementors, etc.). The thesis focuses on all of the positive consequences and all of the negative consequences – the service provided (with all its benefits) and the (direct) costs and other consequences (indirect costs, e.g. GHG emissions) of that service provision. and on how they interact, rather than on focussing on the aforementioned sophisticated considerations of how the business models would be used strategically in any particular market situation. This is because the thesis focuses on innovative infrastructure business models which aim to capture a far wider range of values (e.g. types of social and environmental value) than are captured by typical business models currently used – in transport, there is a criticism that business models generally only focus on cost and time, for example.

<u>Components of a business model (value equation) and its implementation (marketing and growth)</u>

[1] Marketing is a necessary component of implementation of business models, since it is part of the implementation strategy

[2] "Value" based on Bonnedahl & Eriksson work (shareholder vs stakeholder capitalism) and includes consideration of economic value, environmental value and social value.

- Economic value is as it is defined by linear economy, meaning GDP as the only measure of economic progress (input-output tables). GDP is a linear index, meaning it can be analysed using linear regression and principal component analyses. GDP is limited as an index: GDP does not take into account the many 'costs to society' (or externalities). These externalities have been categorised as social and environmental, to align the value definitions with the definitions coming from the circular economy. Other indexes than GDP are more complicated as the partly include externalities and cannot easily be deconstructed.

- To study the environmental value (one set of externalities) the research used the EXIOBASE. EXIOBASE has a clear environmental and resource focus and is based on the input-output tables. The main reason this databased was used is that it has a connection with the economic value (GDP) and once again does not consider any social externalities, allowing the research to have clear boundaries between the three types of values.

- To study the social value (another set of externalities), i.e. how people see things regardless of the economic and the environmental value, the researcher asked society itself (i.e. representative cohorts of individuals). The main reason for this is that was there was no study connecting input-output tables with social value. Social value is the most complicated aspect to establish rigorously as it is difficult to separate from the environmental and the economic value – i.e. social value is affected by environmental and economic factors. The questionnaire study therefore aimed to capture part of the economic value (cost and industrial benefits in the questionnaire) and part of the environmental value. Thus the three types of values are individually investigated, although some elements of social value are compared with elements of environmental or economic value. This means that the study of social value includes some elements of economic and environmental value; when they are summed then this provides a complete picture, so it is not a concern.

[3] The growth engine – another necessary component of implementation of business models – focuses on sources of resources (e.g. investors, partnerships, etc.) who are interested in the social and environmental value too, and in indirect value creation. The stakeholders were taken from the literature (Bryson, 2017) and they were divided based on their interest in environmental and social value.

<u>How research question and objectives were answered</u>

How can infrastructure business models enable key infrastructure stakeholders to understand better the way that transport infrastructure is valued by those who use it and make better informed decisions about infrastructure interdependencies management, and thereby enable infrastructure systems and the services they deliver to flourish and infrastructure performance to be enhanced?

Objective 1: Redefine infrastructure value in terms of the three pillars of sustainability and enable it to escape from its mainstream economic concept. To do so, a new approach should be introduced by identifying and exploiting the social and

environmental characteristics of value.
How it was done: This is done by considering social and environmental factors (systemic thinking) when investigating the value of the business models rather than just economic indexes (linear thinking). Environmental value was derived from existing datasets, but social value could not be, and therefore an ambitious social value survey was carried out.

Objective 2: To explore exemplar infrastructure (inter)dependencies when creating and capturing value.
How it was done: Dependencies and interdependencies were studied inductively by looking at the correlation between each type of value for the different types of infrastructures. Correlation between two variables does not necessarily imply causality (Field, 2009, p. 619-620), i.e. the two variables can certainly be related with causality, but may not be. Since the correlations do not necessarily imply dependency (Field, 2009, p. 619-620), this was confirmed by the theory. In all other cases, a causal relationship (interdependence) between two correlated variables was verified with a rational assumption. The Pearson correlation coefficient approach was used for this study.

Objective 3: To develop a suite of alternative new value-optimized infrastructure business models focusing on the value judgements of the users of transport infrastructure, and the impacts on transport infrastructure systems' value by other four 'economic infrastructures', by considering them as key stakeholders.
How it was done: The thesis used the interactions between the main elements of a business model coming from the theory. In addition it considered the social and environmental value (Afuah & Tucci, 2001; Amit & Zott, 2001; Linder, 2004; Bryson, 2017).

Chapter 3 The concept of value

Business models, as discussed, have their roots in value. The challenge is how to study value as a single system when it is a sum of different types of values: economic, environmental and social. The two main streams to collect data are quantitative and qualitative (Ghauri & Grønhaug, 2010, p. 103). The data collection method derives from ontological and epistemological positions (Long et al., 2000, p. 191). Quantitative collection "*generates or uses numerical data*" (Saunders et al., 2009, p. 151), and considers the underresearched phenomenon as a single system (Morgan & Smircich, 1980, p. 498). In contrast qualitative collection aims to explain how the under-researched phenomenon is sociologically understood (Denzin & Lincoln, 2003; Berg, 2001, p. 7; Malterud, 2001). The quantitative method is founded on any type of data collection technique (e.g., documents) that generates numerical findings (Saunders et al., 2009, p. 151). Regarding value, qualitative approaches may face the problem of the "*double hermeneutic*" (Myers, 2009, p.39), especially since value is overlapping. "*Double hermeneutics*" is the theory that social sciences have a two-way relationship between the object of study (society) and the researcher (Giddens, 1987, p.20-21), since the object of study (society) can think and make choices based on the findings of the social sciences. On the other hand, in the natural sciences the object of study cannot think or make choices based on the findings. "*Double hermeneutics*" may be more if it is considered that some economists refer to the social part of transport infrastructure value as "*social overhead capital*" (Button, 1996, p.148; Bruinsma et al., 1992, p.3-12; Lakshmanan, 1989, p.243; Hirschman, 1958, p.83), since transport infrastructure is the type of good/service needed for economic growth. In this research the value is investigated as a single system (business model) using numerical data, meaning that quantitative collection of data will be used and at the same time to avoid the "*double hermeneutic*" initially the economic, social and environmental value will be studied separately and then will be placed in the same business model.

To observe or to measure quantitatively environmental and social value is challenging (Frischmann, 2012, p.6), since it is observed that pricing systems are "*not based primarily on the user identity or activity*" (Frischmann, 2012, p.6 & p.121), by disabling value-based price discrimination (Frischmann, 2012, p.121-122). By value based price discrimination, it is meant pricing based on the ability and willingness of the final user to pay, and not based on cost (Frischmann, 2012, p.14). This research will try to avoid existing (economic) pricing systems to disable value-based price discrimination.

In view of the aforementioned, the author mainly undertook quantitative and some qualitative analysis through case study analysis, focusing on the case of the United Kingdom. Case study analysis is an empirical inquiry that can be used when the relations between the cause and effect are blurred (Herling et al., 2000; Yin, 2002;

Yin, 1989). Case studies have been used in the past for studying Transport, Energy, Waste, Communication and Water interdependencies (Bijker et al., 1987). Given that the study and development of the subject was based on one country, automatically this country constituted the basic case study for the research and guided the study of the primary research data of economic, social and environmental value. Material of Chapter 3 has been published by the author in international journals (Kalyviotis et al., 2018a,b,c) and conferences (Kalyviotis et al., 2017a,b,c).

3.1 Economic value

As outlined in the previous section, transport is an important infrastructure. Being an integral part of the United Kingdom economy, transport infrastructure was critically affected by the global economic downturn. Despite being an established and longstanding type of infrastructure, it is neither immune to these major events nor technological developments. Based on this information and the return on investment interests, this study aims to perform a financial analysis of transport infrastructure to assess its attractiveness for investments.

The role of infrastructure interdependencies is challenging due to the complexity and dynamic environment of all infrastructures and vital for critical infrastructure systems. There is an ongoing debate about the value of the benefits of the five national infrastructure sectors (energy, water, transport, waste and communication) in the UK and how they interact in terms of social, economic and environmental wellbeing. This study focuses only on one of the three aforementioned values, the economic value. The hypothesis tested is whether the transport sector is economically complemented by the energy, water, waste and communication sector. The author uses the process analysis "*networks and cohorts*", an analysis that uses tables, diagrams, models and networks of interactions along with organizational linkages. Of interest for this study in particular is the grand total of all revenues which create incomes into other sectors and creates dependencies. The latest World Input-Output Database were the primary source of information. The theory underpinning the hypothesis was verified and a model was developed based on the historical data by the value created from the other critical sectors to transport.

The purpose of this chapter is to assess the attractiveness of transport as an investment object and compare it with other infrastructures in the United Kingdom. In order to achieve this, the methodology is two-fold: in a first step, the economic performance of transport infrastructure is assessed, measured and critically analysed by means of value created in the most recent years. The second step is elaborated by comparing investments in transport instead of other types of infrastructures.

3.1.1 Introduction

"*The system of infrastructure networks: Energy, Water, Transport, Waste, Communication, which supports crucial services, faces a multitude of challenges*" (iBUILD, 2017). There is an ongoing debate about the value of the benefits of infrastructures and how to prioritize infrastructure investments in the United Kingdom considering social, economic and environmental wellbeing and considering energy, water, transport, waste, communication (Hall et al., 2016, p.10; iBUILD, 2017; Liveable Cities, 2017; National Infrastructure Plan, 2013). In the framework of this discussion, the development of new business models is required to understand infrastructure financing, valuation and interdependencies under a range of possible futures.

3.1.2 Theoretical methodology

The interdependencies between transport infrastructure and production are very complex. The delimitations of this study include only economic value in terms of growth and no other types of value. The input-output tables are commonly used for tracing infrastructure interdependence through economic value. "*By examining individual cells, we can see how much of this is caused by disruption to other types of infrastructure*" (Rose, 2005, p.4). Economic input-output tables can be found at the Office for National Statistics (2015) where the five main infrastructure sectors are divided in their activities, which add value, so the economic value interdependencies can be studied. The value activities are already divided, as follows:

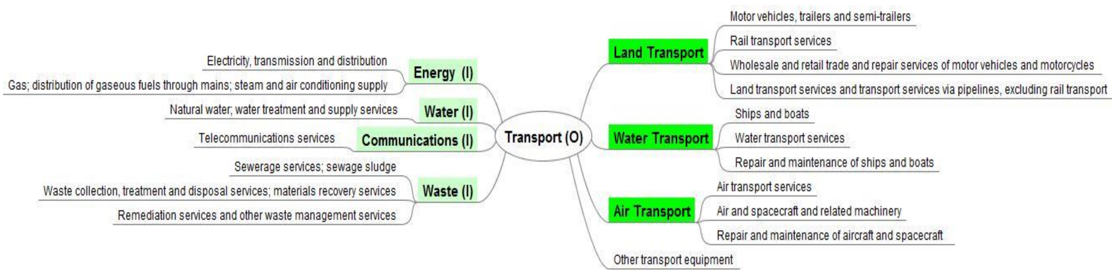


Figure 3.1 The value activities of national infrastructure sectors (Office for National Statistics, 2015)

Table 3.1 The value activities of the national infrastructure sectors

<table>
<tr><th colspan="2">Inputs</th><th colspan="3">Outputs</th></tr>
<tr><td>Electricity, transmission and distribution</td><td rowspan="3">Energy</td><td rowspan="11">Transport</td><td rowspan="4">Land Transport</td><td>Motor vehicles, trailers and semi-trailers</td></tr>
<tr><td rowspan="2">Gas; distribution of gaseous fuels through mains; steam and air conditioning supply</td><td>Rail transport services</td></tr>
<tr><td>Wholesale trade services, except of motor vehicles and motorcycles</td></tr>
<tr><td>Natural water; water treatment and supply services</td><td>Water</td><td>Land transport services and transport services via pipelines, excluding rail transport</td></tr>
<tr><td>Telecommunications services</td><td>Communications</td><td rowspan="3">Water Transport</td><td>Ships and boats</td></tr>
<tr><td>Sewerage services; sewage sludge</td><td rowspan="6">Waste</td><td>Water transport services</td></tr>
<tr><td rowspan="3">Waste collection, treatment and disposal services; materials recovery services</td><td>Repair and maintenance of ships and boats</td></tr>
<tr><td rowspan="3">Air Transport</td><td>Air transport services</td></tr>
<tr><td>Air and spacecraft* and related machinery</td></tr>
<tr><td rowspan="2">Remediation services and other waste management services</td><td>Repair and maintenance of aircraft and spacecraft</td></tr>
<tr><td colspan="2">Other transport equipment</td></tr>
</table>

*Spacecraft may not be relevant and counted as air, but the IOG could not get divided to air and spacecraft

"*In 2008 total contribution of the five national infrastructure sectors to Gross Value Added (GVA) in the U.K. economy was 9.2%,*" with Transport having the largest contribution followed by Communication and then Energy (Hall et al., 2016, p.244). Hall et al. (2016) consider as transport only the traditional transport services (economic approach). This research differs since it is from the engineering point of view. In this case the transport infrastructure sector considered some input-output groups (see Figure 3.1 and Table 3.1) which according to the economic approach belong to the manufacturing sector (e.g. motor vehicles, trailers and semi-trailers, repair services etc.). This happens because, as discussed in Chapter 2, when it comes to civil engineering, the transport sector includes the transport means as part of the infrastructure. Energy and Transport interdependencies in the United Kingdom have been quantified by Tran et al. (2016, p. 227-240). They conclude that, Energy and Transport infrastructure are complementary as any change in the Energy-Transport relationship will require at least new fuelling infrastructures and "*even aggressive energy demand reduction*" of energy "*mean that the requirement for electricity infrastructure will be at least as high as present*" (Tran et al., 2016, p. 230). Furthermore, Tapio et al. (2007) compared Energy and Transport with growth in GDP from 1970 to 2000 in the EU15 countries. Although they conclude that, Transport and Energy have contrary behaviour regarding economic growth (Tapio et al., 2007, p.446), if their interactions between Transport with Energy compare, it can be noticed that in terms of GDP, Energy use in Transport increases as the total passenger travel distance per capita increases, almost proportionally, over the years (Tapio et al., 2007, p.434). This happened to every single country of the EU15 countries (including the United Kingdom), so it can be safely concluded that Energy and Transport are complements. In this study, Waste and Transport interdependencies are studied in terms of economic value considering wastewater and solid waste, but not air pollution (e.g. carbon dioxide emissions), as the Office for National Statistics (2015) does not consider air pollution as an economic factor of the Waste industry. Air pollution is considered by the author as an environmental type of value and it is not studied following the delimitations of this study. Regarding solid waste, "*Changes in waste disposal patterns will have an impact on transport infrastructure capacity utilisation, but as waste transport only forms a small proposition of total freight traffic these impacts are unlikely to be significant at a national scale*" (Hall et al., 2016, p.110). On the other hand the sewerage system is "*consisting of a piped system collecting and transporting wastewater to treatment plants*" (Wong, 2006, p.213). Apart from other requirements (e.g. collection, treatment), the wastewater infrastructure requires high capital investment for transport (Tjandraatmadja et al., 2005, p. 146). This investment is included in "*Land transport services and transport services via pipelines, excluding rail transport*" of Transport (Table 3.1). It is safe to conclude that Waste and Transport are complements. Selvanathan and Selvanathan (1994) discussed Transport and Communication economic dependencies and studied them by estimating the Rotterdam demand equations in the United Kingdom and Australia. They compared (public and private) Transport and Communication and found that they are substitutes in both countries (Selvanathan & Selvanathan, 1994, p.5). The constant terms of the Rotterdam demand equations "*for private transport and public transport are negative while that for communication is positive*" in the United Kingdom (Selvanathan & Selvanathan, 1994, p.5). There are researchers, who found that Transport and Communication are complementary, but all of them are focusing on communication as an infrastructure service and not as an infrastructure system and most of them do not consider only the economic value through growth (e.g. Mokhtarian (2002) compared the growth of the absolute number of uses of each infrastructure without considering their dissimilar economic value). The negative impact of Communication improvement on Transport can be seen from the GDP reduction in every single scenario developed from Hickford et al. (2015, p.21) for the United Kingdom. Although, taking into consideration all the previous studies the impact of communication is under investigation and may be either negative or positive. The Water supply infrastructure system and Transport are always complements not only in United Kingdom but everywhere. Either in traditional water supply or in extreme socio-economic and climate scenarios, large-scale water transfer infrastructure will be required "*to alleviate the disparity between regions with water scarcity and those with water abundance*" (Hall et al., 2016, p.130-131). As can been seen in Table 3.1, one of the Transport industry sectors is the "*Land transport services and transport* *services via pipelines, excluding rail transport*". Within this sector is included the transfer of goods and mainly of water supply. It is obvious that, large-scale water transfer infrastructure is part of Transport, something that explains why Water and Transport are complementary.

3.1.3 Research methodology

The "importance of past dependencies" of infrastructure often failed to be recognised in research (Dick & Rimmer, 2009, p. 125). The empirical data of this current study comes from document analysis and is considered as secondary data analysis since by definition it is "the analysis of pre-existing data" (Heaton, 2000, p. 1). Administrative records and more specifically symmetric (product by product) Input-Output tables show past dependencies by providing estimates of domestic and imported products (product-by-product tables are called industry-by-industry tables in US) to intermediate consumption and final demand and associated multipliers, were used to derive part of the empirical data and fulfil the objective of this research.

The World Input-Output Database provided the economic value dependencies between different sectors. These documents generate numerical findings. In line with the ontology and epistemology stance, this study adopts a quantitative data collection allowing a detailed description and explanation of the value creation in infrastructure interdependencies. The target audience of the documents was investors and the public audience, so there was a lack of scientific or economic data/text to support them. These documents were knowledge drivers and established the guidelines in relation to the processes of the public organizations, helping them to function and develop through the same processes as a whole. These documents were produced from different day-to-day or month-to-month reporting systems over the period 2000 to 2014. Consequently, the research strategy followed is archival. Archival research refers to the analysis of "*administrative records and documents as principal source of data because they are products of day-to-day activities*" (Saunders et al., 2009, p. 587). Another reason that these documents are considered as secondary data is that they were "*originally collected from different person*" (Saunders et al., 2009, p. 150). The documents comprise a variety of written and visual material that represents the values of the related organizations and their existing dependencies. The researcher was aware that these manuals were created for a different purpose than the objective of the current research (Olson, 2010, p. 319-320). Research in archival documents cannot predict the outcome and its nature is iterative (Hill, 1993, p. 6). Archival data usually helps the researcher to identify the true nature of complex networks and show unrecognized human interactions. The relationship between the literature presented and the archival documents is reciprocal (Hill, 1993, p. 62). According to Hill (1993) there is no fixed archival analysis method and the author learn in the process how to extract information. The author decided to implement the process analysis "*networks* *and cohorts*" due to the research nature. This type of analysis uses tables, diagrams, models, networks of interactions along with organizational linkages (Hill, 1993, p. 62). The steps for analysing the documents are as follows: (1) Reading the documents, recognizing and highlighting linkages with the research proposition, (2) creation of networks and/or tables with data needed and (3) mapping economic value interdependencies.

The analysis focused to a certain extent on the development and analysis of transport infrastructure in the United Kingdom.

The term "*model*" is only the standard expression of the experience of the researcher, regarding the nature and the expressions of a phenomenon (Giannopoulos, 2002). Although it is common to use mathematical relations for modelling, it is not essential. Conceptually they can be defined as three types of modeling (Giannopoulos, 2002, p.25-26): mathematical models, operating models and procedural modeling. Regarding the purpose performed by the model, there are the following types (Giannopoulos, 2002, p.27): descriptive models, forecast models and planning models.

This research focuses on value creation and capture. Since, by definition, value can be measured then mathematical models will be used and not procedural. Procedural models are commonly qualitative explanations focusing on reasoning, why these dependencies exist and not how (Giannopoulos, 2002, p.26). Mathematical models consist of mathematical relationships, which usually are called algorithms and they are used for the calculation of the required variables (Giannopoulos, 2002, p.25). Furthermore, an operating model will be devised as a display of a total business model. Operating model is a combination of mathematical relationships and reasonable "*rules of conduct*" (Giannopoulos, 2002, p.25). In this case, the "*rules of conduct*" are the existing infrastructure dependencies and they are coming from the documents. From the moment this research investigates something new and innovative, there are insufficient data for descriptive modeling. The developed model may be a possible forecast model for value creation with conditional predictions and impact analysis (e.g. creation of scenarios). The new business model may be used as a planning model under certain conditions and predetermined criteria. It is worth noting, that the prediction of the future events is critical for considering the new business model as a planning one (deterministic behaviour of the model and not stochastic/probabilistic).

The relationship form $Y = f(X_i) + u$, which is the most common function for mathematical modelling, is considered very general to be used as the starting point of modeling. Linear analysis is one of the best known model-building techniques by studying the relationship between two variables. Let X be the independent variable and Y be the dependent variable. Respectively, the method of multiple linear analysis investigates the relationship between the dependent variable Y and several independent variables X_i. Namely,

$$Y_c = b_0 + b_1 \cdot X_1 + b_2 \cdot X_2 + \ldots + b_\nu \cdot X_\nu$$

[where Y_c: the dependent variable, $X_1, X_2, \ldots X_\nu$: the independent variables, $b_0, b_1, \ldots b_\nu$: partial coefficients, which are determinable parameters]

GDP of Transport is the dependent variable and the demand of each sector is the independent variable..

While it will finally be determined an acceptable forecasting model in all respects $Y = f(X_i)$, the error inevitably enters into the equation. The full form of the relationship is $Y = f(X_i) + u$, where u is the part of the sample not explained from the independent variables X_i (Giannopoulos, 2002, p.39).

The aggregate models' algorithms' starting point (e.g. Aggregate Travel Demand Forecasting) is the linear regression analysis. Linear regression analysis is one of the best known model-building techniques offered by statistical analysis. The method of the simple linear regression, which is the least squares estimator of a linear regression model, studies the relationship between two variables. The difference with simple linear analysis is that $b_0, b_1, \ldots b_\nu$: are partial regression coefficients, which are determinable parameters. The value of Y_c corresponds to a combination of given values of $X_1, X_2, \ldots X_\nu$ in the existing situation and it is calculated with the equation above. For observed values of $X_1, X_2, \ldots X_\nu$ (e.g. during the calculation of the determinable parameters$b_0, b_1, \ldots b_\nu$), the value of Y in fact (the observed value of Y) will, generally, differ from the calculated value of Y_c. The regression analysis requires a wealth of data (Giannopoulos, 2002).

Data generated by the World Input-Output Database (2018) were used to apply linear regression analysis and to derive part of the empirical data and fulfil the objective of this research.

3.1.4 Empirical findings and analysis

Following the three–step process analysis *"networks and cohorts*" (Hill, 1993): Step 1) The symmetric (product by product) Input-Output tables includes product input-output groups (IOGs). The research proposition demands an industry-based analysis focusing on Transport, Energy, Waste, Communication and Water. Each of the IOGs was classified according to their principal product or service as Transport, Energy, Waste, Communication, Water or Other Goods/ Services.

Step 2) Tables with the empirical data discussed above were created:

Table 3.2 Economic infrastructure interdependencies

		Energy		Water	Communication	Waste		
Transport		Electricity, transmission and distribution	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Natural water; water treatment and supply services	Tele-communications services	Sewerage services; sewage sludge	Waste collection, treatment and disposal services; materials recovery services	Remediation services and other waste management services
Land Transport	Motor vehicles, trailers and semi-trailers	✓	✓	✓	✓	✓	✓	✗
	Rail transport services	✓	✓	✓	✓	✓	✓	✗
	Wholesale and retail trade and repair services of motor vehicles and motorcycles	✓	✓	✓	✓	✓	✓	✗
	Land transport services and transport services via pipelines, excluding rail transport	✓	✓	✓	✓	✓	✓	✓
Water Transport	Ships and boats	✓	✓	✓	✓	✓	✓	✗
	Water transport services	✓	✓	✓	✓	✓	✓	✗
	Repair and maintenance of ships and boats	✗	✗	✗	✗	✓	✓	✗
Air Transport	Air transport services	✓	✓	✓	✓	✓	✓	✗
	Air and spacecraft and related machinery	✓	✓	✓	✓	✓	✓	✗
	Repair and maintenance of aircraft and spacecraft	✗	✗	✗	✓	✗	✗	✗
Other Transport Equipment		✓	✓	✓	✓	✓	✓	✗

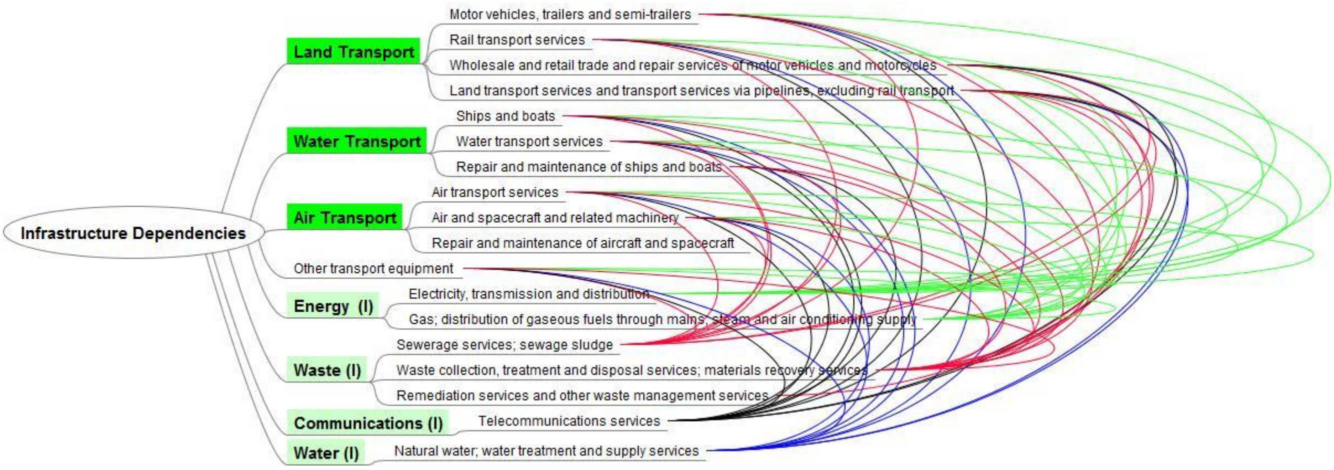


Figure 3.2 Economic infrastructure interdependencies

Table 3.3 Transport Input-Output analytical tables - 2010 Edition, Released: 12 February 2014

	GDP Consumption (2010)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Production (£Million)
GDP Produced by Transport	9,200	52	1,030	181	19	126,843	137,325
	GDP Production (2010)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Consumption (£Million)
GDP Consumed by Transport	9,200	1,662	192	514	43	51,267	62,878
	Capital Value Creation (2010)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Value (£Million)
Transport	0	-1,610	+838	-333	-24	75,576	+74,447

Step 3) The economic value interdependencies were mapped (Table 3.2, Figure 3.2, Tables 3.3) and used for the development of a mathematical model (function). If it is assumed that the value created from the infrastructure dependencies and other goods and services is a result of these dependencies, and at the same time it is assumed that transport value creation is independent from the non-transport dependencies, then for four other sectors (independent variables) we get five unknowns:

$$Y_a = b_1 \cdot X_{a1} + b_2 \cdot X_{a2} + b_3 \cdot X_{a3} + b_4 \cdot X_{a4} + b_5$$

[where X_{a1}: value added from Energy to Transport, X_{a1}: value added from Waste to Transport, X_{a3}: value added from Communication to Transport and X_{a4}: value added from Water to Transport]

World Input-Output Database (2018) were used to derive part of the empirical data and fulfil the objectives of this research. These documents were produced by Timmer et al. (2015; 2016). There are 56 sectors classified according to the International Standard Industrial Classification revision (Timmer et al., 2016). The Input – Output matrixes used were balanced with RAS method (Timmer et al., 2015); "*the most widely known and commonly used automatic procedure… for balancing an Input – Output table*" (Trinh & Phong, 2013, p.135). Although RAS method is not analyzed in this thesis, its equation is provided for understanding reasons (Trinh & Phong, 2013, p.136):

$$X_C{}^{new}(t_n).X_C{}^{new}(t_{n-1})..X_C{}^{new}(t_1).A.X_R^{new}(t_1)\ldots X_R^{new}(t_{n-1}).X_R^{new}(t_n) = A^{new}$$

[where $X_C^{new}(t_i)$: is new vector of gross output follow column of round t_i time, A: is coefficient matrix of direct input, $X_R^{new}(t_i)$: is new vector of gross output follow row of round $t_i$time]

An example of how the RAS method is applied can be found in Trinh & Phong's paper (2013, p.134-136). Although, these data are not random, but are produced for each year, they are based on estimations. The empirical data differentiate from the generated data. This results in selection bias, since it involves non empirical support data biasing the sample. The qualitative approach supports the investigation of documents over which the author had little or no control (Eisenhardt, 1989; Yin, 2009).

Table 3.4 GDP (US dollars) of United Kingdom (2000-2014), World Input-Output Database

Year	Energy	Waste	Commu-nication	Water	Transport
2000	18769	9700	29616	4483	250120
2001	17029	9795	27924	4706	252628
2002	19321	11594	31246	4666	266217
2003	21932	14744	36495	5137	307034
2004	23262	17706	41576	5499	359890
2005	23176	19227	41307	6015	365662
2006	29069	19950	42189	6751	382594
2007	33108	23260	49454	8453	431326
2008	27632	22026	48164	8319	412392
2009	35188	17580	41291	6708	331933
2010	23999	19603	38433	6641	347041
2011	22834	21777	41031	7194	369176
2012	32786	21037	41665	7414	367421
2013	39583	18789	44559	7990	383486
2014	39907	19044	46011	8677	425300

The data (Table 3.4) are in dollars, but since the exchange rate with the British pound is known, then it is expected to get a similar equation at least in terms of the order of magnitude and the same scale of the coefficients. It is not expected to get the same equation, since the data differ and they are from different periods. The process described above, concerning the import of mathematical equations into the model, is now done with proper software and not by hand. This research uses the software of SPSS and Microsoft Excel, which are the most well-known spreadsheet applications.

Table 3.5 GDP correlations of Input-Output model

		Transport	Energy	Waste	Communication	Water	Other
Transport	Pearson Correlation	1	-.728**	-.926**	-.976**	-.921**	-.983**
	Sig. (2-tailed)		.002	.000	.000	.000	.000
	N	15	15	15	15	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

By correlating Transport with Energy, Waste, Communications, Water and Other sections, the p- value (high statistical significance) is not greater than the level of significance (p-value is lower than 0.05) (see Table 3.5), meaning that the correlation is statistically significant. In other words, there is enough evidence that the observed correlation exists. The correlation coefficient is actually the strength of the linear relationship between the two variables and it can be seen that they have a strong negative correlation (Field, 2009, p.189). Transport correlates with the previous infrastructures, so we can apply linear regression analysis. On the other hand, if the p-value was greater than the level of significance, meaning that the correlation is not statistically significant, there would not be enough evidence that this correlation exists or is significant (Field, 2009, p.367). It is more possible that it just occurs by chance. However, this is not the case here.

Table 3.6 Statistical model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.998[a]	.995	.992	5147.659	.995	360.732	5	9	.000

a. Predictors: (Constant), Other, Communication, Energy, Water, Waste
b. Dependent Variable: Transport

R-squared is the fraction of the explained variation with total variation and is the coefficient of multiple determination for multiple regression (Field, 2009, p.179). So this model explains 99.5% of the data (see Table 3.6).

Table 3.7 Statistical model coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	28985.737	11728.527		2.471	.035		
Energy	1.968	.429	.250	4.587	.001	.186	5.375
Waste	6.624	1.454	.491	4.555	.001	.047	21.067
Communication	-3.718	.829	-.406	-4.484	.002	.067	14.855
Water	10.796	4.161	.266	2.594	.029	.052	19.072
Other	-.247	.034	-1.506	-7.245	.000	.013	78.340

a. Dependent Variable: Transport

Variance inflation factor (VIF) shows if multicollinearity exists or not (Field, 2009, 224). Multicollinearity does not exist when $VIF \leq 10$ (Myers, 1990). Multicollinearity is when one or more of the predictor variables in a multiple regression model can be almost accurately calculated from the others using linearity (Field, 2009, p.224). In this situation the model is dynamic since the coefficient may change dramatically in response to small changes in the model or the data (Field, 2009, p.273 & 297). Every variable except Energy has a VIF> 10 (see Table 3.7) with the variable of the Others sectors having 78.340! If we assume that the value added from the other infrastructures is absorbed by the five main infrastructures (as it was done before during the calculation of the value added) then the multicollinearity does not exist for Energy, Water and Waste and is very small for Communication, but the equation changes dramatically. Communication will be considered in the new model, since the data were estimated by the RAS method and this may be a possible explanation why correlation is not statistically significant. It can be seen that Communication changes between positive and negative values in the estimated data although in the real data it is always negative. It can be seen that the negative effect of the Other sectors is transferred to every variables' coefficients by reducing them dramatically.

Table 3.8 Statistical model coefficients without Other sectors

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	T	Sig.	Tolerance	VIF
1	(Constant)	13670.731	28607.883		.478	.643		
	Energy	.706	.972	.090	.726	.485	.223	4.488
	Waste	-1.381	2.345	-.102	-.589	.569	.112	8.910
	Communication	-6.510	1.821	-.711	-3.575	.005	.086	11.648
	Water	-10.701	7.236	-.264	-1.479	.170	.107	9.376

a. Dependent Variable: Transport

To conclude, the model developed is the following (Table 3.8) (see Table 3.9 for the standard deviation – uncertainty):

$$Y_{cr} = 1.968 \cdot X_{cr1} + 6.624 \cdot X_{cr2} - 3.718 \cdot X_{cr3} + 10.796 \cdot X_{cr4} - 0.247 \cdot X_{cr5} + 28985.737$$

[where X_{cr1}: Value Added from Energy, X_{cr2}: Value Added from Waste, X_{cr3}: Value Added from Communication, X_{cr4}: Value Added from Water and X_{cr5}: Value Added from Other sectors]

Table 3.9 Descriptive statistics of the model

	Mean	Std. Deviation	N
Transport	350148.00	58573.888	15
Energy	27173.00	7434.291	15
Waste	17722.13	4341.745	15
Communication	40064.07	6394.193	15
Water	6576.87	1443.761	15
Other	1677611.40	357439.350	15

The order of magnitude and the scale of the coefficients between this equation and the previous equation are different. This may be a result of the lack of data for the first model and the assumptions, as both models are strongly related to the data. However, they both agree on Transport infrastructure interdependencies ranking as follows: (1) Water (positive impact), (2) Waste (positive impact), (3) Energy (positive impact) and (4) Communication (negative impact).

3.1.5 Principal component analysis for the reduction of correlation

Principal component analysis may be used for the reduction of correlation. Energy, waste, communication and water will be studied without dividing them to their IOGs. The other sectors consist of 43 correlated IOGs. The sum of the variables can be transformed to uncorrelated factors using the principal component analysis (Field, 2009, p.633-638). Principal component analysis investigates the linear combination of correlated variables to explain the maximum variability of variables by converting them to linear uncorrelated factors (Field, 2009, p.638) using eigenvalues. This way it would be possible to transform the previous equation to an equation without multicollinearity. Eigenvalues, known also as characteristic roots, characteristic values (Hoffman and Kunze, 1971, p.182), proper values, or latent roots (Marcus and Minc, 1988, p.144-145), give you the factors by which the axes change (the direction of the axes) for a linear transformation (compression). First, the eigenvalues are designed allowing the author to calculate the number of factors that can replace the variables.

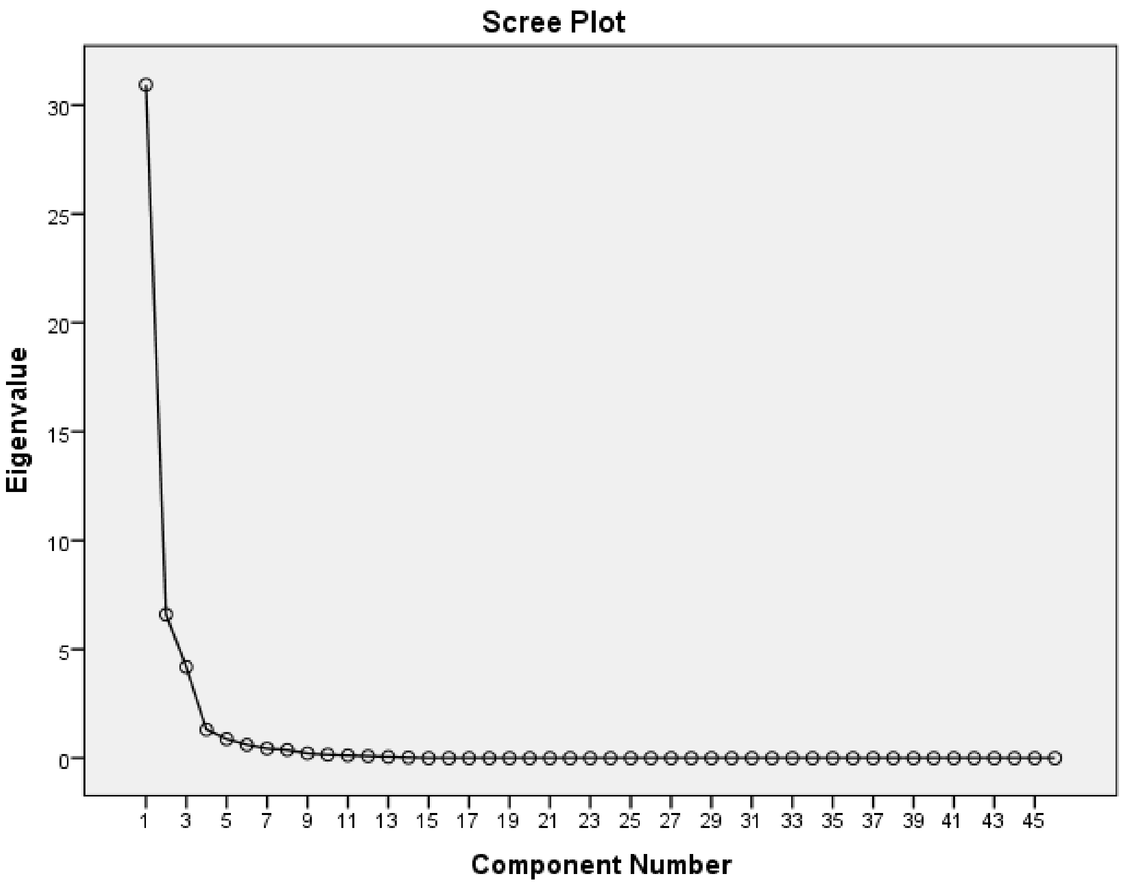


Figure 3.3 Eigenvalues of the correlated variables

The eigenvalues shows us how many new factors may statistically replace the variables, through linear transformation. The y-axis of the eigenvalues-graph shows how many of the old values are explained by their replacement with new factors through linear transformation (x-axis). As can be seen the 47 (43 other sectors and 4 sectors of interest) correlated variables, (one of the IOGs, "*Activities of extraterritorial organizations and bodies*", is always zero that is why it is not included in the diagram) can be transformed to three or four new factors (see Table 3.10).

Table 3.10 Total variance explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Compo-nent	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	30.931	67.241	67.241	30.931	67.241	67.241	27.307	59.363	59.363
2	6.599	14.346	81.587	6.599	14.346	81.587	7.314	15.900	75.264
3	4.190	9.108	90.695	4.190	9.108	90.695	6.666	14.490	89.754
4	1.307	2.842	93.537	1.307	2.842	93.537	1.740	3.783	93.537
5	.876	1.904	95.441						
6	.612	1.331	96.772						
7	.441	.959	97.730						
8	.374	.813	98.544						
9	.215	.468	99.012						
10	.160	.347	99.359						
11	.120	.260	99.619						
12	.090	.197	99.816						
13	.056	.121	99.937						
14	.029	.063	100.000						

Extraction Method: Principal Component Analysis.

Three factors will explain the 90.70% of the variables (89.75% of the rotated) and four new factors will explain the 93.54% of the variables (even the rotated, see Table 3.10). Then four new factors will be used. The main issue with these factors will be that they cannot be based on the sectors of interest, as they will be in a new unit and it will not be possible to calculate easily the values of the sectors of interest. Instead of using the new factors, the components of each factor will get investigated and the highest component will be used considering the sectors of interest. Therefore, the components will be in the same unit with the sectors of interest before the principal component analysis.

The component matrix (Appendix A) represents the correlation between the variables and the factor: The first factor correlates with the "*Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use*" by 0.983 (positive) without any overlap with the other factors. The second factor correlates with the "*Printing and reproduction of recorded media*" by 0.868 (positive) with 0.417 overlap with the third factor. The third factor correlates with the "*Forestry and logging*" by 0.844 (positive) with 0.352 overlap with the second factor. The fourth factor correlates/overlaps different sectors/factors.

Rotated component matrix (Appendix A) represents how the variables are weighted for each factor and the correlation between the variables and the factor: The first factor correlates with "*Education*" by 0.99 (positive) without any overlap with the other factors. The second factor correlates with the "*Printing and reproduction of recorded media*" by 0.947 (positive) without any overlap with the other factors. The third factor correlates with the "*Manufacture of textiles, wearing apparel and leather products*" by 0.954 (positive) without any overlap with the other factors. The fourth factor correlates/overlaps different sectors/factors.

The new four factors than can replace all the variables are calculated using SPSS (see Appendix A) and significantly reduce the correlation (see Table 3.11).

Table 3.11 PCA coefficients

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	350148.000	1342.077		260.900	.000		
	REGR factor score 4 for analysis 1	-4344.721	1389.182	-.074	-3.128	.011	1.000	1.000
	REGR factor score 3 for analysis 1	-14614.460	1389.182	-.250	-10.520	.000	1.000	1.000
	REGR factor score 2 for analysis 1	-17369.565	1389.182	-.297	-12.503	.000	1.000	1.000
	REGR factor score 1 for analysis 1	-53641.786	1389.182	-.916	-38.614	.000	1.000	1.000

a. Dependent Variable: Transport

The challenge is to develop a model which includes energy, waste, water and communication and/or at least a model combined with the same measurement with them, meaning economic demand. The new model (Table 3.11) is based on virtual factors and has virtual measurement units, not the economic demand. Additionally, the negative effect of the other sectors can be seen from the coefficients, which are all negative.

Since a model including energy, waste, water and communication is needed, it was decided to use the four sectors of interest to see which of the four factors align with them and then chose IOGs which cover the most of the missing correlation. Indicatively, a set of models is presented, based on the factor of the principal component analysis (see Appendix A).

It is obvious that the correlation cannon be reduced (VIF>10) regardless of the combination of IOGs, since Energy, Waste, Water and Communication, all majorly effect the first factor. The final model should include the sectors of interest: Energy, Waste, Water and Communication. It is obvious that all the sectors of interest mainly affect the first factor. Then the first factor, based on the R^2 can be a sum of 26.9% waste, 26.84% water, 26.1% communication and 20.16% energy. The second factor is mainly affected by "*Printing and reproduction of recorded media*" (1^{st} in second factor both for Component Matrix and Rotated Component Matrix). The third factor is mainly affected by "*Manufacture of textiles, wearing apparel and leather products*" (1^{st} in third factor both for Component Matrix and Rotated Component Matrix). The fourth factor is mainly affected by "*Mining and quarrying*" (1^{st} in fourth factor for Component Matrix and 3^{rd} for Rotated Component Matrix).

Table 3.12 Final economic model of interdependencies

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	30507.785	33157.797		.920	.379		
	Sum_Interest	6.464	.729	.881	8.872	.000	.350	2.853
	Printing	1.947	2.059	.063	.946	.366	.772	1.295
	Manufacturetextiles	5.131	3.189	.098	1.609	.139	.930	1.075
	Mining	.546	.614	.092	.888	.395	.322	3.109

a. Dependent Variable: Transport

The correlation has significantly reduced (see Table 3.12). The new model explains 98.3% of the variance of the data (see Table 3.13).

Table 3.13 R^2 of the final economic model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.983[a]	.965	.952	12890.002	.965	69.772	4	10	.000

a. Predictors: (Constant), Mining, Manufacturetextiles, Printing, Sum_Interest

To conclude the new model will be as follows (see Table 3.12):

$$Y_{cr} = 1.299 \cdot X_{cr1} + 1.739 \cdot X_{cr2} + 1.687 \cdot X_{cr3} + 1.735 \cdot X_{cr4} + 1.947 \cdot X_{cr5} + 5.131 \cdot X_{cr6} + \\ + 0.546 \cdot X_{cr7} + 30507.785$$

[where X_{cr1}: Value Added from Energy, X_{cr2}: Value Added from Waste, X_{cr3}: Value Added from Communication, X_{cr4}: Value Added from Water, X_{cr5}: Value Added from Printing and reproduction of recorded media, X_{cr6}: Value Added from Manufacture of textiles, wearing apparel and leather products, X_{cr7}: Value Added from Mining and quarrying]

This last exemplar model is not representative of the total value as it does not take into account a lot of sectors, but it a good display of the interdependencies.

3.1.6 Economic Infrastructure Interdependencies

At this point it would be useful to investigate all the infrastructure interdependencies by correlating each infrastructure with the others. Although the correlations do not imply dependency (Field, 2009, p. 619-620), they can show if any and which infrastructure interacts with another infrastructure based on GDP. If the assumption that the Transport output is not a result of the input of the other groups gets ignored, then the GDP of the Input-Output tables' comparison will show the correlations between each infrastructure.

Table 3.14 Infrastructure correlations

		Transport	Energy	Waste	Communication	Water	Other
Transport	Pearson Correlation	1	.728**	.926**	.976**	.921**	.983**
	Sig. (2-tailed)		.002	.000	.000	.000	.000
	N	15	15	15	15	15	15
Energy	Pearson Correlation	.728**	1	.594*	.756**	.832**	.786**
	Sig. (2-tailed)	.002		.019	.001	.000	.001
	N	15	15	15	15	15	15
Waste	Pearson Correlation	.926**	.594*	1	.918**	.852**	.943**
	Sig. (2-tailed)	.000	.019		.000	.000	.000
	N	15	15	15	15	15	15
Communication	Pearson Correlation	.976**	.756**	.918**	1	.907**	.963**
	Sig. (2-tailed)	.000	.001	.000		.000	.000
	N	15	15	15	15	15	15
Water	Pearson Correlation	.921**	.832**	.852**	.907**	1	.959**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
	N	15	15	15	15	15	15
Other	Pearson Correlation	.983**	.786**	.943**	.963**	.959**	1
	Sig. (2-tailed)	.000	.001	.000	.000	.000	
	N	15	15	15	15	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

By correlating Transport with Energy, Waste, Communications, Water and Other sections (see Table 3.14), p-value (high statistical significance) is not greater than the level of significance, meaning that the correlation is statistically significant. In other words, there is enough evidence that the observed correlation exists (Field, 2009, p. 619-620). The correlation coefficient is actually the strength of the linear relationship between the two variables and it can be seen that they have strong positive -because of the signs used in the table- correlation (Field, 2009, p. 619-620). Transport correlates with the previous infrastructures with the following ranking from most to least correlation: 1) Other sections, 2) Communications, 3) Waste, 4) Water and 5) Energy.

Energy has strong positive correlation with Transport, Communications, Water and Other sections and moderate positive correlation with Waste. Energy correlates with the previous infrastructures with the following ranking from most to least correlation: 1) Water, 2) Other sections, 3) Communications, 4) Transport and 5) Waste. Energy has the weakest relationships with the other infrastructures/sections and the weakest relationship is between Energy and Waste.

Waste has strong positive correlation with Transport, Communications, Water and Other sections and moderate positive correlation with Energy. Waste correlates with the previous infrastructures with the following ranking from most to least correlation: 1) Other sections, 2) Transport, 3) Communications, 4) Water and 5) Energy.

Communications has strong positive correlation with Transport, Energy, Waste, Water and Other sections. Communications correlates with the previous infrastructures with the following ranking from most to least correlation: 1) Transport, 2) Other sections, 3) Waste 4) Water and 5) Energy.

Water has strong positive correlation with Transport, Energy, Waste, Communications and Other sections. Communications correlates with the previous infrastructures with the following ranking from most to least correlation: 1) Other sections, 2) Transport, 3) Communications 4) Waste and 5) Energy.

Finally, Other sections have strong positive correlation with transport, energy, waste, communications and water. Other sections correlate with the previous infrastructures with the following ranking from most to least correlation: 1) Transport, 2) Communications 3) Water and 5) Energy. Other sections have the strongest relationships with the other infrastructures/sections followed by Transport and the strongest relationship is between Other sections and Transport.

3.1.7 Conclusions and Recommendations

The hypothesis was verified with some exceptions. These exceptions may exist because of the tenuous assumption due to the lack of data. As all the types of infrastructure are in the same function, it is safe to rank them. The Transport infrastructure interdependencies ranking, based on the findings of this study, is as follows: (1) Water, (2) Waste, (3) Communication (because of the correlation it may affect Transport more than Water and Waste, but communication effects changes based on the methodology) and (4) Energy. To conclude it can be seen that value added in Energy, Waste, Water and Communication adds and creates value to Transport.

As discussed before, there is a debate about the transport-communication relationship. A possible explanation for communication may be that the growth of the communication sector reduces the need for transport (e.g. with telegraphy, communication becomes instant and independent of transport) and additionally transport is dependent on communication, as every single transport system should be controlled and communicated by communication means. On the other hand Energy, Water and Waste are still dependent on Transport. The function developed in this thesis may be used in future scenarios for calculating the value.

Finally, the infrastructure interdependencies function shows that investing in Energy, Water, Waste and Communication in the current situation of the United Kingdom creates value to Transport.

Having defined and analysed the economic value of the infrastructure business models, social and environmental values' definition and analysis should follow to have a holistic approach of the infrastructure business models' value.

3.2 Environmental value

3.2.1 Introduction

The climate change threat to humanity challenges the creation of sustainable transport infrastructure based on the triptych of balancing and maximising environmental, economic and social value. A piece of infrastructure may be created in a sustainable manner, but may be then subsequently used unsustainably, although arguably the creator ought to be able to predict this and hence one might conclude that the infrastructure was always unsustainable. In other words, sustainable transport infrastructure is linked with the use of the most sustainable transport choices, which may not be really sustainable, but the one with the lower negative impact on the environment. Environmental value may be defined by the natural and anthropogenic factors and elements which interact with and influence the natural ecosystem, quality of life, and human health and well-being (Riffat et al, 2016; Khatri & Tyagi, 2015; Summers et al, 2012). Emissions are a widely accepted way by the Food and Agriculture Organization of the United Nations to "*calculate*" environmentally damaging actions (FAO, 2017). Emissions address the production of pollutants and the placement of waste into the environment. The target is to reduce the use of transport modes with high environmental impact (e.g. cars) and replace them with transport modes with low or no environmental impact (e.g. public transport, walking, cycling). The hypothesis tested is that each individual should be able to understand which transport mode is the most sustainable and investigate whether each individual will accept the use of alternative options that consume less energy and generate fewer emissions. The methodology used was statistical inference. The hypothesis regarding the individuals' understanding was verified with some deviations and a table with the environmental infrastructure interdependencies was developed based on EXIOBASE 3 database using the emissions generated from each transport sector for comparison purposes.

Almost one third of total energy (end use energy) in the United Kingdom is used by transport (UK government, 2017). The energy needs of transport increased between 2016 and 2017 in contrast to other industries that have slightly decreased (UK government, 2017). A significant catastrophic environmental impact of vehicles is their contribution to air pollution. Transport emissions significantly reduce air quality. Transport modes have an important role on the quality of air and water. Environmental value may be defined by the natural and anthropogenic factors and elements which interact with and influence the natural ecosystem, quality of life, and human health and well-being (Riffat et al, 2016; Khatri & Tyagi, 2015; Summers et al, 2012). The environment consists of land, subsurface soil and deeper geology, groundwater and surface water, sea, air, flora, fauna and natural resources (FAO, 2017). Environmentally damaging actions may be considered or expressed by factors such as: environmental pollution and degradation of environmental services, compromising biodiversity, and extraction of natural resources which causes serious permanent depletion (FAO, 2017). In the UK 40,000 people die prematurely each year from exhaust emissions (Landrigan, et al., 2018; Holgate, 2017; BBC News, 2016). The target is to reduce the use of transport modes with high environmental impact (e.g. cars) and replace them with transport modes with low or no environmental impact (e.g. public transport, walking, cycling). To achieve this, the user of these transport systems is treated as a responsible citizen and a key stakeholder, one who is capable of thinking and acting in a socially responsible way. The author wants to highlight that there is very little mention of getting rid of cars, though the author argues it is a good idea and the government strategy is rather mixed up. The current government target in the short term is to penalise owners of diesel vehicles (as they kill most of the 40,000 people) to the benefit of those which use unleaded and in the longer term to transfer all to electric cars. A diesel car owner may accept that his/her choice hastens the death of his/her neighbours (slightly), but that the alternative (unleaded) will more rapidly affect global warming and hasten the deaths of people around the world. The former will kill largely older people, the latter people across the ages, which is an impossible dilemma for the individuals, who are not helped by government policy.

This research places great emphasis on the individual and his/her involvement in the decision making process in transport choice. The individuals are considered as responsible citizens (possibly) and this research will try to understand the views of the individuals in the framework of using these views for government policy making. Environmental value has been calculated from the emissions generated, by asking individuals, in a questionnaire survey that was representative of the UK's demography, to indicate their travel distance per year eight transport modes and to declare their understanding of transport modes' environmental and health impacts.

3.2.2 Literature review of the environmental impact of civil infrastructure

A literature review revealed that there are more than 600 publications, between the years 2010 and 2020, on the environmental impact of construction industry and projects (not just infrastructure). These publications present simple or more complicated analyses of parameters for estimating the environmental impact of structures. The key finding from an engineer perspective is that materials can account for up to 80-90% of the total structure embodied GHG emissions (D'Amico & Pomponi, 2018a; Kang et al., 2015; Zhang & Wang, 2016).

Some studies present a simple comparative analysis of environmental impact factors for typical buildings or structures (Asif et al., 2017; Atmaca, 2017; Blok et al., 2019; Ding & Forsythe, 2013; Park et al., 2014; Puskas & Moga, 2015), for specific type structures such as wood constructions (Connolly et al., 2018; Lolli et al., 2019; Niu & Fink, 2019; Robertson et al., 2012), for bamboo-based buildings (Escamilla et al., 2018), for road and pavement infrastructure (Balieu et al., 2019; Said & Al-Qadi, 2019) etc. The simple comparative analyses are based on the structural analysis of the system of interest without developing any new model or theory. Park et al. (2014) compared different construction methods and application of different smart frames to tall buildings (S. C. Park et al., 2014). Robati et al. (2019) and Wang et al. (2020) presented statistical methods to analyse the uncertainty of the material quantities' calculations, such as boxplots (Robati et al., 2019; Wang et al., 2020). Hodková et al. (2012) did a comparative analysis of existing LCA databases followed by a building assessment to highlighted that, inappropriate use of LCA data could lead to unreliable results that cannot be compared with each other (Hodková et al., 2012). Considering the analysis by Hodková et al. (2012), when a building or an infrastructure is studied the focus should initially be on the environmental impact without using an LCA database. This way the uncertainty of the results will be reduced. The environmental impact of structures or infrastructure can get transformed to emissions using any database after the analysis of the structure is finished.. Additionally, the statistical analysis of a significant number of civil projects should provide a range of values for covering the uncertainty of the results (Robati et al., 2019; Y. Wang et al., 2020). So based on the above, the optimum way to study the environmental impact of civil infrastructure in a society, is to have a database of factors that impacts the environment for a huge amount of construction projects. After analysing these factors, the results can be transformed to environmental value (as later as possible in the studing process).

Other studies compared the environmental impact for different construction options of civil infrastructure. Balieu et al. (2019) compared different types of electrified road infrastructures (Balieu et al., 2019), Langston et al. (2018) compared refurnished with new projects (Langston et al., 2018), Lemma et al. (2020) and Meil et al. (2006) compared different type of designs for the same project (Lemma et al., 2020; Meil et al., 2006), Grant and Ries (2013) studied the lifetime and replacement or different elements in existing structures (Grant & Ries, 2013). The comparisons in all this case were not modelled and the publications only discussed how different choices increase or decrease the impact on the environment without any numerical modelling representation. Comparing the different construction options is simple, but numerical modelling is challenging especially if the variable that change cannot be quantified. The approach typically used when it comes to modelling is to represent the dependency between the environmental impact and the parameters/factors effecting the environment with figures.

The parameters of civil infrastructure usually require high level of detail. De Wolf et al. (2016; 2020) combined different parametres with the embodied carbon coefficients to develop their own database to estimate global worming potential (C. De Wolf et al., 2016; Catherine De Wolf et al., 2020). The parameters studied by De Wolf et al. (2016; 2020) were both qualitative and quantitative. Qualitative parameters were the type of structure (residential, commercial, industrial, infrastructure, and other non-residential, mixed-use), the main structural material (concrete, steel, timber, masonry, steel-concrete), the rating scheme certification (e.g. LEED, BREEAM) and the region or country (Catherine De Wolf et al., 2020). Quantitative parameters were geometric such as the size by floor area, the height by number of floors, the number of occupants and the span (Catherine De Wolf et al., 2020). The results were displayed as ranges for different categories (C. De Wolf et al., 2016; Catherine De Wolf et al., 2020) without combing the results with loading analysis, and no models were developed due to this mix of qualitative and quantitative parameters.

Other key parameter impacting the civil infrastructure is the loading analysis. The loading conditions are important, as the structure is required to withstand. Some authors decomposed infrastructure or structure to structural components and estimated the emission generated by using geometric data (e.g. the geometric equilibrium method) combined with loading analyses for each structural component (Collings, 2006; Du & Karoumi, 2013, 2014). The geometric characteristics and inputs are effecting the material quantities and therefore the emissions generated (Collings, 2006; D'Amico & Pomponi, 2018a, 2018b; G. K. C. Ding, 2019; Du & Karoumi, 2013, 2014; H. Q. Le & Hsiung, 2014; Monteiro & Poças Martins, 2013; H. Said & El-Rayes, 2014; Sanjuan-Delmás et al., 2015; Stephan & Crawford, 2014; Sturgis, 2019; Thiebault et al., 2013). Other authors studied different type of structural components, such as beams, columns, walls, bearing walls, shear walls, flat slabs and suggested different optimization systems (structural analysis) to reduce construction materials, therefore, a reduction of CO_2 emissions. (Hong et al., 2010; Lagaros, 2018). Shafiq et al. (2015) studied how carbon emissions generated by concrete and steel of buildings are effected by different dimension of structural elements: roof beams, first floor beams, ground floor beams, slabs, columns, foundations and staircases (Shafiq et al., 2015). The dimensions of the structural elements were calculated with loading analysis, but there were space limitations. The space limitation means that any change on one dimension would affect the other dimensions of the some or other structural elements. To avoid the effect of space limitation, it should be assumed that the project can cover all the space it needs, as our paper assumes. Finally, there are detailed papers focusing on a specific structural component, such as roof-covering materials (A. B. D. Le et al., 2019) or railway sleepers (Rempelos et al., 2020) and not on a full infrastructure project. The decomposition process of infrastructure or structures reduces the uncertainty, but it is challenging to be used on the development of a generalized holistic model in the level this thesis requires. One of the challenges is what to do with missing data. Some authors took the missing data from similar infrastructure projects (Du & Karoumi, 2013, 2014; Thiebault et al., 2013) and/or mathematical models (Thiebault et al., 2013), but again collecting data from secondary sources increases the uncertainty.

A good approach is to develop a holistic model that will include all the system of interest. The holistic model can be either for simple structures such as water tanks (Sanjuan-Delmás et al., 2015) or for more complicated structures (D'Amico & Pomponi, 2018b; Shafiq et al., 2015). Sanjuan-Delmás et al. (2015) studied how the quantities of concrete and steel are affected by volume (m3), diameter (m), height (m), wall thickness (cm), shape (Cylindrical) and material reinforced and presented their results on a Cartesian coordinate system (Sanjuan-Delmás et al., 2015). The use of a Cartesian coordinate system makes easier to the reader to understand how the materials change over a parameter. Holistic models which estimate the emissions generated of complicated structures considering the loading conditions are not easily developed. D'Amico & Pomponi (2018b) created a complex sustainability tool to optimise material quantities of steel in complex constructions (D'Amico & Pomponi, 2018b). Their tool estimated material quantities using simple structural calculations based on the following loading conditions, and geometrical and topological parameters: primary span length [mm], secondary span length [mm], maximum (allowable) span of the floor slab [mm], Floor height [mm], number of bays along the primary grid direction, number of bays along the secondary grid direction, number of floors, wind pressure load [kN/m2], imposed floor load [kN/m2], permanent line-load of the building envelope walls [kN/m], floor slab's self-weight [kN/m2], floor load due to finishes, ceiling/services and partitions [kN/m2]. Due to its complexity, D'Amico & Pomponi (2018b) presented their results by holding all the other parameter constant and changed only one specific parameter for studying how the specific parameter affects the material quantity. This way it was easier for the reader to understand the results. The literature review shows that there are even more parameters that should be taken into consideration. For example Craig (2019) modelled how temperature, surface area, thickness, and thermal properties in naturally ventilated buildings affect material quantities and therefore their environmental impact (Craig, 2019), but the thermal properties and temperature are out of the scope of this study.

Based on the above discussion, loadings, geometric parameters and material quantities external environment of any structure inside the infrastructure system is required to be established for estimating the emissions correctly of every infrastructure project. Combining the reasoning of the work of Catherine De Wolf et al. (C. De Wolf et al., 2016; Catherine De Wolf et al., 2020), of D'Amico and Pomponi, (D'Amico & Pomponi, 2018b), and of Tecchio et al. (Tecchio, Gregory, Ghattas, et al., 2019; Tecchio, Gregory, Olivetti, et al., 2019), it is obvious that for studying the environmental impact of a civil infrastructure system with a lot of projects, a huge amount of parameters is required for every single structure.

The bottom-up approach met in the literature cannot be applied to a research that focuses on infrastructure systems in the society level (considering the means of study that one single individual has). The EXIOBASE 3 database includes 85 types of emissions (Stadler et al., 2018) and is a top-down approach that allows the study of infrastructure systems.

3.2.3 Challenges of environmental value

The discussion and the development of life cycle assessment (LCA) started at 1970s. The main idea was to quantify the environmental impact of a product or service through the pollutants created by them. At 1990s the discussion shifted to the creation of holistic methods including indirect factors such as the energy used for a product etc. (Kikuchi, 2016). Society of Environmental Toxicology and Chemistry (SETAC) defined LCA on 1995 as (Kikuchi, 2016): "*A process to evaluate the environmental burdens associated with a product system, or activity by identifying and quantitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment. The assessment includes the entire life cycle of the product or activity, encompassing extracting and processing raw materials*; manufacturing; distribution; use; re-use; maintenance; recycling and final disposal; and all transportation involved. LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion." The concept of life cycle analysis of a product explained in a very simple and coherent way with the phrase "*cradle-to-grave*" (Curran, 1997; Curran & Young, 1996).

In the framework of this discussion, the International Organization for Standardization (ISO) attempt to create an international standard for the LCA in 1997, which was revised in 2006 and is in force until today (The International Standards Organisation, 2006b). According to The International Standards Organisation (2006): "*LCA* *addresses the environmental aspects and potential environmental impacts*" *of a product*:

- through "*an inventory of input/output data with regard to the system being studied*"
- by providing "*additional information*" for assessing the impact results and understanding "*their environmental significance*"
- by summarizing the results of the inventory or the impact, or both and discussing them "*as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition*"

The major revision between the 1997 and 2006 definitions of ISO was that instead of considering only the environmental aspects and impacts of the product, the environmental aspects and impacts were considered "*throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)*", aligning with the SETAC definition of LCA.

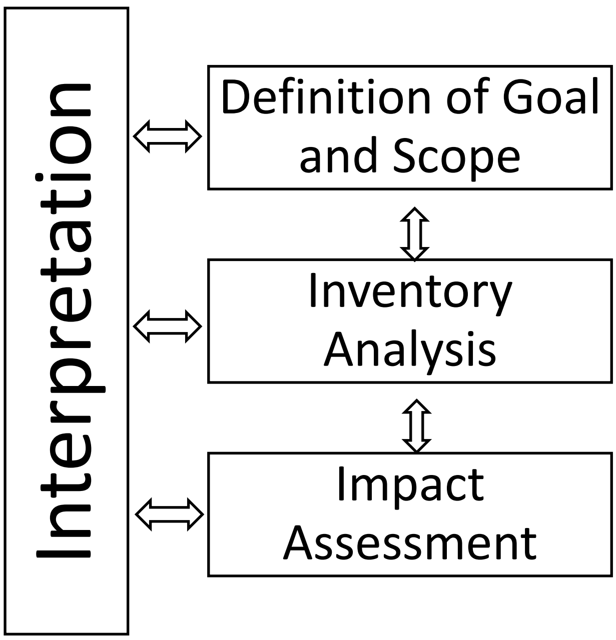


Figure 3.4 LCA structure according to ISO 14040 (The International Standards Organisation, 2006)

The major revision between the 1997 and 2006 definitions of ISO was that instead of considering only the environmental aspects and impacts of the product, the environmental aspects and impacts were considered "*throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)*", aligning with the SETAC

definition of LCA. The challenge is the transformation of a product system to a more complex system, such as an infrastructure system.

"*Infrastructure generally conjures up the notion of a large-scale physical resource made by humans for public consumption*" (Frischmann, 2012). Considering the definitions of sustainability and infrastructure, a major challenge is to determine the "*grave*" of the infrastructure system since as a "*physical resource*" should serve the future generations. Transport sector and subsequently transport infrastructure produces different types of emissions which cannot always grouped. The construction sector of any infrastructure produces, among others, the following air emissions: CO2 , N2O , CH4 , NOx , SOx , NH3 , NMVOC , CO , Pb , Cd , Hg , As , Cr , Cu , Ni , Se , Zn , PM10 , PM2.5 , Benzo-[a]-pyrene , Benzo-[b]-fluoranthene , Benzo-[k]-fluoranthene , Indeno-[1,2,3-cd]-pyrene , PCDD/F (dioxins and furans) and TSP (Merciai & Schmidt, 2018, 2016). The different approached, due to limitations; calculate a specific amount of emissions generated or emission equivalents.

A common way to compote the emissions generated, based on the economic approach, is the usage of rational multipliers (Merciai & Schmidt, 2018). The choice and the estimation of the proper multiplayers in estimating the emissions generated by each sector or action (Merciai & Schmidt, 2018; Stadler et al., 2018). This approach has partly been adopted from the LCA approach using characterization factors. Characterization starts with the categorization of the environmental impact in the proper category, followed by the application of the corresponding model to indicate the results of the category (The International Standards Organisation, 2006b). In other words, characterization is the calculation of category indicator results by summing the products of characterization factor times the inventory results of each category. Then normalization of the results is achieved by presenting them to a relative reference value over a defined period of time (The International Standards Organisation, 2006b). After the normalization the results may be weighted by modifying the results of each category to aggregate results using fixed multipliers between the different impact categories or indicators.

This is the logic behind LCA and on this logic were based all the methodologies developed (even EXIOBASE 3). All the methodologies are based on linear analysis using multipliers called characterization factors. The key element of the LCA methodologies is the conversion of the complicated emission generation relations to linear relations, since it regards all processes as linear (J. B. Guinée et al., 2001). All the methods use characterization factors which "*linearly express the contribution of a unit mass of an emission to the environment*" (Menoufi, 2011). Some steps of LCA methodologies which use non-linear equations can still be transformed to linear ones. Furthermore, it was noticed that, the linearity assumption used either when not enough data were available or when the size of the data was huge with detailed changes, but challenges on creating an explicit model. In transport infrastructure, the linearity assumption used for material usage against emission by spatial placement (volume, distance, area etc.) such as concrete (Chester, 2008), steel (Chester, 2008), herbicides (Chester, 2008), salt (Chester, 2008) etc., for small infrastructure projects against spatial placement (distance, area, volume etc.), such as track construction (Chester, 2008), lighting (Chester, 2008), parking space (Chester, 2008).

Actions causing damage to the environment are difficult to quantify. The effect of each emission on human health is different not only to the human population but to each person individually. Emissions address the production of pollutants and the waste placement into the environment (FAO, 2017). They are a widely accepted way by the Food and Agriculture Organization of the United Nations to “calculate” environmentally damaging actions (FAO, 2017) and therefore the environmental value of each action. Regarding the transport sector, there are different models calculating the emissions generated by each transport mode. The author has access to primary survey data of a representative sample of the UK’s demography describing the percentage of distance covered daily by each transport mode (or for a year for air and water transport).

The survey provided only the type of transport as it is described in the first column of Table 3.15. The missing data/details regarding the transport mode used (e.g. size of car, type of rail transport) do not allow the data to be used as they are. The worst case scenario assumption applied for CO_2 emissions generation for defined passengers (see Table 3.15) assuming that each individual used the most harmful mode of the second column of Table 3.15 for the environment. Still the distance is not accurate as it was provided by the individuals themselves and not by a trustworthy methodology. So the usage of primary data is very challenging.

The transport modes, as considered in this study without the number of passengers as a parameter, is presented in the first column of the Table 3.15. The second column shows how the transport modes were studied by the European Environment Agency (2006) and the United States Environmental Protection Agency (2016) and the average number of passengers each mode had. The third column shows the emissions produced per passenger for each transport mode and the fourth column the ranking of the modes from least to most emissions produced per passenger.

Table 3.15 CO_2 emissions of Transport/ Worst case scenario (European Environment Agency, 2006; United States Environmental Protection Agency, 2016)

Transport Mode	Explanation of transport mode	Worst case scenario of CO_2e (g CO_2/ Km*pax)	Worst case scenario Ranking
Walking	Walking	0	1
Cycling	Cycling	0	1
Rail	Tube / Subway; Tram; International rail; National rail (156/52 passengers)	14/42	3
Bus	Coach bus (12,7 passengers)	68	4
Car	Big petrol car (1,5 passenger)	158	6
Taxi	Taxi (1,5 passenger)	134	5
Air transport	Short-haul/ Long-haul/ Domestic flight (88 passengers)	285	8
Water Transport	Sea/ Inland ship	245	7

The challenge to quantify environmental damage (value) can be seen by focusing only in one single trip with defined distance (e.g. Buenos Aires to London) and to one type of emission (e.g. carbon emissions). The chart below (Figure 3.5) is based on 2011 UK data from DEFRA, except the emissions from electric cars which are taken from a report by EcoMetrica, as this data was absent from the DEFRA data (Beagley-Brown Design, 2012). Figure 3.5 shows the transport carbon emissions of each transport mode with different number of passengers for travelling a defined distance, assuming there was a linear connection between the two spots (Buenos Aires to London) and applying the existing legislation/rules for air/water transport.

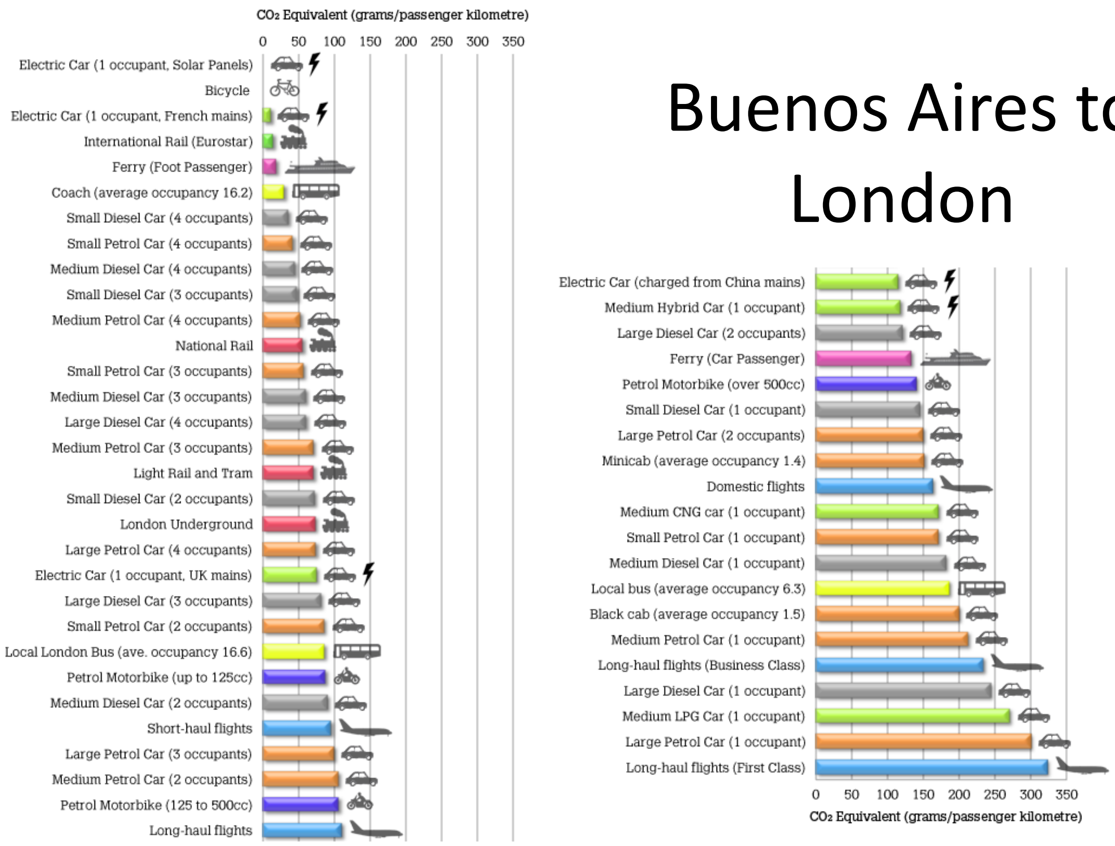


Figure 3.5 Transport Carbon Emissions (Equivalent) per passenger km (Beagley-Brown Design, 2012)

The major issue with electric vehicles is that the origin of the electricity used cannot be known in exact level. Even at a strategic level (e.g. country level) the differences are large. It can be seen that the emissions produced indirectly from an electric car in China are more than using a large petrol car with three occupants or a medium petrol car with two occupants. Additionally, a car plugged into the mains in France is producing fewer emissions than the same car in the United Kingdom since the energy sector (electricity etc) in France produces fewer emissions and if this energy is produced by solar panels then it would be a zero-emission process. Another issue is the calculation of the emissions of air transport. Every increase at the weight of the airplane or the altitude of the flight has major impact on emissions produced and on global warming. The highest the altitude the emissions released the bigger the impact on global warming (Beagley-Brown Design, 2012). Although this is not strictly true as there are certain critical altitudes for emissions (Sausen et al., 2005), but still the altitude effects differently the environmental impact of the emissions. Additionally, each type of flight and sometimes even each organization have different safety rules and combing it with the type of the aircraft (Beagley-Brown Design, 2012). To conclude the primary data provided by a survey are difficult to be used and not accurate.

3.2.4 Water and air pollution

Secondary data of transport emissions may be found from previous studies. The EXIOBASE 3 database includes 85 types of emissions both for water and air pollution (Stadler et al., 2018). EXIOBASE 3 includes environmentally extended multiregional input-output tables linked with the economic input-output tables of each country (Stadler et al., 2018). The emissions should, inductively, be reduced based on what is of interest to this study, because the size limitation of this research does not allow the development of the theory (deduction) of all types of emissions. The emissions will be studied for water and waste pollution. Of interest to this study are transport, energy, water, waste and communication sectors. It will be checked by which IOG (input-output group) each emission is produced and if it is of interest to this study. The separation of the sectors/ IOGs differentiates than the separation of sectors/IOGs done in the economic input-output tables (Chapter 3.1).

The EXIOBASE 3 database is the empirical data used to conclude which types of emissions were produced by transport, energy, water, waste and communication, a general conclusion, and the theory will come from the resultant observations, as induction commands (see Chapter 1.3; Ghauri & Grönhaug, 2010; May, 2011).

Transport sector includes the IOGs of transportation (economic approach):
1) Transport via railways, 2) Other land transport, 3) Transport via pipelines,
4) Sea and coastal water transport, 5) Inland water transport, 6) Air transport and the IGOs of manufacturing of vehicles and transport related services (engineering approach): 7) Manufacture of motor vehicles, trailers and semi-trailers,
8) Manufacture of other transport equipment, 9) Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories and
10) Retail sale of automotive fuel.

Energy sector includes: 1) Production of electricity by coal, 2) Production of electricity by gas, 3) Production of electricity by nuclear, 4) Production of electricity by hydro, 5) Production of electricity by wind, 6) Production of electricity by petroleum and other oil derivatives, 7) Production of electricity by biomass and waste,
8) Production of electricity by solar photovoltaic, 9) Production of electricity,
10) Transmission of electricity, 11) Distribution and trade of electricity, and
12) Manufacture of gas; distribution of gaseous fuels through mains.

Water sector includes: 1) Steam and hot water supply and 2) Collection, purification and distribution of water.

Communication sector includes: 1) Post and telecommunications.

Waste sector includes: 1) Incineration of waste: Food, 2) Incineration of waste: Paper, 3) Incineration of waste: Plastic, 4) Incineration of waste: Metals and Inert materials, 5) Incineration of waste: Textiles, 6) Incineration of waste: Wood, 7) Incineration of waste: Oil/Hazardous waste, 8) Biogasification of food waste, incl. land application, 9) Biogasification of paper, incl. land application, 10) Biogasification of sewage slugde, incl. land application, 11) Composting of food waste, incl. land application, 12) Composting of paper and wood, incl. land application, 13) Waste water treatment, food, 14) Waste water treatment, other, 15) Landfill of waste: Food, 16) Landfill of waste: Paper, 17) Landfill of waste: Plastic, 18) Landfill of waste: Inert/metal/hazardous, 19) Landfill of waste: Textiles and 20) Landfill of waste: Wood.

Table 3.16 Emissions produced by the transport sector

Emission	Type of emissions (European Environment Agency, 2006)	Assessment method (European Environment Agency, 2006)	Literature/Theory
CO_2	Fuel-Related Pollutants	Fuel Consumption	COPERT model (Laou, 2013)
CH_4	Non-Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
N_2O	Non-Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
SO_x	Non-Regulated Pollutant	Fuel Consumption	COPERT model (Laou, 2013)
NO_x	Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
NH_3	Non-Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
CO	Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
Benzo(a)pyrene	Fuel-Related Pollutants	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)

Benzo(b)fluoranthene	Fuel-Related Pollutants	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)
Benzo(k)fluoranthen	Fuel-Related Pollutants	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)
Indeno(1,2,3-cd)pyrene	Fuel-Related Pollutants	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)
PCDD_F	Fuel-Related Pollutants	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)
NMVOC	Non-Regulated Pollutant	Total percentage of Volatile organic compound	COPERT model (Laou, 2013)
PM_{10}	Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
$PM_{2 5}$	Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
TSP	Regulated Pollutant	Emissions Coefficients	COPERT model (Laou, 2013)
As	Heavy metals	n/a	(Stadler et al., 2018)
Cd	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
Cr	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
Cu	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
Hg	Heavy metals	n/a	(Stadler et al., 2018)
Ni	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
Pb	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
Se	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)

Zn	Heavy metals	Fuel Consumption	COPERT model (Laou, 2013)
NMVOC (non combustion)	Non-Regulated Pollutant	n/a	(Stadler et al., 2018)

To conclude inductively 26 emissions were found to be produced by the transport sector based on the empirical data (see Table 3.16). The next step is to look for a connection with the theory as induction demands. 23 of the 26 emissions are calculated by the engineering combustion model COPERT - Calculation of Emissions from Road Transport (Laou, 2013). Two of the missing ones (As and Hg) are produced only by water transport and the other one (NMVOC) is a non-combustion pollutant (Stadler et al., 2018).

3.2.5 Environmental value

Since the economic demand of each sector is calculated and published by the UK government (Office for National Statistics, 2015; see Chapter 3.1), it is easy to calculate the total production of each emission; it is equal to the demand of each sector multiplied by the environmental coefficient of each pollutant. For the United Kingdom the environmental coefficients of the transport sector are in the following table (see Table 3.17).

Table 3.17 Environmental value of transport infrastructure in the UK*

Combustion	/M.EUR	Transport via railways	Other land transport	Transport via pipelines	Sea and coastal water transport	Inland water transport	Air transport
CO_2	kg	111343.9	75817.3	71681.5	1108655.2	18300000.0	1862350.6
CH_4	kg	6.2	4.6	4.3	78.7	1257.0	14.3
N_2O	kg	42.2	28.7	27.1	73.2	4603.2	53.2
SO_x	kg	17.1	2.0	1.9	17143.4	152268.4	568.8
NO_x	kg	1811.1	519.3	490.9	25327.9	408003.5	6118.8
NH_3	kg	0.3	1.1	1.0	0.1	0.1	0.2

CO	kg	371.9	178.3	168.5	2609.1	41939.4	11860.3
Benzo(a)-pyrene	kg	0.0	0.0	0.0	0.0	0.0	0.0
Benzo(b)-fluoranthene	kg	0.0	0.0	0.0	0.0	0.1	0.0
Benzo(k)-fluoranthen	kg	0.0	0.0	0.0	0.0	0.0	0.0
Indeno(1,2,3-cd)pyrene	kg	0.0	0.0	0.0	0.0	0.0	0.0
PCDD_F	kg I-TEQ	0.0	0.0	0.0	0.0	0.0	0.0
NMVOC	kg	160.2	28.6	27.0	844.8	13600.9	435.2
PM_{10}	kg	50.2	30.3	28.6	2122.4	18402.1	12.5
$PM_{2\ 5}$	kg	47.8	27.9	26.4	2122.3	18402.0	57.9
TSP	kg	53.4	44.3	41.9	2123.1	18402.6	14.2
As	kg	0.0	0.0	0.0	154.9	1086.6	0.0
Cd	kg	0.0	0.0	0.0	9.3	65.2	0.0
Cr	kg	0.0	0.0	0.0	0.1	0.6	0.0
Cu	kg	0.1	0.1	0.1	154.9	1086.6	0.0
Hg	kg	0.0	0.0	0.0	6.2	43.6	0.0
Ni	kg	0.0	0.0	0.0	9.3	65.4	0.0
Pb	kg	0.0	0.0	0.0	0.1	0.8	0.0
Se	kg	0.0	0.0	0.0	0.1	1.6	0.0
Zn	kg	0.0	0.0	0.1	0.3	3.7	0.0
NMVOC (NC)	Kg	94.0	117.3	1.2	11.1	22.7	44.9

*The raw data of Table 3.17 is in Appendix D.

In Table 3.17 there are coefficients which are used to transform input-output tables' demand and production of each sector to emissions. The first column shows the emission, the second column shows the unit that the emission is calculated in and the other 6 columns shows the coefficient to transform each sector's production and demand to this emission. For example, the production of "Transport via railways" IOG in Millions of Euros has to be multiplied with 111343.9 for estimating the kg of CO_2

Table 3.17 presents the IOGs' environmental coefficients of the transport sector as it is defined by the economists and not by engineers, meaning excluding vehicles and transport related services. Vehicles and services are considered as manufacturing and services sectors by the economic theory and not as part of the transport sector as transport engineering theory considers.

At first glance transportation via pipelines is the most sustainable way since it produces the least pollutants and the inland water transport is the most harmful for the environment. Of course this is a quantitative conclusion based on the number of the pollutants and not a qualitative one since this research does not compare the effect between the different pollutants. In other words, a specific pollutant which is mostly produced by the sector with lower levels of less other pollutants (transportation via pipelines) may harm majorly the environment regardless of the quantity of other pollutants. This needs a deeper analysis from scientists of other fields (e.g. chemical engineers, environmental scientists etc.)

The sustainability ranking changes based on each pollutant, but this matrix is a good way to evaluate each transport sector in the United Kingdom. Air transport is less harmful than water transport and more harmful than land transport. This differs from the previous findings in the literature (e.g. European Environment Agency, 2006). Although the literature presented before (e.g. European Environment Agency, 2006) did not consider the freight transport. Additionally, the EXIOBASE are estimated emissions per millions of euros of demand of each sector, so the results cannot be compared with the real generation of the emissions, since the cost is not representative of the distance covered, the weight of the freight goods transferred etc. The findings are useful and viable when they are combined with the economic value (demand) presented in chapter 3.1, since the assumptions of the EXIOBASE align with the real relations and the assumptions of the demand driven input-output tables.

In a questionnaire survey a representative sample of the UK's demography was asked, above others, to score between −5 and 5 the effect of each transport mode to the environment and on human health. The individuals recognized the ranking with some deviations (see Table 3.18).

Table 3.18 Transport mode environmental impact ranking

Transport Mode	Environment evaluation mean	Health evaluation mean	Environment Ranking	Health Ranking	European Environment Agency Ranking (2014)
Walking	3.9100	3.7100	1	1	1
Cycling	3.8500	3.4033	2	2	1
Rail	-1.5900	-2.4333	3	4	3
Bus	-2.9367	-2.5900	5	6	4
Car	-3.9133	-2.8233	8	8	6
Taxi	-3.6700	-2.6000	7	7	5
Air transport	-3.3367	-2.4733	6	5	8
Water Transport	-2.4500	-1.8167	4	3	7

The main difference is that the participants thought that the car/taxi is the most harmful for the environment and not the air and water transport, as the literature shows in the context of the planet. This difference may depend on the context in which the participants were asked the questions. The questionnaire had the air/water transport evaluation apart from the land transport evaluation. This may mean that some participants evaluated land transport in the context of a city and air/water transport in the context of the planet when others evaluated them in the same context. The other difference is that the participants were unable to track the effect of the water to the environment and they thought it is less than other transport modes, although it is the second worst after air transport.

To conclude, environmental value is related to the emissions generated. Emissions calculated were translated into estimated emission coefficients for each sector which equal an average sector rate per GDP. This was done with the EXIOBASE which is a multi-regional environmentally extended Input-Output database. In other words, emissions are generated with an almost linear relationship and consequently environmental value has a negative linear relationship with GDP since the emission is something negative for the environment.

3.2.6 Environmental infrastructure interdependencies

Different methodologies were used for calculating the EXIOBASE emissions of each type of industry meaning that any correlation will be a result of dependency between the different industries. Additionally, each country/area has different sizes of industry developed over the lifecycle.

The key challenge is how to cross-correlate the environmental coefficients to see how they are correlated. Pearson correlation is a common method to expose the correlation between series, but since the data were calculated by developing time series of detailed environmentally extended multi-regional input-output tables, the spurious regression or spurious correlation case should eliminated. Spurious regression was reduced as follows:

Stadler et al. (2018) removed all the perfectly correlated indicators (14 indicators) a priori and the remaining 105 indicators, which also showed very high correlations, were reduced with the principal component analysis (PCA) and an optimization methodology based on the PCA results. This way the correlation based on the calculating indicators and the within-series dependence were eliminated. This can be seen even if coefficients from the same group of sectors are compared with Pearson’s correlation, since although similar indicators were used, the correlation is not high in every case and never perfect.

Additionally, the research did not use the chronological development of the data (time-series), but the regional development (same year different country). Each country has a different way of development over time, different legislation and is in the different stage of development. This means it is possible to accept the linearity of the data (linear regression analysis) and assume this linear relationship extends to the total world activity, so enabling the application of the Pearson correlation method. This is a safe assumption, as the authors of the EXIOBASE 3 do it too and are reliable as the EXIOBASE 3 is widely used by input-output modelers worldwide. The unknown activity rate is estimated for each year by applying linear regression with a constant offset parameter. In mathematical terms, it can be seen that it is not the ideal method, but it makes up only a small part of the missing data where the real values are missing. (Stadler et al., 2018, S3 – 7). Additionally, “*the input-output models are linear and do not assume increasing or decreasing returns to scale*” (Chester, 2008, p.210).

To conclude the IOGs that belong in the same sector group are correlated because a similar methodology was used to estimate the emissions produced. So these correlations are rejected since it is not clear if they are a result or as a result of the estimation methodology. Most probably, they are the result of the estimation methodology meaning that the results are biased.

A table with the calculated correlations between the sectors of interest for each pollutant was created. Table 3.19 is the example table of CO_2. The sectors within the same group were highlighted and removed (see column 3 at Table 3.19). Then the number of missing data points was checked and if the missing data were more than 10%, the connection was removed too (see column 2 at Table 3.19). e.g. EnergyNuclear may be dependent with other sectors, but since a lot of the areas studied do not have this type of energy it is not possible to identify the connection

Table 3.19 CO_2 emission generation correlation between sectors

IOGs	Correlation – CO_2/zeros	Type
WIPlastic - WITextile	1.000/***x***	**W-W**
WBFood - WBPaper	0.999/***x***	**W-W**
WIMetal - WCFood	0.999/***x***	**W-W**
WIMetal - WIOil	0.993/***x***	**W-W**
NWaterSupply -WIMetal	0.993/***x***	N-W
NWaterSupply - WCFood	0.992/***x***	N-W
WLFood - WLTextile	0.991/✓	**W-W**
WLPaper - WLTextile	0.990/✓	**W-W**
WLFood - WLPaper	0.990/✓	**W-W**
WLPlastic - WLWood	0.957/✓	**W-W**
WIOil - WCFood	0.928/***x***	**W-W**
NWaterSupply - WLMetal	0.919/✓	N-W
NWaterSupply - WIOil	0.919/***x***	N-W
WIMetal - WLMetal	0.919/***x***	**W-W**
EnergyTransm - EnergyDistrib	0.918/✓	**E-E**
WCFood - WLMetal	0.913/***x***	**W-W**

WLFood - WLWood	0.893/✓	**W-W**
WLPaper - WLWood	0.888/***x***	**W-W**
WIOil - WLMetal	0.887/***x***	**W-W**
WIFood - WIPaper	0.874/***x***	**W-W**
WLTextile - WLWood	0.872/✓	**W-W**
EnergyCoal - EnergyDistrib	0.846/✓	**E-E**
EnergyTransm - NWaterDistrib	0.841/✓	E-N
EnergyCoal - EnergyTransm	0.828/✓	**E-E**
WWFood - WWOther	0.816/✓	**W-W**
TManufMotor - TPipelines	0.803/✓	T-T
EnergyNuclear - EnergyWind	0.767/***x***	**E-E**
EnergyDistrib - NWaterDistrib	0.761/✓	E-N
WLPaper - WLPlastic	0.753/✓	**W-W**
WLFood - WLPlastic	0.750/✓	**W-W**
EnergyOcean - WCPaper	0.731/***x***	E-W
TSaleFuel - Communic	0.725/✓	T-C
WLPlastic - WLTextile	0.715/✓	**W-W**
EnergyCoal - NWaterDistrib	0.707/✓	E-N
TRail – Communic	0.617/✓	T-C
EnergyPetrol - TAir	0.598/✓	T-E
WWFood - WLFood	0.591/✓	**W-W**
TSea - WIPlastic	0.591/***x***	T-W
TSea - WITextile	0.591/***x***	T-W
EnergyGeoth - TPipelines	0.589/***x***	E-T

WWFood - WLPaper	0.579/✓	**W-W**
WIOil - WWOther	0.579/*x*	**W-W**
WWFood -WLTextile	0.565/✓	**W-W**
TManufMotor - EnergyGeoth	0.556/✓	T-E
TOther - TAir	0.554/✓	**T-T**
TManufMotor - TManufOther	0.553/✓	**T-T**
EnergyBiomass - EManufGas	0.547/✓	E-E
EnergySolar2 - EnergyGeoth	0.545/*x*	E-E
WWOther - WLMetal	0.538/✓	**W-W**
EnergyNuclear - NWaterDistrib	0.537/*x*	E-N
EnergyTransm - TOther	0.492/✓	E-T
TManufOther - TPipelines	0.489/✓	**T-T**
EnergyNuclear - TAir	0.488/*x*	E-T
WIFood-WIPlastic	0.487/*x*	**W-W**
WIFood-WITextile	0.487/*x*	**W-W**
TManufMotor - TRail	0.484/✓	**T-T**
EnergyTransm - TOther	0.483/✓	E-T
EnergyNuclear - EnergyTransm	0.481/*x*	**E-E**
EnergyNuclear - TOther	0.477/*x*	E-T
NWaterDistrib - TOther	0.474/✓	N-T
EnergyBiomass - TPipelines	0.468/✓	E-T
TManufMotor - EnergyWind	0.464/✓	T-E
EnergyPetrol - TOther	0.463/✓	T-E
Energynec - WWOther	0.462/✓	E-W

EnergyWind - NWaterDistrib	0.462/*x*	E-N
EnergyPetrol - EnergyDistrib	0.475/✓	**E-E**
Energynec - WWFood	0.455/*x*	E-W
NWaterSupply - WWOther	0.449/*x*	N-W
EnergyWind - EnergyTransm	0.444/*x*	**E-E**
EnergyCoal - EnegryPetrol	0.442/✓	**E-E**
EnergyWind -TPipelines	0.440/*x*	**E-E**
WBFood - WBSewage	0.434/*x*	**W-W**
TSea - WIWood	0.430/*x*	T-W
WBPaper - WBSewage	0.430/*x*	**W-W**
WIMetal - WWOther	0.428/*x*	**W-W**
WWFood - WLMetal	0.421/*x*	**W-W**
EnergySolar1-EnergySolar2	0.420/*x*	**E-E**
WCFood - WWOther	0.420/*x*	**W-W**
EnergyNuclear - EnergyDistrib	0.410/*x*	**E-E**
EnergyNuclear - EnegryPetrol	0.409/*x*	**E-E**
WIOil - WWFood	0.407/*x*	**W-W**
TSaleFuel - WLPaper	0.407/*x*	T-W
TRail-TSaleFuel	0.406/✓	**T-T**
EnergyGas - Communic	0.405/✓	E-C
EnergySolar1 - TRail	0.401/*x*	E-T
TSaleFuel - WLFood	0.396/✓	E-W
TSaleFuel - WLTextile	0.387/✓	T-W
EnergyGas - TRail	0.385/✓	E-T

WBFood - WCPaper	0.381/***x***	**W-W**
WWFood - WLWood	0.381/***x***	**W-W**
EnergyGas - TWaterLand	0.378/✓	E-T
WBPaper - WCPaper	0.377/***x***	**W-W**

The IOGs glossary of the first column of the Table 3.19 is as follows:

- TRail is the "Transport via railways" IOG of Exiobase
- Tother is the "Other land transport" IOG of Exiobase
- TPipelines is the "Transport via pipelines" IOG of Exiobase
- TSea is the "Sea and coastal water transport" IOG of Exiobase
- TManufMotoris the "Manufacture of motor vehicles, trailers and semi-trailers" IOG of Exiobase
- TManufOther is the "Manufacture of other transport equipment" IOG of Exiobase
- TAir is the "Air transport" IOG of Exiobase
- TSaleFuel is the "Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories" IOG of Exiobase
- EnergyCoal is the "Production of electricity by coal" IOG of Exiobsase
- EnergyGas is the "Production of electricity by gas" IOG of Exiobase
- EnergyNuclear is the "Production of electricity by nuclear" IOG of Exiobase
- EnergyWind is the "Production of electricity by wind" IOG of Exiobase
- EnergyHydro is the "Production of electricity by hydro" IOG of Exiobase
- EnergySolar1 is the "Production of electricity by solar photovoltaic" IOG of Exiobase
- EnergySolar2 is the "Production of electricity by solar thermal" IOG of Exiobase
- EnergyTransm is the "Transmission of electricity" IOG of Exiobase
- Energynec is the "Production of electricity nec" IOG of Exiobase
- EnergyPetrol is the "Production of electricity by petroleum and other oil derivatives" IOG of Exiobase
- EnergyBiomass is the "Production of electricity by biomass and waste" IOG of Exiobase
- EnergyOcean is the "Production of electricity by tide, wave, ocean" IOG of Exiobase
- EnergyGeoth is the "Production of electricity by Geothermal" IOG of Exiobase
- EnergyTransm is the "Transmission of electricity" IOG of Exiobase
- EnergyDistrib is the "Distribution and trade of electricity" IOG of Exiobase
- Communic is the "Post and telecommunications" IOG of Exiobase
- NWaterSupply the "Steam and hot water supply" IOG of Exiobase
- NWaterDistrib is the "Collection, purification and distribution of water" IOG of Exiobase

- WIFood is the "Incineration of waste: Food" IOG of Exiobase
- WIPaper is the "Incineration of waste: Paper" IOG of Exiobase
- WIMetal is the "Incineration of waste: Metals and Inert materials" IOG of Exiobase
- WITextile is the "Incineration of waste: Textiles" IOG of Exiobase
- WIWood is the "Incineration of waste: Wood" IOG of Exiobase
- WIOil is the "Incineration of waste: Oil/Hazardous waste" IOG of Exiobase
- WWFood is the "Waste water treatment, food" IOG of Exiobase
- WWOther is the "Waste water treatment, other" IOG of Exiobase
- WCFood is the "Composting of food waste, incl. land application" IOG of Exiobase
- WCPaper is the "Composting of paper and wood, incl. land application" IOG of Exiobase
- WBPaper is the "Biogasification of paper, incl. land application" IOG of Exiobase
- WBFood is the "Biogasification of food waste, incl. land application" IOG of Exiobase
- WBSewage is the "Biogasification of sewage slugde, incl. land application" IOG of Exiobase
- WLFood is the "Landfill of waste: Food" IOG of Exiobase
- WLPaper is the "Landfill of waste: Paper" IOG of Exiobase
- WLPlastic is the "Landfill of waste: Plastic" IOG of Exiobase
- WLMetal is the "Landfill of waste: Inert/metal/hazardous" IOG of Exiobase
- WLTextile is the "Landfill of waste: Textiles" IOG of Exiobase
- WLWood is the "Landfill of waste: Wood" IOG of Exiobase

The third column of Table 3.19 shows the environmental dependence between the sectors of Transport (T), Communication (C), Energy (E), Water (N) and Waste (W), e.g. T-C means that Transport and Communication Sectors are dependent for the specific IOG.

The same process repeated for the other 25 emission and the results are shown to the following table (Table 3.20).

Table 3.20 Environmental infrastructure interdependencies

Emission	Transport Dependency	Air	Land	Water
CO_2	Energy; Communication; Water; Waste	Energy; Communication; Water; Waste	Energy; Communication; Water; Waste	Energy; Communication; Water; Waste
CH_4	Energy	Energy	Energy	–
N_2O	Energy; Communication	–	Energy; Communication	–
SO_x	Energy; Communication; Water; Waste	Energy; Waste	Energy; Communication;	–
NO_x	Energy; Communication; Water; Waste	Communication	Energy; Communication; Water	–
NH_3	Energy; Communication; Water; Waste	Energy; Water; Waste	Energy; Communication; Water; Waste	Energy; Water; Waste
CO	Energy; Communication; Water; Waste	Energy; Communication	Energy; Communication; Water; Waste	–
Benzo(a)pyrene	Energy; Communication; Waste	–	Energy; Communication; Waste	–
Benzo(b)fluoranthene	Energy; Communication; Waste	–	Energy; Communication	Energy
Benzo(k)fluoranthen	Energy; Communication	Energy	Energy; Communication	Energy
Indeno(1,2,3-cd)pyrene	Energy; Communication; Water	Energy	Energy	–

PCDD_F	(Missing values)	(Missing values)	(Missing values)	(Missing values)
NMVOC	Energy; Communication; Water	Energy	Energy; Communication; Water	–
PM_{10}	Energy; Communication; Water	Energy	Energy; Communication; Water	–
$PM_{2.5}$	Energy; Communication; Water	Energy	Energy; Communication; Water	–
TSP	Energy; Communication; Water	Energy	Energy; Communication; Water	Energy
As	(Missing values)	(Missing values)	(Missing values)	(Missing values)
Cd	Energy; Water	Energy; Water	Energy; Water	–
Cr	Energy; Communication	Energy	Energy; Communication	–
Cu	Energy; Communication; Water	Energy	Energy; Communication; Water	Waste
Hg	(Missing values)	(Missing values)	(Missing values)	(Missing values)
Ni	Energy	Energy	Energy	–
Pb	Energy; Communication; Water	Energy; Water	Energy; Communication; Water	–
Se	Energy; Communication; Water	Energy	Energy; Communication; Water	–
Zn	Energy; Communication; Water	Energy	Energy; Communication; Water	–
NMVOC (non-combustion)	Energy; Water; Waste	–	Energy; Water; Waste	–

For comparison reasons the pollutants generated by the other infrastructures of interest (energy, waste, water and communication) in the United Kingdom are provided in the appendix (see Appendix D).

3.2.7 Conclusions

The statistical inference of the EXIOBASE showed quantitative emissions generation interdependencies and of the primary data showed the environmental impact of the transport mode as it is understood by the individuals. The reader should take into consideration that the linearity assumptions impact the analysis, but LCA and EXIOBASE are still widely accepted. For example, the most of the models of transport infrastructure are normalized by distance since the functional units used were passenger kilometer/mile travelled or track kilometer/mile travelled or construction length. Even researches which consider the different type of infrastructure, such as the research of National Rail (2009), they present the results normalized per distance. This means that the linear assumption was transferred in the normalization too. The major challenge is that comparing different type of transport infrastructures can produce biased results.

A deeper environmental analysis is required of how the different pollutant production interacts with each other (cause-effect relationship), because essentially these relationships are the result of economic analysis (similar to hybrid LCA methods) based on quantitative data and not qualitative. The results, in combination with the qualitative relationship between the pollutants, may be used by the policy makers to decide which type of transport infrastructure to promote. The environmental infrastructure interdependencies relations can be generalized as the data used were generated from all over the world not only from the United Kingdom.

On the other hand the results regarding the understanding of the environmental impact of each transport mode by the individuals can only be considered applicable in the United Kingdom since this was the area the survey took place. Broadly speaking the participants were able to recognize the environmental impact ranking of transport modes with some deviations especially on water and automobile transport, probably because of lack of information. Nevertheless, the best practices were recognized to be walking, cycling and public transport.

.

3.3 Social value

3.3.1 Introduction

A value proposition articulates the essence of a business, defining how products and services are assembled and delivered to final users in order to meet their needs (Kambil et al., 1996). Maslow (1954) developed value curves of the human need groups relative to time and the sum of the curves yields an almost sigmoid curve. Winters et al. (2001) created transportation groups of needs including: safety and security, time, societal acceptance, cost and comfort, and convenience. This research studied social value as something holistically affected by all the above factors by asking individuals, in a structured interview process that was representative of the UK's demography, to evaluate the social value of eight transport modes. The hypothesis tested is that the value to the individual relative to the aforementioned factors should have an almost sigmoid curve. This was verified: the social value function fits a cubic-spline function. Accordingly, the cubic-spline function model is used to represent the exponential increase of the studied phenomenon for a period of time, followed by a levelling off at the critical point. The inference is if infrastructures' social evaluation has passed the critical point, they do not require further investments as the social value growth is slow.

The infrastructure systems that operate in countries and cities are interrelated in different ways, but all have a strong relationship to 'transport' – there is a cost and a utility associated with movement. Infrastructure systems are ultimately created to serve individuals, who place a value on them. In order to explore all forms of investment and value realisation – what is commonly termed a business model – the relationship between an individual and the transport systems needs to be established. The hypothesis being tested in this research is that it is possible to identify both the full range of value created and investments required, and hence to establish a robust business model for transport systems (iBUILD, 2017; Liveable Cities, 2017). The study reported herein contributes to this new business model by defining the social value, since business models, by definition, focus on value creation and how value is captured (Magretta, 2002; Aho, 2015). This study focuses only on utility for individuals; other types of utility (for example commercial and business enterprise) are excluded because the social aspects of business travel are conflated with an economic function, which might mean that considerations such as facility for working on the train might dominate the traveller's perspective.

This research specifically focusses on the social value from transport infrastructure investments in the United Kingdom since the context is always a governing factor in such analyses. The economic value invested by the government on behalf of the individuals can be easily calculated based on data from the ONS. The social value gained from (i.e. invested by) the individual is difficult to calculate due to the different attitudes and behaviours of each individual. Indeed, the unique behaviour of each individual makes it challenging to determine accurately their collective behaviour. Nevertheless, previous work has attempted to quantify (and monetise) the social value of transport infrastructure investments, based on notions of subjective well-being (Currie & Stanley, 2008).

Additionally, it is difficult to separate the economic from the social, since they are interrelated. The value of time, for example, reflects both, although an economic perspective from minimising the time taken in the journey to work might be different to that of visiting friends or family because the 'time value' relates to travel in a different context, such as the social value may be the opportunity provided to meet with friends. The distinction between economic value and social value is taken herein as the following: the economic value includes the group value (money invested by the government) and the individual value (the direct cost that the individual pays) of the transport mode used by individuals living in metropolitan areas in United Kingdom. Metropolitan areas generally have more transport mode options than non-metropolitan areas in the United Kingdom. The group value is constant and concerns the whole of the group to which the individual belongs (e.g. individual's socio-economic group). The individual value concerns the individual in question and is different for every single individual, but can be defined in monetary terms. On the other hand social value focuses on the coverage of individuals' needs, is different for every single individual as each individual would spend a different amount of money to cover the same need (i.e. they would value the same social value differently), and therefore a qualitative measurement is more appropriate than a quantitative measurement.

3.3.2 Theoretical frame of reference

The challenge of deducing collective behaviour may be addressed by considering the individual user as a rational key-stakeholder, who affects the decision-making process, and not as the final user, who ultimately uses the infrastructure without interacting in the decision-making process. The individuals living in a specific urban area may be considered as '*key stakeholders*' (not just as '*final users*') since they elect the government through their voting behaviour and participate, indirectly, in the decision-making process. Previous studies have shown that transport infrastructure investment alone is not significantly linked with regional growth, but its success is more strongly linked to growth in regions with better governance (i.e. higher quality, or more effective, local government, Rodríguez-Pose, 2015). Citizens elect governments to act on their behalf – if they do not, they risk being voted out at the next election. For example, governments try to improve the utility provided to their citizens through the promotion of growth and development strategies that may involve investment in transportation infrastructure. In this regard, notions of cohesion/connectivity/accessibility become part of the decision-making calculus;

citizens indirectly make the choices based on their voting behaviour, but their utility may be enhanced/diminished by decision-makers elected by a majority that do not have values that are representative of all citizens. Social value may or may not have anything to do directly with growth, but may affect development. "*The social value is primarily focused on the attitude of the society toward the project*" (Doloi, 2018) and so the influence of stakeholders and the impact of the infrastructure on society should be analysed. Social value affects and is affected by citizens, who are the key-stakeholders in this study. The idea of social value arose from psychology, and more specifically it is based on the principle of "*independence of irrelevant alternatives*" from the game theory introduced by Luce and Raiffa (1957). According to the principle of "*independence of irrelevant alternatives*", each alternative situation (j) has an utility/value (V_{ij}) for the individual (i), and this value is a function of the features of the alternative situation (X_j) and of the characteristics of the individual (S_i) who makes the choice: $V_{ij} = V\left(X_j, S_i\right)$. Further, it is assumed that the individual who makes the choice has a clear and measurable knowledge of the value that each choice provides. However, not every individual will choose the option with the highest value; there is an element of uncertainty regarding an individual's choice. Although even after the evaluation of each choice, it is a tentative situation regarding the choice of the individual. In other words, there is an element of possibility. However, under the same principle of Luce and Raiffa (1957), the possibility of a choice is in direct ratio to its value. In essence, the assumptions constitute a "*strict utility choice mode.*" The exponential form of the value function: $V_{ij} = \exp\left[V\left(X_j, S_i\right)\right]$ is achieved by simple transformations of the "*strict utility choice mode*", where X and S have a linear correlation and leads to the "*multiple or multinomial logit model*":

$$P_j^i = \frac{\exp V\left(X_j, S_i\right)}{\sum_k^m \exp V\left(X_j, S_i\right)}$$

where,

P_j^i : is the possibility that the individual i will choose the transport mean j

V : is the linear relationship of X and S .

The exponential functions of the total value have a sigmoid form relative to the linear function of the value of each possible choice. This means that the exponential function may have a sigmoid form relative to the X-axis or Y-axis, based on the defined axes and values.

The choice of any individual can be ascertained if there is a particular list of alternative transport modes. The alternative choices are assumed to be independent of each other. The challenge exists to identify the relationships between the preferences of the individual and the features of the alternative modes, with which the value function V can be estimated. The challenge exists to identify the relationships between the features of the individuals and the features of the alternative situation, with which the value function V can be estimated. The main difference between the psychological and the previously mentioned economical approach is that while in the first approach the choice of the mean is determined with possibilities, in the second approach the choice is deterministic based on the maximum socioeconomic value. In the economical approach, the group value function $V^{'}$ can be estimated, but the individual value function E is unknown. Moving from theory to practice, it is assumed that the individual value E is distributed randomly using different distributions (e.g. Weibull distribution, which is also known as Gumbel distribution). The models derived from this process are called "*random value models*". Accepting that human behaviour indicates the social value, then the social value is indicated by the social needs which each individual attempts to satisfy. This is not something new; according to Kambil et al. (1996), a value proposition articulates the essence of a business, defining how products and services are assembled and delivered to final users in order to meet their needs. According to Maslow's (1954) Hierarchy of Needs, these needs belong to specific groups, which have the following hierarchy (Figure 3.6): [1] physiological needs, [2] safety needs, [3] love and belonging, [4] esteem and [5] self-actualization.

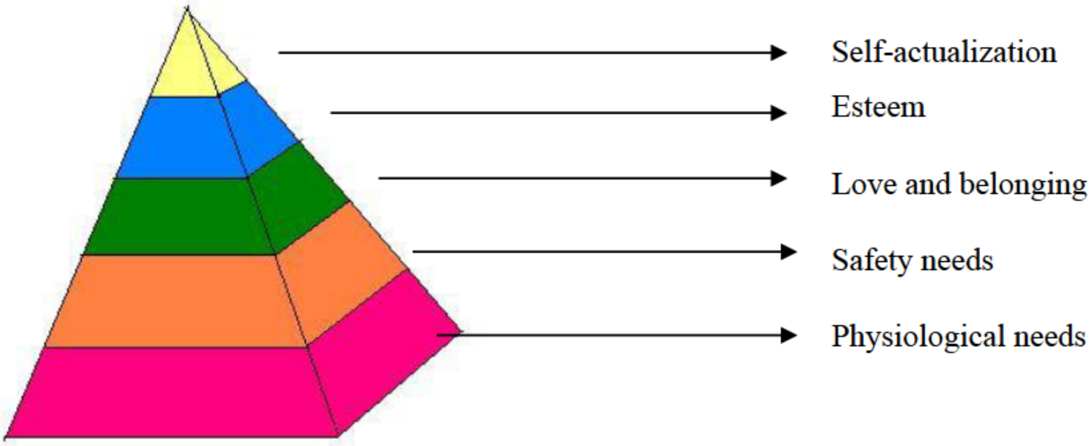


Figure 3.6 Maslow's Hierarchy of Needs (1954)

The hierarchy relates to importance without any indicator of scale, since each individual has different understanding of the needs regarding how essential or important they are. Additionally, the hierarchy shows the typical order the needs appear in the life of an individual. The '*physiological needs*' category includes all the needs associated with the existence of humankind as a biological being, such as oxygen, water, food, clothing, health, etc. '*Safety needs*' come next and include housing, permanent employment, availability of pension, etc. The category '*love and belonging*' includes the human need to belong to one or more social groups, to be accepted by them, to develop friendly relations, to gain and to offer love and affection. '*Esteem*' includes prestige, fame, appreciation, respect of the environment, the need for success, competence, knowledge, independence, freedom, influence and power, but also includes self-respect and self-esteem. Finally, '*self-actualization*' is the highest category of needs. According to Maslow, it can never be fulfilled, since it includes the need of the individual to become what he/she wants, he/she dreams in a utopian situation. Maslow developed value (utility) curves of each category of needs relative to the age of the individual.

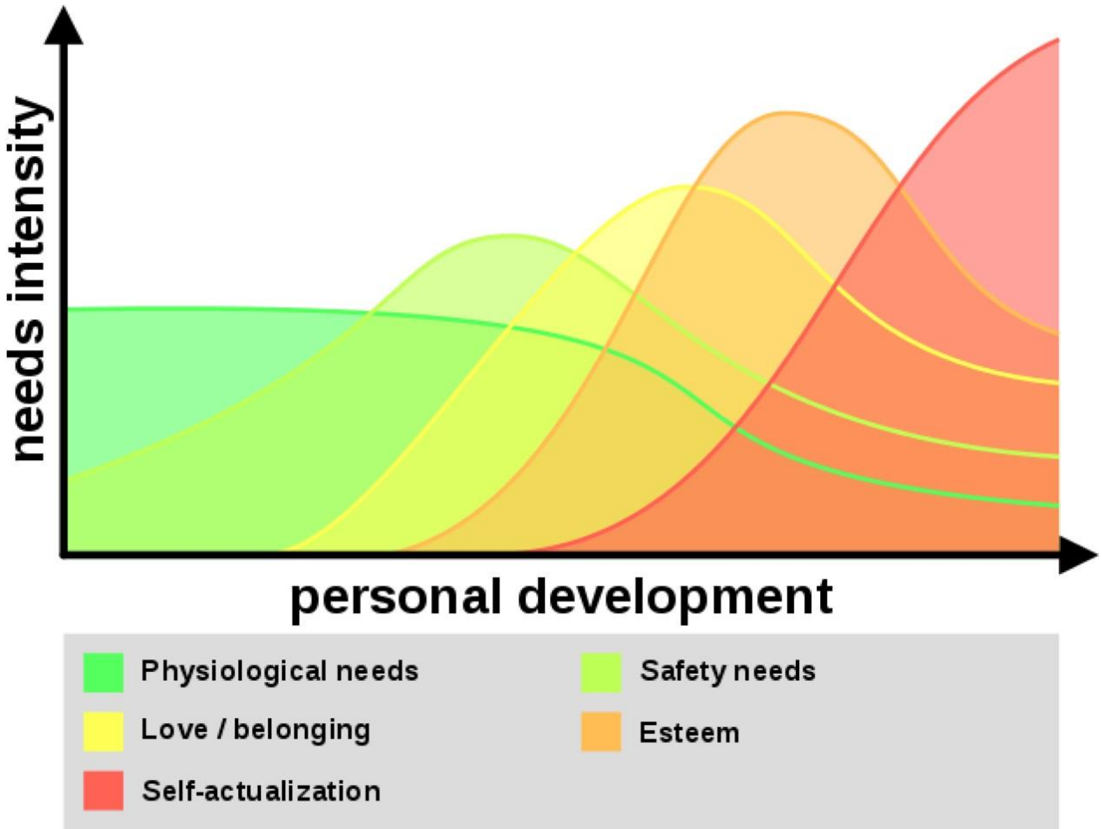


Figure 3.7 Need curves of Maslow's Hierarchy of Needs over personal development

This study uses “*value*” and “*utility*” interchangeably, as the approach to social value is rooted in mainstream value of engineering. Bourantas (2002) used these curves to evaluate the investment behaviour of individuals relative to time in general. Bourantas’ work was both an empirical and theoretical validation of Maslow’s theories in the management of several large organizations. The sum of curves (see Figure 3.7) generates a sigmoid curve over time.

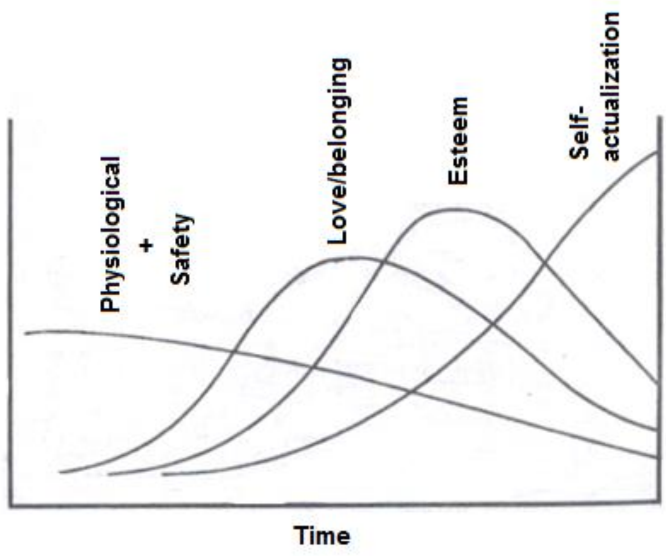


Figure 3.8 Value curves of Maslow's Hierarchy of Needs (Bourantas, 2002)

But why focus on Maslow's Hierarchy of Needs as it has been heavily criticised in contemporary philosophy and social science? Maslow's value resembles the value of the business and economics approach, as they are both linked with the satisfaction of the individual (McKenzie & Lee, 2006, p.115). The main difference lies in economic constraints, as Maslow includes an individual's wishes based on culture, environment and ethics, but without considering an individual's productivity or income (McKenzie & Lee, 2006, p.115). In this study social and economic value are separated, as discussed above, and using Maslow's Hierarchy of Needs, both types of value can be incorporated in the same business model as different variables. Additionally, not all the aspects of Maslow's Hierarchy of Needs have been used, as some of the aspects oppose other recognized theories. For example, both theories of human needs (Doyal & Gough, 1984 & 1991) and the capability approach (Sen 1993; Nussbaum, 1988) see needs as non-hierarchical and non-substitutable. The theory of human needs cannot apply here, as we try to solve a tactical and pragmatic problem (the social value equation in a business model) and Doyal & Gough (1984, p.32) recognized that many of their "*arguments have been highly abstract*" and they "*might be accused of self-indulgence by those primarily interested in tactical and pragmatic questions*". On the other hand, Maslow's Hierarchy of Needs is applied as a matter of course to managerial problems (Bourantas, 2002).

The literature on human needs explicitly contrasts social value with needs and wants as two very different things (Doyal & Gough, 1984), but the scope limitations of this study claim that the social value is indicated by the needs. Furthermore, the capability approach cannot apply here because it ignores the distribution of basic needs for the varying circumstances of the most vulnerable people, e.g. women (Nussbaum, 2004).

This study tries to include all the population living in the metropolitan areas of the United Kingdom. Since there are many recognized theories which see needs as non-hierarchical and non-substitutable, it provides a justification of why the authors did not actually use the hierarchical aspect in this study and used the sum of the curves of the needs to solve a business problem.

Finally, Maslow (1954) claims that the individual, by trying to reach '*self-actualization*', benefits others or, "*the greater good*." This does not apply in individualistic societies, but only in collectivist societies (Cianci & Gambrel, 2003). The self-centred approach in individualistic societies sometimes opposes "*the greater good*" in terms of environmental value (Cianci & Gambrel, 2003). Therefore, within the social value, the author will investigate whether the society is collectivist or individualistic.

Regarding transport infrastructure, transport is a type of infrastructure that may be characterized as *"… the notion of a large-scale physical resource made by humans for public consumption*" (Frischmann, 2012, p.3). In traditional civil engineering parlance, infrastructure has in the past been connected with major construction projects and more specifically in transport engineering it is connected with roads and highways, railroads, ports, airports, pipelines and canals – some owned by public entities and some owned by private corporations. Infrastructure develops over time to cover more or new needs arising from socio-economic developments during the operation period (Bakker et al., 2017), while the civil engineering focus has broadened to embrace infrastructure systems and their interdependencies with all other urban systems (Rogers, 2018), and this inevitably blurs the boundaries between needs and wants (Liveable Cities, 2017). The social value of an infrastructure will differ with a sigmoid form over time as suggested by Maslow's Hierarchy of Needs and over the value of each choice, as the strict utility choice model demands.

Since the social value is so broad, a Transportation Hierarchy of Needs is required aligning with Maslow's suggestions for understanding the social value of transport. Winters et al. (2001) produced such a hierarchy by identifying different factors and evaluating them through multiple surveys (expert panel, different stakeholders, etc.). They found the following transport hierarchy of needs: [1] safety and security, [2] time, [3] societal acceptance, [4] cost and [5] comfort and convenience. Some researchers have modified these rankings. For example, Alfonzo (2005) studied a specific transport mode – walking – and found that time is valued higher than safety. This may be explained by the fact that each transport mode may have a different ranking of needs. Winters et al. (2001) developed a broader approach by comparing different transport modes, so their approach is more appropriate for this research.

The current research has studied value as something undivided/non-substitutable affected by all the above factors by summing the values of each factor. The reason we did not study each factor separately is that it is mathematically unattainable in terms of the dependency of the variables. Each infrastructure project is expected to be in a different stage of its lifecycle (e.g. stage of project development, age), so this may mean that the importance of each factor may differ. In this fashion, the effect of the different rankings of needs will be reduced and time will be a part of the needs. The total value of all individuals, collectively, would have an almost sigmoid curve relative to the needs covered by transport as a result of the sum of the value curves of Maslow's Hierarchy of Needs and assuming a strict utility choice mode.

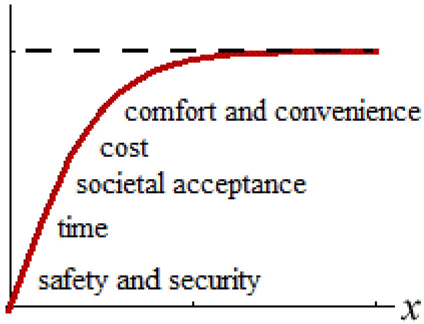


Figure 3.9 Expected Value curve of Transport

In other words the hypothesis tested is: Social Value is expected to have an almost sigmoid curve over the defined sub-values (Figure 3.9). There is a strong link here with Wilson's (1969) notion of generalised cost, which synthesised multinomial logit share models using common travel attributes (e.g. excess time, time, cost).

3.3.3 Research methodology

To define the total value and the sub-values, a structured interview process was conducted. The goal was to use survey data to demonstrate that the aggregate 'social value' of transport modes has a sigmoidal relationship with the needs covered over time, by accepting that infrastructure develops to cover needs over time and as infrastructures age (Bakker et al., 2017). The needs are covered differently based on infrastructures' developed time/age and every respondent has a different understanding of this coverage based on respondents' age. Other factors affect the need coverage too, but the respondents' age is critical for using Maslow's Hierarchy of Needs . The goal of the study, at this point, was not to understand how different people value different aspects of transportation, but how they understand the total value over all different elements of transportation. The structured interviews aimed to provide the required data to verify the sigmoid form of the social value. As previously elaborated, the UK's metropolitan areas served by each type of transport mode provide the targeted sample chosen to shed light on the hypothesis. The number of citizens living in a metropolitan area served by each type of transport mode is 32,455,357, equating to 51.5% of the total population of the United Kingdom. The boundaries of UK metropolitan areas are defined by the European Union's ESPON project (2007) with morphological and functional urban factors. The purposive sampling method was applied and the sample was chosen to ensure it covered the characteristics of the population and the purpose of the study, as this research method demands (Saunders et al., 2009). In other words, there was a targeted number of participants in each subgroup of metropolitan area, gender, ethnic group and age, but each individual of the sample was randomly selected.

The Science, Technology, Engineering and Mathematics Ethical Review Committee of the University of Birmingham reviewed the study and provided a full ethical approval under reference number: Application for Ethical Review ERN_16-1291 “Infrastructure Management: Devising of a Business Model for Transport Infrastructure Interdependencies Management”, before the field research started. During the field research, there were semi-structured interviews, where the surveyor was holding the questionnaire and filling in the form for the participants. The participant could interact with the surveyor through the face-to-face interview and ask for clarification if necessary. In this way, it was ensured that each participant had the same understanding of the questions and that the questionnaire was fully understood by all participants. The participants were approached by the surveyor in public places. The surveyor was observant and avoided any situation that would bring about conflict or confrontation. The surveyor obtained the permissions required from different stakeholders (station authorities, transport mean authorities, etc.). Participants’ data were not identifiable. The participant was able to withdraw at any point during the interview. If any participant wanted to withdraw his/her consent after the interview, this was possible by providing to the researcher his/her postcode, age and ethnic group. In this way the researcher could identify his/her questionnaire. The probability of two individuals or more having the same postcode, age and ethic group is highly unlike. In the scenario that someone asked to withdraw and more than one questionnaire had the same postcode, age and ethic group, then all these questionnaires were removed.

Sampling quotas were established as required for targeted sample studies focusing on specific data (Saunders et al., 2009; Silverman, 2011). The critical sampling quotas were based on age, gender, income, accessibility to each transport mode, number of cars and ethnic group. Additionally, the role and responsibilities (e.g. level of contribution to social policy making) of each individual in the society, ideally should be identified as they are considered as key-stakeholders. However, this was not possible as the sample was so large; hence, it was decided to consider that all individuals have the same role and responsibilities during the stakeholder analysis. Based on the previous research methodology discussion, the following percentages of participants are expected (see Table 3.21).

Table 3.21 Sample distribution per metropolitan area, gender, ethnic group and age

Area	Population	Percentage (%)	Expected questionnaires
Belfast	585,996	1%	3
Birmingham	3,701,107	12%	36
Bristol	1,006,600	3%	9
Cardiff	1,097,000	3%	9
Edinburgh	1,339,380	4%	12
Glasgow	1,858,517	6%	18
Leeds	2,302,000	7%	21
Liverpool	2,241,000	7%	21
London	13,879,757	43%	129
Manchester	2,794,000	9%	27
Newcastle	1,650,000	5%	15
Total	32,455,357	100%	300

Gender	Percentage (%)	Expected questionnaires
Male	49.11%	147
Female	50.89%	153
Total	100%	300

Ethnic group	Percentage (%)	Expected questionnaires
White	87.17%	262
Asian	6.92%	21
Black	3.01%	9
Other	2.90%	8
Total	100%	300

Age	Total Percentage (%)	Survey (%)	Expected questionnaires
0-15	17.6%	0	0
15-19	6.3%	7.65%	23
20-29	13.6%	16.50%	50
30-39	13.1%	15.90%	48
40-49	14.6%	17.72%	53
50-59	12.2%	14.81%	44
60-65	6.0%	7.28%	22
65+	16.6%	20.15%	60
Total	100%	100%	300

Considering the number of individuals living in metropolitan areas, the author believes that the samples, within the boundaries of the defined population and the scope limitations of this study, will be sufficiently diverse to capture the variability within the tested hypotheses since they are random. For each urban area the sample was not split equally by gender, age group, ethnic group, but this does not bias it, since each metropolitan area is not studied separately. After setting the sampling quotas (expected number of participants in Table 3.21), a pilot study was conducted in Birmingham, Leeds, Newcastle and London with 30 participants. The author managed to test the interview proforma and to obtain basic insights into the expected outcomes. After the pilot study, the final version of the interview proforma was developed and the potential participants were requested to take part randomly in public areas in the aforementioned metropolitan areas. All these areas have the complete set of transport modes being studied, i.e. urban rail, light rail, etc., so the individuals would be able to compare their values for different transport modes. However, there was one exception. The age group of 65+ was approached at churches and/or places of gathering of social groups of elderly people (e.g. bingo hall), as they were difficult to find at random places outdoors. The study was conducted during peak travel periods (06:00-9:00, 11:00-14:00 and 16:00-19:00), when individuals are often travelling to or from work, school or places of higher education.

All interviews were conducted face-to-face to obtain immediate answers, expressions and gestures, and to achieve a minimum common understanding of the questions by the targeted individuals. In general, each interview lasted between 30 and 90 minutes (most of them took approximately 45 minutes), excluding approach time. The interviews used were only those that were answered completely and for which the participants provided their consent for the data to be used in this study. The participants were asked questions according to the interview proforma guidelines (see Appendix G). This research studied value as something holistically affected by all the above factors (time, cost, comfort & convenience, safety and security) by asking individuals representative of the UK's demography to evaluate the social value of eight transport modes (walking, cycling, rail, bus, car, taxi, water and air) and each factor for each mode. The "*societal acceptance*" need of the Transportation Hierarchy of Needs (Winters et al., 2001) was removed from the interview proforma (see Table 3.22) after the pilot study as the individuals were positively biased towards the transport mode they used most without really considering the need itself. This may sound arbitrary, and therefore potentially lacking in rigour, but almost every individual assigned the maximum value to the transport modes they use and the minimum value to the ones they do not use (except the car). It was assumed that this need is included in the other factors and it was replaced with an "*excess time*" attribute of generalised cost (Wilson, 1969).

Participants’ data are not identifiable. The participant was able to withdraw at any point of the interview, something that was clearly stated in the document accompanying the questionnaire and was approved by the Science, Technology, Engineering and Mathematics Ethical Review Committee of the University of Birmingham (Application for Ethical Review ERN_16-1291). If any participant wanted to withdraw his/her consent after the interview (this never happened during this research), he/she had to provide to the researcher his/her postcode, age and ethnic group. In this way the researcher would be able to identify his/her questionnaire. The probability of two individuals or more having the same postcode, age and ethnic group is highly unlike. In the scenario that someone would ask to withdraw and more than one questionnaire had the same postcode, age and ethnic group, then all these questionnaires would be removed. A specific date/timescale as the deadline for participant withdrawal was included, as presumably there would was a point beyond which it was not possible to withdraw data from the study.

											Dependency														Benefits				
Postcode	Age	Ethnic	Gender	Individuals	Cars/Vehicles	Income (x1000)	Distan (Km)		Percent	Goods		Energy	Water	Waste	Communic.	Main	Evaluation		Travel Time	Excess Time	Travel Cost	Confort & Conven.	Safety & Security	Health	Recreation	Environme-ntal	Industrial	Congestion
London N19L	30-39	White	F	2	0	>100	55	Walking	1		Walking	0	1	0	0	Rail	-1	Walking	-3	5	5	2	5	5	5	5	3	5
								Cycling	9	X	Cycling	1	1	0	1		3	Cycling	0	5	5	3	4	5	5	5	4	4
								Rail	55		Rail	4	1	0	3		5	Rail	5	2	-1	4	5	4	4	4	5	5
								Bus	35	X	Bus	4	1	0	3		3	Bus	2	-1	-1	2	4	4	4	4	5	4
								Car			Car	5	0	0	3		0	Car	2	-2	-5	4	3	-5	2	-5	3	-5
								Taxi			Taxi	5	0	0	3		1	Taxi	2	-1	-2	5	5	1	0	1	-2	3
Adjust to society:			Yes	Main reason:		Cost & Environment			Trips	Distance																		
I feel comfortable and safe to use my bike and public transport for all my transportation needs, as a great percentage of my co-citizens.								Air	6	8880	Air	5	0	0	5	General	-3	Air	3	-1	-5	4	2	-3	0	-5	3	0
								Water	2	14	Water	5	5	0	5		0	Water	0	0	-1	5	4	0	5	-1	0	0

Table 3.22 Interview Proforma Template

The accessibility of each individual to every public transport mode was measured in terms of distance using their postcode (see Table 3.22). All the 300 participants had access to every public transport mode with less than 10 minutes of walking (see Appendix B). If they did not have access to at least one of the public transport modes, they were excluded from the research. Walking was considered possible for all the participants, as none of the participants had any disabilities. The accessibility to cycling and car was checked by asking the individuals if they have/use a car or a cycle (see Table 3.22). The information provided by the interview was an evaluation of the social value of the eight transport modes and each factor for each mode between -5 and 5.

Finally, a check was made to determine whether respondents considered society to be dominantly individualistic by asking the individuals or whether they adjust their mode of transport out of considerations for the wellbeing of society, e.g. by taking into consideration the environment or effects on other individuals (see Table 3.22). 68.3% of the participants answered "*No*," thus allowing us to conclude that we have a primarily individualistic society.

3.3.4 Empirical findings

Since the purpose of this study is to design curves of needs of the UK population arising from transport and compare them with the existing theory, quantitative interviewing was conducted to provide the required data for the curve design. The focus was on obtaining numerical data so the final users themselves generate the subject matter which was the needs coverage by each transport mode. Three-hundred individuals were asked to evaluate on a scale from -5 to 5 eight transport modes (walking, cycling, rail, bus, car, taxi, water and air) and the coverage of each need (time, cost, comfort and convenience, safety and security) by each mode [4] creating a database of 2400 evaluations. The sample of the three-hundred participants had the same characteristics as the population of the UK, as purposive sampling demands [11], meaning there was the same percentage of participants based on the age, ethnic group, area where they lived and gender as the population of the UK. The data collected were considered as values of a Cartesian coordinates system to design curves. Different Cartesian systems were developed based on the two subjects studied: 1) total evaluation of transport modes over the sum of the evaluations of the aforementioned needs covered by each mode and 2) needs covered by the transport modes which the individuals use accounting for the age of the individuals.

3.3.4.1 Participants' attitudes towards the transport modes

The following section analyses participants' attitudes towards eight transport modes, namely walking, cycling, rail, bus, car, taxi as well as air, and transport modes. They were asked to evaluate them in a scale from -5 to 5, - regardless of whether they use it regularly or not for their transportation. The given data are interval data and they are analyzed accordingly using SPSS Statistics [12].

The means of the given evaluations were calculated and are presented below. As illustrated in Table 3.23, the mode with the highest evaluation is the [1] car followed by [2] air, [3] walking, [4] taxi, [5] water, [6] rail, [7] cycling and, [8] bus. Based on standard error, the mode with the highest uncertainty in the evaluations given is the [1] rail, followed by [2] cycling, [3] car, [4] walking, [5] bus, [6] taxi, [7] air and, [8] water.

Table 3.23 Descriptive statistics of participant's evaluations of the eight transport modes

Mode	Mean	Standard Error	Standard Deviation
Walking	1,16	,186	3,215
Cycling	-,56	,193	3,348
Rail	-,46	,215	3,725
Bus	-,89	,179	3,106
Car	1,66	,186	3,229
Taxi	,18	,177	3,060
Air	1,54	,175	3,026
Water	-,21	,167	2,888

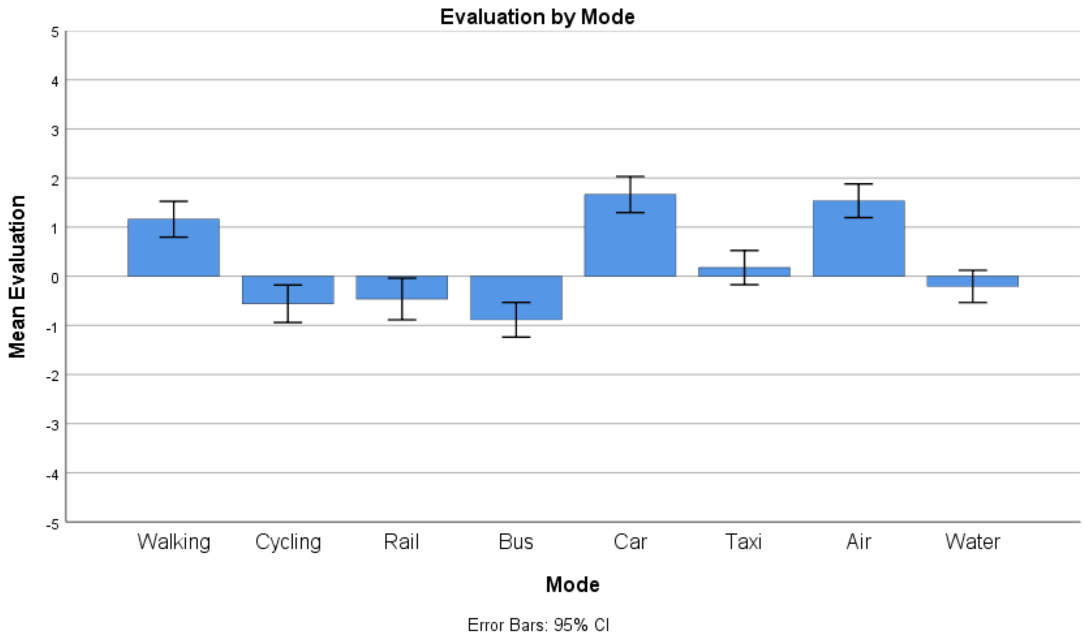


Figure 3.10 Participant's evaluations of the eight transport modes

In order to detect whether the evaluations for the eight transport modes differed, a one-way ANOVA was performed. Transport mode was inserted as the independent variable and evaluation as the dependent variable. The analysis demonstrated that there was a significant main effect of transport mode on evaluations ($F(7,2399)=29.684$; $p<.001$).

Post-hoc comparisons with Bonferroni correction showed that evaluations for cars were not significantly higher than the ones for walking and air (p= 1.000 for both comparisons). They were significantly higher though compared to cycling, rail, bus, taxi and water (p<.001 for all comparisons). Similarly, air transport evaluations were not found to be significantly higher than walking evaluations (p = 1.000). Both air transport and walking were evaluated significantly higher than the other modes (p<.001 for all comparisons except for walking vs. taxi, p= .005).

Travelling by taxi was evaluated significantly lower than car, air, and walking transportation, as reported above, but it was evaluated significantly higher than bus (p=.001). No significant difference were found when compared with cycling (p= .139) and rail (p=.410). Travelling by water was evaluated significantly lower than travelling by car, air, and walking, as reported above but no significance difference was found when compared to cycling, rail, taxi (p=1.000 for all comparisons), and bus (p=.266). Travelling by rail received significantly lower evaluation when compared to car, air and walking as mentioned earlier but no significant difference was revealed when compared to the other modes of transport, such as water, cycling, bus (p=1.000 for all comparisons), and taxi (p=.410). Continuing with cycling, it was found to be evaluated significantly lower than the car, air and walking mode (comparison values reported above), the difference with rail, bus, water, and taxi did not reach a significant level (p=1.000 for the first three comparisons; p= .139 for the latter). Finally, travelling by bus was evaluated significantly lower than travelling by car, air, walking (p<.001 for all comparisons) and taxi (p=.001) but it was not found to differ with cycling and rail (p=1.000 for both comparisons) and water (p=.266).

Summing up, the results from the one-way ANOVA confirmed the intuitive hypothesis that the transport modes were evaluated differently, some of them were higher evaluations and some were given lower evaluations. Bonferroni analysis showed that the differences reached a significantly level for a number of comparisons, however some differences were found to be lesser.

Looking closer to the results, the question arises as to whether participants of different Age, Gender, and Ethnic group evaluated the transport modes differently.

Since the initial one-way ANOVA demonstrated a main effect of transportation, every mode will be examined and discussed separately. However, in order to obtain a broader idea as to the overall effect of these factors on the results, one-way ANOVAs were also performed when taking evaluations as a whole.

<u>Age factor</u>

The following table explores participants' evaluations as a function of age. The following table illustrates participants' overall evaluation, meaning for the eight transport modes combined, for the different age groups.

Table 3.24 Overall Evaluations per age group

Age group	Age range	Mean	Standard Deviation	Standard Error
Group 1	15 to 19 yrs.	0.04	3.376	0.249
Group 2	20 to 29 yrs.	0.78	3.323	0.166
Group 3	30 to 39 yrs.	0.85	3.439	0.176
Group 4	40 to 49 yrs.	0.23	3.405	0.165
Group 5	50 to 59 yrs.	-0.33	3.195	0.17
Group 6	60 to 65 yrs.	-0.25	3.259	.246
Group 7	65 yrs. +	0.3	3.224	0.147

As reported in the Table 3.24, the age group that gave the highest evaluations is group 3 (M=.85), immediately followed by group 2 (M=.78) whereas the lowest evaluations were given by groups 6 and 5 (M= -.25 and M= -.33 respectively) which were also the only two groups to assign an, overall, negative evaluation. A one-way ANOVA showed that there was a main effect of age (F(6,2393)=6.300, p<.001), indicating that participants' responses were differentiated to a significant degree as a function of age. Post-hoc comparisons with Bonferroni correction showed that the effect stemmed from the significant differences between the groups having given the highest vs. the groups that having given the lowest evaluations, that is group 3 gave significantly higher evaluations compared to group 5 (p< .001) and group 6 and (p= .012) the same applied for group 2 (p<.001 and p=.006 respectively). No other comparisons reached a significant level.

It thus seems that overall, young participants, 20 to 39 yrs. old tended to give more positive evaluations than older participants, aged 50 to 65 yrs. old. This finding could suggest that older participants feel that the different ways of transportation do not cover or correspond to their transportation needs. A closer look into the different modes is necessary in order to comprehend whether this trend applies across modes or it is more relevant to specific ones.

The following section discusses how participants' responses were differentiated as function of age for every transport mode and whether any differences reached a significant level. One-way ANOVAs were performed for every transport mode, followed by Bonferroni post-hoc comparisons when a significant main effect was revealed. Transport modes are presented in descending order, starting with the one gathering the highest overall evaluation (car) and concluding with the one with the lowest evaluation (bus).

For the car, the group which gave the highest evaluations was group 6 (M=2.41 ± 0.595, SD= 2.789), followed by group 1 (M=2.35 ± 0.513, SD= 2.461), group 4 (M=2.26 ± 0.405, SD= 2.949), group 3 (M=1.63 ± 0.497, SD= 3.443), group 7 (M=1.50 ± 0.415, SD= 3.213), group 2 (M=1.16 ± 0.514, SD= 3.633) and finally by group 5 (M=1.05 ± 0.505, SD= 3.348). Crucially, an one-way ANOVA test with Age Group as the independent variable and Evaluations as the dependent one demonstrated that there was no main effect of age (F(6, 299)= 1.17, p= .319).This finding indicated that the participants' evaluations for the car mode did not differ as a function of age.

Continuing with the air transport, the highest evaluations were given by group 3 (M=2.88 ± 0.376, SD= 2.606) and group 2 (M=2.50 ± 0.370, SD= 2.613), followed by group 4 (M=1.89 ± 0.374, SD= 2.722), group 6 (M=1.23 ± 0.773, SD= 3.624), group 1 (M=1.13 ± 0.747, SD= 3.584), and group 7 (M=0.92 ± 0.381, SD= 2.948). The group that gave the lowest evaluations was group 5 (M=-0.23 ± 0.414, SD= 2.744). The statistical analysis revealed a significant main effect of age (F(6, 299)= 6.11, p<.001) indicating that participant's responses were differentiated to a statistical significant level as a function of age. Bonferroni post-hoc tests demonstrated that groups 2, 3 and 4 gave significantly higher evaluations than group 5 ($p<.001$, $p<.001$ & $p=.008$ respectively). Group 3 evaluations were significantly higher when compared to group 7 as well ($p= .011$). Overall, it seems that the younger groups evaluated the air mode higher than the older groups.

Moving on to walking, the highest evaluations were given by group 2 ($M=1.86 \pm 0.459$, $SD= 3.245$), followed by group 5 ($M=1.48 \pm 0.453$, $SD= 3.008$), group 3 ($M=1.27 \pm 0.473$, $SD= 3.279$), group 7 ($M=1.22 \pm 0.406$, $SD= 3.147$), group 4 ($M=0.68 \pm 0.459$, $SD= 3.338$), group 1 ($M=0.48 \pm 0.711$, $SD= 3.409$), and group 6 ($M=0.41 \pm 0.650$, $SD= 3.050$). Statistical analysis demonstrated that there was not a main effect of age ($F(6, 299)= 1.05$, $p= .393$), suggesting that participants' age did not affect the evaluations that they gave for walking to a significant degree.

Regarding the taxi, the younger groups -group 3 ($M=1.31 \pm 0.441$, $SD= 3.054$), 2 ($M=0.48 \pm 0.452$, $SD= 3.196$), and 1 ($M=0.26 \pm 0.600$, $SD= 2.880$)- gave the highest evaluations, followed by group 7 ($M=0.17 \pm 0.401$, $SD= 3.104$), 4 ($M=-0.11 \pm 0.418$, $SD= 3.042$), 6 ($M=-0.14 \pm 0.618$, $SD= 2.900$), lastly by group 5 ($M=-0.93 \pm 0.414$, $SD= 2.748$). Crucially, the statistical analysis demonstrated a significant main effect of age ($F(6,299)= 2.32$, $p= .033$), suggesting that participants' age had an impact on the evaluations given for the taxi mode, namely younger participants evaluated taxi more positively than older participants. Nevertheless, post-hoc comparisons with Bonferroni correction showed that the only difference that reached a significant level was between group 3 versus group 5 ($p= .009$).

The rest four transport modes (water, rail, cycling, bus) had an overall negative evaluation.

For the water transport, group 3 ($M=0.83 \pm 0.392$, $SD= 2.716$) and 2 ($M=0.22 \pm 0.392$, $SD= 2.772$) gave the highest evaluations, followed by group 7 ($M=-0.08 \pm 0.395$, $SD= 3.060$), group 5 ($M=-0.61 \pm 0.385$, $SD= 2.554$), group 4 ($M=-0.61 \pm 0.405$, $SD= 2.951$) and lastly by group 1 ($M=-1.00 \pm 0.622$, $SD= 2.985$). The statistical analysis revealed a main effect of age ($F(6,299)= 2.20$, $p= .042$). Bonferroni post-hoc comparisons though showed that the differences between the age groups were not significant.

For the rail mode, it was the oldest group that gave the highest evaluations among groups ($M=.35$), followed by group 2 ($M=0.16 \pm 0.502$, $SD= 3.548$), group 1 ($M=-0.48 \pm 0.841$, $SD= 4.032$), group 4 ($M=-0.66 \pm 0.553$, $SD= 4.028$), group 5 ($M=-0.82 \pm 0.563$, $SD= 3.737$), group 3 ($M=-1.02 \pm 0.534$, $SD= 3.699$), and lastly by group 6 ($M=-1.68 \pm 0.646$, $SD= 3.030$). Nevertheless, no main effect of age emerged ($F(6, 299)= 1.38$, $p= .221$), suggesting that participants evaluations did not differ to a significant degree as a function of age ($F(6, 299)= 2.20$, $p= .22$)

Continuing with cycling, the highest evaluations were given again by group 2 (M=0.84 ± 0.510, SD= 3.605), followed by groups 3 (M=0.08 ± 0.542, SD= 3.758), 4 (M=-0.60 ± 0.454, SD= 3.307), 1 (M=-0.65 ± 0.676, SD= 3.242), 5 (M=-0.93 ± 0.477, SD= 3.165), and 7 (M=-1.20 ± 0.368, SD= 2.851) and, as for walking, group 6 (M=-2.45 ± 0.496, SD= 2.324) gave the lowest evaluations. A one-way ANOVA demonstrated that there was a significant main effect of age (F(6, 299)= 3.56, p= .002). Bonferroni comparisons showed that group 2 gave significantly higher evaluations compared to the two oldest groups, namely group 6 (p= .002) and group 7 (p=.026) while the difference between groups 3 and 6 was also found to be close to significant (p=.058). It thus seems that again, participants aged 20 to 39 yrs. old are the ones who give the most positive evaluations.

Lastly, for the bus, the transport mode with the overall lowest evaluation, the highest evaluations were given by groups 3 (M=-0.21 ± 0.499, SD= 3.458), 7 (M=-0.45 ± 0.396, SD= 3.067), 2 (M=-0.96 ± 0.391, SD= 2.762), 6 (M=-1.05 ± 0.619, SD= 2.903), and 5 (M=-1.66 ± 0.460, SD= 3.050). The lowest evaluations were given by the youngest age group that is group 1. Yet, no main effect of age was revealed (F(6, 299)= 1.34, p= .236), indicating that participants' evaluations for bus did not diverge as a function of age.

Summing up, the results so far indicate that young adults, aged 20 to 39 (groups 2 and 3) are the ones who gave the highest evaluations. That applied for the majority of transport modes, namely the air, taxi, water, and cycling modes. However no age differences were manifested for the car and the walking modes, which had high evaluations across age groups and for the bus mode, which attracted low evaluations, again across age groups. Interestingly, the reverse pattern applied for the rail mode for which the highest evaluations were given by the oldest participants (65+ yrs. old). Based on the exploration of the age factor so far, it could be argued that for the transport modes that an age effect did occur, they were the teenagers and older participants who were not satisfied.

<u>Gender factor</u>

The section explores whether men and women evaluated differently the transport modes. As for the Age factor, the first analysis is about the effect of gender on overall evaluations, with no distinction between the different transport modes.

Since there are only two groups -men (M=0.33 ± 0.098, SD= 3.348) vs. women (M=-0.28 ± 0.095, SD= 3.333), independent t-tests were performed on the data. The results of the statistical analysis demonstrated that, contrary to the age factor, participants responses did not differ between the groups (t(2398)= .382, p= .702). A series of independent t-tests was performed, assessing the difference between the two groups across transport modes. The descriptive statistics of participant's evaluations of each transport mode by gender are provided in Table 3.25.

Table 3.25 Descriptive statistics of participant's evaluations of each transport mode by Gender

Mode	Gender	Mean	Standard Deviation	Standard Error
Walking	Male	1.24	3.215	0.265
	Female	1.08	3.224	0.261
Cycling	Male	-0.44	3.271	0.270
	Female	-0.67	3.428	0.277
Rail	Male	-0.50	3.766	0.311
	Female	-0.42	3.697	0.299
Bus	Male	-0.94	3.165	0.261
	Female	-0.84	3.057	0.247
Car	Male	1.80	3.185	0.263
	Female	1.53	3.275	0.265
Taxi	Male	0.22	3.093	0.255
	Female	0.14	3.037	0.246
Air	Male	1.61	3.024	0.249
	Female	1.47	3.037	0.246
Water	Male	-0.35	2.842	0.234
	Female	-0.07	2.934	0.237

All comparisons showed that there was no statistical difference between men and women (car: $t(298)= .732$, $p= .46$; air: $t(298)= .385$, $p= .70$; walking: $t(298)= .412$, $p= .68$; taxi: $t(298)= .227$, $p= .82$; water: $t(298)= -.824$, $p= .41$; rail: $t(298)= -\ .182$, $p= .85$; cycling: $t(298)= .597$, $p= .55$; bus: $t(298)= -.284$, $p= .77$), illustrating that the two groups provided comparable evaluations.

Ethnic group factor

For the ethnic group variables, four categories were formulated: White (M=0.32 ± 0.073, SD= 3.340), Asian (M=0.07 ± 0.269, SD= 3.492), Black (M=0.28 ± 0.368, SD= 3.118) and Other (M=0.53 ± 0.403, SD= 3.222). Participants were also given the choice to not reply by the "Prefer not to say" option, however all participants provided an answer. Participants' recruitment was aligned to UK demographics. That is the majority of participants was White (N=262), followed by Asian (N=21), Black (N=9) and Other (N=8).

Prior of assessing potential effect of ethnicity on given evaluations for every transport mode separately, a one-way ANOVA with ethnic group as the independent variable and overall evaluations as the dependent one was performed on the data. The statistical analysis showed no effect of ethnic group ($F(3,2396)= .393$, $p= .75$).

A series of one-way ANOVA tests for every transport mode showed that there was no main effect of ethnicity for either transport mode (car: $F(3,299)= 1.067$, $p= .36$; air: $F(3,299)= .682$, $p= .56$; walking: $F(3,299)= .456$, $p= .71$; taxi: $F(3,299)= .436$, $p= .72$; water: $F(3,299)= .164$, $p= .92$; rail: $F(3,299)= 2.012$, $p= .11$; cycling: $F(3,299)= .565$, $p= .63$; bus: $F(3,299)= .383$, $p= .76$)

Table 3.26 Descriptive statistics of participant's evaluations of each transport mode by Ethnicity

Mode	Ethnic Group	Mean	Standard Deviation	Standard Error
Walking	White	1.18	3.236	0.200
	Asian	1.33	3.104	0.677
	Black	1.33	3.082	1.027
	Other	-0.13	3.271	1.156
Cycling	White	-0.54	3.353	0.207
	Asian	-1.29	3.538	0.772
	Black	0.33	3.041	1.014
	Other	-0.25	3.240	1.146
Rail	White	-0.30	3.755	0.232
	Asian	-2.24	3.590	0.783
	Black	-1.44	2.242	0.747
	Other	-0.13	3.523	1.246
Bus	White	-0.92	3.065	0.189
	Asian	-0.24	3.548	0.774
	Black	-1.00	3.000	1.000
	Other	-1.38	3.739	1.322
Car	White	1.72	3.174	0.196
	Asian	0.86	3.719	0.811
	Black	0.78	4.177	1.392
	Other	2.88	2.357	0.833
Taxi	White	0.10	3.055	0.189
	Asian	0.81	3.124	0.682

	Black	0.67	2.915	0.972
	Other	0.38	3.543	1.253
Air	White	1.46	3.061	0.189
	Asian	1.90	2.862	0.625
	Black	1.67	3.317	1.106
	Other	2.88	1.808	0.639
Water	White	-0.18	2.925	0.181
	Asian	-0.62	2.801	0.611
	Black	-0.11	2.713	0.904
	Other	0.00	2.390	0.845

Recapitulating so far, the given evaluations were found to be independent of participants' gender or ethnic group. They were found however to be subject to participants age, at least for the air, taxi, water, and cycling modes for which they were the young adults who gave the highest evaluations compared to teenagers and participants aged 40+ yrs. old.

Number of cars per household

Seeking to look even closer to participants' profile another aspect taken into consideration was the number of cars a person had. Participants answered that they had from 0 to 3 cars in their household. Table 3.27 and Figure 3.11 presents the number of participants that had 0, 1, 2, or 3 cars. As illustrated the majority had either none or one car whereas only 6 out of the 300 participants owned 3 cars.

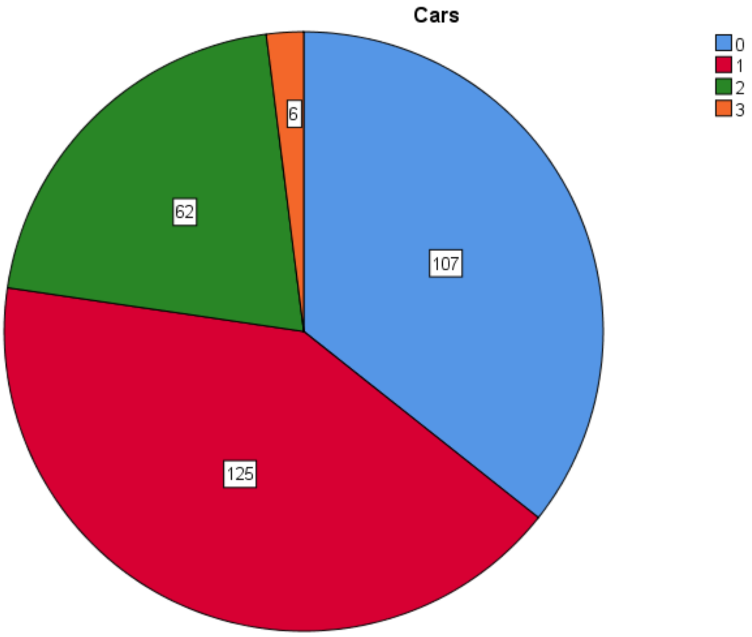


Figure 3.11 Number of cars per household

Table 3.27 Number of cars per household

Number of Cars	Participants
0	107
1	125
2	62
3	6

In order to explore whether participants' evaluations were related to the number of cars they owned, a series of Pearson correlation analyses was performed for every transport mode.

The analyses showed that, out of the eight transport modes, only the car and the taxi modes were significantly correlated with the number of cars that participants had in their household. There was a significantly positive correlation between number of cars and the evaluations to the car mode (p=. 017, r=.138). That means that participants that had more cars, gave higher evaluations to the car mode. Additionally, a negative correlation was revealed between the number of cars that participants had and the evaluations that they gave to the taxi mode (p=. 019, r=-.135). That means that the more cars they had, the lower the evaluations that gave to the taxi mode.

The results suggest that the more cars participants had, the more they appreciate the mode or, from another point of view, the more they appreciate the car mode, the more cars they own. Participants that did not appreciate the taxi mode, owned more cars or, from a different point of view, the more cars participants had, the lower the evaluations they gave to the taxi mode. Interestingly, the number of cars a participant had access to, was not found to be associated with evaluations for the public transport modes, i.e. the bus and the rail mode, or with the modes requiring physical activity, i.e. walking and cycling.

Household income

Another factor that was taken into consideration was that of the annual household income. Participants were asked to tick their household income and they were grouped accordingly: group 1: £0 - £10,000, group 2: £10,000 - £20,000, group 3: £20,000 - £30,000, group 4: £30,000 - £40,000, group 5: £40,000 - £50,000, group 6: £50,000 - £60,000, group 7: £60,000 - £70,000, group 8: £70,000 - £80,000, group 9: £80,000 - £90,000, group 10: £90,000 - £100,000 and, group 11: £100,000 and more. The following table provides the descriptive statistics on groups' evaluations for the different transport modes.

Table 3.28 Descriptive statistics of participant's evaluations of each transport mode by Income

Mode	Income group	Mean	Standard Deviation	Standard Error
Walking	1	1.94	2.351	0.588
	2	2.00	3.162	0.674
	3	1.27	3.247	0.469
	4	1.13	3.171	0.374
	5	1.13	3.383	0.423
	6	0.76	3.231	0.562
	7	0.17	3.884	0.916
	8	1.30	3.368	1.065
	9	1.71	2.812	1.063
	10	-1.67	1.528	0.882
	11	1.57	2.760	1.043
Cycling	1	0.31	3.754	0.939
	2	0.09	3.766	0.803
	3	0.44	3.045	0.440
	4	-0.58	3.543	0.418
	5	-1.30	3.038	0.380
	6	-0.33	3.198	0.557
	7	-2.44	2.727	0.643
	8	0.50	3.866	1.222
	9	-0.14	2.968	1.122
	10	-2.67	1.528	0.882
	11	-1.71	3.729	1.409
Rail	1	-0.50	3.759	0.940
	2	0.59	3.554	0.758

	3	-0.33	3.521	0.508
	4	-0.46	3.439	0.405
	5	-0.81	4.128	0.516
	6	-1.52	3.650	0.635
	7	-0.94	3.523	0.830
	8	0.50	4.197	1.327
	9	1.43	3.952	1.494
	10	0.67	5.132	2.963
	11	1.00	4.203	1.589

Mode	Income group	Mean	Standard Deviation	Standard Error
Bus	1	-0.88	3.074	0.769
	2	-1.41	3.112	0.663
	3	0.31	3.068	0.443
	4	-1.29	3.191	0.376
	5	-0.92	3.159	0.395
	6	-0.82	3.321	0.578
	7	-1.83	2.256	0.532
	8	-0.90	2.424	0.767
	9	-0.71	4.192	1.584
	10	-2.00	2.000	1.155
	11	-0.57	2.299	0.869
Car	1	1.81	3.146	0.786
	2	-1.00	3.612	0.770
	3	1.83	3.491	0.504
	4	1.53	3.310	0.390
	5	1.67	3.008	0.376
	6	2.42	2.538	0.442
	7	2.17	3.111	0.733
	8	1.60	2.951	0.933

	9	3.71	2.628	0.993
	10	1.67	4.163	2.404
	11	3.00	2.000	0.756
Taxi	1	0.56	3.326	0.832
	2	-0.32	3.524	0.751
	3	0.46	2.681	0.387
	4	0.15	3.309	0.390
	5	-0.08	3.258	0.407
	6	0.85	2.751	0.479
	7	-0.22	2.238	0.527
	8	0.40	2.366	0.748
	9	-0.71	4,030	1.523
	10	-0.67	4.933	2.848
	11	0.29	1.976	0.747

Mode	Income group	Mean	Standard Deviation	Standard Error
Air	1	2.19	2.588	0.647
	2	2.14	2.850	0.608
	3	1.56	3.222	0.465
	4	1.53	3.049	0.359
	5	1.31	3.106	0.388
	6	1.61	3.082	0.536
	7	0.78	2.840	0.669
	8	1.70	3.368	1.065
	9	2.71	1.976	0.747
	10	0.33	1.528	0.882
	11	0.86	3.976	1.503
Water	1	1.06	3.549	0.887
	2	0.45	2.703	0.576
	3	-0.69	3.075	0.444

	4	-0.19	2.963	0.349
	5	-0.52	2.714	0.339
	6	0.18	2.627	0.457
	7	-0.94	3.019	0.712
	8	-0.30	2.669	0.844
	9	1.57	1.902	0.719
	10	2.00	2.000	1.155
	11	-1.71	2.215	0.837

The household income factor was examined separately for every transport mode. A series of one-way ANOVAs with household income category as the independent variable and evaluations as the dependent one were performed.

A main effect of household income was manifested for the car mode ($F(10,299)= 2.246$, $p= .01$) and the cycling mode ($F(10,299)= 1.880$, $p= .04$). Interestingly, the first one is the transport mode with the overall highest evaluation ($M= 1.66$) whereas the second is at the other end of the spectrum ($M= -.56$), being one place before the end. The effect was not found to be significant for the other transport modes (air transport: $F(10,299)= .494$ $p= .89$; walking: $F(10,299)= .734$, $p= .692$; taxi: $F(10,299)= .438$, $p= .927$; water transport: $F(10,299)= 1.463$, $p= .15$; rail mode: $F(10,299)= .912$, $p= .52$; bus: $F(10,299)= 1.122$, $p= .34$).

Looking closer at the main effect of household income on the evaluations participants gave for the car mode, the descriptive statistics illustrate that the highest evaluations were given by participants above the threshold of £50,000, namely by groups 6 ($M= 2.42$), 7 ($M= 2.17$), 9 ($M= 3.71$) and, 11 ($M= 3$) whereas the lowest evaluations were given by group 2 ($M= -1$) which were found significantly lower than the ones provided by group 3 ($p=.03$), 5 ($p=.04$), 6 ($p=.006$), and 9 ($p=.03$).

Coming to the main effect for cycling, the descriptive statistics demonstrate that participants with a household income above £30,000 give overall negative evaluations (group 4: $M= -.58$; group 5: $M= -1.3$; group 6: $M= -.33$, group 7: $M= -2.44$; group 9: $M= -.14$, group 10: $M= -2.67$; group 11: $M= -1.71$), with the exception of group 8 ($M=0.5$), whereas participants with a household income below £30,000 give overall positive, albeit not high, evaluations (group 1: $M= .31$; group 2: $M= .09$; group 3: $M= 0.4$). Planned comparisons with the Bonferroni correction showed than none of the differences were significant.

Summing up, household income was found to have an effect on only two of the transportation modes in question, namely the car and the cycling mode. For the car mode, the highest evaluations were given by participants earning more than £50,000 a year whereas for the cycling mode the highest evaluations were given by participants earning annually less than £30,000.

3.3.4.2 Transport needs effect on participants' evaluations

Apart from how participants evaluated a transport mode as a whole, the questionnaire also explored how they evaluate it with respect to [1] travel time, [2] excess time, [3] travel cost, [4] comfort, and [5] safety. Travel time is defined as the amount of time spent while using the transport mode. Excess time expresses the uncertainty as to how long it will ultimately take to arrive to their destination when using the corresponding transport mode. Travel cost refers to the amount of money they need in order to use it while comfort stands for how comfortable they find it and safety how safe they think it is. Participants were asked to rate every transport mode for these five factors on a scale from -5 to 5. Crucially, participants were asked to rate all transport modes, regardless of whether they use it in their everyday life or not.

Seeking to detect whether the 7 transport modes were evaluated differently with respect to these five factors, a statistical analysis was conducted. One-way ANOVAs were performed for each one of the five factors with transport mode as the independent variable and participants' evaluations as the dependent variable. The analyses demonstrated a main effect of transport of mode for all factors, namely for travel time ($F(7,2392)=84.002$, $p<.001$), for excess time ($F(7,2392)= 40.589$, $p<.001$), for travel cost ($F(7,2392)=139.925$, $p<.001$), for comfort ($F(7,2392)=77.416$, $p<.001$), and for safety ($F(7,2392)=53.823$, $p<.001$). The results demonstrate that participants considered that the different transport modes were differentiated as to how fast (travel time), reliable with respect to time (excess time), cheap (travel cost), comfortable (comfort), and safe (safety) they are.

<u>Travel time</u>

Beginning with travel time, the transport mode evaluated the highest was the car ($M=2.93 \pm 0.166$, $SD= 2.867$), followed by air mode ($M=2.68 \pm 0.158$, $SD= 2.732$), and taxi ($M=2.25 \pm 0.167$, $SD= 2.890$). Rail ($M=0.45 \pm 0.202$, $SD= 3.501$) had lower although overall positive evaluations and the bus ($M=-0.36 \pm 0.189$, $SD= 3.277$), cycling ($M=-0.55 \pm 0.187$, $SD= 3.242$), walking ($M=-0.70 \pm 0.190$, $SD= 3.294$), and the water modes having overall negative evaluations (descriptive statistics in table above).

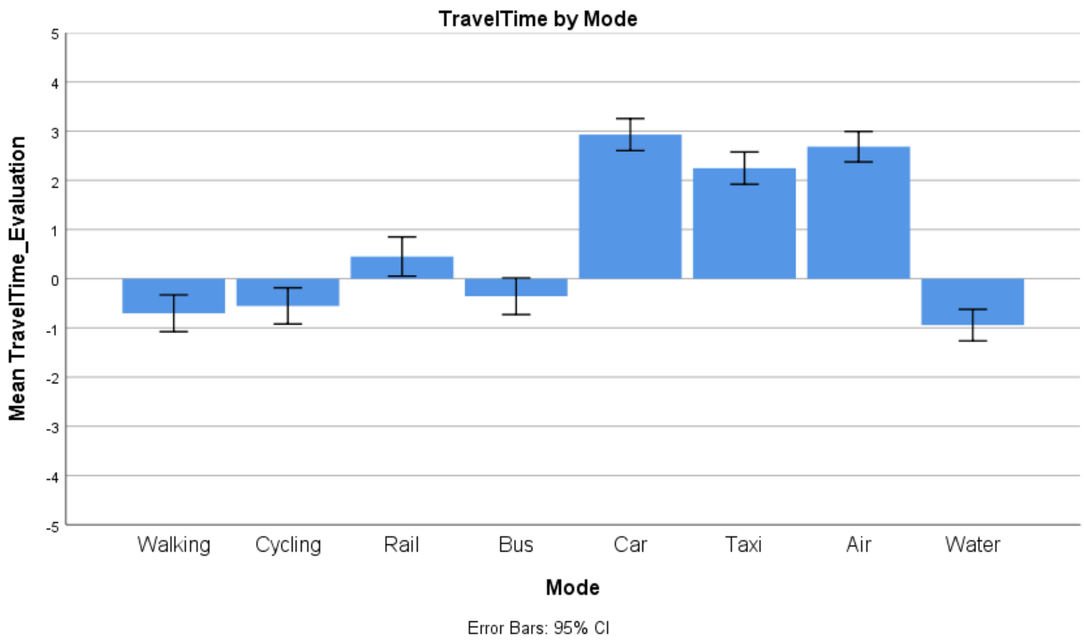


Figure 3.12 Travel Time effect

Bonferroni comparisons showed that the car gained significantly higher evaluations when compared to the other modes (p<.001 for all comparisons), except for air (p= 1.000) and taxi (p=. 191). Air and taxi also had significantly higher evaluations when compared to the other modes (p<.001 for all comparisons). The differences between the water mode on the one hand and the walking, the cycling and the bus mode on the other were not significant (p= 1.000, p= 1.000, and p= .564 respectively) however water mode evaluations were significantly lower than the ones for the rest of the modes (p<.001 for all comparisons).

<u>Excess time</u>

For the travel excess, the mode with the highest evaluation is walking (M=1.62 ± 0.193, SD= 3.344), meaning that participants believed that when walking, the uncertainty regarding what time they will ultimately arrive to their destination is diminished. The walking mode was followed by the car (M=1.40 ± 0.194, SD= 3.357), the cycling (M=0.41 ± 0.190, SD= 3.299), and the air mode (M=0.19 ± 0.179, SD= 3.099). The water (M=-0.09 ± 0.154, SD= 2.667), rail (M=-0.99 ± 0.182, SD= 3.147), taxi (M=-0.99 ± 0.189, SD= 3.274), and bus (M=-1.61 ± 0.164, SD= 2.833) mode had overall negative evaluations with the bus mode having the lowest, suggesting that participants felt uncertain when using these transport modes as to how long it will take to reach their destination.

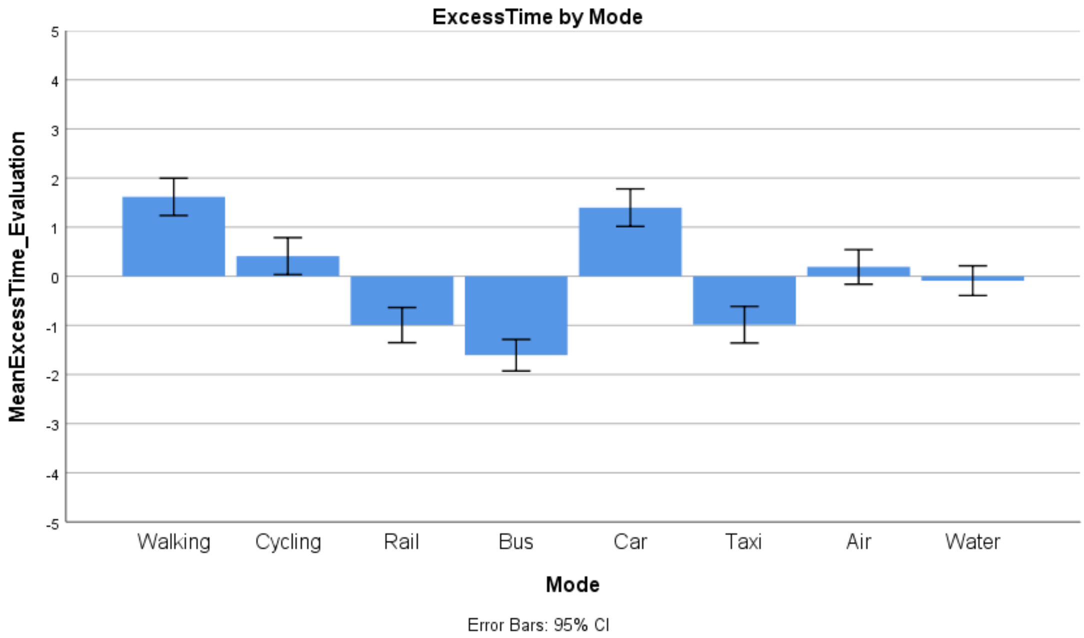


Figure 3.13 Excess Time effect

The difference between walking and the car was not significant (p= 1.000) but these two modes were evaluated significantly greater than the others (p<. 001 for all comparisons but for the car versus cycling: p= .003). The bus mode was evaluated significantly lower compared to all modes (p<. 001 for all comparisons) but for taxi (p= .436) and rail (p= .468).

<u>Travel cost</u>

Coming to the travel cost, the only transport modes evaluated positively were the walking (M=2.65 ± 0.146, SD= 2.529) and the cycling modes (M=1.40 ± 0.166, SD= 2.874). The air (M=-0.52 ± 0.184, SD= 3.184), the water (M=-0.69 ± 0.144, SD= 2.489), the rail (M=-1.30 ± 0.167, SD= 2.897), the bus (M=-1.31 ± 0.167, SD= 2.898), the car (M=-1.44 ± 0.188, SD= 3.262) and the taxi (M=-3.68 ± 0.124, SD= 2.156) modes were, overall, evaluated negatively.

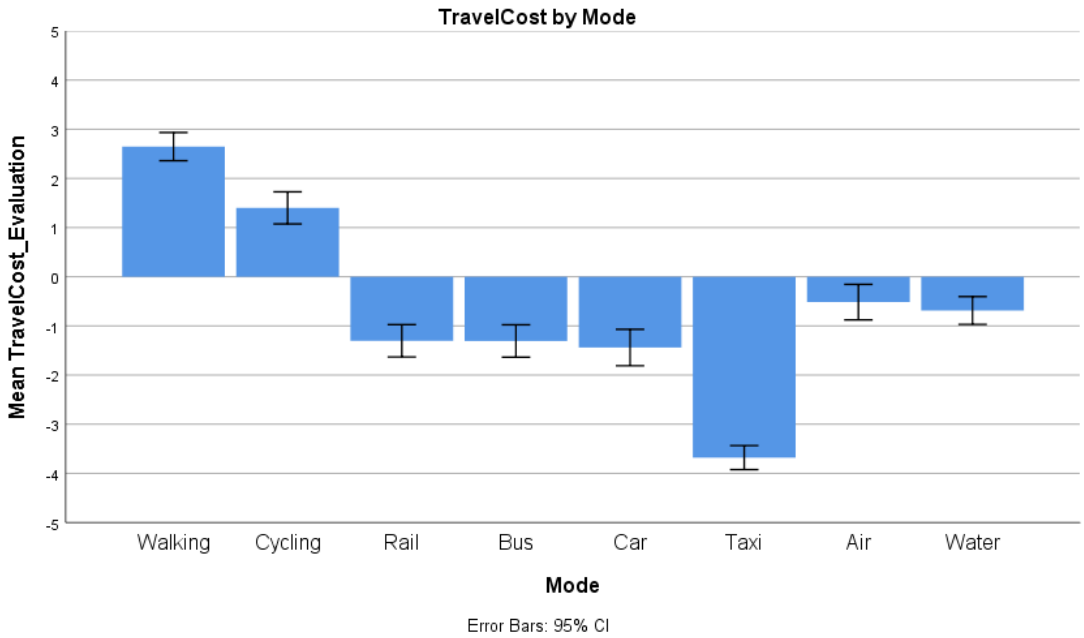


Figure 3.14 Travel Cost effect

The taxi mode gathered the lowest evaluations, being significantly lower when compared to all the other modes (p<. 001 for all comparisons). On the other end of the spectrum, the walking and the cycling modes were evaluated higher than all the other modes (p<. 001 for all comparisons).

Comfort

Moving on to comfort, the transport mode evaluated the highest is the car (M=3.03 ± 0.152, SD= 3.626), closely followed by the taxi (M=2.44 ± 0.158, SD= 2.742).

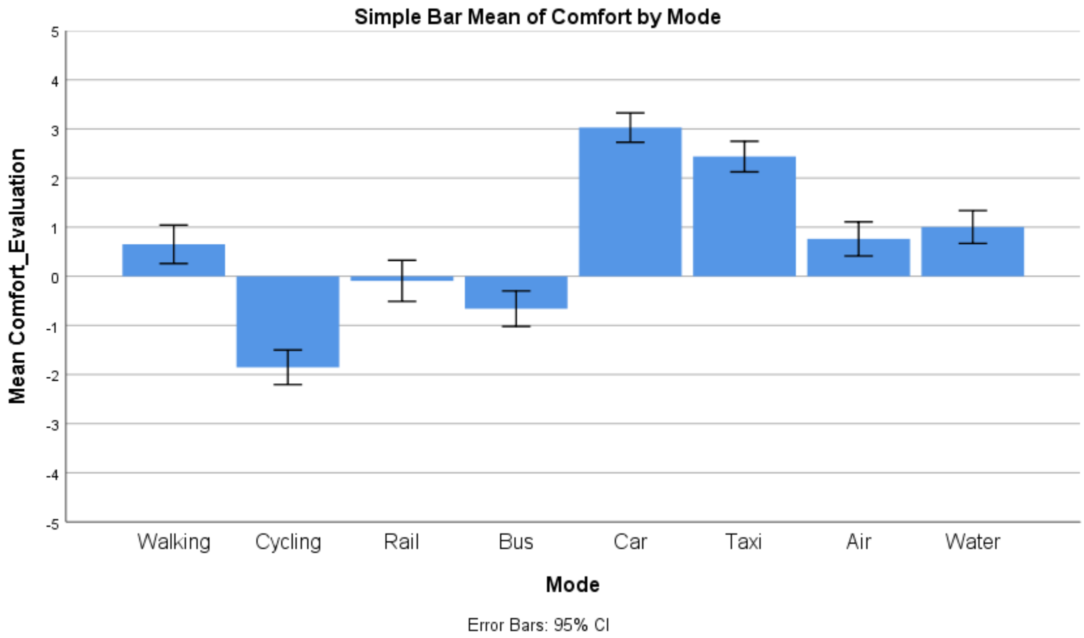


Figure 3.15 Comfort effect

The water (M=1.00 ± 0.170, SD= 2.946), air (M=0.76 ± 0.176, SD= 3.050), and walking (M=0.65 ± 0.199, SD= 3.448) modes were also positively evaluated, but evaluated significantly lower than the car and the taxi (p<. 001 for all comparisons). Rail (M=-0.09 ± 0.213, SD= 3.687) and bus (M=-0.66 ± 0.183, SD= 3.176) were negatively evaluated with the mode gathering the lowest evaluations being the cycling (M=-1.85 ± 0.179, SD= 3.098) mode. Actually, the cycling mode was found to be significantly lower compared to all the other modes (p<. 001 for all comparisons).

<u>Safety</u>

Finally, the transport modes evaluated the highest with respect to safety are the car (M=2.40 ± 0.157, SD= 2.715) and the taxi (M=1.81 ± 0.152, SD= 2.639) modes, evaluated significantly higher than the rail (M=0.73 ± 0.180, SD= 3.125), air (M=0.47 ± 0.183, SD= 3.170), walking (M=0.22 ± 0.183, SD= 3.176), bus (M=0.18 ± 0.168, SD= 2.914), and water (M=-0.33 ± 0.157, SD= 2.711) modes. The transport mode evaluated the lowest regarding safety is cycling (M=-1.61 ± 0.165, SD= 2.856), which was significantly lower when compared to all the other modes (p<. 001 for all comparisons).

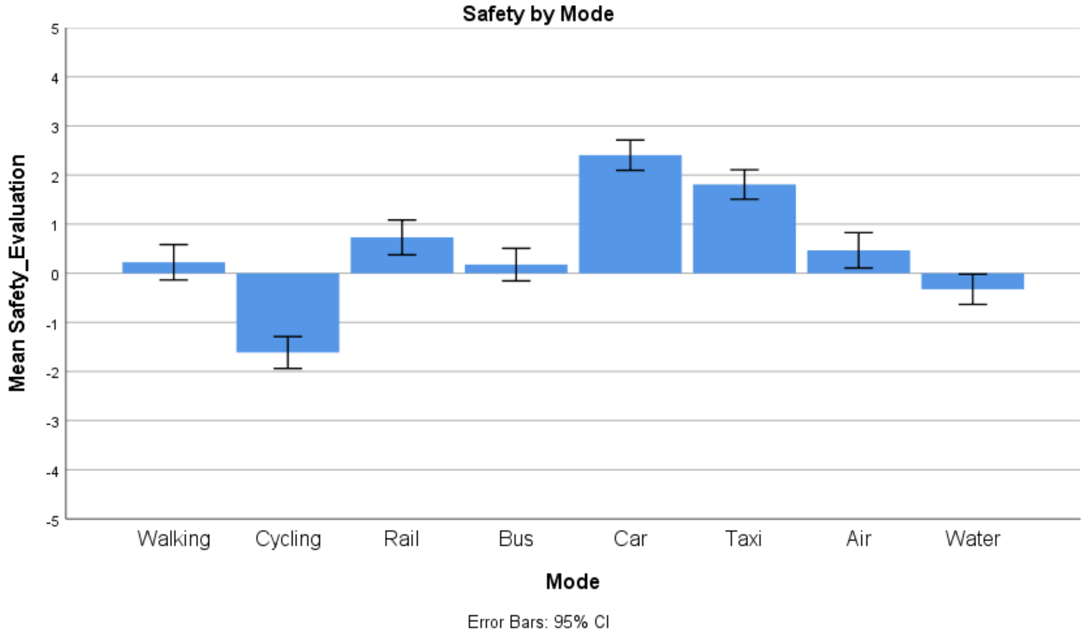


Figure 3.16 Safety effect

Recapitulating so far, the transport mode evaluated the highest regarding travel time, comfort, and safety is the car mode. Walking was found to be the most reliable mode with respect to time, also evaluated the highest with respect to travel cost.

3.3.4.3 Transport needs ranking for every transport mode

Apart from exploring how the eight transport modes were ranked as to how fast, reliable with respect to time, cheap, comfortable, and safe they are, what was also analyzed was how these factors were ranked for every transport mode. For the car mode for example, which factor was evaluated the highest and which the lowest? The following section provides an overview of how the different factors were ranked for every transport mode.

For the car mode, the factor evaluated the highest was comfort, closely followed by travel time whereas travel cost was evaluated the lowest, being the only one having a negative value. All the differences were found to be significant ($p<.05$) except for comfort and travel time ($p=.558$). These two factors were evaluated significantly higher than safety, excess time, and cost ($p<.001$ for all comparisons).

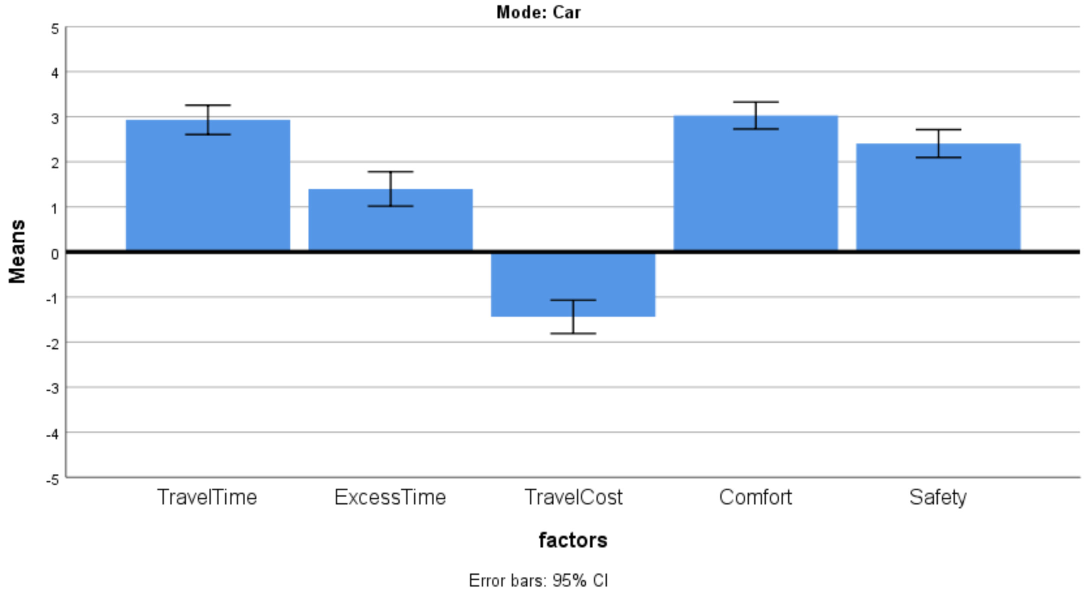


Figure 3.17 Car evaluations

A similar pattern occurred for the air mode, with travel time evaluated the highest than all other factors ($p<.001$). Crucially, comfort, safety and excess time were evaluated positively, they were close to zero, however, still significantly higher than travel cost which received the lowest evaluations ($p<.001$ for all comparisons).

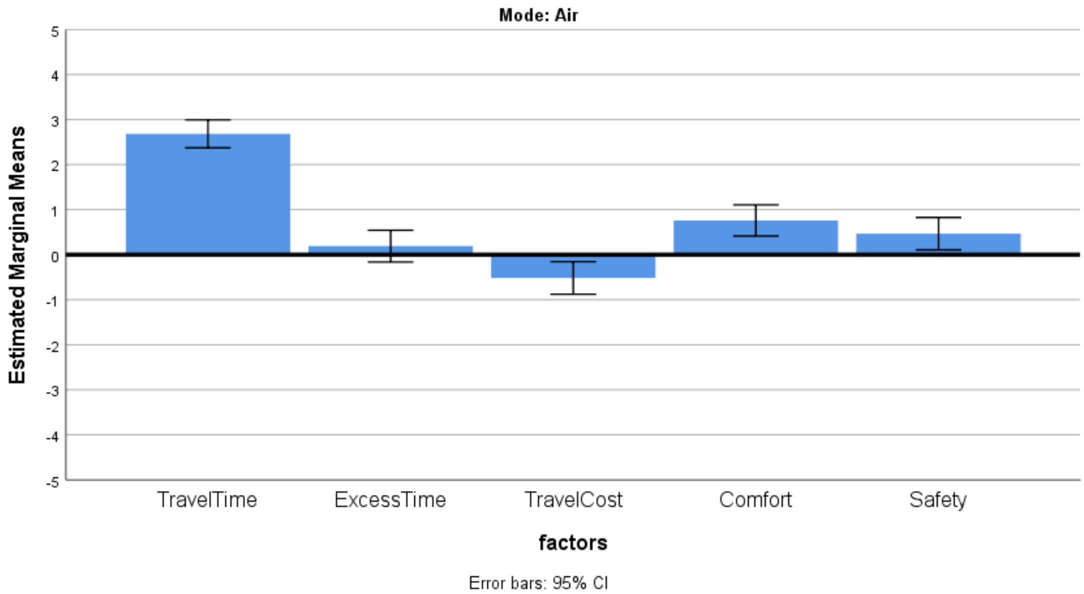


Figure 3.18 Air evaluations

The factor ranked the highest for the walking mode is travel cost, followed by excess time, comfort, safety, and lastly by travel time, the only factor having an overall negative evaluation for the walking mode. Travel cost was found to be evaluated significantly higher than all the other factors (p<.001 for all comparisons). Travel time on the other hand was ranked in the lowest place and it was evaluated significantly lower compared to the other factors (p<.001). The other comparisons also reached a significant level (p<.05).

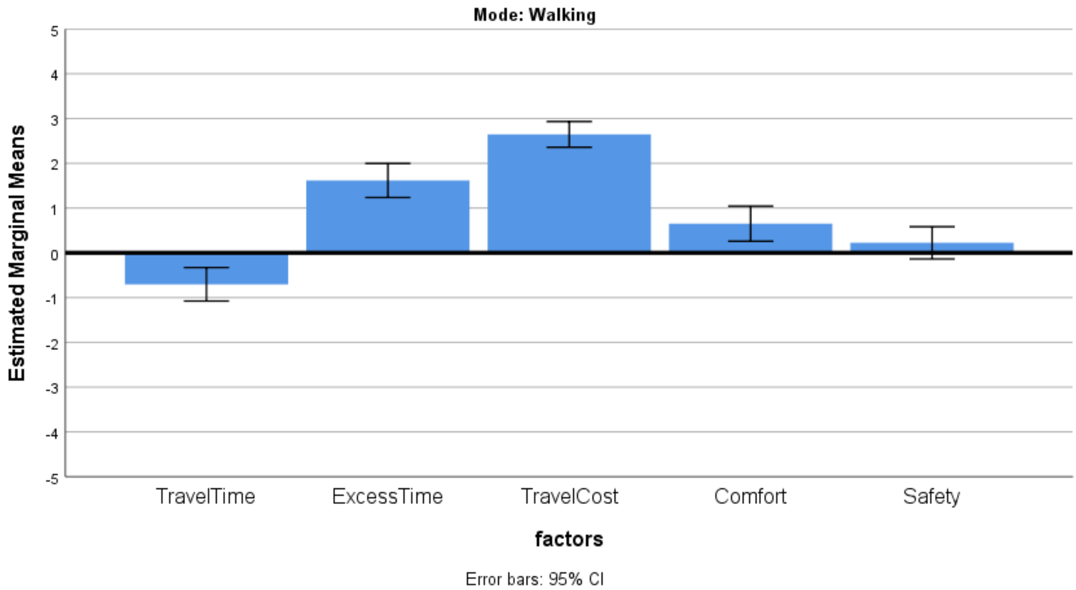


Figure 3.19 Walking evaluations

Similarly to the car and the air mode, comfort and travel time were evaluated the highest for the taxi mode as well, with no statistical difference between the two factors ($p=.262$). The lowest evaluations was given to travel cost, which was found to be significantly lower than all the other factors ($p<.001$). Safety was evaluated positively, and excess time negatively, with the difference between them being significant ($p=.01$).

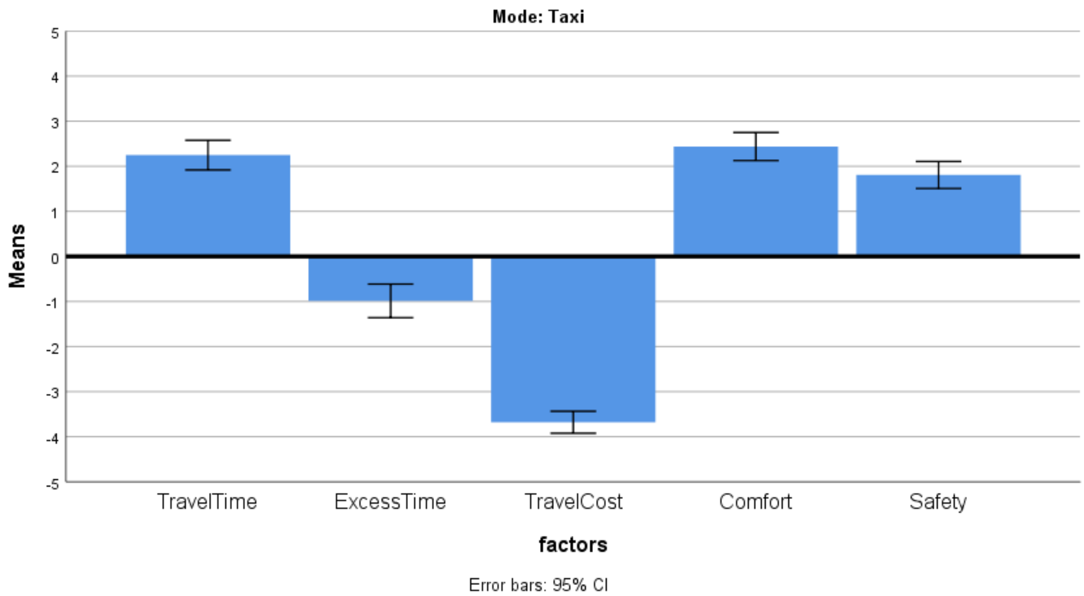


Figure 3.20 Taxi evaluations

For the water mode, the highest ranked factor, and the only one positively evaluated, is comfort. Comfort was evaluated significantly higher than all the other factors ($p < .001$ for all comparisons). Travel time and travel cost were evaluated the lowest, significantly less than all the other factors ($p < .05$) but without significant difference between them ($p = .174$). Excess time and safety were also poorly evaluated, with mean values close to zero. There was significant difference between them as well ($p = .154$).

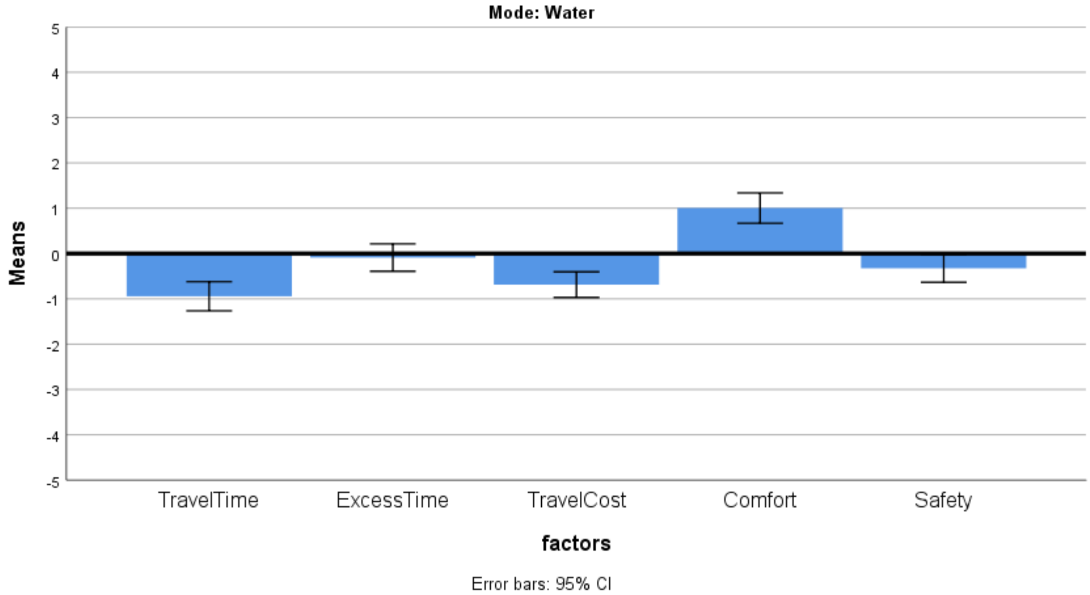


Figure 3.21 Water evaluations

The factor most appreciated for the rail mode is safety, closely followed by travel time ($p<.147$). It should be noted however that both of them do not have a mean above 1. Nevertheless, they are ranked higher than comfort, excess time, and travel cost ($p<.001$ for all comparisons). The travel cost of the rail was found to be the least appreciated factor, closely followed by the excess time ($p= .09$).

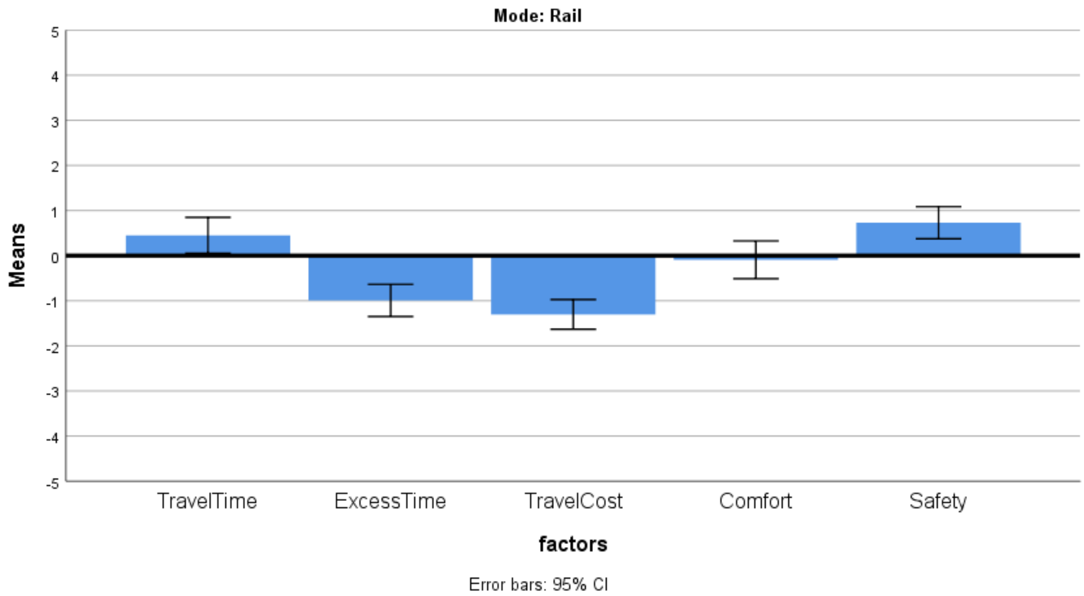


Figure 3.22 Rail evaluations

Travel cost was found to be the highest ranked factor for the cycling mode, exceeding all the other four (p<.001 for all comparisons). All the other differences also reached a significant level (p<.001) except for the one between the two lowest evaluations, namely for comfort and safety, which did not differ to a statistical degree (p= .163).

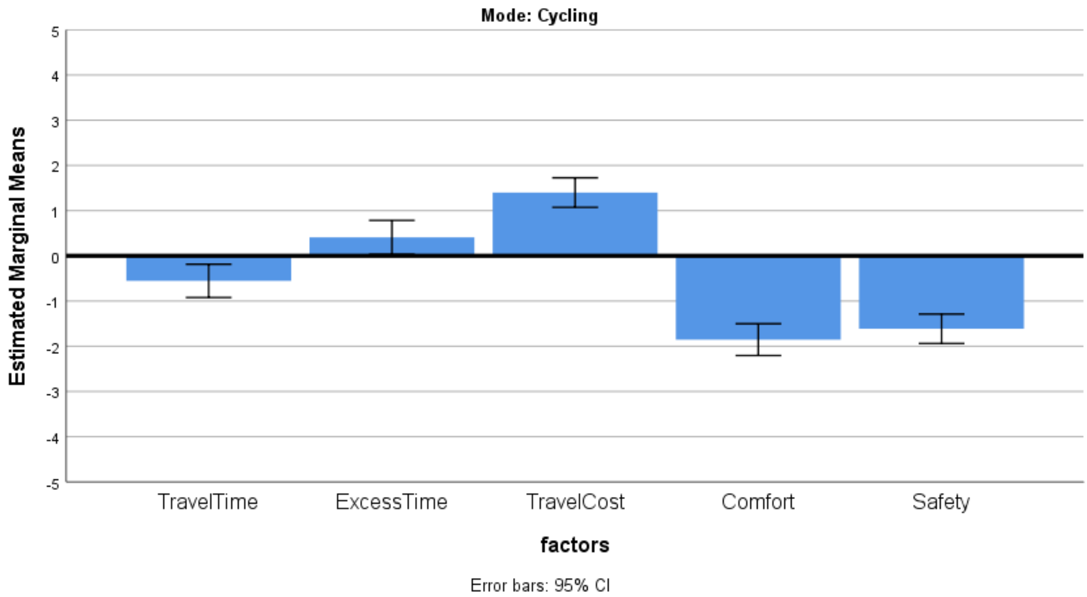


Figure 3.23 Cycling evaluations

For the bus mode, safety was the only factor evaluated positively and even though it was close to zero (M=.18), it was significantly higher than all the other factors (p=.01 for travel time, p<.001 for the other factors). Reliability as to how fast participants would believe they reach their destinations was evaluated the lowest, closely followed by how they evaluated the price for the ride (p=.150). Excess time and travel cost were evaluated significantly lower than all the other factors (p<.05).

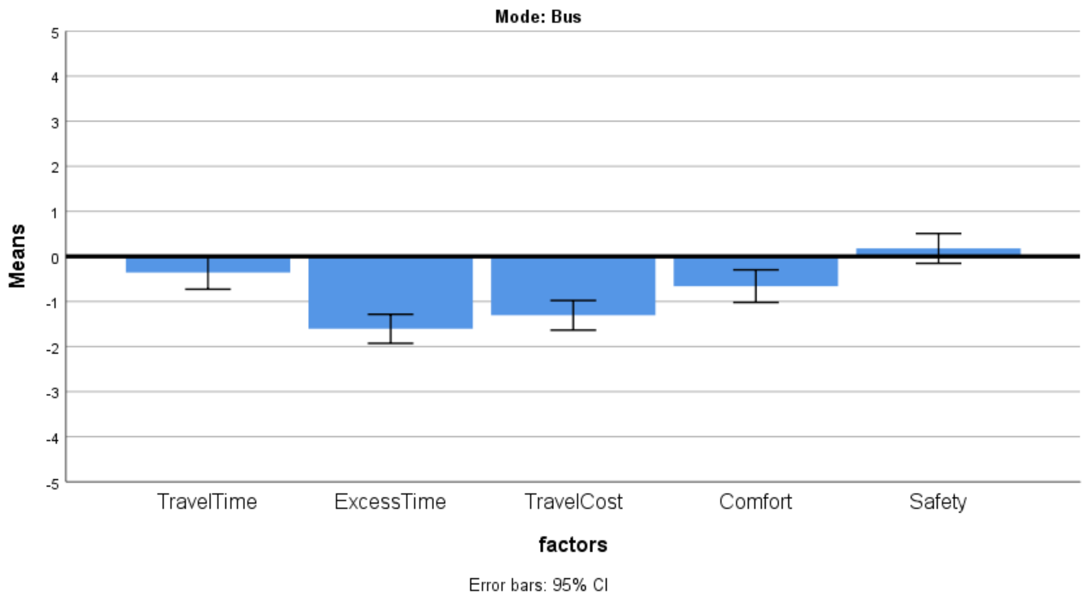


Figure 3.24 Bus evaluations

Recapitulating the main points, table presents which factor was evaluated the highest and which the lowest for the eight transport modes.

Table 3.29 Transport needs ranking

Transport mode	Highest evaluated factor	Lowest evaluated factor
1. Car	Comfort & Travel time	Travel cost
2. Air	Travel time	Travel cost
3. Walking	Travel cost	Travel time
4. Taxi	Comfort & Travel time	Travel cost
5. Water	Comfort	Travel time & Travel cost
6. Railing	Safety & Travel time	Travel Cost & Excess time
7. Cycling	Travel cost	Comfort
8. Bus	Safety	Excess time

3.3.4.4 Correlation of needs with participants' evaluations

After assessing how the different transport modes are evaluated in relation to the aforementioned factors, the next question to be investigated it whether these evaluations are associated with participants' overall evaluations. To this end, Pearson correlations were run between participants' evaluations on the [1] travel time, [2] excess time, [3] travel cost, [4] comfort, and [5] safety for every transport mode on the one hand and overall evaluations for the respective transport mode on the other hand (see Table 3.30).

Table 3.30 Correlations between overall evaluations and transport needs' evaluations

			Evaluation	TravelTime	ExcessTime	TravelCost	Comfort	Safety
Walking	Evaluation	Pearson Correlation	1	.620**	.609**	.429**	.659**	.554**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Cycling	Evaluation	Pearson Correlation	1	.685**	.583**	.407**	.643**	.616**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Rail	Evaluation	Pearson Correlation	1	.773**	.700**	.581**	.813**	.675**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Bus	Evaluation	Pearson Correlation	1	.676**	.555**	.473**	.604**	.573**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Car	Evaluation	Pearson Correlation	1	.608**	.562**	.396**	.498**	.532**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Taxi	Evaluation	Pearson Correlation	1	.502**	.548**	.197**	.422**	.404**
		Sig. (2-tailed)		0.000	0.000	0.001	0.000	0.000
Air	Evaluation	Pearson Correlation	1	.551**	.604**	.433**	.597**	.559**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000
Water	Evaluation	Pearson Correlation	1	.580**	.534**	.362**	.521**	.497**
		Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The results demonstrated that there were positive correlations at a statistically significant level between all five factors and overall evaluations for all transport modes. This finding suggests that the more the participants thought that a transport mode was fast (travel time), reliable with respect to time (excess time), cheap (travel cost), comfortable (comfort), and safe (safety), the higher they evaluated it.

3.3.4.5 Benefits effect on paticipants' evaluations

Apart from the above mentioned needs, participants were also asked to evaluate the eight transport modes as to the benefits they bring. More specifically, they were asked to evaluate them as to how they beneficiate their health (health), how much they enjoy themselves when they use them (recreation), how environmentally friendly they are (environmental), how much they contribute to country's industrial development (industrial) and finally, how much they help diminish traffic congestion (congestion).

To explore whether the transport modes were evaluated differently with respect to these 5 benefits, one-way ANOVAs were performed for each one of the five benefits with transport mode as the independent variable and participants' evaluations as the dependent variable. The analyses demonstrated a main effect of transport of mode for all benefits, namely for health ($F(7,2392)= 352.995$, $p<.001$), for recreation ($F(7,2392)= 25.991$, $p<.001$), for environmental ($F(7,2392)= 517.485$, $p<.001$), for industrial ($F(7,2392)= 184.462$, $p<.001$), and for congestion ($F(7,2392)= 168.794$, $p<.001$). The results demonstrate that participants considered that the different transport modes were differentiated as to how good they are for their health, how entertaining they are, how good they are for the environment, for the industrial development, and for congestion relief.

The next section presents a detailed analysis as to how the transport modes were evaluated with respect to the five benefits.

Beginning with health, the transport mode evaluated the highest is, not surprisingly, walking, closely followed by cycling ($p= 1.000$).

Table 3.31 Descriptive statistics of health benefit of each transport mode

Mode	Mean	Standard Deviation	Standard Error
Walking	3.91	1.807	0.104
Cycling	3.85	1.895	0.109
Rail	-2.43	2.906	0.168
Bus	-2.59	2.819	0.163
Car	-2.82	2.835	0.164
Taxi	-2.60	2.912	0.168
Air	-2.47	2.914	0.168
Water	-1.82	3.285	0.190

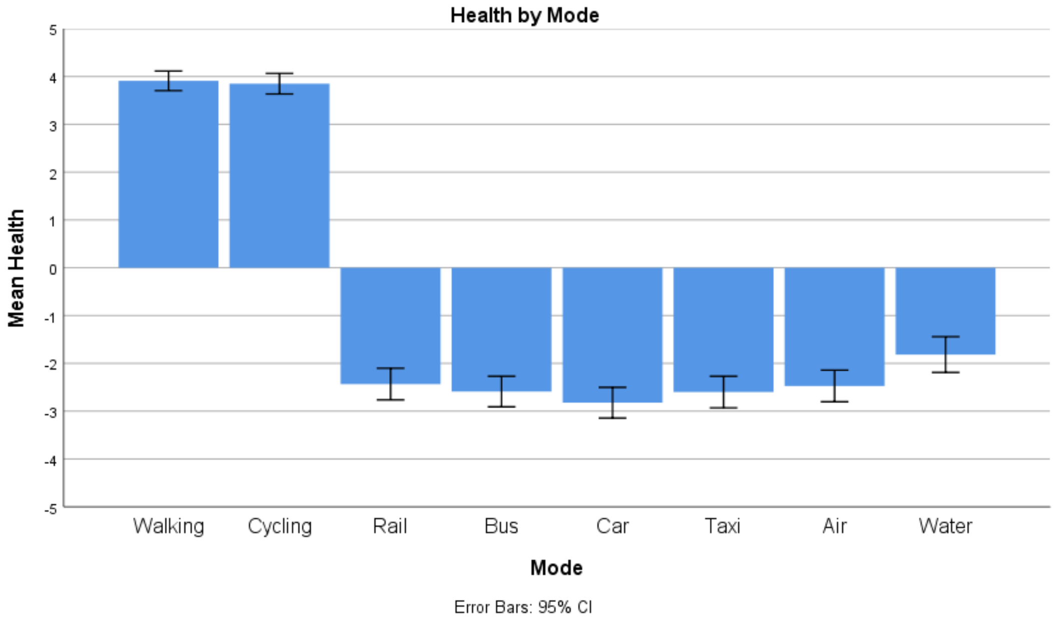


Figure 3.25 Descriptive statistics of health benefit of each transport mode

Walking and cycling are the only transport modes evaluated positively and they outperformed all the rest ($p<.001$ for all comparisons). In a descending order, water, rail, air, bus, taxi, and car were evaluated negatively, with the car mode being evaluated the lowest. No statistical differences emerged between the negative evaluated modes, except for the water mode evaluated significantly higher than taxi, bus and car ($p= .012$; $p= .014$; $p< .001$ respectively).

Moving to recreation, the modes evaluated the highest, however not surpassing the 2 points threshold, is car and walking (p= 1.000). Air and water followed, with no statistical difference emerging between these four modes (p<.05).

Table 3.32 Descriptive statistics of recreation benefit of each transport mode

Mode	Mean	Standard Deviation	Standard Error
Walking	1.53	3.368	0.194
Cycling	-0.10	3.552	0.205
Rail	-0.31	3.110	0.180
Bus	-1.03	2.965	0.171
Car	1.60	3.013	0.174
Taxi	0.56	2.807	0.162
Air	0.91	3.127	0.181
Water	0.90	3.116	0.180

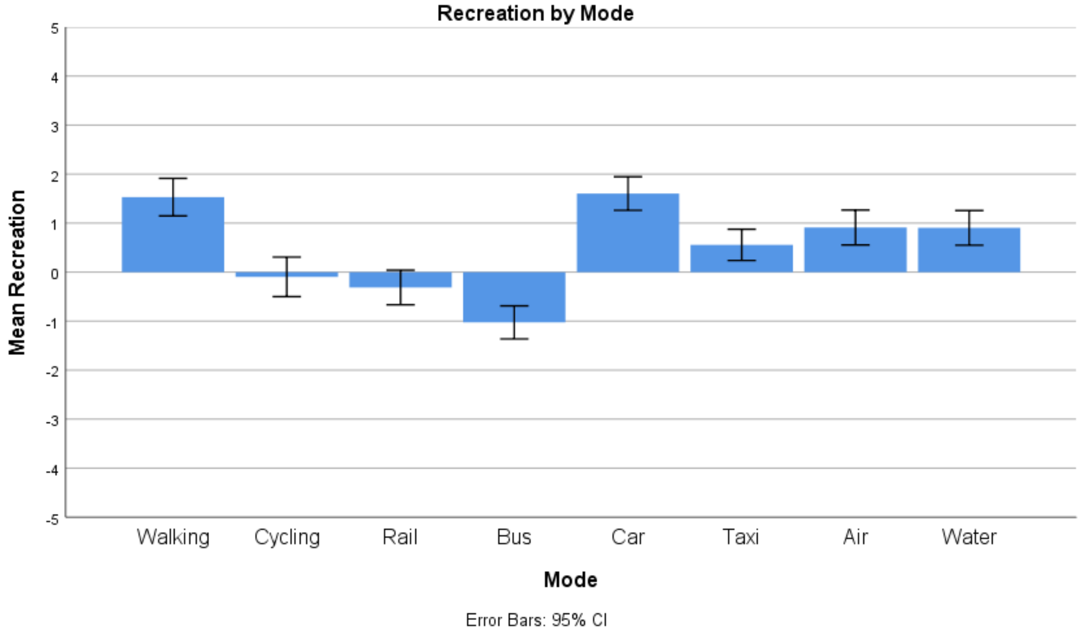


Figure 3.26 Descriptive statistics of recreation benefit of each transport mode

On the other end of the spectrum, bus was evaluated as the least entertaining transport mode, outperformed by all the rest ($p<.000$), except for rail ($p=.152$).

Coming to the environmental aspect, a pattern similar to the one for the health benefit appears. Walking and cycling are not only evaluated highly, with no statistical difference between them ($p=1.000$), but they are also the only transport modes evaluated positively. They outperform all the other transport modes to a statistical degree ($p<.001$).

Table 3.33 Descriptive statistics of environmental benefit of each transport mode

Mode	Mean	Standard Deviation	Standard Error
Walking	3.71	1.946	0.112
Cycling	3.40	2.182	0.126
Rail	-1.59	3.103	0.179
Bus	-2.94	2.502	0.144
Car	-3.91	1.735	0.100
Taxi	-3.67	1.999	0.115
Air	-3.34	2.425	0.140
Water	-2.45	2.766	0.160

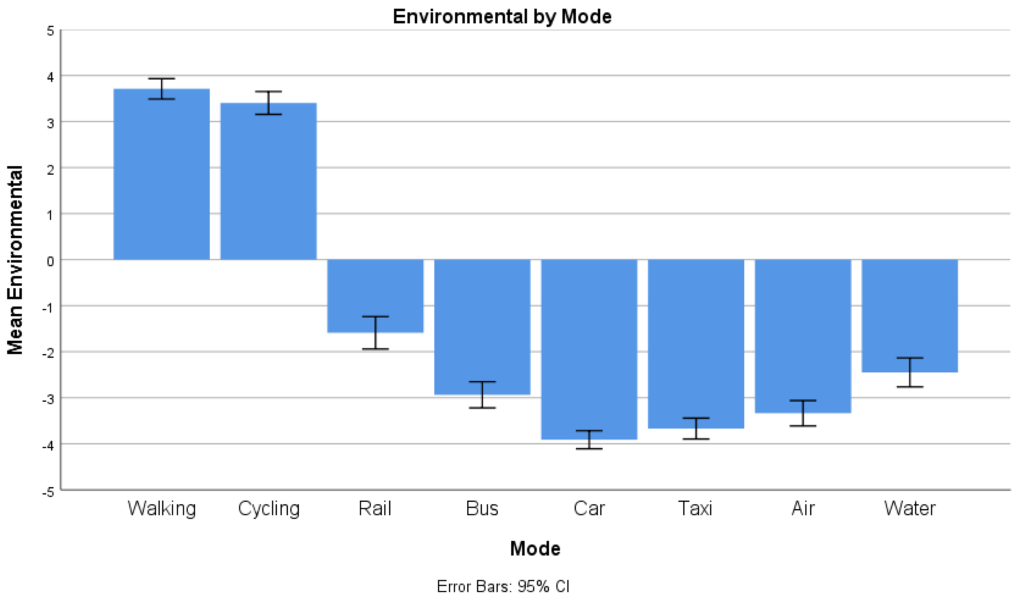


Figure 3.27 Descriptive statistics of environmental benefit of each transport mode

Crucially however, there is larger variability when it comes to the negatively evaluated modes. The car, taxi, and air modes are in the lowest positions, with no significant difference between them (p<.05). Car and taxi are evaluated significantly lower than the rest of the modes. The same applies for the air mode but interestingly, there is no statistical difference between it and the bus mode (p= 1.000). The bus mode was evaluated significantly compared to rail (p<.001) but not when compared to the water mode (p=.336).

When participants were asked as to how much every transport mode benefits the industry, the most highly ranked was the air mode, closely followed by the rail and the car modes, with no statistical difference between them (p= 1.000). Water, taxi, bus modes were also positively evaluated. The cycling mode, even though marginally positive, was evaluated significantly lower that all the previously mentioned modes (p<.001). Not surprisingly, walking was in the lowest ranking, with the difference with the other modes being significant (p<.001), except for cycling (p= .580).

Table 3.34 Descriptive statistics of industrial benefit of each transport mode

Mode	Mean	Standard Deviation	Standard Error
Walking	-0.12	1.402	0.081
Cycling	0.22	1.326	0.077
Rail	3.24	1.788	0.103
Bus	2.94	1.781	0.103
Car	3.18	1.816	0.105
Taxi	2.62	1.939	0.112
Air	3.33	2.080	0.120
Water	3.01	2.101	0.121

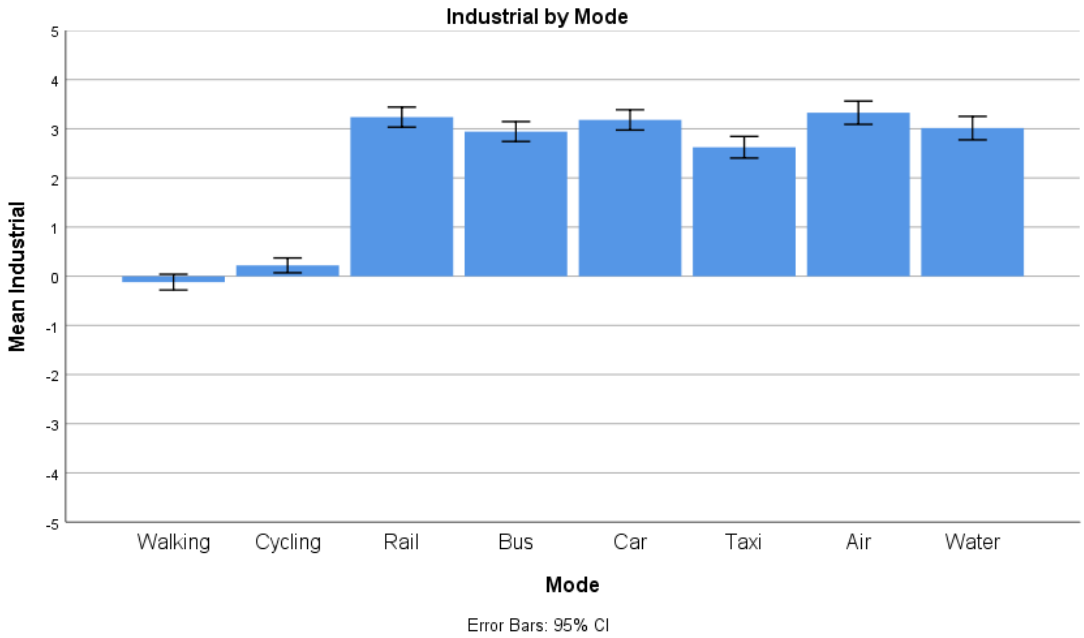


Figure 3.28 Descriptive statistics of environmental benefit of each transport mode

Finally, walking was evaluated as the mode the most beneficial as to congestion relief ($p<.001$ for all comparisons). Cycling was ranked in a high position as well, evaluated significantly higher than all the rest ($p <.05$). Rail, air, water were also positively, even though not highly evaluated. Surprisingly, a public transportation mode, namely the bus mode, was evaluated negatively, significantly lower than all ($p <.001$, but the water mode ($p= .08$). The car and the taxi modes were evaluated the lowest, with the difference with all the other modes being significant ($p< .001$ for all comparisons).

Table 3.35 Descriptive statistics of congestion of each transport mode

Mode	Mean	Standard Deviation	Standard Error
Walking	2.97	2.540	0.147
Cycling	1.83	3.171	0.183
Rail	1.02	3.134	0.181
Bus	-0.35	3.368	0.194
Car	-3.01	2.932	0.169
Taxi	-2.66	3.050	0.176
Air	0.75	1.783	0.103
Water	0.32	1.518	0.088

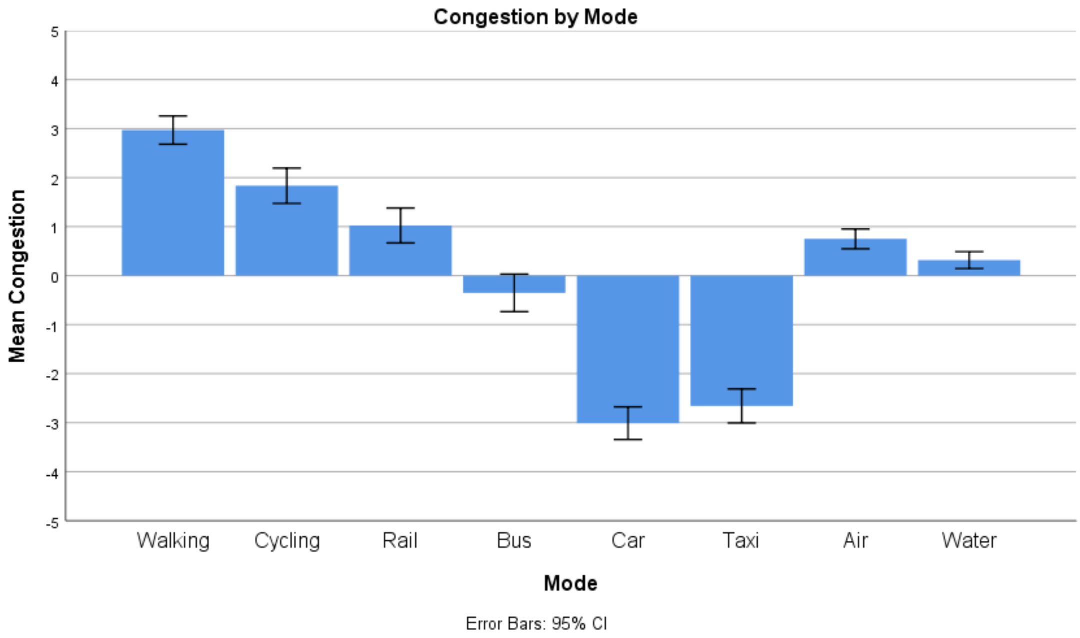


Figure 3.29 Descriptive statistics of congestion of each transport mode

After exploring how the eight transport modes were ranked as to how much they contribute to participants' [1] health and [2] enjoyment, to [3] environment, to [4] industrial development, and to [5] congestion relief, the next question is how these five benefits are ranked for every transport mode. For the walking mode for example, which benefit was evaluated the highest and which the lowest?

The next part presents how these benefits were ranked for the every transport mode. The means, the standard errors and the standard deviations can be found in the tables above which present the data for every benefit. The transport modes are presented in the order they were ranked in the overall evaluation.

Beginning with the car mode, contribution to industrial development and recreation were the only benefits evaluated positively, even though the first was evaluated significantly higher than the second ($p<.001$). Health and congestion were evaluated negatively, significantly lower than industrial and recreation ($p< .001$) but with no difference between them ($p= .418$). The environmental aspect was ranked last, evaluated the lowest when compared with all the other benefits, including the negatively evaluated ones ($p< .001$ for all comparisons).

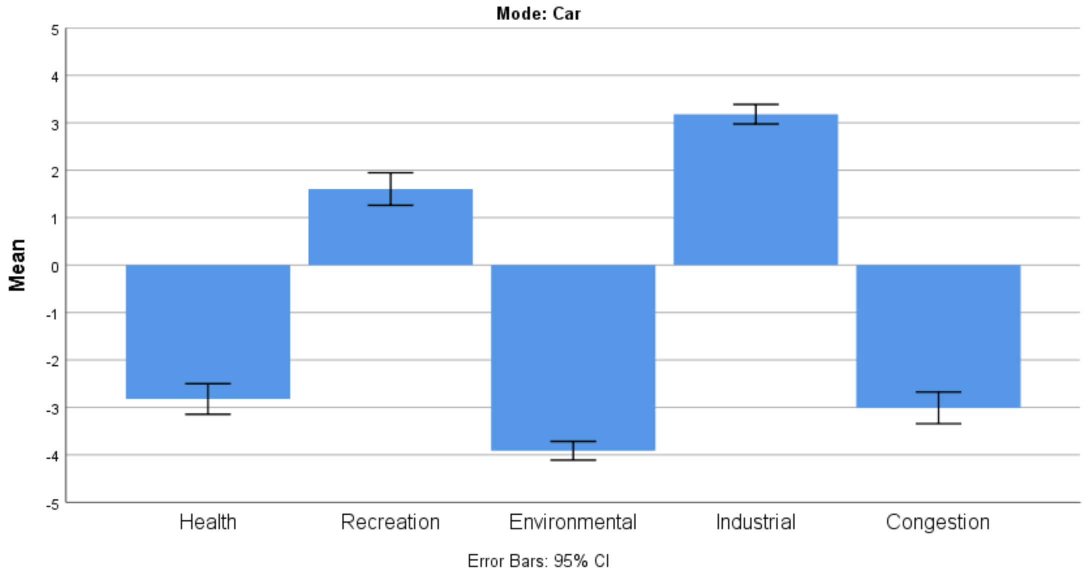


Figure 3.30 Car benefits evaluation

Contribution to industrial development was evaluated the highest for the air mode. The difference with all the other benefits was significant (p<.001). Recreation and congestions were also evaluated lower but still positively, with no statistical difference between them (p=.434). The health and the environmental aspect were evaluated negatively, with the last one being the lowest of all (p<.001).

The majority of benefits were evaluated positively for the walking mode. Health was evaluated the highest, closely followed by the environmental aspect, with no statistical difference between them (p= .121). Both of them were evaluated higher than congestion, recreation, and contribution to industrial development (p<.001 for all comparisons). The last one was evaluated, not surprisingly, the lowest with all the differences being significant (p<.001).

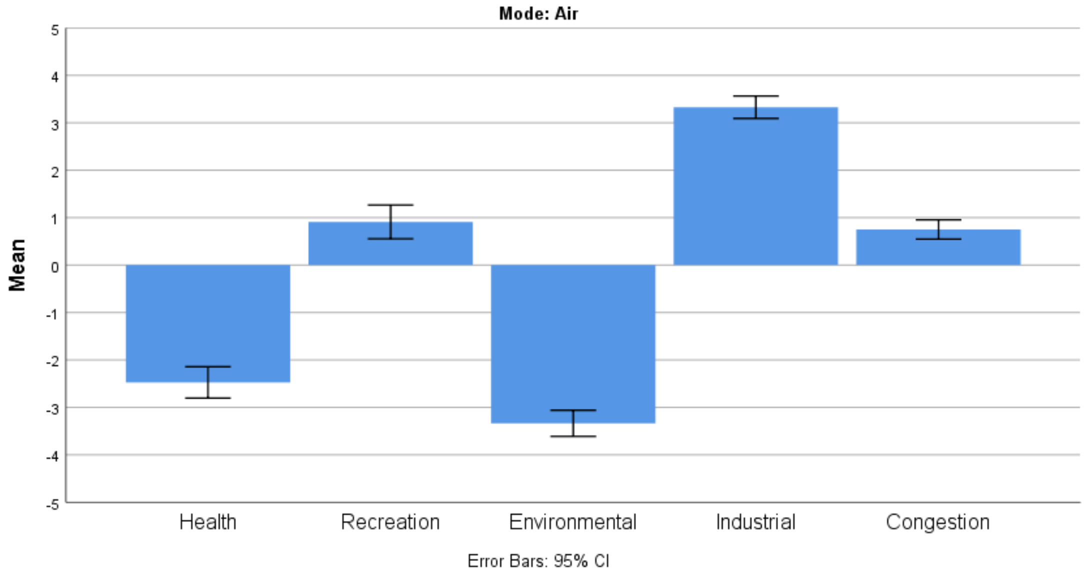


Figure 3.31 Air benefits evaluation

The environmental aspect was evaluated the lowest for the taxi mode, while health and congestion relief were also evaluated negatively. Recreation was evaluated positively, however not highly, and industrial development was evaluated the highest. All the differences between the different benefits were statistically significant ($p < .001$).

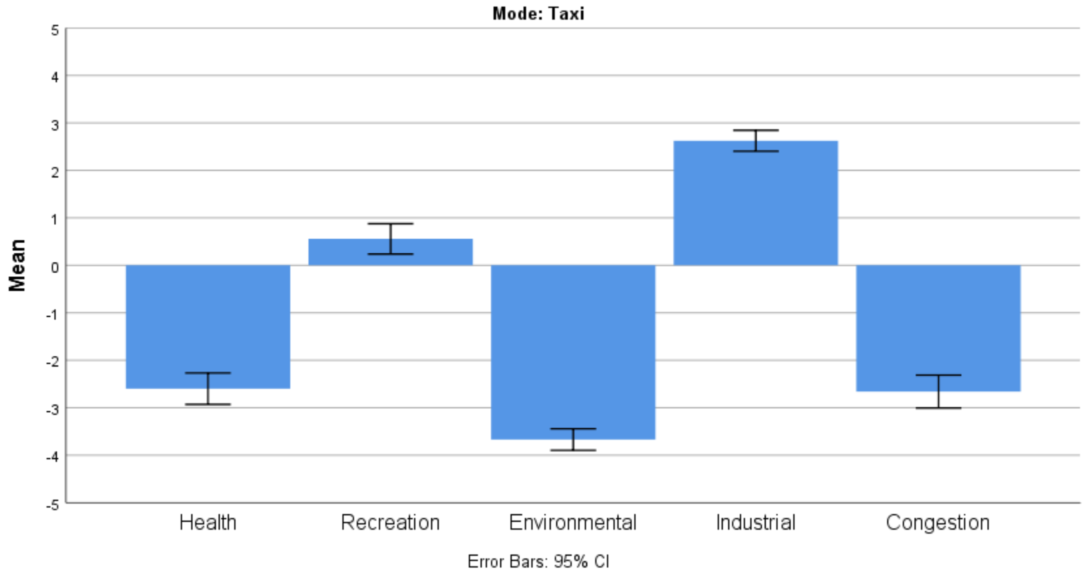


Figure 3.32 Taxi benefits evaluation

Contribution to industrial development and recreation were also evaluated the highest for the water mode, however the first one was significantly higher than the latter ($p< .001$). Congestion was evaluated marginally positive but significantly lower than industrial and recreation ($p< .001$ & $p= .003$ respectively). The health and the environmental aspect were evaluated negatively, with the difference between them and with the other benefits, being significant ($p< .001$).

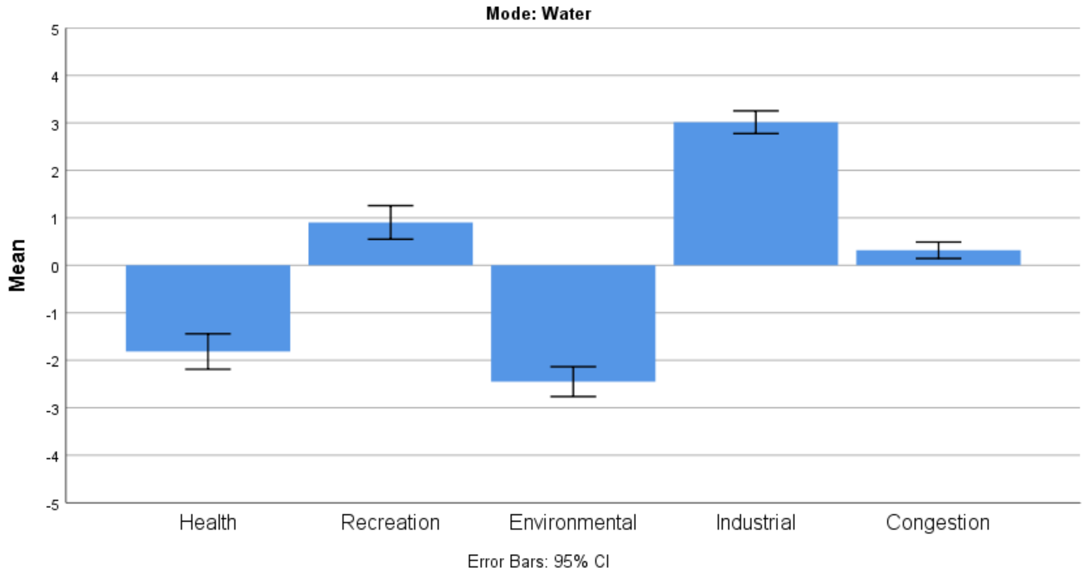


Figure 3.33 Water benefits evaluation

Contribution to industrial development seems to be the biggest benefit of rail use for the participants as it was evaluated the highest against all the other ($p < .001$). Contribution to congestion relief was also evaluated positively and significantly higher than the health, recreation, and environmental aspects ($p < .001$). Recreation was evaluated negatively, but close to 0 and significantly higher than the two other negatively evaluated benefits. Health was the lowest evaluated one, with the differences with all the other benefits being significant ($p < .001$ for all comparisons).

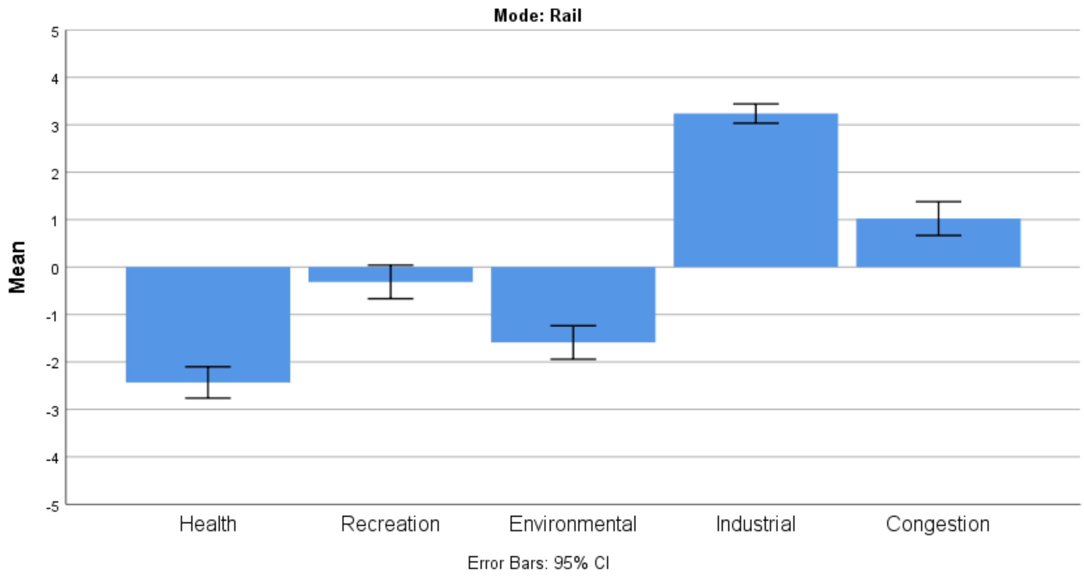


Figure 3.34 Rail benefits evaluation

Even though the overall evaluation of the cycling mode was low (M= 0.41), participants evaluated the five benefits positively. The health, the environmental, and the congestion relief benefits were evaluated the highest, and the differences with the recreation and the industrial aspects were all significant (p< .001 for all comparisons). Crucially, the health benefit was significantly higher than all the others (p= .002 against the environment benefit and p< .001 for all the other comparisons). The environmental benefit was evaluated higher than the congestion relief one (p< .001). No statistical difference occurred between the lowest evaluated benefits, namely the recreation and the industrial benefit (p= .143).

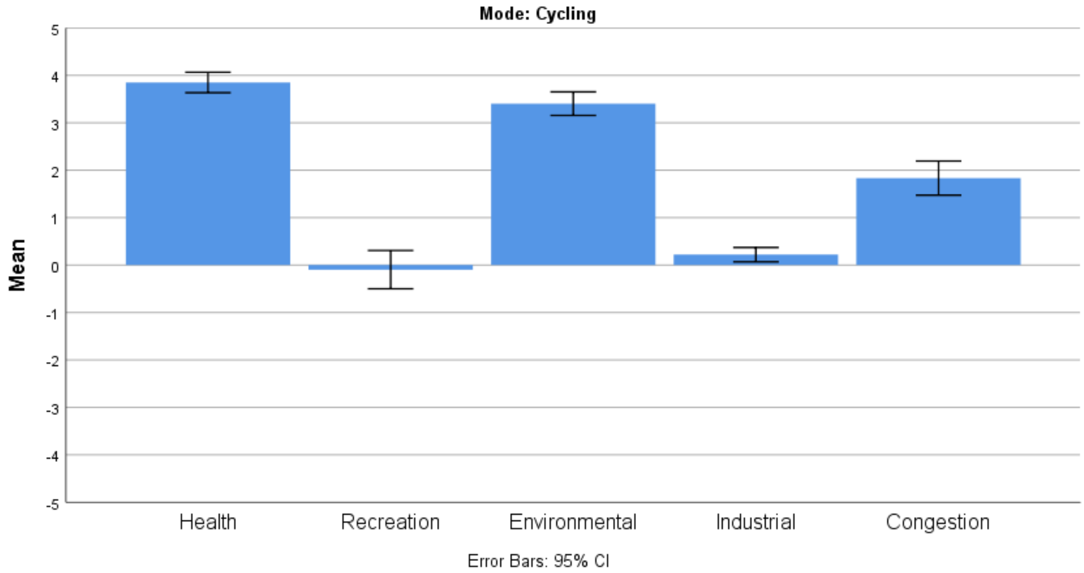


Figure 3.35 Cycling benefits evaluation

Only one benefit was evaluated positively for the bus mode, namely contribution to industrial development, and it was evaluated significantly higher than the rest ($p < .001$). The environmental and the health aspect were evaluated the lowest ($p < .001$ against all other benefits) but with no statistical difference between them ($p = .057$). Participants evaluated bus's contribution to congestion relief close to zero, even though statistically higher than the other negatively evaluated benefits ($p = .004$ against recreation; $p < .001$ for all the other comparisons).

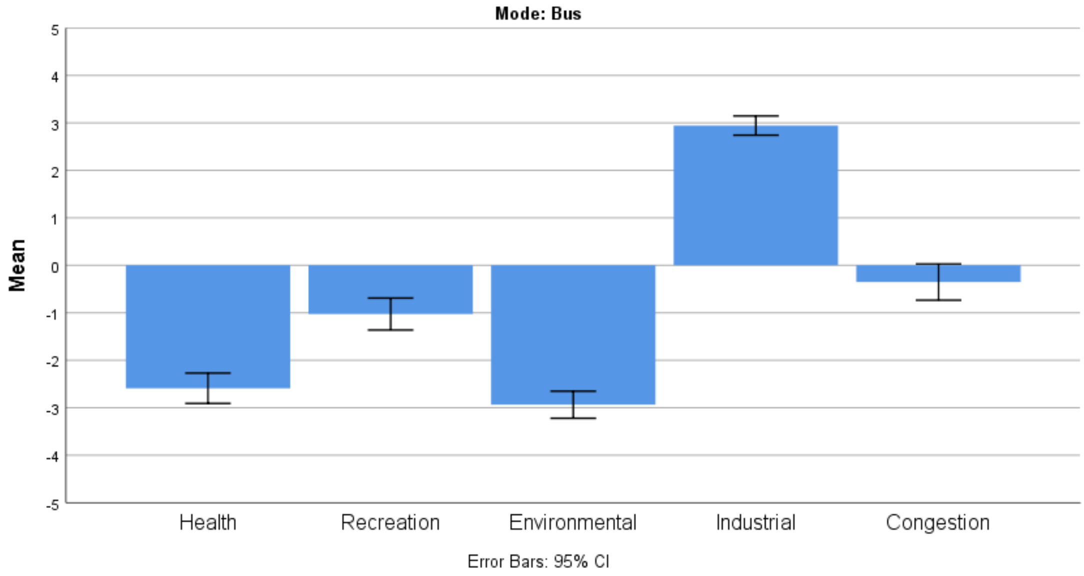


Figure 3.36 Bus benefits evaluation

3.3.4.6 Correlation of benefits with participants' evaluations

Having explored how the different transport modes are evaluated in relation to the aforementioned benefits, the next question to be investigated it whether these benefits are related to participants' overall evaluations. To this end, Pearson correlations were run between participants' evaluations on the [1] health, [2] recreation, [3] environmental, [4] industrial, and [5] congestion relief benefits for every transport mode on the one hand and their overall evaluations for the on the other hand.

Table 3.36 Correlations between overall evaluations and benefits' evaluations

			Evaluation	Health	Recreation	Environmental	Industrial	Congestion
Walking	Evaluation	Pearson Correlation	1	.122*	.627**	0.073	0.038	.169**
		Sig. (2-tailed)		0.034	0.000	0.209	0.516	0.003
Cycling	Evaluation	Pearson Correlation	1	.124*	.586**	0.024	-0.006	.193**
		Sig. (2-tailed)		0.031	0.000	0.683	0.917	0.001
Rail	Evaluation	Pearson Correlation	1	0.036	.560**	0.058	-.118*	.181**
		Sig. (2-tailed)		0.537	0.000	0.320	0.042	0.002
Bus	Evaluation	Pearson Correlation	1	0.110	.496**	0.091	-.155**	.154**
		Sig. (2-tailed)		0.056	0.000	0.117	0.007	0.007
Car	Evaluation	Pearson Correlation	1	0.004	.497**	0.070	0.108	.115*
		Sig. (2-tailed)		0.941	0.000	0.225	0.061	0.047
Taxi	Evaluation	Pearson Correlation	1	0.043	.443**	0.030	0.039	.156**
		Sig. (2-tailed)		0.453	0.000	0.600	0.502	0.007
Air	Evaluation	Pearson Correlation	1	0.113	.560**	0.063	.158**	.179**
		Sig. (2-tailed)		0.051	0.000	0.277	0.006	0.002
Water	Evaluation	Pearson Correlation	1	0.005	.480**	0.059	.137*	.181**
		Sig. (2-tailed)		0.926	0.000	0.311	0.017	0.002

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

At this point, it would be useful to recall the findings from the correlation analysis between the overall evaluations of the transport modes and the evaluation of the five factors under investigation (travel time, excess time, travel cost, comfort, and safety). The analysis demonstrated that all the correlations reached a significant level, indicating that the more the participants thought that a transport mode was fast, reliable with respect to time, cheap, comfortable, and safe, the higher they evaluated it.

The question arises as to whether the same pattern applies when it comes to the benefits under investigation. That is whether there is an association between the overall evaluation given to a transport mode and to how it was evaluated with respect to health, recreation, environmental, industrial, and congestion relief benefits.

The results demonstrated that significant correlations did appear but, interestingly, not across the board (all values on the Table above). The health benefit was positively associated with overall evaluations only for the walking and the cycling mode. The industrial development benefit was associated with the air, the water, the rail and the bus transport mode. No correlation reached a significant level for the environmental benefit. On the contrary, all associations were significant for the recreation and the congestion relief factor. Crucially however the correlations for the recreation benefit were stronger, as suggested by the larger r values.

It thus seems that, even though the recreation benefit was not evaluated specifically highly for the eight transport modes, it proves to be strongly associated with the overall evaluation participants gave. The environmental aspect on the other hand, despite being evaluated particularly low for the majority of the transport modes, does not appear to be correlated with the overall evaluations, since no significant correlations, neither positive nor negative, emerged.

3.3.4.7 Analysis of the distance travelled

This section presents an overview of the distances travelled by every mode in a year. As illustrated by the descriptive statistics below, the longest distance is travelled by the car mode, followed by the air mode and rail mode. The bus, the walking and the cycling modes follow while the taxi and the water modes are used when shorter distance is to be travelled. A one-way ANOVA with transportation mode as the independent variable and kilometers as the dependent one was run to investigate whether the eight transport modes differ as a function of the distance participants travel with them. The results showed that there is a main effect of transport mode on the distance, ($F(7, 2399)= 54.100$, $p< .001$), suggesting that participants differentiate their transport mode choice as a function of the distance they have to travel.

Table 3.37 Distance travelled per transport mode in a year

Mode	Mean	Standard Deviation	Standard Error
Walking	595.74	919.531	53.089
Cycling	435.38	1419.904	81.978
Rail	1548.90	3512.732	202.808
Bus	986.47	2366.569	136.634
Car	5343.73	8147.224	470.380
Taxi	96.51	327.845	18.928
Air	2254.71	7051.052	407.093
Water	28.86	299.164	17.272

Pearson correlation analysis was employed in order to examine whether the evaluation given to a transport mode is associated to the distance travelled by it. The results showed that there was an overall positive association between how much participants use a transport mode and how they evaluate it since there are statistically significant correlations for all but the rail mode. This finding suggests that the more they use the walking, the cycling, the bus, the car, the taxi, the air, and the water mode, the higher the evaluation that they give to it, or from another point of view, the higher they evaluate these modes, the more they use it in a year.

Table 3.38 Correlations between overall evaluations and benefits' evaluations

	Distance	
Mode evaluation	Pearson Correlation	Sig. (2-tailed)
Walking	.174**	0.003
Cycling	.400**	0.000
Rail	.092	0.112
Bus	.228**	0.000
Car	.201**	0.000
Taxi	.143*	0.013
Air	.251**	0.000
Water	,136*	0,019

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.3.4.8 Evaluations only by participants who use the respective modes

Up to this point, the analysis was about how all participants (N=300) evaluated the eight transport modes and five factors and five benefits associated to transportation. This part presents the overall evaluations again but only by the participants who use the respective mode and a different pattern than before emerges.

Before proceeding to the analysis, it should be noted that the means for the eight transport modes do not derive from an even number of participants. The majority of participants use walking and car in their everyday transportation (N= 206 & N= 172 respectively) while cycling, taxi, and water were used by smaller numbers (N= 45, N= 43, & N= 21 respectively).

Table 3.39 Evaluations by participants

Mode	Number of participants	Mean	Standard Deviation	Standard Error
Walking	206	1.67	3.100	0.216
Cycling	45	3.07	2.783	0.415
Rail	105	0.15	4.249	0.415
Bus	81	0.41	3.312	0.368
Car	172	2.41	2.763	0.211
Taxi	43	1.35	3.015	0.460
Air	66	3.24	2.170	0.267
Water	21	2.14	2.455	0.536

As evident from the table above, the transport modes with the highest evaluations were the air and the cycling modes, both exceeding the threshold of Mean= 3. Car and water followed, being above Mean = 2. Walking and taxi were next, while bus and rail were ranked in the last positions.

Table 3.40 Evaluations by users vs evaluations by participants

Evaluations by all participants	Evaluations only by participants who use the respective mode
[1] car	[1] air
[2] air	[2] cycling
[3] walking	[3] car
[4] taxi	[4] water
[5] water	[5] walking
[6] rail	[6] taxi
[7] cycling	[7] bus
[8] bus	[8] rail

The biggest surprise comes from the cycling mode, having the second highest evaluation while it was second from the end when all participants were asked to evaluate it, regardless of whether they use it or not. Rail and bus evaluated low in both cases. Crucially however, when taking into consideration only participants who use the modes they evaluate, there are no negative mean values.

3.3.4.9 Usage of Transport Modes in Metropolitan Areas

The usage of each transport mode in the metropolitan areas studied was compared with the national usage in the Great Britain. Since the distances between the travel points (e.g. work, shopping, friends' houses, etc.) are smaller and the public transport infrastructure is denser in metropolitan areas than in non-metropolitan areas, the usage of car and taxi should be lower than the national usage (see Table 3.41).

Table 3.41 Usage of Transport Modes in Metropolitan Areas

Transport mode	**National usage**	**Expected usage without Other**		**Percentage of usage in this study**	**Difference between national and study's usage**
Walking	3%	3.09%	**Walking**	6.62%	3.52%
Cycling	1%	1.03%	**Cycling**	4.83%	3.80%
Rail	10%	10.31%	**Rail**	17.20%	6.89%
Bus	5%	5.15%	**Bus**	10.95%	5.80%
Car/Taxi	78%	80.41%	**Car/Taxi**	59.33%	-20.01%
Other	3%	-		1.07%	
Total	100%	100%	**Total**	100%	0%

As was expected, walking, cycling, rail and bus usages were found to be greater than the national usage by 3.5%, 3.8%, 6.9% & 5.8%, respectively; on the other hand, car and taxi usage was less than the national usage by 20.0%. Additionally, the interviews were conducted randomly in public areas, so there is a risk that this sampling procedure results in sampling bias, and perhaps especially so for a survey on transport. The reason for this is that people who travel through public spaces by modes other than by car will be greatly oversampled, while others will be undersampled. The inherent limitations of the purposive sampling adopted in the research affected the sample, but this is not a weakness. Rather, it is a choice: the reason for using purposive sampling is to focus on particular characteristics (metropolitan areas, accessibility, gender, ethnic group and age) of a population that are of interest, which will best enable us to have several different answers for each transport mode.

3.3.5 Analysis and modelling

To generate the population values, each individual's evaluations of the factors for each transport mode were summed and a corresponding value was estimated for the same individual for the separate transport modes. The next step was to try to fit a mathematical expression to these computed social values.

After plotting the raw data onto axes, statistical equations were fitted to them by using the SPSS software. The sigmoid curve appeared in different analyses of Maslow's Hierarchy (1954) which considered value. Harrigan & Commons (2015) replaced Maslow's needs hierarchy with an account based on stage and value and they conclude that it "*may be interpreted as an interaction between stage and value*" (Harrigan & Commons, 2015, p.26). They model arithmetically "*the ways in which reinforcement value for different things changes with the stage the person in question is operating at*" (Harrigan & Commons, 2015, p.29). The numerical findings of

Harrigan & Commons (2015) on how individuals value something between the different stages (over time or over input of interest) are represented at Figure 3.37.

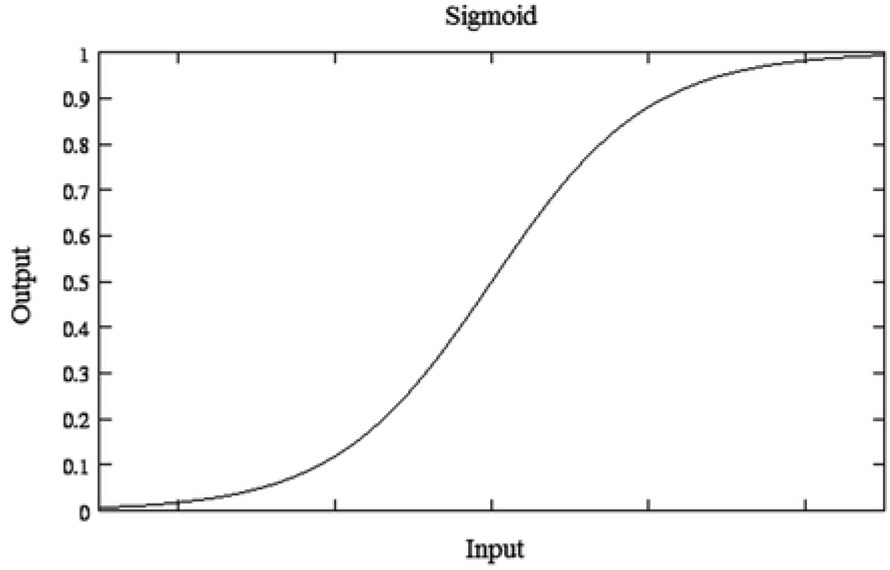


Figure 3.37 Value curve between two different successive stages, either time stages or of any other input, of individuals (Harrigan & Commons, 2015, p.31)

As discussed before, in valuing infrastructure case, it considered the interaction of value and stage of performance both of the individuals and the infrastructures. This means that the input data are considered as a sum of the value and stage of each individual and each infrastructure. Value is based on safety and security, time, societal acceptance, cost and comfort & convenience and stage is based on the age of the individual and the infrastructure. Harrigan and Commons' approach presents a smooth symmetrical change before and after the centre point (y=0.5).

The theory of Maslow (1954) is offered as a theory of the individual needs fulfillment, "*but it is natural to inquire whether it can be extended to describe the need fulfillment of*" other types of need e.g. nations' (Hagerty, 1999, p.250) or infrastructures' needs for a comprehensive, functional and efficient transport network. Hagerty (1999) tested the hypothetical S-shaped curves predicting the fulfilment of different needs of nations over time using statistical analysis. To quantify his observations, he applied polynomial regression (Hagerty, 1999, p.262) to each need and he designed the curve of each need. He expected to get an S-curve for each need. Harrigan and Commons' (2015) and Hagerty's (1999) approach oppose, partly, Bourantas' (2002) approach who has different curves for each need than the S-curves for all of them and expects to get only as a total an almost sigmoid curve. Bourantas developed these curves as part of applying Maslow's Theory in business management, so his approach is more appropriate that Harrigan and Commons' and Hagerty's, who all apply it in psychology. It is worth noting that Harrigan and Commons understood since they claim in their conclusion that "*needs described by Maslow are mentalistic inferences*" (Harrigan & Commons, 2015, p.30), but in management the needs are studied like something measurable. To conclude, since transport infrastructure is a need of each nation, then it can be analysed through statistical analysis too and test Maslow's Theory and Bourantas' curves.

The challenge is how to explain the data collected with a mathematical relationship (curve), since it is difficult to decide for example whether the data is explained with a parabolic or exponential relationship. Therefore, it is very useful for non-linear relationships to be formed so that they can be represented by a linear relationship (linearisation), because then linear regression can be applied. Linear regression analysis covers a broad field of model-building techniques within statistical analysis. If the relationship between dependent and independent variable is found to be non-linear, then either the dependent or independent variables may be transformed to yield a linear relationship. Examples of such transformations are:

Non-linear relationship	Corresponding linear relationship
$Y = a \cdot b^x$	$log\, Y = log\, a + x \cdot log\, b$
$Y = a \cdot x^b$	$log\, Y = log\, a + b \cdot log\, x$
$Y = a_0 \cdot {x_1}^{a_1} \cdot {x_2}^{a_2} \cdot \ldots \cdot {x_v}^{a_v}$	$ln\, Y = ln\, a_0 + a_1 \cdot ln\, x_1 + a_2 \cdot ln\, x_2 + \ldots + a_v \cdot ln\, x_v$
$Y = 1/(a + x^b)$	$1/Y = a + x^b$ and take the logarithm of it
$Y = e^{(a_0 + a_1 x_1 + \ldots + a_v x_v)}$	$ln\, Y = a_0 + a_1 x_1 + \ldots + a_v x_v$

It can be seen that linear regression analysis can represent different relationships both at the established business models and at the new business model. The challenge occurs when some independent variables are calculated as dependent of different factors and when some independent variables of the established business model are dependent in the new business model. In this case, further checks (at least one more) are required.

Additionally, linear regression analysis has the issue of the "*illusion of linearity*". The tendency to imply, wrongly, linearity relationships and to apply their properties is called the "*illusion of linearity*". This phenomenon, apart from "*illusion of linearity*", may be reported in the literature as "*linearity trap*" or "*linear obstacle*". Freudenthal (1983, p. 267) noticed that "*linearity is such a suggestive property of relations that one readily yields to the seduction to deal with each numerical relation as though it were linear*". Additionally, the challenge of $Y = f(X_i) + u$ arises when the different variables X_i are raised to the power n_i, where $n_i > 1$, within the function. As it already discussed $Y = f(X_i) + u$ where u the part of is the sample not explained from the independent variables X_i (Giannopoulos, 2002, p.39).

Statistical modelling is the proper methodology. To avoid issues like the "*illusion of linearity*" and variables rise to power (${x_i}^n$), statistical analysis using the SPSS program (IBM, 2018) of the social value data was performed.

SPSS (IBM, 2018) considers the following models to interpret the results: 1) Linear model, whose equation is $y = b_0 + b_1 \cdot x$ and the social value is modelled as a linear function of the five aforementioned factors (safety and security, time, societal acceptance, cost and comfort & convenience). 2) Logarithmic model whose equation is $Y = b_0 + b_1 \cdot ln(x)$ and aligns with some sigmoid curves. 3) Inverse model whose equation is $Y = b_0 + \frac{b_1}{x}$. 4) Quadratic model whose equation is $y = b_0 + b_1 \cdot x + b_2 \cdot x^2$ and aligns partly with some sigmoid curves. 5) Cubic model whose equation is $y = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3$ and aligns with some sigmoid curves. 6) Compound model whose equation is $Y = b_0 \cdot (b_1^x)$or $ln(Y) = ln(b_0) + x \cdot ln(b_1)$. 7) Power model whose equation is $Y = b_0 \cdot x^{b_1}$or $ln(Y) = ln(b_0) + (b_1 \cdot ln(x))$. 8) S-curve model whose equation is $Y = e^{b_0 + \frac{b_1}{x}}$ or $ln(Y) = b_0 + \frac{b_1}{x}$ and it is a pure sigmoid model. 9) Growth model whose equation is $Y = e^{b_0 + b_1 \cdot x}$ or $ln(Y) = b_0 + b_1 \cdot x$. 10) Exponential model whose equation is $Y = b_0 \cdot e^{b_1 \cdot x}$ or $ln(Y) = ln(b_0) + b_1 \cdot x$. 11) Finally, logistic model whose equation is $Y = \frac{1}{\frac{1}{u} + b_0 \cdot b_1^x}$ or $ln\left(\frac{1}{Y} - \frac{1}{u}\right) = ln(b_0) + x \cdot ln(b_1)$ where u is the upper boundary value. After selecting Logistic, the upper boundary value is specified to 5.01 to use in the regression equation, since the value must be a positive number that is greater than the largest dependent variable value. It is a sigmoid model too.

The logarithmic, the inverse, the compound, the power, the S-curve, the growth, the exponential and the logistic models require all values to be positive (no negative or zero). As it can be seen in the following table (Table 3.42), both dependent and independent variables contain non-positive values, meaning that their transforms cannot be applied and their models cannot be calculated.

Table 3.42 Variable processing summary

		Variables	
		Dependent	Independent
		Real_Evaluation	Sum_Factors
Number of Positive Values		1167	1229
Number of Zeros		287	271
Number of Negative Values		946	900
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Under these conditions with negative values only three models can be tested: the linear, the quadratic and the cubic. The three models explain more than 70% of the data (Table 3.43), but only the cubic model has almost s-curve shape (Figure 3.38).

Table 3.43 Model summary and parameter estimates

Dependent Variable: Real_Evaluation

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.706	5758.507	1	2398	.000	-.017	.257		
Quadratic	.706	2880.604	2	2397	.000	-.053	.257	.000	
Cubic	.728	2136.016	3	2396	.000	-.093	.333	.000	.000

The independent variable is Sum_Factors.

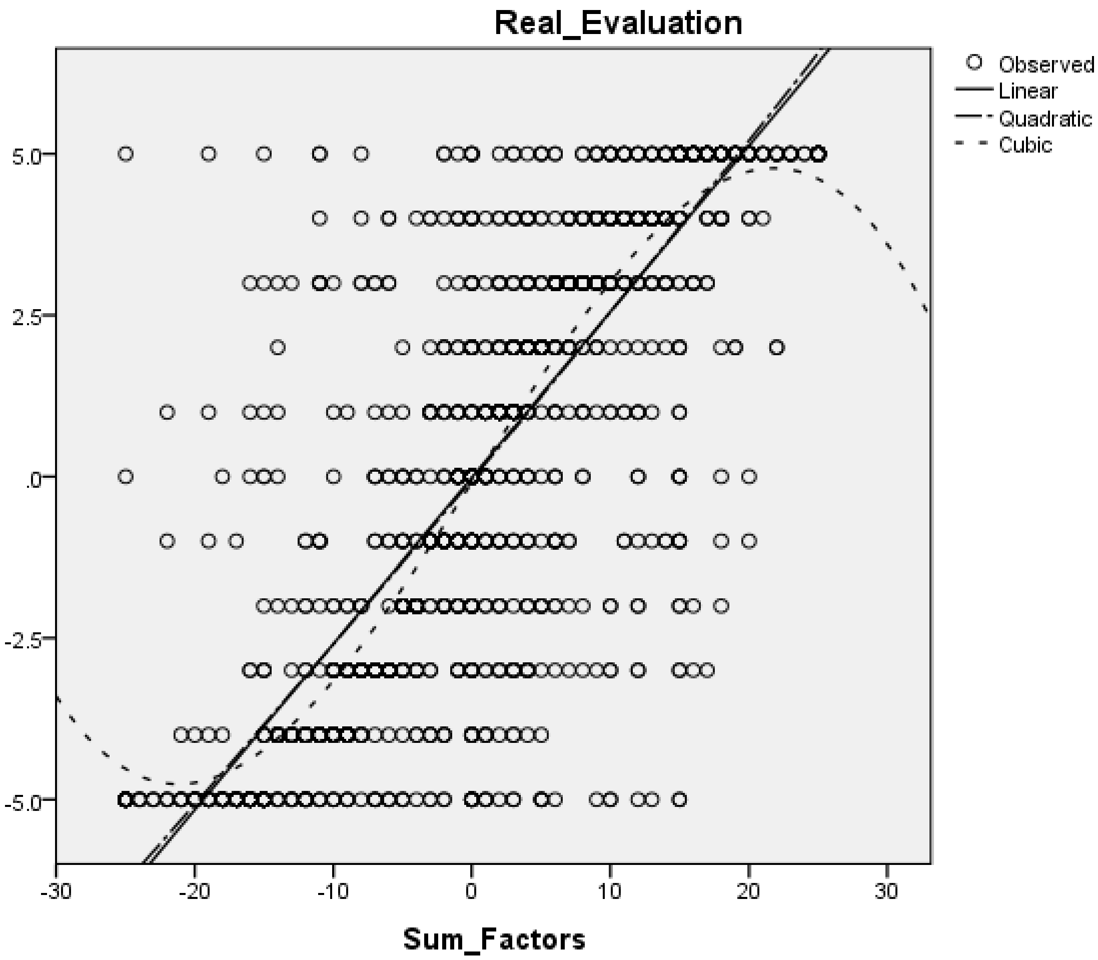


Figure 3.38 Fitting raw data onto SPSS models

For comparison purposes, both dependent and independent variables' values were transformed to positive values by adding 10 (twice the maximum) to Y-axis and 50 (twice the maximum) to X-axis. This way there will be no negative values without changing the scale (the graph will just move within the positive area. The reducible data would be possible to identify the percentage of the results that can be explained by the models which require all values to be positive (Table 3.44).

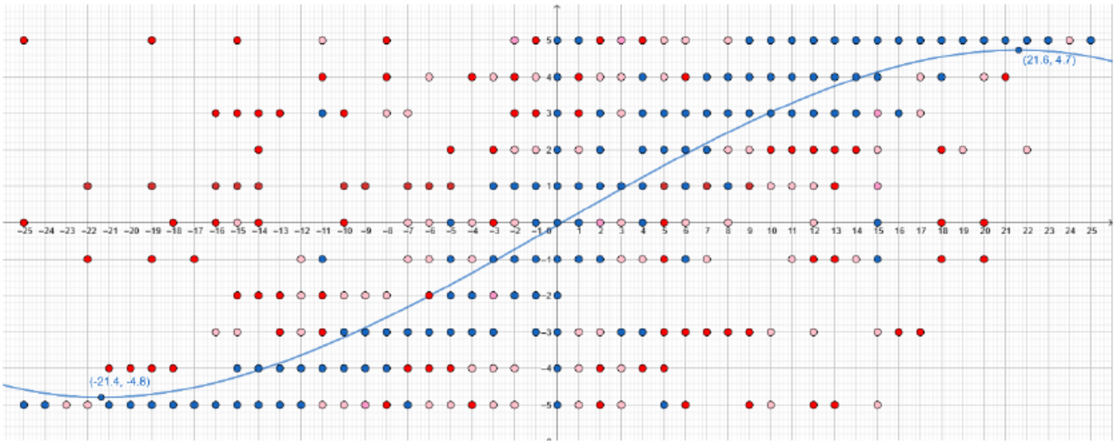


Figure 3.39 Cubic model

Figure 3.39 shows the cubic-spline function model which explains most of the raw data and has an almost s-curve shape. Evaluations provided by one individual are represented with red colour, evaluations provided by two or three individuals are represented with pink colour and evaluations provided by four individuals or more are represented by blue colour.

Table 3.44 Variable processing summary of the reducible data

		Variables	
		Dependent	Independent
		Real_pos	Sum_pos
Number of Positive Values		2400	2400
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Since all the values are positive all the models can be applied. The three previous models (the linear, the quadratic and the cubic) will be tested too and it is expected to get exactly the same R^2, which happened (see Table 3.45).

Table 3.45 Model summary and parameter estimates of the reducible data

Dependent Variable: Real pos

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.706	5758.507	1	2398	.000	-2.875	.257		
Logarithmic	.679	5083.896	1	2398	.000	-36.383	11.935		
Inverse	.613	3801.618	1	2398	.000	20.512	-496.000		
Quadratic	.706	2880.604	2	2397	.000	-2.162	.227	.000	
Cubic	.728	2136.016	3	2396	.000	23.805	-1.488	.036	.000
Compound	.696	5484.870	1	2398	.000	2.351	1.028		
Power	.696	5490.980	1	2398	.000	.058	1.308		
S	.654	4524.465	1	2398	.000	3.414	-55.467		
Growth	.696	5484.870	1	2398	.000	.855	.028		
Exponential	.696	5484.870	1	2398	.000	2.351	.028		
Logistic	.696	5484.870	1	2398	.000	.425	.973		

The independent variable is Sum_pos.

The cubic model fits better to the raw data (72.8%) followed by the linear (70.6%), the quadratic (70.6%), the compound (69.6%), the power (69.6%), the growth (69.6%), the exponential (69.6%) and the logistic (69.6%) models. Cubic model is significantly better than the logarithmic (67.9%), the inverse (61.3%) and the S-curve (65.4%) models.

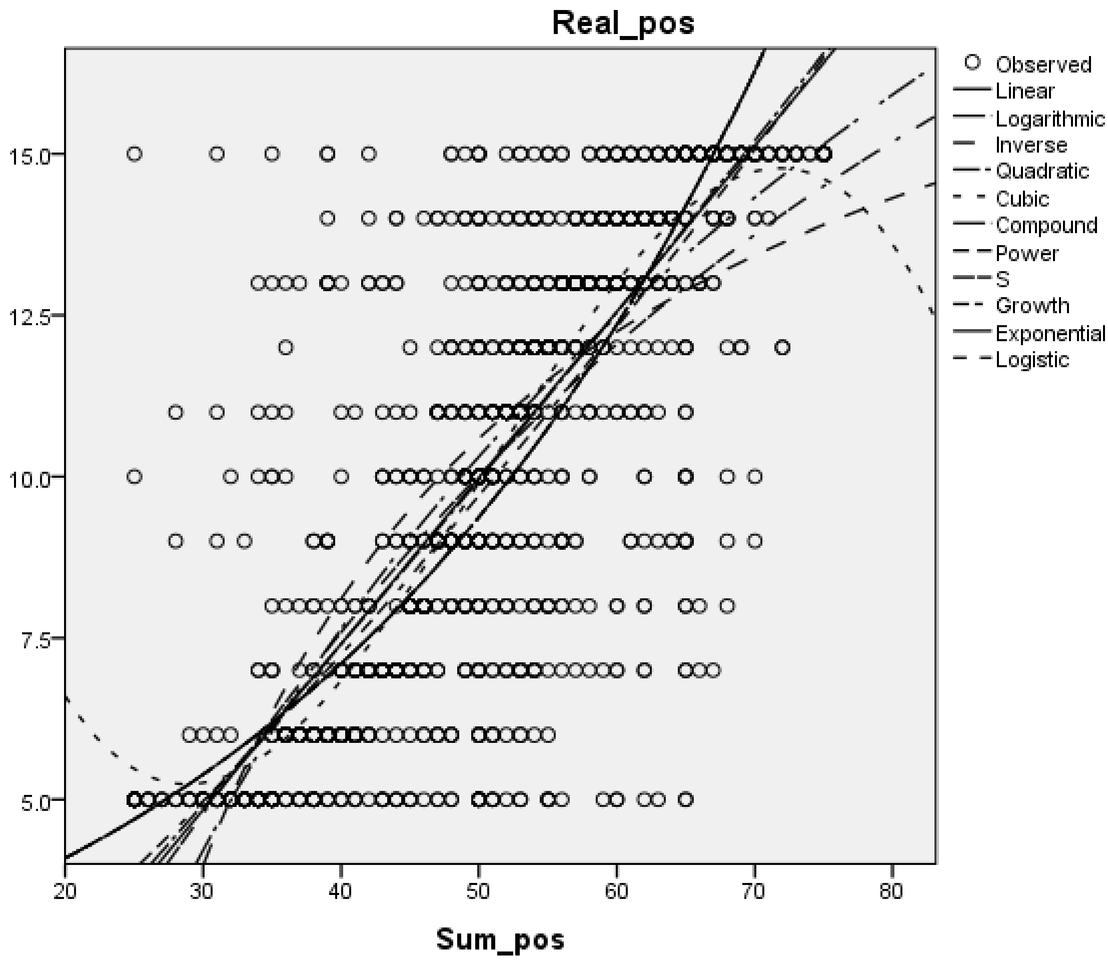


Figure 3.40 Fitting reducible raw data onto SPSS models

The three statistical models which have R-Squares higher than 0.70 are defined both on the positive and on the negative real numbers. The linear and the quadratic models do not agree with the hypothesis that the value to the individual relative to safety and security, time, societal acceptance, cost and comfort & convenience (which combined represents the social value) should approximate to a sigmoid curve. Additionally, the cubic models do not contain the fixed point of origin (0,0) for the Cartesian coordinate system. This may be explained because individuals view the zero social value as likely to be a negative sum of the social value factors. Before investigating this, it should be found if there are fixed-point models which work. The fixed-point model was examined by forcing function intercept (set at point 0,0) in order for the regression line to follow the initial hypothesis logic in this case (orange function in Figure 3.41). The fixed-point models were expected to explain less of the primary data.

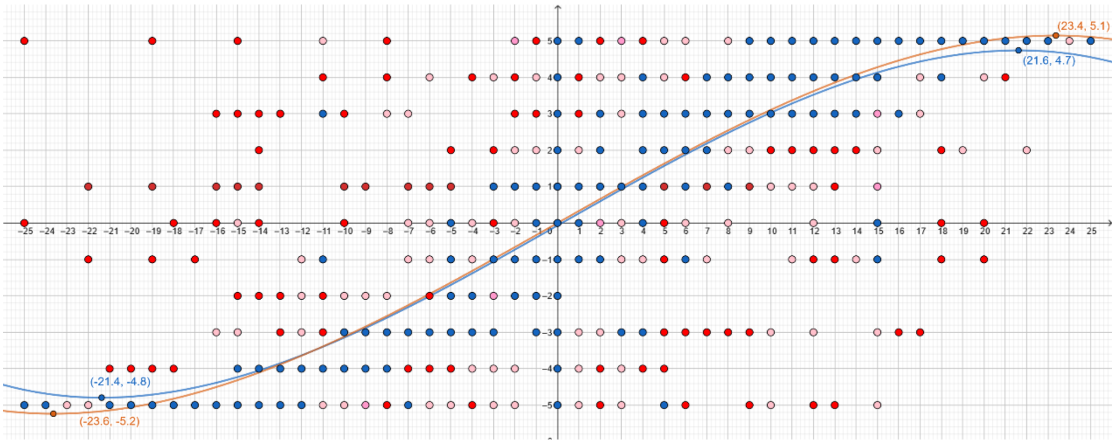


Figure 3.41 Fitting raw data with setting the intercept point (0,0)

Indeed, the new fixed-point equations explained marginally less (72.74% < 72.8% for the cubic model) /or the same amount (70.6% for the linear and the quadratic models) of primary data. However, the only equation which agrees the hypothesis theory is the cubic model whose equation is:

$$Y = -0.092605 + 0.332628 \cdot x + 0.000215 \cdot x^2 - 0.000240 \cdot x^3$$

It was decided to investigate the non-fixed-point models, because the individuals may view the zero social value as likely to be a negative sum of the social value factors.

Table 3.46 Real evaluation distribution

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-5	290	12.1	12.1	12.1
	-4	163	6.8	6.8	18.9
	-3	168	7.0	7.0	25.9
	-2	156	6.5	6.5	32.4
	-1	169	7.0	7.0	39.4
	0	287	12.0	12.0	51.4
	1	183	7.6	7.6	59.0
	2	191	8.0	8.0	67.0
	3	250	10.4	10.4	77.4
	4	217	9.0	9.0	86.4
	5	326	13.6	13.6	100.0
	Total	2400	100.0	100.0	

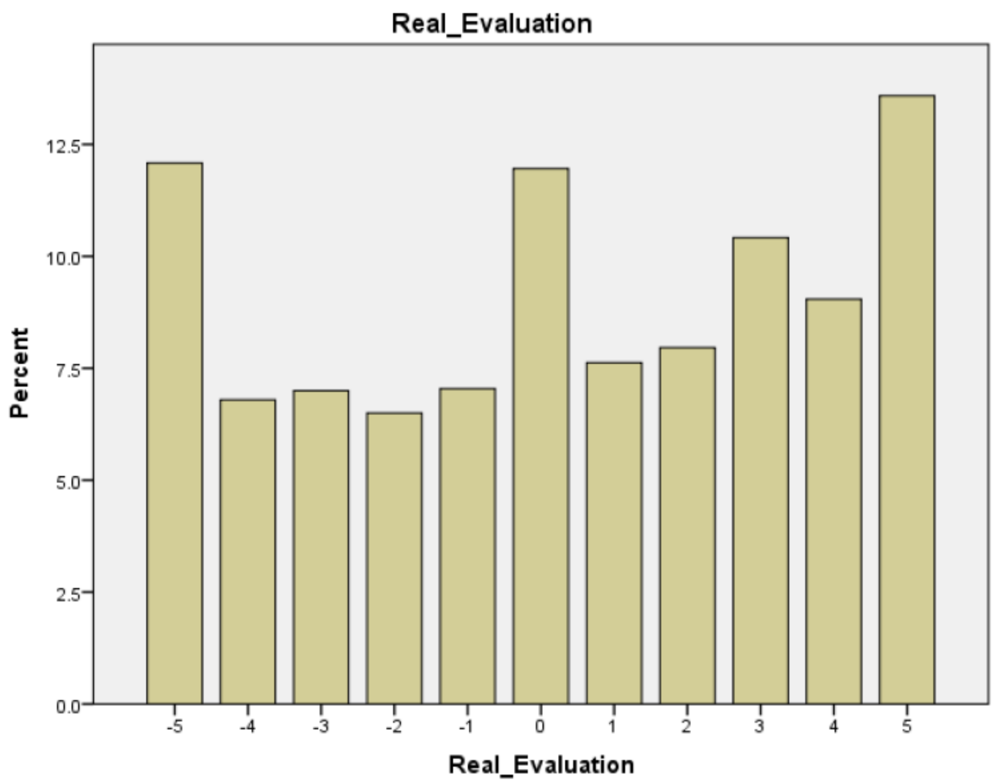


Figure 3.42 Real evaluation distribution

The same results can be seen for factors of the social value on the X-axis (Table 3.47 & Figure 3.43) since a complete correspondence exists between the two models for the 51.2% of the evaluations (the differentiation between the Y and X axis is because the answers that are not explained by the models considered).

Table 3.47 Social factors distribution

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-25	48	2.0	2.0	2.0
	-24	4	.2	.2	2.2
	-23	3	.1	.1	2.3
	-22	5	.2	.2	2.5
	-21	6	.3	.3	2.8
	-20	15	.6	.6	3.4
	-19	15	.6	.6	4.0
	-18	21	.9	.9	4.9
	-17	29	1.2	1.2	6.1
	-16	45	1.9	1.9	8.0
	-15	60	2.5	2.5	10.5
	-14	32	1.3	1.3	11.8
	-13	25	1.0	1.0	12.8
	-12	32	1.3	1.3	14.2
	-11	41	1.7	1.7	15.9
	-10	37	1.5	1.5	17.4
	-9	40	1.7	1.7	19.1
	-8	39	1.6	1.6	20.7
	-7	47	2.0	2.0	22.7
	-6	43	1.8	1.8	24.5
	-5	64	2.7	2.7	27.1
	-4	69	2.9	2.9	30.0
	-3	62	2.6	2.6	32.6
	-2	62	2.6	2.6	35.2
	-1	56	2.3	2.3	37.5
	0	271	11.3	11.3	48.8
	1	52	2.2	2.2	51.0

	2	87	3.6	3.6	54.6
	3	83	3.5	3.5	58.0
	4	103	4.3	4.3	62.3
	5	83	3.5	3.5	65.8
	6	88	3.7	3.7	69.5
	7	62	2.6	2.6	72.0
	8	65	2.7	2.7	74.8
	9	44	1.8	1.8	76.6
	10	53	2.2	2.2	78.8
	11	49	2.0	2.0	80.8
	12	57	2.4	2.4	83.2
	13	36	1.5	1.5	84.7
	14	43	1.8	1.8	86.5
	15	100	4.2	4.2	90.7
	16	39	1.6	1.6	92.3
	17	30	1.3	1.3	93.5
	18	38	1.6	1.6	95.1
	19	30	1.3	1.3	96.4
	20	28	1.2	1.2	97.5
	21	7	.3	.3	97.8
	22	8	.3	.3	98.2
	23	7	.3	.3	98.5
	24	2	.1	.1	98.5
	25	35	1.5	1.5	100.0
	Total	2400	100.0	100.0	

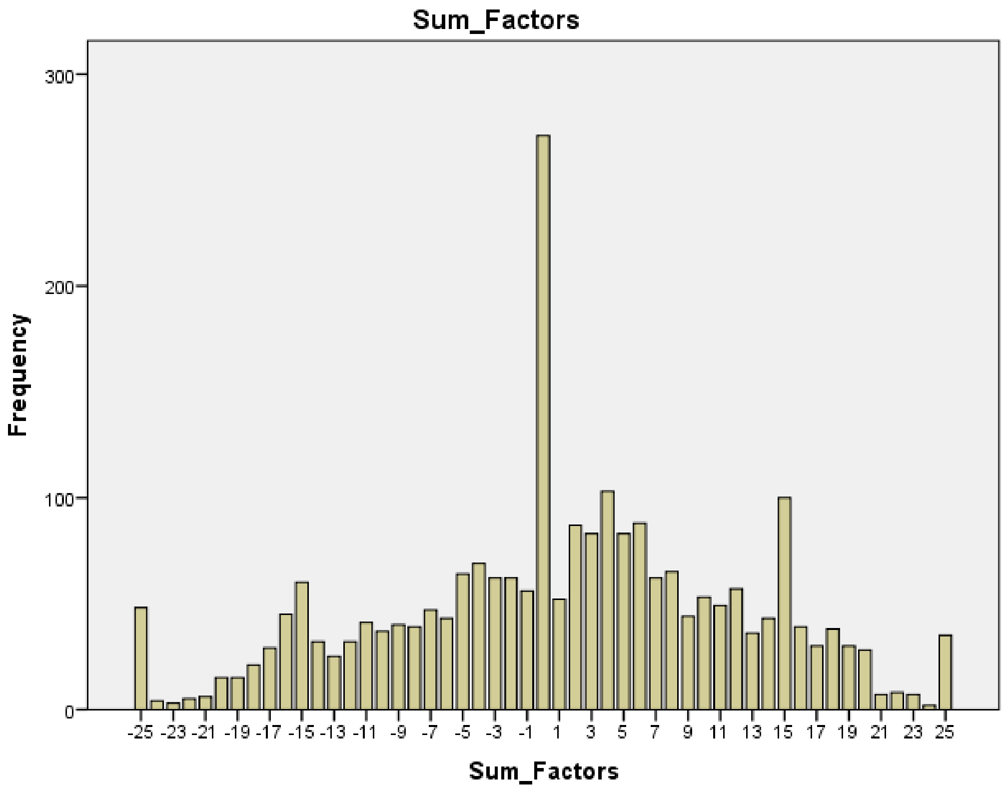


Figure 3.43 Social factors distribution

The cubic function gradually gets away from maximum as x increases. Another feature of the cubic model is that the data in the first and third quartile behave different. In the first quartile (positive opinions) the function changes at a slower rate than in the third quartile (negative opinions); meaning that the positive opinions (x) for an infrastructure with positive social value (y) grow slower over need-coverage than the reduction of the social value for an infrastructure with negative social value ($\frac{dx}{dy}\Big|_{x,y>0} < \frac{dx}{dy}\Big|_{x,y<0}$) .Additionally, this means the negative views are more absolute than the positive ones. This contradicts the assumption, which subconsciously was made by the author, that the change of rate of the function in the first and third quartile is the same. Additionally, Maslow's Hierarchy of Needs was developed in the first quartile without taking into account negative values, meaning that the hierarchy may differentiate if negative values are taken into account.

The cubic model can be optimized through $\nabla f = gradf = 0$ as it is not a strictly monotonic function. The partial derivative is the same with the total derivative since there is one independent variable. The first derivative is the following:

$$Y = -0.00072x^2 + 0.00043x + 0.332628$$

and the model has two extremes which are the critical points (critical points were discussed previously). In other words another positive of the statistical model is that the critical point is not a political decision, but it is defined by the mathematics. The function (without excluding the outliers) turns at $x_1 = -21.1973$ in the third quartile and at the $x_2 = 21.7945$ in the first quartile. If we exclude the outliers, it will result in a better model with a much higher percentage of explanation of the results. The evaluations being in the first and the third quartile are used (2059 out of the 2400 evaluations) and the previous process is repeated.

Table 3.48 Variable processing summary (excluding outliers)

		Variables	
		Dependent	Independent
		Real Eval	Sum Eval
Number of Positive Values		1071	1071
Number of Zeros		202	202
Number of Negative Values		786	786
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Table 3.49 Model summary and parameter estimates (excluding outliers)

Model Summary and Parameter Estimates

Dependent Variable: Real Eval

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Cubic	.944	11578.194	3	2055	.000	.011	.398	.000	.000

The independent variable is Sum_Eval.

The new model is different than the previous one and it explains a higher percentage of 94.4% of the data than the previous one (see Figure 3.44).

$$y = -0.000351 \cdot x^3 - 0.000246 \cdot x^2 + 0.398328 \cdot x + 0.011379$$

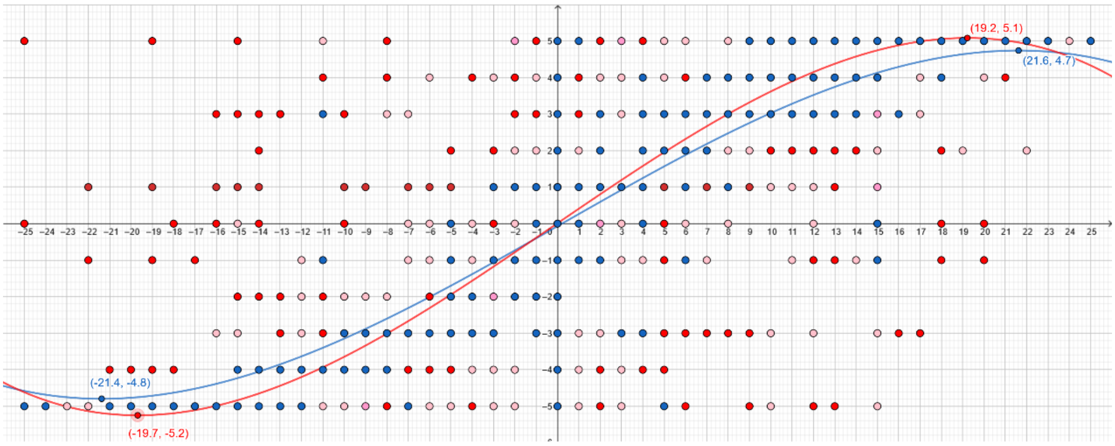


Figure 3.44 Fitting raw data (excluding outliers)

3.3.6 Transport hierarchy of needs

As mentioned before, Bourantas (2002) developed the curves of human's needs by applying Maslow's Theory in business management and Harrigan and Commons and Hagerty by appling it in psychology. Since this research studies a business model, the demonstration of the needs is expected to be as it was described by Bourantas and not sigmoid. The goal of this chapter is to use survey data to demonstrate that each need/factor of the social value of the transport modes has a curve relationship aligning with Bourantas' curves and not a sigmoidal relationship with respondents' age. Bourantas' curves (Figure 3.45) align with the Maslow's dynamic hierarchy of needs (1954) presented at Figure 3.45 (Wikipedia, 2018). To do that, only the evaluations of the transport modes used from the individuals were considered and not the evaluations of the modes which they do not use. It is assumed that the individual who makes the choice has a clear and measurable knowledge of the value that each choice provides (Luce & Raiffa, 1957), so they choose, subconsciously, the mode covering their needs in the way described by Bourantas. The value curves of Maslow's Hierarchy of Needs were changed following Winters et al. (2001) Transport Hierarchy of Needs (see Figure 3.46).

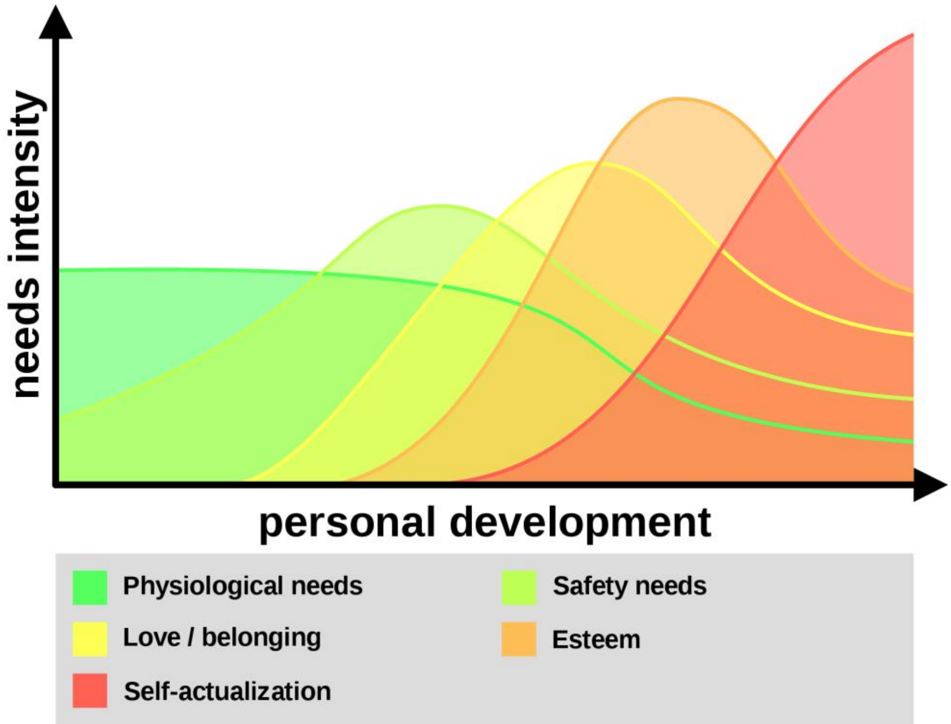


Figure 3.45 Need curves of Maslow's Hierarchy of Needs over personal development (Wikipedia, 2018)

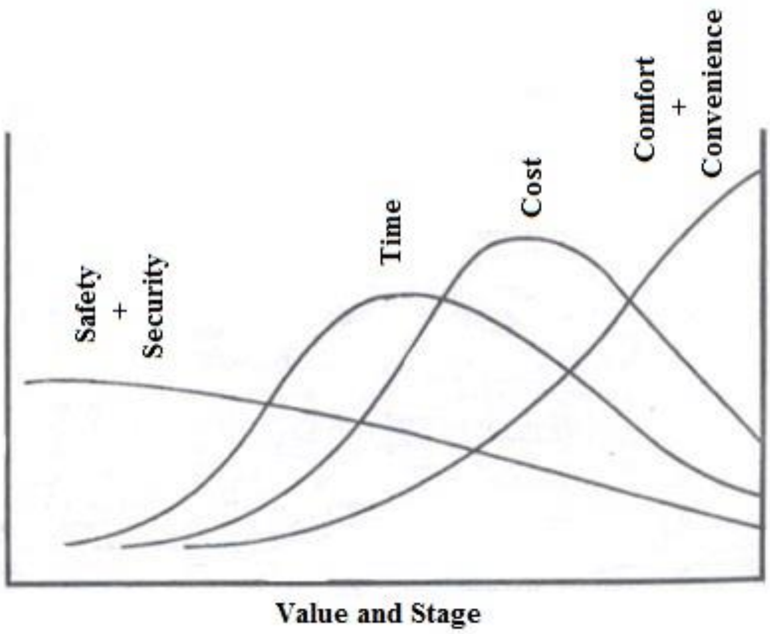


Figure 3.46 Transport value curves of Maslow's hierarchy of needs

Then, the 738 evaluations of the transport modes used by the individuals in the surveys were considered. Each transportation group of needs (safety and security, time, cost and comfort & convenience), which combined represents the social value, had more positive than negative values (see Table 3.50).

Table 3.50 Transportation groups of needs summary

		Variables					
		Dependent					Independent
		ExcessTime	Time	Confort	Cost	Safety	Age
Number of Positive Values		426	499	507	344	481	738
Number of Zeros		93	34	31	92	51	0
Number of Negative Values		220	206	201	303	207	0
Number of Missing Values	User-Missing	0	0	0	0	0	0
	System-Missing	0	0	0	0	0	1

The comparison between the positive and negative answers of the individuals responses shows that the choice of the individuals is affected from most to least by: [1] comfort & convenience, [2] time, [3] safety and security [4] excess time and [5] cost.

Table 3.51 Identification of the age groups

Group number	Age (years)	Participants
	0-15	0
1	15-19	23
2	20-29	50
3	30-39	48
4	40-49	53
5	50-59	44
6	60-65	22
7	65+	60

The age groups were identified from the survey as it is described in Table 3.51. The groups are not evenly separated and not uniformly distributed, since the targeted sample was chosen using the purposive sampling method (Saunders et al., 2009). The sample was chosen to ensure it covered the characteristics of the targeted population (e.g. the percentages of participants should be the same with the percentage of the individuals in each age group). Since the empirical data does not provide the exact age of each individual the curves developed are conceptual and cannot be transformed to realistic equations.

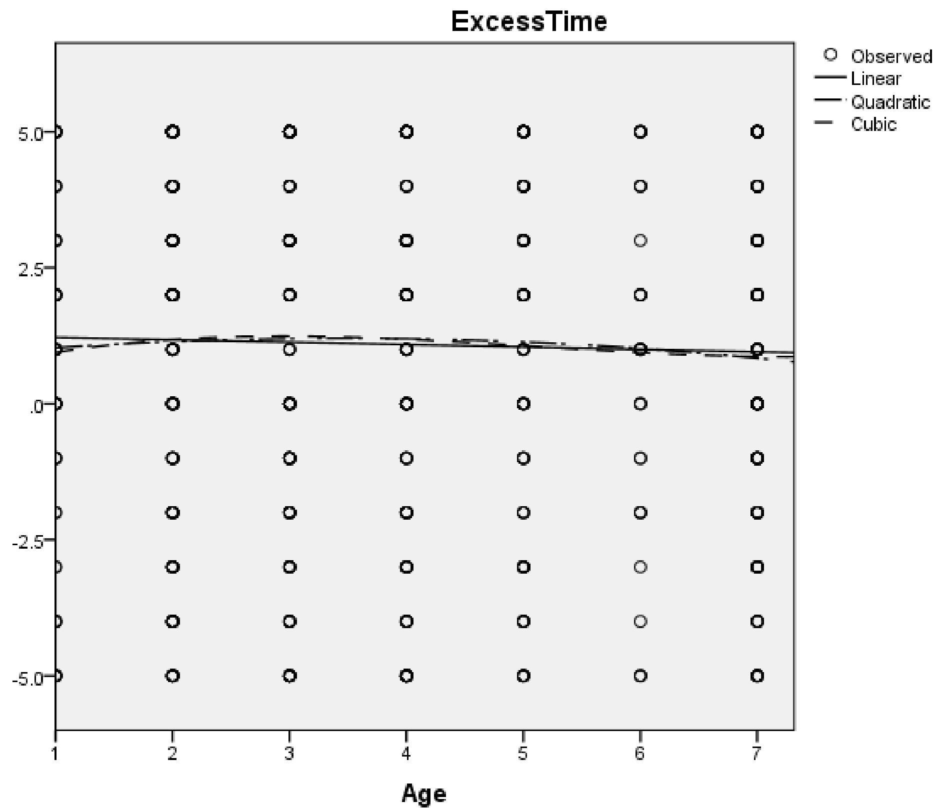


Figure 3.47 Curve of excess time need over respondents' age

The Excess Time (see Figure 3.47), which is not comparable with any transportation group of needs, initially increases and then decreases as the age of the individual increases without abrupt changes. The rest of the needs can be compared with the transport value curves of the hierarchy of needs, so they are demonstrated together for the reader's convenience.

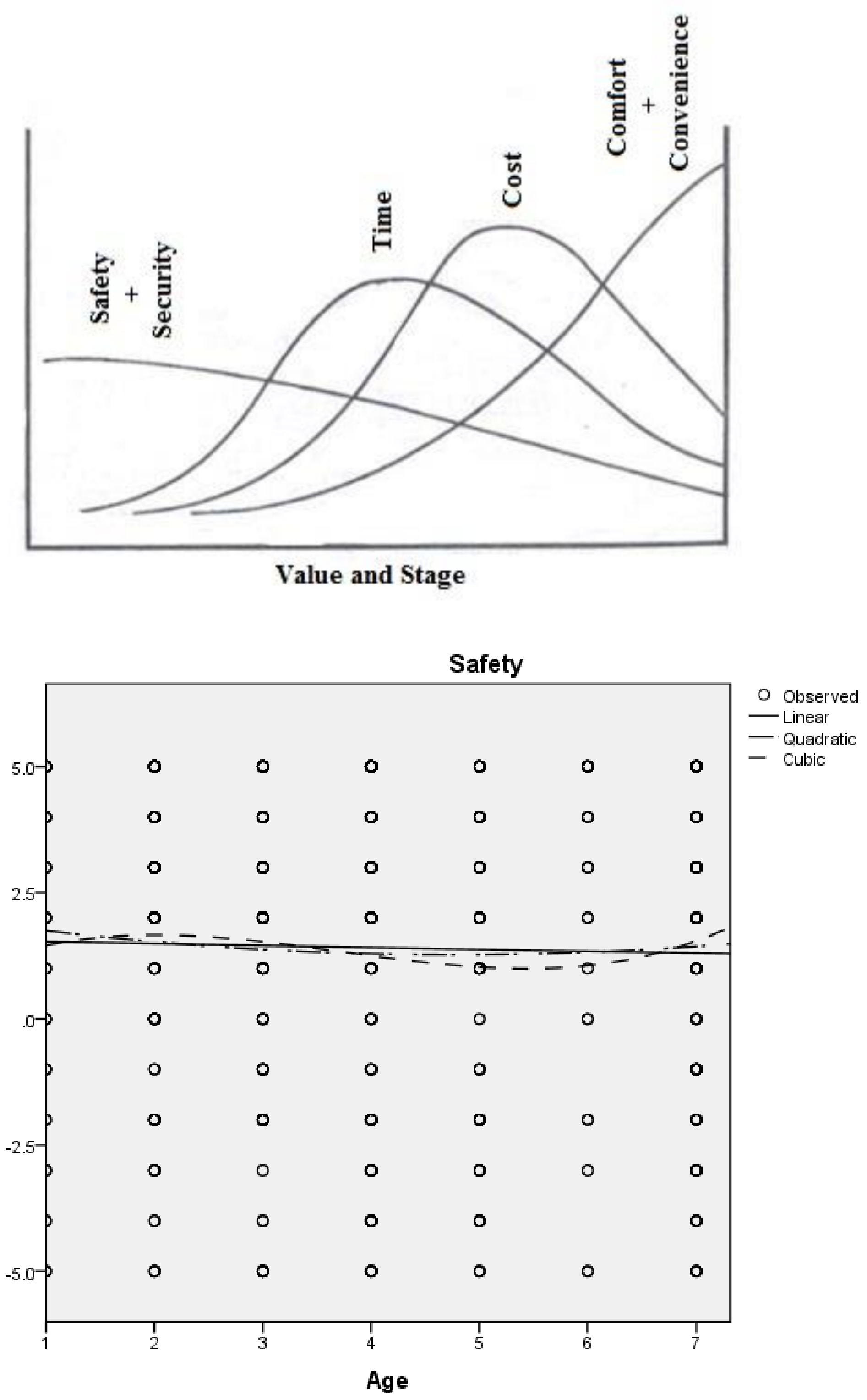
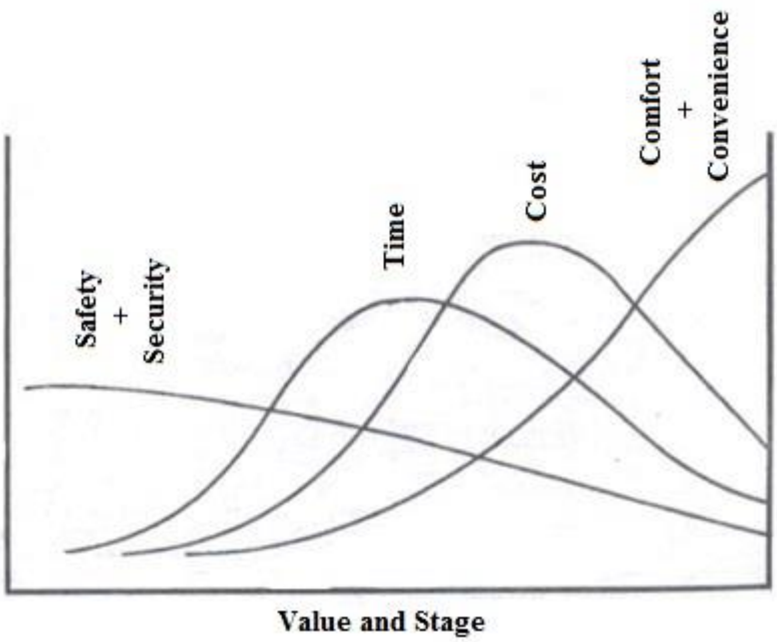


Figure 3.48 Curve of safety and security need over respondents' age



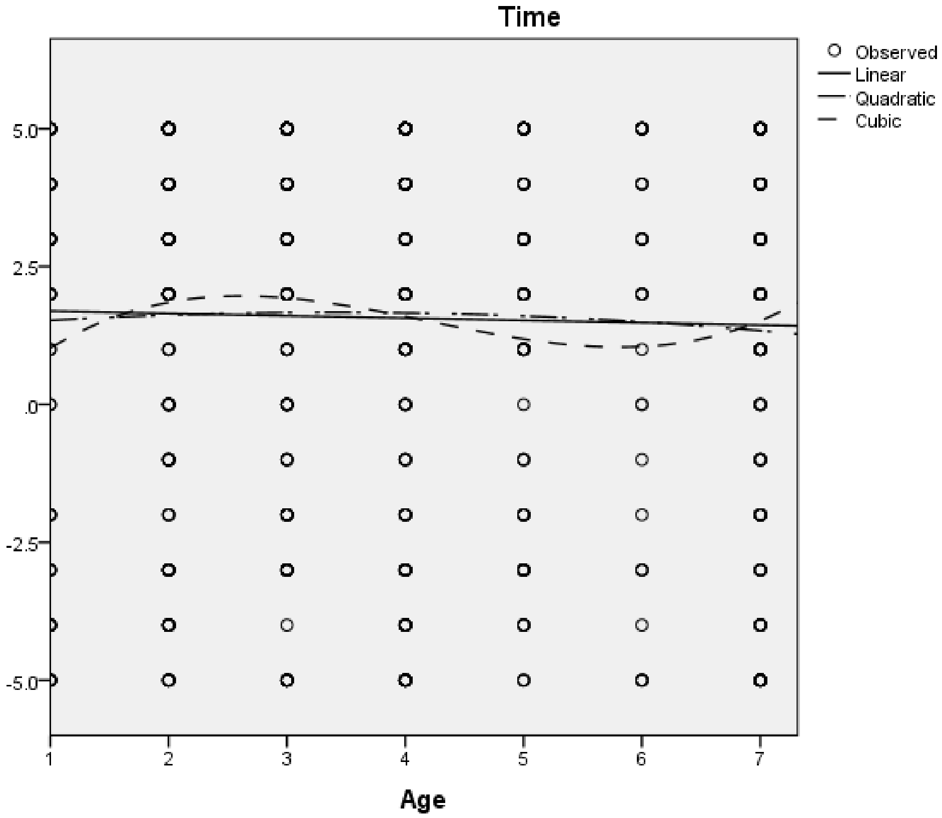
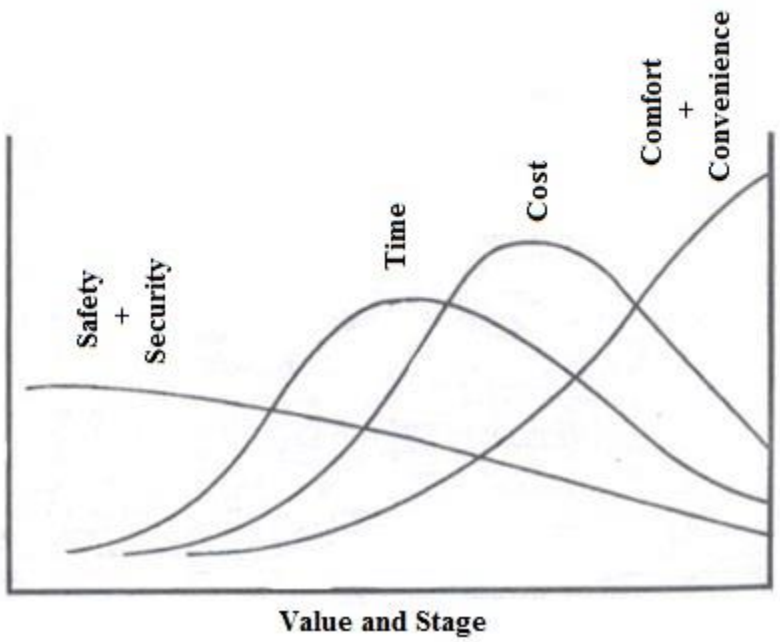


Figure 3.49 Curve of time need over respondents’ age



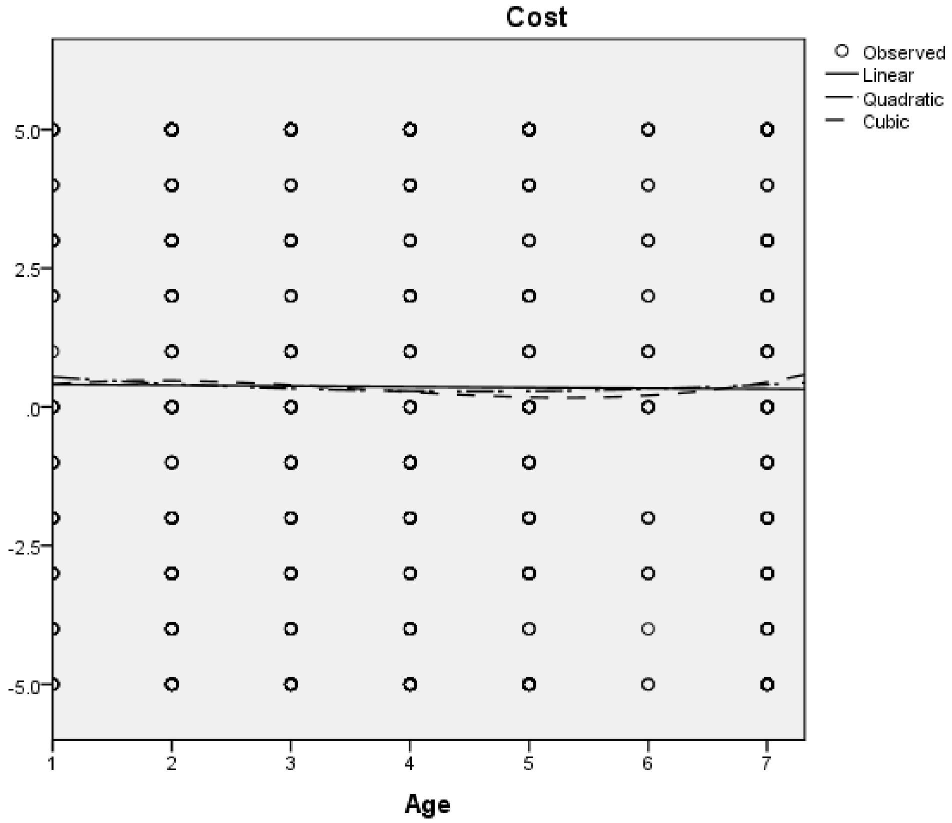
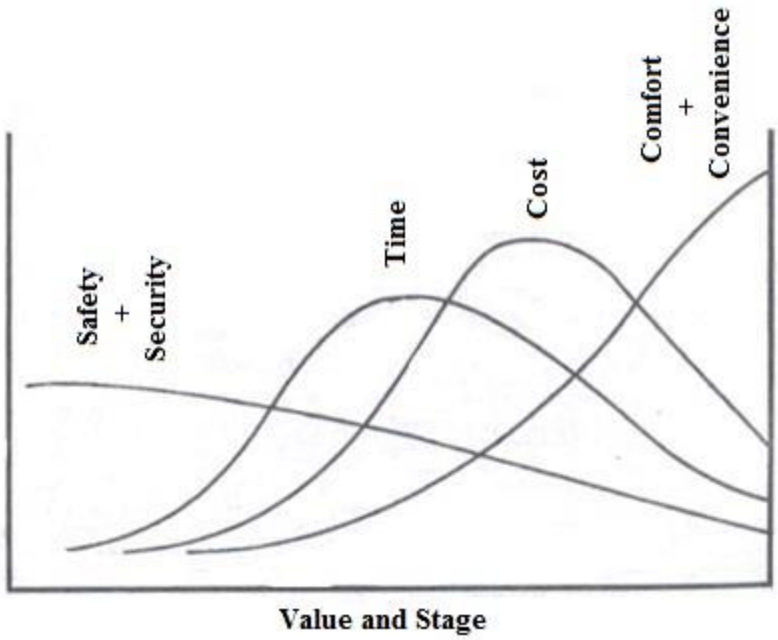


Figure 3.50 Curve of cost need over respondents' age



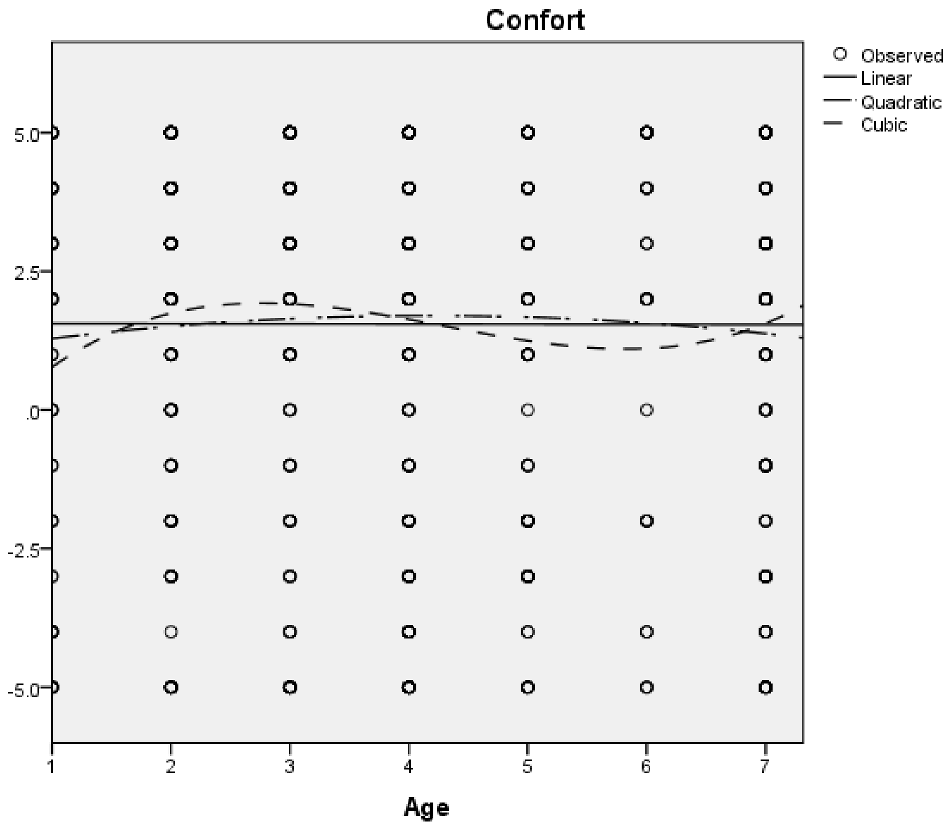


Figure 3.51 Curve of comfort need over respondents' age

The correspondence between the transport needs and the human needs may by itself cause differentiations.

The Safety and Security curve (see Figure 3.48) decreases as the age of the individual increases without abrupt changes, aligning with dynamic expected curve, until before the two last groups of ages (individuals with 60+ age), where it starts to increase. It can be seen that there is an abrupt change in the oldest-age group. This change can be either explained from the fact that this group of the sample were approached differently (not in public places) or they are afraid of something else, which is age-related. However, there is no fact to prove fear of something else, because such information was not available in the data collected. Gullone (2000) studied the development of normal fear and reported an age-related decrease of fear. Other studies on the development of fear of real or imagined threats in relation to age concluded depending upon age and a decrease of fear (Ferraro & LaGrange, 1992; Hall, 1897). To the best of the author's knowledge, there are not many studies investigating transport fears in relation with age, but Levasseur et al. (2015) found that older individuals choose to travel with the safest modes when possible. Based on the findings of this research, the age differences in the importance of safety and security of transport modes should be reconsidered. It is obvious that the oldest people consider safety and security more than the young (highest than any point of the curve) and this determines their transport mode choice. If the last age group of the participants will not get considered, the findings of this research verified the decrease of safety importance as a need and dynamic curve.

The Time curve (see Figure 3.49) initially increases and then decreases as the age of the individual increases, aligning with the dynamic expected curve. Again a mismatch between the two curves appears in the oldest age group. The curve of the need of short travel time over the age of the participants increases in the last group (65+ group). If the last age group of the participants was not included in the analysis, the findings of this research verified the dynamic time curve.

Regarding the Cost (see Figure 3.50), there is initially a small increase to the coverage of the need of the Cost followed by a small decrease without abrupt changes as the dynamic curve predicts. Although, one more time the eldest group does not follow the curve. If the last age group of the participants does not consider, the findings of this research verifies the shape and the direction of dynamic cost curve, but without predicting the abrupt changes in its direction.

Finally, the curve of Comfort & Convenience (see Figure 3.51) needs increases until the age group of 30-40 and then decreases dramatically at the age group of 50-60 with an abrupt increase as the curve of the need of the Cost does.

The problem with the oldest groups may be the understanding those people had for evaluating each mode. The author had the feeling that the oldest people, participated in the survey, but had difficulties understanding the negative sign when they were filling it in. Maybe that was the reason that the median of their answer was so high and it changed the curves.

As mentioned before, based on the comparison between the positive and negative answers of the individuals, there is the following ranking from the most to least important need: [1] comfort & convenience, [2] time, [3] safety and security [4] excess time and [5] cost. If we consider this ranking without considering the number of participants from each group (strong assumption) and ignore the eldest group, it may be concluded that the curves should be as follows (see Figure 3.52):

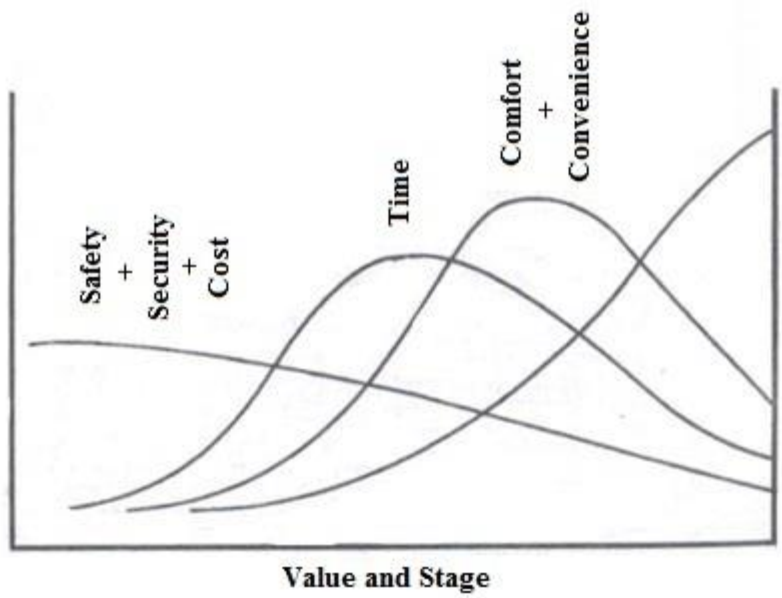


Figure 3.52 Empirical Transport Value curves of Maslow's Hierarchy of Needs

3.3.7 Benefits and needs analysis

Winter's theory (2001) claims that the transport social value depends on the following needs: time, cost, comfort and safety. Pearson correlation coefficient checks the linear correlation (dependency) between the variables. It can be used here, because although the model is an s-curve model, the linear model explains more than 70% of the variability of the data.

Table 3.52 Benefits and Needs correlation

		Evaluation	TravelTime	ExcessTime	TravelCost	Comfort	Safety	Health	Recreation	Environmental	Industrial	Congestion	Distance
Evaluation	Pearson Correlation	1	.626**	.602**	.359**	.608**	.552**	.035	.559**	.007	.025	.100**	.202**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.084	.000	.726	.220	.000	.000
TravelTime	Pearson Correlation	.626**	1	.371**	-.003	.491**	.437**	-.145**	.352**	-.219**	.144**	-.093**	.206**
	Sig. (2-tailed)	.000		.000	.866	.000	.000	.000	.000	.000	.000	.000	.000
ExcessTime	Pearson Correlation	.602**	.371**	1	.329**	.342**	.321**	.164**	.350**	.153**	-.084**	.183**	.132**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000
TravelCost	Pearson Correlation	.359**	-.003	.329**	1	.016	.028	.358**	.217**	.407**	-.278**	.326**	.067**
	Sig. (2-tailed)	.000	.866	.000		.421	.168	.000	.000	.000	.000	.000	.001
Comfort	Pearson Correlation	.608**	.491**	.342**	.016	1	.522**	-.137**	.492**	-.178**	.143**	-.121**	.170**
	Sig. (2-tailed)	.000	.000	.000	.421		.000	.000	.000	.000	.000	.000	.000
Safety	Pearson Correlation	.552**	.437**	.321**	.028	.522**	1	-.157**	.301**	-.167**	.132**	-.094**	.174**
	Sig. (2-tailed)	.000	.000	.000	.168	.000		.000	.000	.000	.000	.000	.000
Health	Pearson Correlation	.035	-.145**	.164**	.358**	-.137**	-.157**	1	.066**	.686**	-.460**	.352**	-.124**
	Sig. (2-tailed)	.084	.000	.000	.000	.000	.000		.001	.000	.000	.000	.000
Recreation	Pearson Correlation	.559**	.352**	.350**	.217**	.492**	.301**	.066**	1	.036	.023	.062**	.093**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.001		.077	.256	.003	.000
Environmental	Pearson Correlation	.007	-.219**	.153**	.407**	-.178**	-.167**	.686**	.036	1	-.474**	.424**	-.089**
	Sig. (2-tailed)	.726	.000	.000	.000	.000	.000	.000	.077		.000	.000	.000

		Evaluation	TravelTime	ExcessTime	TravelCost	Comfort	Safety	Health	Recreation	Environmental	Industrial	Congestion	Distance
Industrial	Pearson Correlation	.025	.144**	-.084**	-.278**	.143**	.132**	-.460**	.023	-.474**	1	-.204**	.099**
	Sig. (2-tailed)	.220	.000	.000	.000	.000	.000	.000	.256	.000		.000	.000
Congestion	Pearson Correlation	.100**	-.093**	.183**	.326**	-.121**	-.094**	.352**	.062**	.424**	-.204**	1	-.082**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.003	.000	.000		.000
Distance	Pearson Correlation	.202**	.206**	.132**	.067**	.170**	.174**	-.124**	.093**	-.089**	.099**	-.082**	1
	Sig. (2-tailed)	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

The evaluations of the transport modes by the individuals correlate with all the needs so the theory is verified. There is the following ranking from the most to least correlated/important need (Table 3.52): [1] time (0.626), [2] comfort & convenience (0.608), [3] excess time (0.602), [4] safety and security (0.552) and [5] cost (0.359). The differentiation with the importance ranking presented previously is a result of considering both why and why not the individuals chose a mode and the previous importance is based only on why they chose a mode.

Regarding the benefits investigated (Table 3.52):

- the total evaluations of the transport modes by the individuals correlate only with recreation, congestion and distance but the correlation with congestion and distance is so small (0.1 and 0.202 respectively) that it may not be taken into account.
- the benefit of health correlates all the needs and benefits, but the correlation is significant only with the environmental benefits (0.686) and the industrial benefits (-0.46). This makes sense since the environment and the human health are intertwined and the industrial extension leads to environmental degradation.
- the recreational benefits correlate with all the needs and benefits, but the correlation is, apart from the total evaluation, significant only with comfort (0.492)
- environmental benefits behave similarly with the benefits of health with the only difference that it correlates with congestion too (0.424), something that make sense since the transport modes that are friendly to the environment reduce the congestion too.

Additionally, the individuals were asked a qualitative question on the main reason affecting their choice of mode. This way it was possible to compare the quantitative results with the individuals' answers. In the case that an individual gave more than one reason (58 individuals gave two reasons), the reasons were equally weighted (times 0.5 in the case of two reasons, 0.333 in the case of three reasons etc). The qualitative answers created a ranking of reasons that the individuals think affects their transport mode choice (see Table 3.53).

Table 3.53 Individuals' transport choice reason ranking (Qualitative data)

		Reason + Another Reason (x0.5)	Total
Time	95	19	104.5
Cost	49	7	52.5
Comfort	38	10	43
Distance	21	5	23.5
Safety	12	4	14
Environment	10	4	12
Age	9	2	10
Weather	7	5	9.5
Health	6	2	7
Recreation	4	0	4
No reason	4	0	4
Other reasons	16	0	16
Total	271	58 (x0.5)	300

The ranking of the needs the individuals claim affects their choice differentiates from the ranking of the needs coming from the correlation between the needs and the transport mode evaluation (see Table 3.5) and with the ranking of needs based on the highest need evaluation of the transport mode the individual uses (see Table 3.54).

Table 3.54 Ranking of needs affecting transport mode choice

<table>
<tr><td colspan="2"></td><td>Individuals' Ranking</td><td colspan="2">Real Ranking</td></tr>
<tr><td colspan="2">List of Needs</td><td>Ranking based on survey</td><td>Ranking based on correlation</td><td>Ranking based on the usage</td></tr>
<tr><td colspan="2">Time</td><td>1st</td><td>1st</td><td>2nd</td></tr>
<tr><td colspan="2">Comfort</td><td>4th</td><td>2nd</td><td>1st</td></tr>
<tr><td colspan="2">Distance</td><td>5th</td><td>6th</td><td>6th</td></tr>
<tr><td colspan="2">Cost</td><td>2nd</td><td>5th</td><td>5th</td></tr>
<tr><td colspan="2">Safety</td><td>6th</td><td>4th</td><td>4th</td></tr>
<tr><td colspan="2">Environment</td><td>7th</td><td>7th</td><td>7th</td></tr>
<tr><td rowspan="6">Personal/ Other reasons</td><td>Age</td><td rowspan="6">3rd</td><td rowspan="6">3rd</td><td rowspan="6">3rd</td></tr>
<tr><td>Weather</td></tr>
<tr><td>Health</td></tr>
<tr><td>Recreation</td></tr>
<tr><td>No reason</td></tr>
<tr><td>Other reasons</td></tr>
</table>

Distance was not considered as a need, but it was the fifth most popular answer given affecting the choice of mode. Additionally, the distance was not asked to be evaluated by the individuals, but it was considered as constant. So the individuals, when they claimed that distance was the reason of choosing a specific transport mode they were either meant time (the distance is constant but the time travel changes) or the comfort (the distance is constant but the way they choose to travel this distance changes). By allocating the answer "*distance*" to comfort and time, the following ranking appears (Table 3.55):

Table 3.55 Ranking of needs affecting transport mode choice without distance

		Individuals' Ranking	Real Ranking	
List of Needs		Ranking based on survey	Ranking based on correlation	Ranking based on the usage
Time		1st	1st	2nd
Comfort		2nd	2nd	1st
Cost		3rd	5th	5th
Safety		5th	4th	4th
Environment		6th	6th	6th
Personal/ Other reasons	Age	4th	3rd	3rd
	Weather			
	Health			
	Recreation			
	No reason			
	Other reasons			

In every ranking either first or second need is time and comfort. The first conclusions between the different rankings is that the individuals claim (both qualitative and quantitative) that time is the most important need affecting their transport mode choice, but their use of the transport mode is mainly affected by comfort.

Regarding the need of cost, the individuals think that is important since it is the 3rd most important need in the qualitative answers, but subconsciously it is not so important as both the qualitative answers and the usage ranked it 5th most important need out of six. On the other hand, the personal needs were the 3rd most important needs both quantitative and based on the usage and were 4th in the qualitative answers.

Safety was the 4th most important need both quantitative and based on the usage and was 5th in the qualitative answers. This may be explained by that the fact that the society has reached to a safety level enough to make the individual feel safe.

The most worrying finding was that in every ranking the environment was last. This may be a result of the way the questionnaire was performed, since there was not a clear question for the importance of the environment on choosing the transport mode, but still this finding is important.

3.3.8 Analysis of each benefits and need by transport mode

The individuals evaluate the different transport modes using a scale. Therefore the numerical expressions can be transformed to a ranking, since the evaluations are based on different mitigation measures. The mitigation measures were different for each individual, but the evaluations were a result of the individuals comparing the transport modes to each other. This means that it safe to rank the evaluations using the mean of the numerical answers of the individuals. For comparison reasons the median and the mode of each evaluation are provided too.

The individuals were asked to evaluate the needs coverage of the transport modes they use or have access to, but they were asked to generally evaluate the modes for the benefits they provide to society. This means that the benefits ranking can be compared with rankings coming from theory, but this is not possible for the needs coverage. The individuals were from different areas and they were using or having access to different transport modes even if the transport mode was in the same category e.g. rail transport. This means that it is not safe to rank the transport modes even to each area and compare it with previous studies related to specific areas e.g. London.

To conclude, needs coverage ranking will be provided without comparing it with previous ranking and benefits ranking will be provided and compared with previous studies.

The descriptive statistics of the transport modes in the United Kingdom can be found at the Appendix F.

Based on the understanding of the individuals, the quickest modes are ranked as follows: 1) car, 2) (air transport), 3) taxi, 4) rail, 5) bus, 6) cycling, 7) walking and 8) (water transport).

The less excess time (waiting time) needed ranking is as follows: 1) car, 2) walking, 3) cycling, 4) (air transport), 5) (water transport), 6) taxi, 7) rail and 8) bus.

The cheapest modes are as follows: 1) walking, 2) cycling, 3) (air transport), 4) (water transport), 5) rail, 6) bus, 7) car and 8) taxi.

The most comfortable transport mode ranking is as follows: 1) car, 2) taxi, 3) (water transport), 4) (air transport), 5) walking, 6) rail, 7) bus and 8) cycling.

The safest transport mode ranking is as follows: 1) car, 2) taxi, 3) rail, 4) (air transport), 5) walking, 6) bus, 7) cycling and 8) (water transport)

Air transport and water transport are in brackets, because they were in a different part of the survey and this may subconsciously affect the individuals not to compare them with the land transport modes. This may be the reason that the individuals gave a higher travel time evaluation to the car than the air transport. Another reason is that many individuals who did not use air or water transport rank water and air transport with zero, but they gave an evaluation to the other land transport modes. Finally, it is not realistic to compare water and air transport modes with land-based transport modes since generally they are not used for equivalent types of trips. In other words, when it comes to water and air transport wording must be cautious in this research.

Benefits analysis does not have the aforementioned restrictions, since the individuals were asked to evaluate the transport modes in an unbiased way. The health and the environment benefits ranking of the transport modes can be found in the next chapter (Chapter 3.3.4) since these benefits are related with environmental value. Industrial benefits were ranked based on the demands of each sector. The demands of each sector shows the influence of each sector on the total UK economy (industrial benefits). The ranking of the sectors is as follows (Office for National Statistics, 2015): 1) Other transport including car, taxi and bus (£42127millions), 2) air transport (£15675millions), 3) water transport (£133824millions), 4) rail transport (£9848millions) and finally 8) walking and 8) cycling do not create any direct demand to the economy (at least according to economic theory).For the same year the demand for buses and coaches was £5.3billions and for taxis and private hire vehicles was approximately £2.3-2.7billions in the UK (Department for Transport, 2015). It is worth noting that even the manufacture and services sectors related with each transport mode considered the ranking does not change (this is not sure for taxi since it was not possible to divide the manufacture demand from the cars). So the industrial ranking is as follows: 1) car, 2) air transport, 3) water transport, 4) rail transport, 5) bus, 6) taxi, 8) cycling and 8) walking.

Congestion is the status of a transport mode when its network infrastructures (roads, rail lines etc.) are above capacity (Eddington, 2006). The congestion in the roads is a result of the vehicles using these roads and it is different for each area, type of road and time of the day in the United Kingdom (Department for Transport, 2016). Vans, cars and taxis are in the same category for road congestion (Department for Transport, 2016).

Congestion in the rail transport sector in terms of too many vehicles on the network, is much more complex since it is a result of the overcrowding of passengers, the delayed trains and the cross-effect to other trains (Office of Rail and Road, 2017). Air and water transport is not related with the day-to-day congestion so it was not taken into account in this research. The best way to compare road and rail congestion is the value of time as it is calculated by the Department for Transport (2015) for the individuals travel to work. Based on Department for Transport’s (2015) findings, the values of travel time savings are better for the rail network (28.99 £/hr) than the road network (8 to 25.74£/hr). For the road network it is affected by the distance covered. If the distance is less than 20 miles (32.18688 Km) the travel time saving value by the car (8.21 £/hr) is much less than using the bus (15.64 £/hr). Between 20 and 100 miles (160.9344 Km) the car has a little better (15.85 £/hr>15.64 £/hr) travel time saving value than bus and for more than 100 miles the car has much better value (25.74£/hr) than bus (15.64 £/hr). In this research, the average distance travelled by the participants was 24.68 Km and none of them travelled more than 100 miles. Maybe this results from the study focussing only on urban areas. If we consider the impact of the cars to the number of the vehicles on the roads, it is safe to conclude that the bus has a better impact on congestion. The impact of walking and cycling on congestion is difficult to calculate since their network is a part of the road. Additionally, there are not enough data on when the networks for walking and cycling are over their capacity, meaning that either the size of their network is enough (or assumed enough by the designers) for the number of the users or the network is optimal as it is (or comparing it with the other transport modes). Considering the previous discussion, the author concluded that walking and cycling have the best impact on congestion in urban areas, but it was decided not to compare them between each other.

Table 3.56 Transport modes benefits ranking

Transport Mode	Recreation	Industrial	Congestion	Industrial	Congestion
Walking	2	8	1	8	1
Cycling	6	7	2	8	1
Rail	7	2	3	4	3
Bus	8	5	4	5	4
Car	1	3	6	1	6
Taxi	5	6	5	6	6
Air transport	3	1	-	2	-
Water Transport	4	4	-	3	-

The individuals were able to identify the congestion ranking, but they could not identify the industrial ranking (see Table 3.56). Regarding the industrial ranking, the individuals recognized the sectors with the smallest economic impact but not the ones with the highest. This means that the individuals are not a trustworthy stakeholder and it is not safe to let them participate in the decision and policy making process.

Finally, the recreation ranking was not compared with the theory because most of the participants answered this question based on how "*happy*" they are when they are using a specific transport mode and a small part based on when they use a transport mode for recreation purposes e.g. to go for a trip and it was not possible to divide these groups. The recreation ranking is as follows (see Table 3.56): 1) car, 2) walking, 3) air transport, 4) water transport, 5) taxi, 6) cycling, 7) rail and 8) bus.

3.3.9 Transport infrastructure investment evaluation

The subject being studied, (transportation cost-benefits) and the approach (which comes across as being purely theoretical) should not mismatch. The approach should not be devoid of any consideration of the applicability of the findings. The goal of the study is to understand how different people value different aspects of transportation. As it appears that a quite extensive data collection process was undertaken to obtain the raw data upon which the analysis was based. Maslow's value resembles the value of business and economics' approach, as they are both linked with the satisfaction of the individual (McKenzie & Lee, 2006, p115). The main difference lies in economic constraints, as Maslow includes individual's wishes based on culture, environment and ethics, but without considering an individual's productivity or income (McKenzie & Lee, 2006, p115). This research will consider an individual's income as a test factor and not as a factor under investigation, meaning that it will not investigate how the income of an individual affects his/her choices, but it will be used for evaluating the transport behaviour of the society.

So how can the value be expressed mathematically? The Strong Law of Large Numbers may be applied by asking the individuals to define the utility of the investment, but it requires a huge sample. The most appropriate methodology for this research is Von Neumann–Morgenstern utility theorem (1953), which accepts the existence of a utility function u(x) and assumes that the individual will try to maximize this utility no matter what. They formulated Mathematical axioms, based on preference relationships. If P1 and P2 are two possible choices/investments, such that P1>P2 then u(P1) > u(P2), and for any P1 and P2 one of the following three relationships applies: P1 >P2 or P2 >P1 or P1 ~P2. Then the utility function for the individual is:

$$u(w - G) = E(u(w - X)),$$

where:

X is the maximum loss of value during a defined period

G the value that the individual should pay to protect his investment during a defined period w is the total value of an investment during a defined period

E is the expected value during a defined period

The analysis is not limited to the findings of the curves, but an investment evaluation, useful to transportation policy, can be done based on the attitude of the individuals as a total. The attitude of the individuals, collectively (i.e. as a generalization), can be classified in three categories, based on the value of u'(x) and u''(x) and their risk aversion relating to wealth (Saylor Academy, 2012, Chapter 3.3):

[1] If u'(x) >0 and u''(x) > 0 the individuals are not moderate/conservative regarding their value (risk-seeking individual). The utility increases at a decreasing rate for each additional unit of wealth (see Figure 3.53). In other words, the investment will not be sustainable from the individuals' point of view, as it is considered harmful/risky for the individuals.

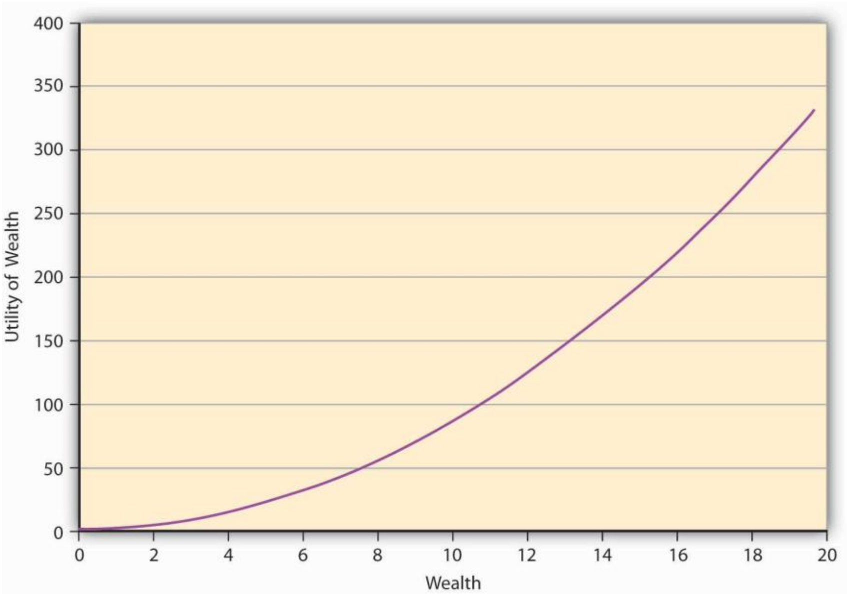


Figure 3.53 A Utility Function for a Risk-Seeking Individual (Saylor Academy, 2012, Figure 3.3)

[2] If u'(x) < 0 and u''(x) < 0 the individuals are moderate/conservative regarding their value (risk-averse individual). The utility increases at an increasing rate for each additional unit of wealth (see Figure 3.54). In other words, the investment will be sustainable from the individual's point of view, as it is considered beneficial for the individuals.

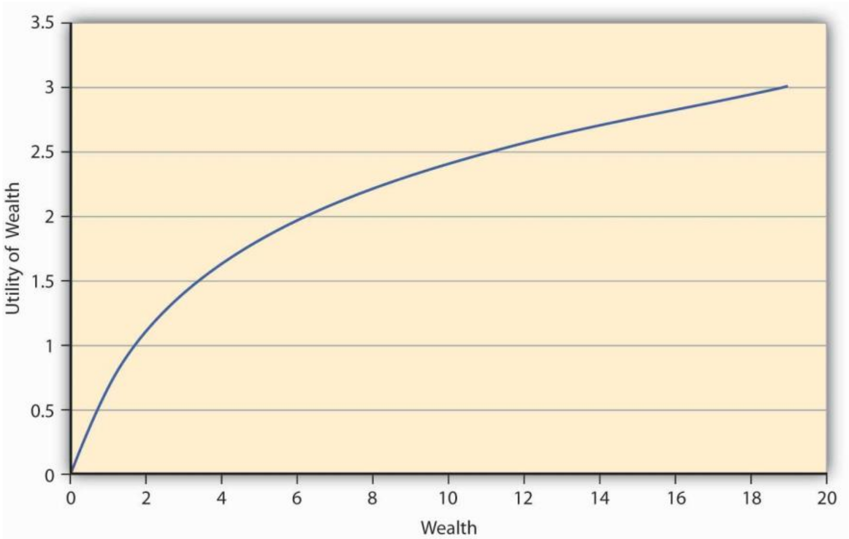


Figure 3.54 A utility function for a risk-averse individual (Saylor Academy, 2012, Figure 3.2)

[3] Finally, the individuals may be neutral regarding their value (risk-neutral individual). The utility increases at a standard rate for each additional unit of wealth. In other words, the investment will be neither beneficial nor harmful (see Figure 3.54).

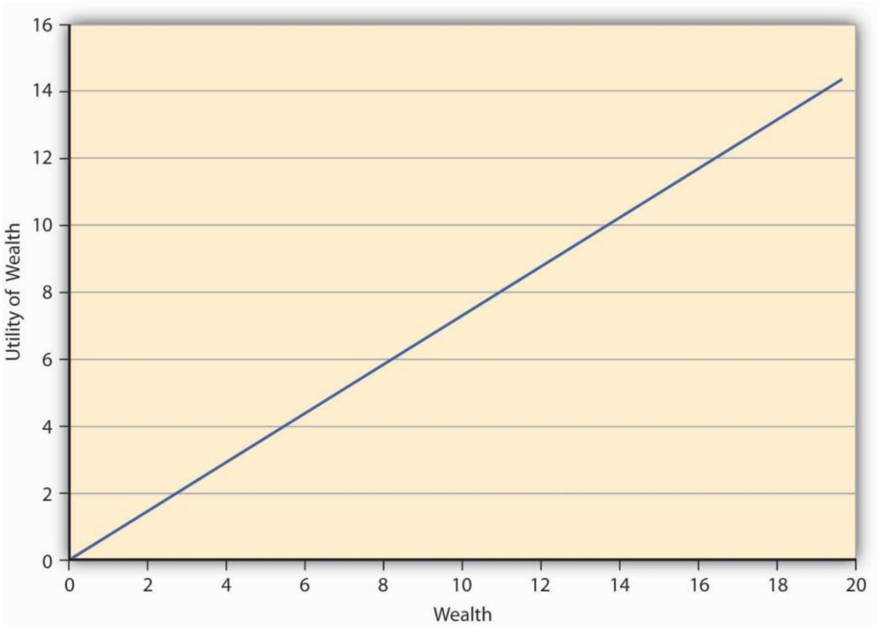


Figure 3.55 A utility function for a risk-neutral individual (Saylor Academy, 2012, Figure 3.4)

By accepting that the individuals within the United Kingdom are moderate/conservative regarding their social value, we expect to meet the second case. Although, this is not certain since the redefined value, which is in favour of sustainability, may change what it is considered as conservative. The wealth of each individual was based on household income and the social utility on the value the individual claims to get.

Table 3.57 Household income of participants

Group number	Income (x1000)	Participants
1	0-10	16
2	10-20	22
3	20-30	48
4	30-40	72
5	40-50	64
6	50-60	33
7	60-70	18
8	70-80	10
9	80-90	7
10	90-100	3
11	>100	7

Since the empirical data does not provide the exact income of each individual (see Table 3.57), the curves developed are conceptual and cannot be transformed to realistic equations. The value for each individual was calculated as the sum of the product of the percentage of the distance covered with a mode times the value of the mode given by the same individual.

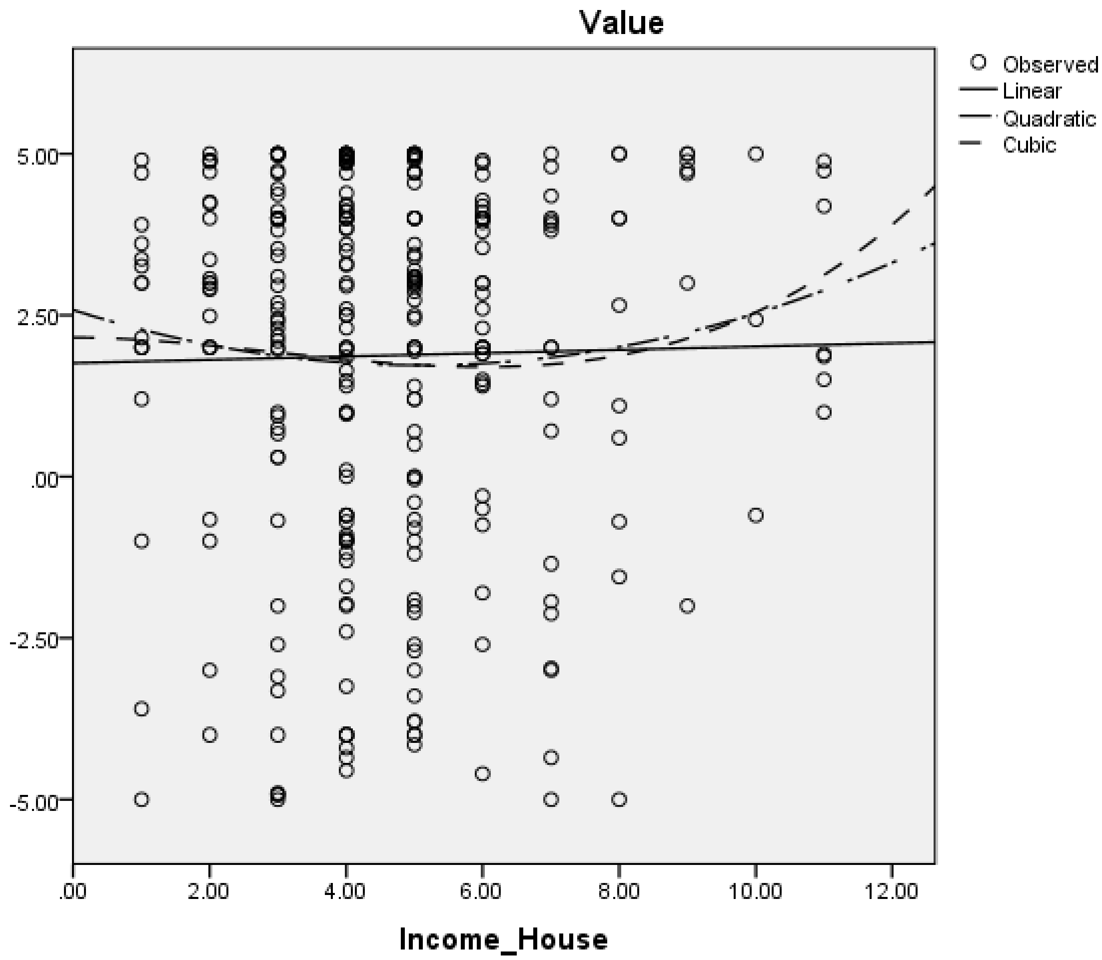


Figure 3.56 Utility curve over the household income

The models/equations of the conceptual curve (Figure 3.56) can be used to evaluate the transport infrastructure investment in the United Kingdom.

Table 3.58 Social investment per house evaluation model summary

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.000	.104	1	298	.747	1.756	.026		
Quadratic	.006	.949	2	297	.388	2.582	-.338	.033	
Cubic	.007	.699	3	296	.553	2.154	-.007	-.036	.004

The independent variable is Income House.

Dependent Variable: Value

R^2 is so small because the curves are conceptual (Table 3.58). The quadratic model is as follows:

$$y = 2.581836 - 0.338248 \cdot x + 0.033287 \cdot x^2$$

The first derivative is:

$$y = -0.338248 + 0.066574 \cdot \mathrm{x}$$

$$y = -0.338248 + 0.066574 \cdot \mathrm{x} > 0, \text{ when } x > 5.08078 \text{ meaning income} > 50000$$

The second derivative is:

$$y = 0.066574 > 0$$

The cubic model is as follows:

$$y = 2.154044 - 0.006589 \cdot x - 0.035869 \cdot x^2 + 0.004045 \cdot x^3$$

The first derivative is:

$$y = -0.006589 - 0.071738 \cdot \mathrm{x} + 0.012135 \cdot x^2$$

$$y = -0.006589 - 0.071738 \cdot \mathrm{x} + 0.012135 \cdot x^2 > 0, \text{ when } x > 6.00212 \text{ meaning income} > 60000$$

The second derivative is:

$$y = -0.071738 + 0.02427 \cdot \mathrm{x}$$

$$y = -0.071738 + 0.02427 \cdot \mathrm{x} > 0, \text{ when } x > 2.95583 \text{ meaning income} > 30000$$

u'(x) > 0 and u''(x) > 0 for both the quadratic and the cubic models in specific areas. Since u'(x) > 0 and u''(x) > 0 in the value increasing areas and before reaching this point these areas it was decreasing, then the individuals are not moderate/conservative regarding their value. The utility increases at a decreasing rate for each additional unit of wealth after one point and before that point it was decreased. In other words, the investment is not sustainable from the individual's point of view, as it is considered harmful/risky for the individual. If these results are taken into account, they mean that the current transport investments in the United Kingdom are risky for the individuals who are treated as key stakeholders who participate in the decision-making process.

Another approach to try to explain exactly what happens in the United Kingdom is to take into account how many individuals live in each house by dividing the household income with the individuals living in it.

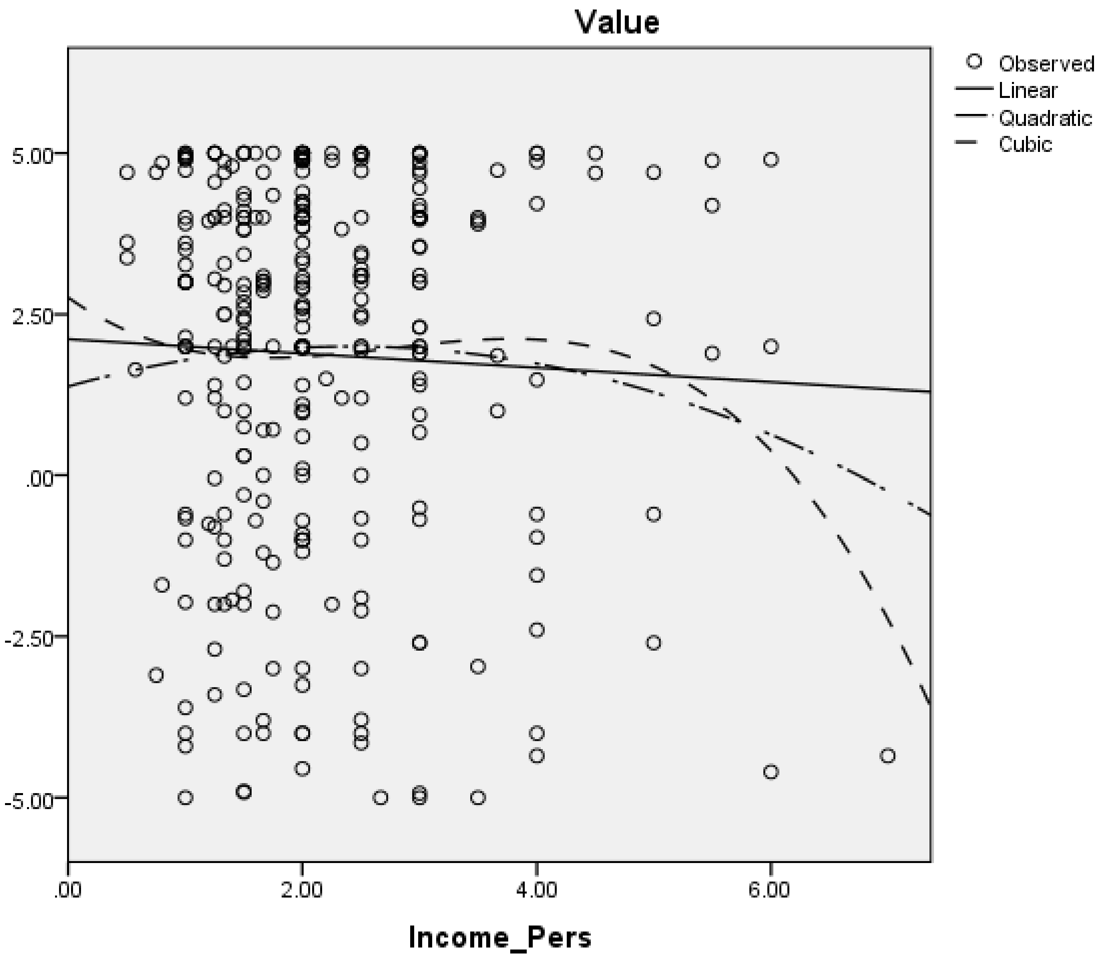


Figure 3.57 Utility curve over the personal income

In this case the, it can be seen in the conceptual curves that the utility of the quadratic model increases in the beginning and then decreases at a increasing rate for each additional unit of wealth (risk-averse individual) after a point, but the utility of the cubic model decreases until a point then increases and then decreases again (Figure

3.57). Using the cubic model equation of the conceptual model, the point that this change happens can be calculated.

Table 3.59 Social investment per individual evaluation model summary

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.002	.500	1	298	.480	2.114	-.111		
Quadratic	.006	.955	2	297	.386	1.378	.516	-.107	
Cubic	.011	1.141	3	296	.333	2.763	-1.291	.547	-.066

The independent variable is Income Pers.

Dependent Variable: Value

The model is as follows (Table 3.59):

$$y = 2.763314 - 1.291078 \cdot x + 0.547490 \cdot x^2 - 0.066424 \cdot x^3$$

The first derivative is:

$$y = -1.29108 + 1.09498 \cdot x - 0.199272 \cdot x^2$$

zeroed in points:

$$x = 1.71328 \;\&\; x = 3.78162$$

There are 24 participants beyond 3.78162 and 10 of them are single families with £30000-40000 income, so the personal income cannot be considered as an indicator of wealth by itself. Although, to conclude for both analyses the current transport investments in the United Kingdom are risky for the individuals who are treated as key stakeholders who participate in the decision-making process.

The investments may be sustainable either by reducing the value of the individuals with the individuals in the upper social strata or by increasing the value of the individuals in the middle classes. The factor of the social value with the most negative evaluations of the mode used by the individuals in the middle classes was Cost. The reduction of the direct cost of the transport modes will probably make the transport investments socially sustainable.

3.3.10 Social infrastructure interdependencies

Bijker et al. (1987) using case studies dealing with Transport, Energy, Waste, Communication and Water infrastructure interdependencies emphasized the social value of technology. The social infrastructure interdependencies were investigated with an interview, where three hundred individuals were chosen to be reasonably representative of aspects of the UK's demography were asked to identify the dependency between transport and other infrastructures. The individuals were asked to evaluate the dependency with an integer between 0 and 5 and the mean, the median and the mode were calculated for walking, cycling, rail, bus, car, taxi, air transport and water transport with energy, water, waste and communication infrastructure (see Appendix C).

Table 3.60 shows the mean, the median and the mode of the dependency evaluations between the different sectors by the individuals. When two (median and mode) of the calculated values had the same value, then the value was accepted. In any other case, the mean was considered as the accepted value for the dependency. This happens because as it can be seen from the previous figures that the distribution of the answers is not normal and that is why the author presented analytically in figures the results too. Causality exists since the individuals were asked if they perceive a rational dependency and to evaluate it.

Table 3.60 Social infrastructure interdependencies

	Mean				Median				Mode			
Transport	Energy	Water	Waste	Communication	Energy	Water	Waste	Communication	Energy	Water	Waste	Communication
Walking	0.16	0.47	0.75	0.79	0	0	0	0	0	0	0	0
Cycling	0.17	0.51	0.76	0.74	0	0	0	0	0	0	0	0
Rail	4.55	0.55	0.80	3.30	5	0	0	4	5	0	0	5
Bus	4.67	0.35	0.76	2.66	5	0	0	3	5	0	0	5
Car	4.67	0.36	0.41	1.59	5	0	0	1	5	0	0	0
Taxi	4.67	0.31	0.47	3.03	5	0	0	3	5	0	0	5
Air	4.72	0.52	0.62	3.88	5	0	0	5	5	0	0	5
Water	4.35	4.41	0.66	2.63	5	5	0	2	5	5	0	5

3.3.11 Discussion and conclusions

The hypothesis that the value to the individual relative to safety and security, time, societal acceptance, cost and comfort & convenience (which combined represents the social value) should approximate to a sigmoid curve was verified. The numerical expression of a cubic-spline function, which is a sigmoid function, was shown to provide a good fit to most of the quantitative social value data deriving from interviews of representative cohorts of individuals from a variety of UK metropolitan areas. The deviations were attributed to one or more of the non-rational biased logic of individuals, misconceptions on the part of individuals and of in-built assumptions, that the individual's needs are covered by the infrastructure over time. Social value may be defined as a sigmoid curve of the needs covered over time.

It was evident from the interviews that some of the individuals had strong negative opinions about a transport mode, although their evaluations of the factors of each transport mode contrasted with their initial evaluations (the fourth quarter; 4.88%). In other words, they had a positive sum of evaluations regarding time, cost, comfort &

convenience, safety and security, but they did not "*like*" a particular mode of transport for personal or emotional reasons. The same problem, conversely, was noticed with positive opinions about a transport mode and negative sums of opinions on the factors (second and the fourth quarters; 7.8%). There were discrepancies (7.8%) between the model and reality, and since *de facto* the reality is true, these deviations could be studied in follow-up research, where the (quantitative) evaluations of each individual will be compared with their qualitative answers.

To conclude, while social values of citizens, as users of the transport infrastructure, need to be considered during the decision making process for transport infrastructure investments, they do not provide a conclusive evidence base on which to base decisions as misconceptions and/or other personal attitudes of the individuals do not allow us, certainly without further detailed analysis of the nuanced arguments in the qualitative components of the interviews, necessarily to consider the individual as a major rational key-stakeholder. This has important implications for the use of simple transport survey results.

Chapter 4 Development of the transport infrastructure business model elements

Having defined and analysed all types of value of the infrastructure business models, the infrastructure business model can be designed, including the equations developed for each type of value.

4.1 Economic, Social and Environmental Value

4.1.1 Economic Value Hypothesis

Hypothesis tested: The transport infrastructure is economically complemented by the energy, water, waste and communication infrastructures meaning that investing in Energy, Water, Waste and Communication in the current situation of the United Kingdom creates value to Transport.

Methodology and Analysis: “Networks and cohorts” (Hill, 1993) and linear regression analysis. The data provided by the national statistical office were not sufficient to test the hypothesis, forcing us to use data by the World Bank. The linear regression found multicollinearity forcing us either to remove “Communication” infrastructure from the model or to try to reduce multicollinearity. After trying unsuccessfully different methodologies and datasets, principal component analysis was applied using all the IOGs. This method creates “new” variables for the model, but in this case the four types of infrastructure were used for “creating” the same “new” variable (let’s call it Variable 1). Luckily all the “old” variables were in the same unit (pounds or dollars) and this allowed us to change Variable 1 with a combination/sum of the “old” variable of interest. The researcher got the idea from engineering as this is something that survey engineers or computer scientists do when they use PCA on data with the same unit such as distance on earth.

4.1.2 Environmental Value Hypothesis

Hypothesis tested: After a detailed literature review, environmental value was studied using an inductive approach, rather than a deductive approach. The business model in terms of value includes economic and social value, and what the author of this thesis had done is to carry out a major study of the social value of transport infrastructure. However, there are synergies between the environmental consequences of operating the five 'national infrastructures', and which were established and correlated. It was tested if the different EXIOBASE pollutant indicators of the five national infrastructures of interest correlate. Then we removed the correlations than would be possible to exist due to methodology or database (e.g. pollutant indicators coming from the same source etc.). The existing correlations were presented in the model as interdependencies between pollutant indicators. Additionally, the indicators for transforming the GDP to quantities of pollutants were presented. A key finding was the ranking of the LCA Methods based on data requirements and uncertainty

4.1.3 Social Value Hypothesis

Hypothesis tested: Different cohorts of the population value transport infrastructure differently and this demographic influence is important in the formulation of effective transport business models.

Thinking: In testing this hypothesis, it was explored whether Maslow Hierarchy of Needs explains the coverage of needs by transport infrastructure (verified by the theory), whether different factors affect how people value the different transport modes (verified by the theory or logical assumption such as the people who own cars or a higher income have more positive opinion for the cars than the others), and whether expected utility theory can explain the data of the questionnaire.

Methodology and Analysis: Questionnaires were analysed using ANOVA, t-tests, SPSS statistical models.

4.2 Transport infrastructure business model design

Value creation is crucial to understanding the business model of transport infrastructure and its relationship with stakeholders. The new Transport Infrastructure Business Model is presented in Figure 4.1 to give a holistic picture of how the value is created and the stakeholders who capture this value. Supported by the academic literature, the interdependencies are designed based on the correlated empirical data and illustrated in Figure 4.1 The numerical attributions of the economic value in the figure are indicative, since the economic variables used for the linear analysis were highly correlated. On the other hand, social and environmental values were calculated with no correlated primary data and taken directly from existing matrices, respectively.

The environmental interdependencies are only presented in terms of pollutants without any attempt to create a quantitative result. The main reason for this is that the author did not want to present a purely economic representation of environmental value, which may be used as an excuse for individuals or organizations to damage, or even in some cases destroy, the environment and pay the "*right*" amount of money as compensation.

The new business model was developed using FreeMind, a mind-mapping software, which can be used to illustrate the structure of both established and the new business models (Hillar, 2012). The considered system in the United Kingdom is at the macro-level. The degree of detail in the considered system can be divided into three levels: the first level is the broad type of infrastructure and the stakeholders, the second level is the detailed type of infrastructure and the growth engine, and the third level is the type of value.

The relationships in the model were tracked with the Pearson correlation coefficient. The economic infrastructure interdependencies were investigated by correlating the demand of each infrastructure with other infrastructure demand. Although the correlations do not imply dependency (Field, 2009, p. 619-620), they can show if any, and which, infrastructure interacts with another infrastructure based on demand. The GDP of the Input-Output tables' comparison will show the correlations between each infrastructure. The causality exists since Input-Output tables show the grand total of all revenues, which are inputs into other sectors and create dependences (see Chapter 3.1).

The environmental value interdependencies were calculated using EXIOBASE 3 by correlating the emission coefficients (emissions generated per GDP of each sector) of 48 major economies. The dependencies between the coefficients of the sectors constitute transport infrastructure and the sectors of waste, water, energy and communications were recorded and presented for transport as a total and for the subgroups of air, land and water transport (see Chapter 3.2).

The social infrastructure interdependencies were investigated via interviews, where three hundred individuals chosen to be reasonably representative of aspects of the UK’s demography were asked to identify the dependency between transport and other infrastructures. The individuals were asked to evaluate the dependency with an integer between 0 and 5 and the mean, the median and the mode were calculated (see Chapter 3.3).

In the new business model (Figure 4.1) on the left (Figure 4.1a) can be seen the stakeholders (growth engine) of the model and on the right (Figure 4.1b) the value creation by the different type of infrastructure to air, land and water transport and by transport itself. Green is used to represent the environmental value, red the economic and blue the social value. Additionally the figure shows which type of value each stakeholder captures by connecting them to the appropriate colour line. Representative qualitative information has been placed for each type of value in the business model based on secondary and primary data used. Material of Chapter 4 has been published by the author in an international journal (Kalyviotis et al., 2018b).

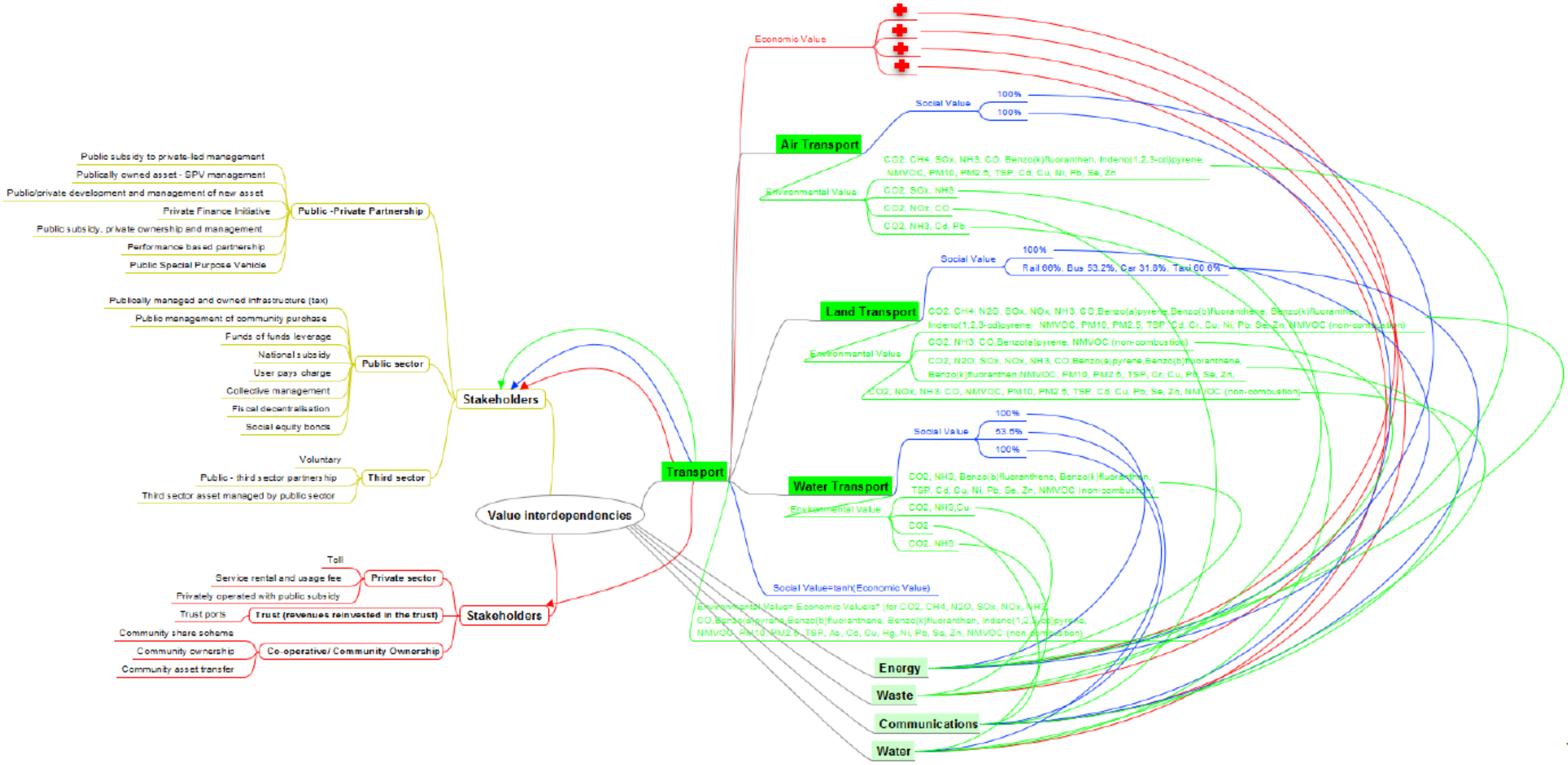


Figure 4.1 The New Business Model for Transport Infrastructure Interdependencies Management

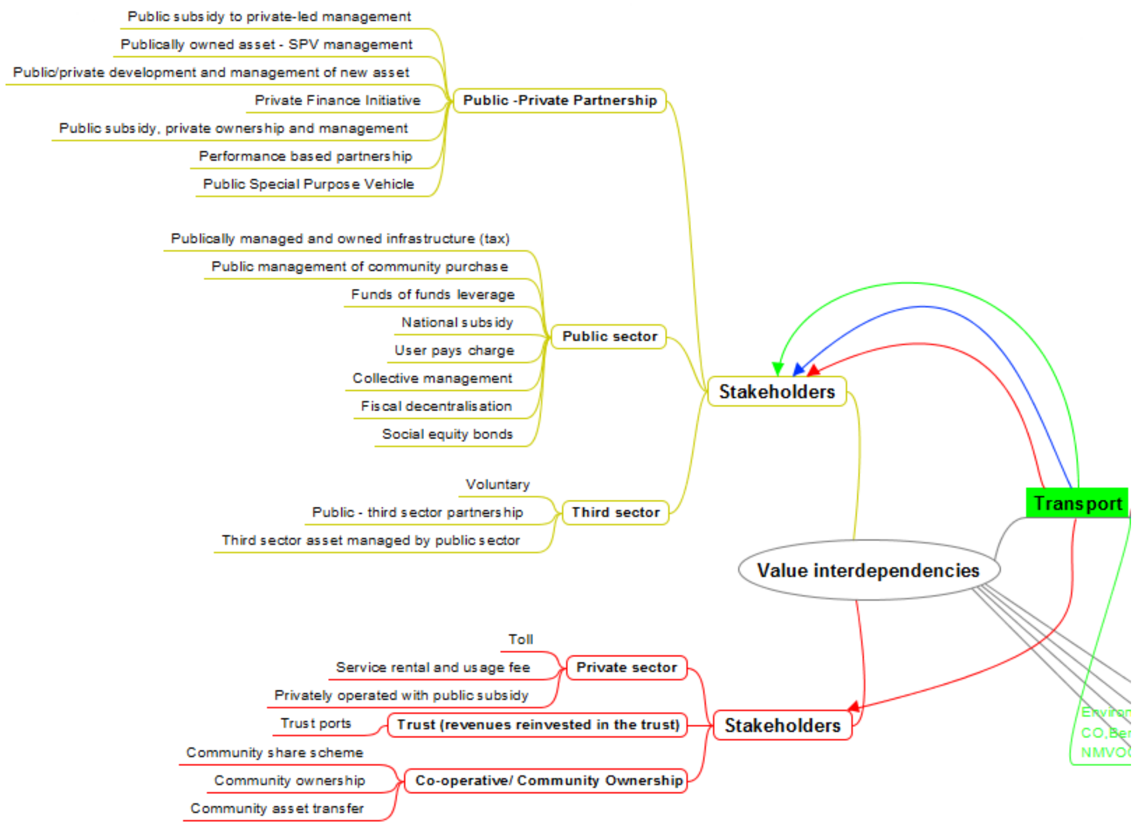


Figure 4.1a The New Business Model for Transport Infrastructure Interdependencies Management (part A)

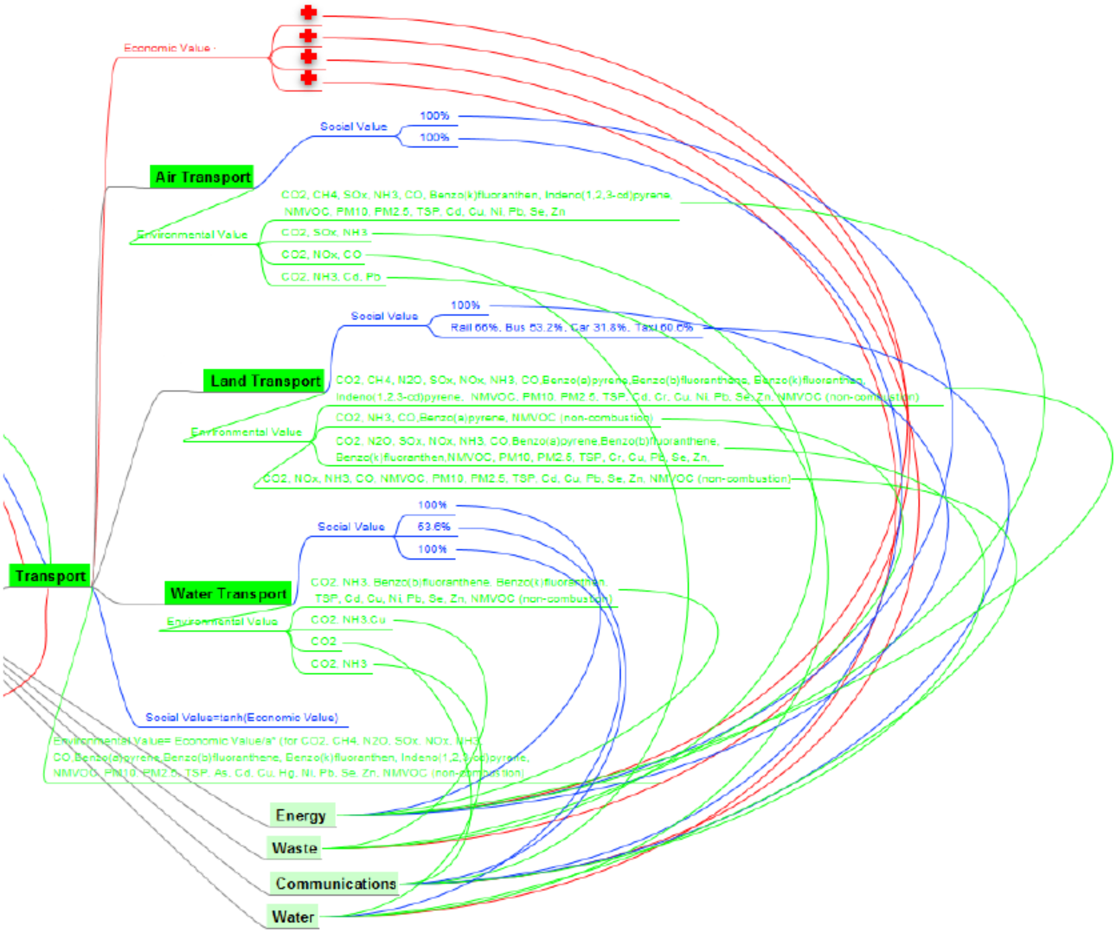


Figure 4.1b The New Business Model for Transport Infrastructure Interdependencies Management (part B)

The new business model is a hierarchical model. Hierarchical models group the possible choices, in this case transport modes, according to their similarities and differences in levels (Giannopoulos, 2002, p.165) to address the different challenges found and discussed in this thesis. For example transport is grouped into land, water and air based on the vehicle, network and terminal similarities to address the complexities of the multi-level analysis of each transport mode. Some levels are not shown in the final model, because of the size limitations of the model, as someone can claim that it is already too complicated to be processed. For example value is grouped into social, environmental and economic, but some levels that constitute each value (social factors, environmental emissions' quantities, economic IOGs, etc.) are not shown and can only be found in the previous chapters in this thesis.

"*Cross-correlation*" is included in the new model by investigating the interdependencies. According to Giannopoulos (2002, p.165), in the hierarchical model, the higher value in the hierarchy is always considered as the result of the variables in the lower level in the hierarchy. The challenge which occurs is that all the new investigated interdependencies are at the same level. This means that it should be discussed which values are considered dependent and which independent (e.g. social and environmental are dependent on the economic value). The real challenge of this assumption/issue is deeper, as this research claims that all interdependencies amenable to a mathematical formula act with independent variables for each type of value. In other words it is not safe to develop a mathematical model which will include, simultaneously, all the type of values (economic, social and environmental) in one equation.

Finally, the social interdependencies were a result of the logic of the individuals, but based on the findings of this research the logic is not always rational. That is why it was decided to combine three different descriptive statistical "*averages*" to develop this business model.

Chapter 5 Conclusions and implications

In this chapter the results of this research are summarized regarding the business model for transport infrastructure interdependencies management in the United Kingdom. In particular, results are presented and analysed from both the academic and the empirical aspect in response to the research question which the author set as a basis for the preparation of this thesis. Material of Chapter 5 has been published by the author in international journals (Kalyviotis et al., 2018a,b,c) and conferences (Kalyviotis et al., 2017a,b,c).

5.1 Conclusions and recommendations

This thesis explores infrastructure interdependencies to see how they impact on the three-pillar value judgements. The purpose of this research was to develop a transport infrastructure business model which will take into consideration the environmental and the social value and value dependencies and interdependencies, apart from the economic ones. A critical literature review tracked the three main components of a business model and how these components interact. The theory reported in the literature was applied to develop a model that shows how the main components interact in infrastructure business models. Infrastructure business models are defined as the system of physical artefacts, agents, inputs, activities and outcomes that aim to create, deliver and capture economic, social and environmental values over the whole infrastructure life cycle. Focus was placed upon balancing economic, social and environmental value. To achieve this, it was necessary to investigate each value individually aligning the investigation with the scope and the research gap of the study. Then the outcomes of each type of value were combined to develop the final business model.

The main finding, which addressed the main question of this thesis, is the determination of the value dependencies between the transport infrastructure and the other four ‘economic infrastructures’. The economic value was investigated considering the demand for the transport sector in the UK and how this demand interacts with the demand for energy, water, communications and waste. This study was conducted from an engineering perspective meaning that some industries considered in the manufacturing sector were considered as part of the transport sector and approaches such as the input–output tables were used. The World Input-Output Database provided economic data for linear regression, statistical analysis and principal component analysis, well beyond the input-output tables determined from the Office for National Statistics. The analysis of the economic data provided the required data for a generalized model and an economic linear model was developed. The economic transport infrastructure interdependencies, based on the demand between sectors, were identified. The transport infrastructure is economically complemented by the energy, water and waste infrastructures and partially economically substituted by the communication infrastructure.

Based on a review of the theory, the input-output analysis has more uncertainty than process-based and less than pseudo, simplified and parametric. The environmental value was taken from secondary data coming from the input-output tables of the EXIOBASE and linked with the economic demand of each sector. The analysis applied was an inductive analysis. The conceptual base of the analysis was the observations on the EXIOBASE (induction) and not the theory behind them (deduction). Based on the inductive analysis, the transport sector generates the following twenty-five air emissions: CO_2, CH_4, N_2O, SO_x, NO_x, NH_3, CO, Benzo(a)-pyrene, Benzo(b)-fluoranthene, Benzo(k)-fluoranthen, Indeno(1,2,3-cd)pyrene, PCDD_F, NMVOC, PM_{10}, $PM_{2.5}$, TSP, As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn and one water pollutant NMVOC. EXIOBASE provided characterization factors to transform the economic demand to pollutants. This means that the environmental value of the transport sector has an almost linear relationship with the economic demand assuming that environmental value is a result of the pollutants produced by each sector for a specific demand. The interaction between the different sectors was analysed by looking for statistical significance between the characterization factors of each pollutant. Dependency exists between: Transport-Energy, Transport-Communication, Transport-Water and Transport-Waste. A deeper environmental analysis is required of how the different pollutant production interacts with each other, because essentially these relationships are the result of a specific database based on quantitative data.

The major contribution and the place where most effort was given to is on understanding the social value of transport infrastructure. Social value was combined with (traditionally dominant) economic value and environmental value (drawn from databases).

In order to establish a quantitative social value with accuracy on the numerical results, the social value model was developed and validated against theory. Maslow's hierarchy of needs (1954) and the transformation of the need to dynamic were tested. The basic needs during travel with a transport mode presented by Winters et al. (2001) as an extension of Maslow's Hierarchy of Needs (Maslow, 1954) were safety and security, time, societal acceptance, cost and comfort and convenience, and these were used for this test. Since the purpose of the social model is to design curves of needs of the UK population covered by transport and compare them with the existing theory, quantitative interviewing was conducted by the author of this thesis to provide the required data for the curve design. The focus was on obtaining numerical data so the final users themselves contour the subject matter, which was the needs coverage by each transport mode. Three-hundred individuals were asked to evaluate on a scale from -5 to 5 eight transport modes (walking, cycling, rail, bus, car, taxi, water and air) and the coverage of each need (time, cost, comfort and convenience, safety and security) by each mode creating a database of 2400 evaluations. The sample of the three-hundred participants had the same characteristics as the population of the UK, as purposive sampling demands meaning same percentage of participants based on the age, ethnic group, area living and gender with the population of the UK. The data collected were considered as values of a Cartesian coordinates system to design curves. Different Cartesian systems were developed based on the three subjects studied: [1] social value over the needs coverage and over the age of the participants, [2] hierarchy and ranking of needs for each transport mode and [3] social value transport infrastructure interdependencies.

The hypothesis that the social value (coverage of transportation needs) to the individual is relative to safety and security, time, societal acceptance, cost and comfort and convenience should approximate to a sigmoid curve was verified with some deviations due to the statistical analysis. The evaluations by the individuals of how their needs are covered by each transport mode in the UK was used to develop a statistical model and to sketch curve of needs over the participants' age. Regarding the transport hierarchy of needs in the UK, it was evident from the individual analysis of each group of needs that Maslow's curves align with the curves presented in this research. Safety and security and cost curves align with the curve of psychological needs. Time and excess time curves align with the love and belonging curve. Finally, comfort and convenience align with the esteem curve.

The hypothesis of Winters et al. (2001) regarding the transport hierarchy of needs confirmed, the transport hierarchy of need in the UK over the individual's personal development (age/time) is as follows: [1] safety and security, [2] cost, [3] time, and [4] comfort and convenience. Finally, an analysis of each need by transport mode took place based on the understanding of the individuals. The quickest land transport modes are ranked as follows: 1) car, 2) taxi, 3) rail, 4) bus, 5) cycling, and 6) walking. The less excess time (waiting time) needed ranking is as follows: 1) car, 2) walking, 3) cycling, 4) taxi, 5) rail, and 6) bus. The cheapest modes are as follows: 1) walking, 2) cycling, 3) rail, 4) bus, 5) car, and 6) taxi. The most comfortable transport mode ranking is as follows: 1) car, 2) taxi, 3) walking, 4) rail, 5) bus, and 6) cycling. The safest transport mode ranking is as follows: 1) car, 2) taxi, 3) rail, 3) walking, 4) bus, and 5) cycling. Further analysis is required to generalize the hierarchy of needs and the ranking of the transport modes outside the UK, considering other parameters such as that the UK is a western developed country with what that entails for the coverage of needs by the transport modes.

The survey participants did not identify a list of dependencies between transport and other infrastructures. The results indicate that young adults, aged 20 to 39, derived greatest value from the transport infrastructure (are the ones who gave the highest evaluations, for the majority of transport modes, namely the air, taxi, water, and cycling modes). However no age differences were manifested for the car and the walking modes, which were valued highly across all age groups, and for the bus mode, which were not valued highly across all age groups. Interestingly, the reverse pattern applied for the rail mode, for which the highest evaluations were given by the oldest participants (65+ yrs. old). Based on the exploration of the age factor, it could be argued that an age effect did occur for the transport modes: there were teenagers and older participants who were not generally satisfied. No main effect of gender or ethnic group was found on how transport was valued, both when looking at the overall data or for every transport mode separately. The more cars participants had access to (hence driving was well facilitated), the more they appreciate the mode, or, from another point of view, the more they appreciate the car mode, the more cars they own. Participants that did not value the taxi mode, owned more cars or, from a different point view, the more cars participants had, the lower the evaluations they gave to the taxi mode. Interestingly, the number of cars a participant had access to was not found to affect their evaluations of the public transport modes, i.e. the bus and the rail mode, or their evaluations of the modes requiring physical activity, i.e. walking and cycling. Household income was found to have an effect on only two of the transportation modes in question, namely the car and the cycling mode. For the car mode, the highest evaluations were given by participants earning more than £50,000 a year whereas for the cycling mode the highest evaluations were given by participants earning annually less than £30,000.

Regarding the transport infrastructure business model, the research gap of this thesis to develop an innovative business model including social and environmental value was fulfilled. The economic, environmental and social factors and the relationships between the different infrastructures were used in a final business model. Since the relationships of the above system are based on the dependencies, then correlation of the appropriate data was used to identify the economic, social and environmental value connections between the different types of infrastructure. The general depiction of the relationships between transport, water, waste, communication and energy permits better understanding of how the overall system works by policy makers and hence better decisions on which types of infrastructure to focus on, if the aim is to add value to society.

Furthermore, since the business model, apart from the value, is linked with the final user, the position of the final user should be reconsidered. The involvement of the final user as a key-stakeholder through co-creation was challenging. The questionnaire developed for the social value showed that it was not possible to identify some strategic and important relationships for the final user in the business model and the final user was sometimes biased towards some practices without really taking into consideration their value. The study of the infrastructure interdependencies involving the final users based on the survey proved that most of the final users did not recognize some of the dependencies such as water infrastructure – air transport, water infrastructure – land transport, waste – any transport, but they were able to recognize the energy requirements of each transport mode in terms of importance.

Finally, the dependence of business models on the definition of value makes them flawed or vulnerable to any change of how the value is defined and to any change of how the end user understands this value. This limitation affects the discussion and the models presented above to such an extent that if someone wants to use the models it is necessary first to adjust (calibrate) them to the value definition of interest.

The research took place in the United Kingdom; therefore, the application of the results can be generalized in terms of infrastructure business models in the United Kingdom for the same period of time with any limitation discussed, e.g. correlated findings cannot get generalised. It must be mentioned that the transport industry is in its maturity phase (Gómez Ortega et al., 2014, p.13) so competition is fierce, and therefore different transport infrastructures are trying to differentiate themselves through service levels and quality, gaining customer's brand loyalty and cutting operating costs at the same time. In terms of target market, traditionally transport authorities have not focused on business travellers and customers who appreciate a premium service, but day-to-day travellers. The findings of this study cannot safely suggest any expiation to luxurious services, but a new target audience should be introduced: well-travelled individuals and children (maximising social value, but considering environmental value too). The focus on children is in line with public authorities' most important strategies to generate family-friendly means of transport (VisitBritain, 2018; Department for Transport, 2013).

5.2 Significance and contribution

The results are significant and useful both in academia and in the wider business context; however, they are significantly limited by the procedure as laid down by the research methodology and data.

From an academic perspective, this thesis contributes to the theory of infrastructure business models and to the economic, social and environmental value of transport infrastructure in particular. Furthermore, this study illustrates a new business model for transport infrastructure interdependencies management. The innovative features of this study can be found in the design of the business model, as the connections between the different sectors are not linear but they are dependent on each other (interdependencies, which add value indirectly).

According to Whetten (1989, p.492-494), theoretical contribution can be either with:

- Whats; by "…adding or subtracting factors (Whats) from an existing model" (p. 492), something that this thesis not only did but presented new models too

or

- Hows; by identifying how a change "…affects the accepted relationships between the variables" (p. 492), something that can be seen in the new business model.

Apart from these Whetten (1989, p.494-495) claimed that research adds value when it has some specific features which answer the following questions: (1) What's new? (2) Are the author's assumptions explicit and views believable? (3) Will the theory likely change the existing practice? (4) Well done with multiple theoretical elements? (5) Done well with the central ideas easily accessed? (6) Why now? (7) Who cares?

In this regard, the previous questions should be answered (see the number in the brackets for highlighting the answers to the theoretical contribution questions in Section 5.2; each number 1 to 7 corresponds to the Whetten's question answered by each phrase) and the academic and practical implications should be presented.

The ongoing debate about the value of the benefits of infrastructures (6) and about prioritization of the infrastructure investments by the UK government (7) can answer the most of the Whetten's questions, since they show the need for a new business model (1). This thesis critically reviewed the literature (4) and complemented it with new findings mainly by quantifying qualitative data from previous or this research and by transforming the data to models. An innovative definition of value was presented in Chapter 3 aligning with the literature review (1, 4, 5). Regarding the social value theory, there were amendments to (1) on the transportation hierarchy of needs developed by Winter et al. (2001) and on the coverage of needs for the seniors as Maslow (1954) expected.

The methodology used to develop these models may be applicable to similar academic data and to point to a new method of model building (5).

Within the potential economic, social and environmental values, the infrastructures dependencies and interdependencies were established, including dependencies and interdependencies not previously identified in other conceptualisation of the infrastructure business models (1). To the best of the author's knowledge, there is no quantitative relationship (function) of economic, social and environmental value including the five infrastructures' dependencies and interdependencies at the same time (2).

This study considered the final user of the infrastructure as the key stakeholder, thus advancing beyond the existing theory, through co-creation. For final users participation in the decision making process opened a new discussion / direction of study, as in previous studies the final user was not considered as a key-stakeholder (1, 6).

The prior literature and especially the empirical findings (data) from the United Kingdom case study have several practical implications and can be useful for infrastructure business models practitioners (7) and policy makers (7) who deal with complex organizational systems with dependencies and interdependencies. The findings suggest how infrastructure business models will provide the environment to key-stakeholders for successful infrastructure interdependencies management and infrastructure systems' delivery in a way that the services will flourish and enhance infrastructure performance (1). Since there is no specific business model that fits all the transport infrastructures around the world, this study provides practitioners with awareness and serves as a guide to the relationships and variables that need to be taken into consideration in order to add value to society (7). Policy makers must be aware that environmental and social values should be taken into consideration in the value proposition of the infrastructure business models as they are key elements for the successful provision of services (6, 7). Additionally, based on the findings of this study the final users do not always know what the best practice is, therefore policy makers should educate the individuals before involving them in the decision-making process. These observations may serve as guidelines to avoid risks and threats during the operation of existing or new transport infrastructure.

Finally, although it is not purely aligned with the scope of this research, the author believes that the statistical analysis and methodology used can apply to similar research focused on dependencies and interdependencies (4).

5.3 Future research directions

Considering the limited time and scope of this study, there are many things that can enrich it in the future. It would be interesting to investigate different sectors focusing on waste, water, energy or communication with similar studies within the same context and compare the findings.

Economic value models could be investigated by means of survey. Beyond the research gap, the study could be extended to other types of values too or to decompose the economic, social and environmental value to more types of values, or to extrapolate to other countries to track patterns in infrastructure interdependencies. According to the European Commission – DG Mobility and Transport (2014) there are many external costs (values) of transport: congestion costs, accidents costs, air pollution costs, noise costs, climate change costs, etc., some of which were not taken into consideration in this research.

Methodologically, the subjective perception of the social data is a result of the data collection method. It would be more useful to collect the travel data of the participants using technological means (e.g. trackers with GPS and detailed distance and time recorders), instead of asking the participants. Furthermore, it would be beneficial for this research to use ethnographic techniques for choosing the survey participants instead of using a demographic targeted sample of participants randomly approached. This way the research will be strengthened and enhanced.

Another method that can be tested is analysing the data by conducting Agent Based Modelling, as an alternative to the empirical curve fitting approach, to explore the diversity and complexity of the social data collected (e.g. Bozeman et al., 2021).Finally, the inclusion of data from different time periods and agents affects the validity of the research, but the author only had access to this type of information. Using data from the same time period and agents will increase the validity of the research.

References

Ackerman F & Heinzerling L (2002) *Pricing the priceless: Cost-benefit analysis of environmental protection*. University of Pennsylvania Law Review 150(5): 1553–1584.

Afuah A & Tucci CL (2001) *Internet business models and strategies: Text and cases.* New York: McGraw-Hill.

Aho AM (2015) *Product Data Analytics Service Model for Manufacturing Company*. 10th International Conference, Knowledge Management in Organizations. Maribor, Slovenia, August 24-28.

Alfonzo M (2005) *To Walk or Not to Walk?: The Hierarchy of Walking Needs.* Environment and Behavior 37(6): 808-836.

Allenby B & Chester M (2018) *Reconceptualizing Infrastructure in the Anthropocene*. Issues in Science and Technology 34(3): 58–64.

Amit R & Zott R (2001) *Value creation in E-business*. Strategic Management Journal 22(6-7): 493-520.

Amit R & Zott R (2010) *Business Model Design: An Activity System Perspective*. Long Range Planning 43(2-3): 216-226.

Andersen MS (2007) *An introductory note on the environmental economics of the circular economy.* Sustainability Science 2(1): 133–140.

Asif M, Dehwah A, Ashraf F, Khan H, Shaukat M & Hassan M (2017) *Life Cycle Assessment of a Three-Bedroom House in Saudi Arabia*. Environments 4(3): 52

Atkins G, Davies N & Bishop TK (2017) *How to value infrastructure*. Project Management Institute , UK.

Atmaca N (2017) *Life-cycle assessment of post-disaster temporary housing.* Building Research and Information 45(5): 524–538.

Ayres RU (1995) *Life cycle analysis: A critique*. Resources, Conservation and Recycling 14(3–4) :199–223.

Bakker J, Frangopol DM & van Breugel K (2017) *Life-Cycle of Engineering Systems: Emphasis on Sustainable Civil Infrastructure*, CRC Press, Taylor and Francis, London.

Balieu R, Chen F & Kringos N (2019) *Life cycle sustainability assessment of electrified road systems*. Road Materials and Pavement Design 20(sup1): 19–33.

BBC News (2016) *UK air pollution 'linked to 40,000 early deaths a year'*. See <http://www.bbc.co.uk/news/health-35629034> (accessed 31/05/2018).

Beagley-Brown Design (2012) *Planes, Trains or Automobiles? – Carbon Emissions Compared for Different Forms of Transport*. See <http://www.beagleybrown.com/planes-trains-or-automobiles-carbon-emissions-compared-for-different-forms-of-transport/> (accessed 31/052018).

Berg BL (2001) *Qualitative Research Methods for the Social Sciences* (4th Edition). Boston: Allyn and Bacon.

Berman B (2002) *Should your firm adopt a mass customization strategy?* Business Horizons, 45(4): 51-60.

Beylot A, Corrado S & Sala S (2019), *Environmental impacts of European trade: interpreting results of process-based LCA and environmentally extended input–output analysis towards hotspot identification*. The International Journal of Life Cycle Assessment 25: 2432–2450.

Bhaskar R & Danermark B (2006*). Metatheory, Interdisciplinary and Disability Research: A Critical Realist Perspective*. Scandinavian Journal of Disability Research, 8(4): 278-297.

Bijker W, Hughes T & Pinch T (1987) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, MA.

Bjelle EL, Többen J, Stadler K, Kastner T, Theurl MC, Erb K-H, Olsen K-S, Wiebe KS & Wood R (2020). *Adding country resolution to EXIOBASE: impacts on land use embodied in trade*. Journal of Economic Structures 9(1).

Blais P (2010) *Perverse Cities: hidden subsidies, wonky politics, and urban sprawl*. Vancouver: UBC Press.

Blecker T & Friedrich G (2007) *Mass Customization Information Systems in Business*. New York: Information Science Reference.

Blok R, Smits J, Gkaidatzis R & Teuffel P (2019) *Bio-Based Composite Footbridge:*

Design, Production and In Situ Monitoring. Structural Engineering International 29(3): 453–465.

Bonciu F (2014). *The european economy: From a linear to a circular economy*. Romanian Journal of European Affairs 14 (4): 78-91.

Bonnedahl KJ & Eriksson J (2011) *The role of discourse in the quest for low-carbon economic practices: A case of standard development in the food sector.* European Management Journal, 29(3): 165-180.

Bordalo P, Gennaioli N & Shleifer A (2016) *Competition for Attention*. Review of Economic Studies, 83: 481–513.

Bourantas D (2002) *Management*. Stamoulis Press, Greece.

Bozeman J F, Mulrow J, Derrible S, & Theis T L (2021) *Urban Carbon Management Strategies*. In *Advances in Carbon Management Technologies* (p. 229-250). CRC Press.

Branigan J & Ramezani F (2018) *Assessing the value of public infrastructure at a regional level: cost benefit analysis supplemented by economic impact analysi*s. Australasian Journal of Regional Studies 24 (2): 147-168.

Bruinsma F, Nijkamp P & Rietveld P (1992). *Regional economic transformation and social overhead investments.* Tijdschrift voor Economische en Sociale Geografie, TESG 83: 3–12.

Bryman A & Bell E (2011) *Business Research Methods* (3rd Edition) New York: Oxford University Press.

Bryson JR (2017) *Infrastructure Business Models and the iBUILD on-line local infrastructure tool*. Valuing Infrastructure Conference: Valuing the Infrastructure of Cities, Regions and Nations. Leeds, United Kingdom, 26 – 27 April.

Bryson JR, Mulhall RA, Song M, Loo BPY, Dawson RJ & Rogers CDF (2018) *Alternative-substitute business models and the Provision of Local Infrastructure: Alterity as a Solution to Financialization and Public-Sector Failure*". Geoforum 95: 25-34.

Bueno G, Hoyos D, & Capellán-Pérez, I (2017*) Evaluating the environmental performance of the high speed rail project in the Basque country, Spain*. Research in Transportation Economics 62: 44–56.

Button K (1996) *Ownership, Investment and Pricing of Transport and Communications Infrastructure*. Infrastructure and the Complexity of Economic Development, David F Batten & Charlie Karlsson eds.: 147-165.

Canada's Public Policy Forum (2014) *International approaches to infrastructure governance: Experiences from the united states, the united kingdom and australia - final report Public Policy Forum*. < https://deslibris.ca/ID/244501> (accessed 03/06/2020).

Casadesus-Masanell, R & Heilbron, J (2015) *The Business Model: Nature and Benefits*. Harvard Business School Strategy Unit Working Paper No. 15-089. See < https://ssrn.com/abstract=2606692> (accessed 05/03/2018).

Casadesus-Masanell R & Ricart JE (2010) *From Strategy to Business.* Long Range Planning, 43: 195-215.

Castellani V, Beylot A, & Sala S (2019*) Environmental impacts of household consumption in Europe: Comparing process-based LCA and environmentally extended input-output analysis*. Journal of Cleaner Production 240: 1–12.

Crawford RH, Bontinck PA, Stephan A, Wiedmann T & Yu M (2018). *Hybrid life cycle inventory methods – A review*. Journal of Cleaner Production 172: 1273–1288.

Ceci F & Prencipe A (2008) *Configuring capabilities for integrated solutions: Evidence from the IT Sector.* Industry and Innovation 15(3): 277-296.

Chan KMA, Balvanera P, Benessaiah K, Chapman M, Sandra Díaz, Erik Gómez-Baggethun, Gould R, Hannahs N, Jax K, Klain S, Luck GW, Berta Martín-López, Muraca B, Norton B, Ott K, Pascual U, Satterfield T, Tadaki M, Taggart J & Turner N (2016) *Opinion: Why protect nature? Rethinking values and the environment*, Proceedings of the National Academy of Sciences 113(6): 1462-1465.

Chester MV (2008) *Life-cycle Environmental Inventory of Passenger Transportation in the United States*. Institute of Transportation Studies Dissertation at University of California, Berkeley.

Chester M & Horvath A (2010) *Life-cycle assessment of high-speed rail: the case of California* Environmental Research Letters 5: 014003.

Christensen CM (1997) *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Cianci R & Gambrel PA (2003) *Maslow's Hierarchy of Needs: Does It Apply In A Collectivist Culture.* Journal of Applied Management and Entrepreneurship 8(2): 143-161.

Clark WC, Turner BL, Kates RW, Richards J, Mathews JT & Meyer W (1990) *The Earth as Transformed by Human Action.* Cambridge: Cambridge University Press.

Coase RH (1960) *The Problem of Social Cost*. The Journal of Law and Economics 3: 1–44.

Collings D (2006) *An environmental comparison of bridge forms*. Proceedings of the Institution of Civil Engineers: Bridge Engineering 159(4): 163–168.

Connolly T, Loss C, Iqbal A & Tannert T (2018) *Feasibility study of mass-timber cores for the UBC tall wood building*. Buildings 8(8).

Couture L-E, Saxe S & Miller EJ (2016) *Cost-Benefit Analysis of Transportation Investment: A Literature Review*. iCity: Urban Informatics for Sustainable Metropolitan Growth. University of Toronto <> (accessed 06/04/2020)

Craig CS & Douglas SP (2000) *Configural Advantage in Global Ma*rket. Journal of International Marketing 8(1): 6-26.

Craig S (2019) *The optimal tuning, within carbon limits, of thermal mass in naturally ventilated buildings*. Building and Environment 165(August): 106373.

Cruijssen F, Dullaert W & Fleuren H (2007) *Horizontal Cooperation in Transport and Logistics: A Literature Review.* Transportation Journal, 46(3): 22-39.

Currie G & Stanley J (2008) *Investigating Links between Social Capital and Public Transport.* Transport Reviews 28(4): 529-547.

D'Amico B & Pomponi F (2018a) *Accuracy and reliability: A computational tool to minimise steel mass and carbon emissions at early-stage structural design*. Energy and Buildings 168(March): 236–250.

D'Amico B & Pomponi F (2018b) *Sustainability Tool to Optimise Material*

Quantities of Steel in the Construction Industry. Procedia CIRP, 69(May): 184–188.

David M & Sutton CD (2011) *Social Research: An Introduction*. London. UK: SAGE Publications Ltd.

Dennehy K (2018) *Journal explores database that quantifies environmental impacts in a 'global' world*. YALE SCHOOL OF FORESTRY & ENVIRONMENTAL STUDIES <http://environment.yale.edu> (accessed 02/03/2020)

De Wolf C, Yang F, Cox D, Charlson A, Hattan AS & Ochsendorf J (2016) *Material quantities and embodied carbon dioxide in structures*. Proceedings of the Institution of Civil Engineers: Engineering Sustainability 169(4): 150–161.

De Wolf C, Hoxha E, Hollberg A, Fivet C & Ochsendorf J (2020) *Database of Embodied Quantity Outputs: Lowering Material Impacts Through Engineering*. Journal of Architectural Engineering 26(3): 04020016.

Dietzenbacher E, Los B, Stehrer R, Timmer M & Gaaitzen Vd (2013) *The Construction of World Input–Output Tables in the WOID Project*. Economic Systems Research 25(1): 71-98.

Dona S & Singh A (2017) *Telescope Construction Faces Challenges*. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction 9(3): 5017005.

Doyal L & Gough I (1984) *A theory of human needs.* Critical Social Policy 10: 6-38.

Doyal L & Gough I (1991) *A theory of human need.* New York: Palgrave Macmillan.

Denzin N & Lincoln Y (2003) *The Discipline and Practice of Qualitative research in Collecting and Interpreting Qualitative Materials* (2nd edition). Thousand Oaks, California: Sage.

Department for Transport (2013) *Door to Door: A strategy for improving sustainable transport integration. See* <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/706255/door-to-door-strategy.pdf> (accessed 17/05/2016).

Department for Transport (2015) *Values of travel time savings and reliability: final reports)* See <https://www.gov.uk/government/publications/values-of-travel-time-

savings-and-reliability-final-reports> (accessed 31/05/2018).

Department for Transport (2016) *Transport Statistics Great Britain 2016* See <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/576095/tsgb-2016-report-summaries.pdf> (accessed 31/05/2018).

Department for Transport (2017) *Statistics at Department for Transport* See < https://www.gov.uk/government/organisations/department-for-transport/about/statistics> (accessed 31/05/2018).

Ding G & Forsythe PJ (2013) *Sustainable construction: Life cycle energy analysis of construction on sloping sites for residential buildings*. Construction Management and Economics 31(3): 254–265.

Ding GKC (2019) Chapter 10. Emissions. In Sustainable Construction Technologies. Elsevier Inc. < https://doi.org/10.1016/B978-0-12-811749-1.00008-0>

Du G (2012) *Towards Sustainable Construction: Life Cycle Assessment of Railway Bridges.* KTH Royal Institute of Technology.

Du G & Karoumi R (2013) *Life cycle assessment of a railway bridge: comparison of two superstructure designs*. Structure and Infrastructure Engineering 9(11): 1149–1160.

Du G & Karoumi R (2014) *Life cycle assessment framework for railway bridges: Literature survey and critical issues*. Structure and Infrastructure Engineering 10(3): 277–294.

Dubner SJ & Levitt SD (2008) *Not-So-Free-Ride.* The New York Times.

Duncombe W & Wong W (1998) *Building State and Local Government Analytic Capacity: Using Regional Economic Models for Analysis of Public Policy.* State and Local Government Review 30(3): 165–180.

Duray R & Milligan GW (1999) *Improving Customer Satisfaction Through Mass Customization*. Quality Progress, 32(8): 60-66.

Dynan K & Sheiner L (2018) *GDP as a Measure of Economic Well-being*. Hutchins Center on Fiscal & Monetary Policy at Brookings. <> (accessed 28/05/2020).

Eddington R (2006) *The Eddington Transport Study*. See

<http://webarchive.nationalarchives.gov.uk/20090115123503/http://www.dft.gov.uk/162259/187604/206711/executivesummary.pdf> (accessed 31/05/2018).

Ekvall T. & Finnveden G (2001) *Allocation in ISO 14041 - a critical review*. Journal of Cleaner Production 9(3): 197–208.

Escamilla EZ, Habert G, Daza JFC, Archilla HF, Fernández JSE & Trujillo D (2018) *Industrial or traditional bamboo construction? Comparative life cycle assessment (LCA) of bamboo-based buildings*. Sustainability 10(9).

Enoch M (2012) *Sustainable transport, mobility management and travel plans.* Surrey, England: Ashgate Publishing Limited.

ESPON project (2007) *MUAs and FUAs delineation.* European Spatial Planning Observation Network.

European Commission (2014) *Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020*. Publications Office of the European Union.

European Commission - DG Mobility and Transport (2014) *Update of the Handbook on External Costs of Transport*. Ricardo - AEA/R/ ED57769, Issue Number 1.

European Environment Agency (2006) *CO2 emissions from passenger transport*. See <https://www.eea.europa.eu/media/infographics/co2-emissions-from-passenger-transport/view> (accessed 31/05/2018).

Ewing R, Bartholomew K, Winkelman S, Walters J & Anderson G (2008) *Urban development and climate change*. Journal of Urbanism 1(3): 201–216..

Ferraro KF & LaGrange LR (1992) *Are Older People Most Afraid of Crime? Reconsidering Age Differences in Fear of Victimization.* Journal of Gerontology 47(5): S233–44.

Field A (2009) *Discovering Statistics Using SPSS* (3rd edition). Thousand Oaks, CA: SAGE Publications.

Finkbeiner M., Inaba A, Tan RBH, Christiansen K & Klüppel H-J (2006) *The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044*. The International Journal of Life Cycle Assessment, 48(2): 80–85.

Finkbeiner M, Wiedemann M & Saur K (1998) *Life-Cycle-Assessment (ISO 14040) in* *the Context of Environmental Management Systems (ISO 14001).* SAE Technical Paper Series 980474- Design and Manufacture for the Environment.

Flynn KM & Traver RG (2011) *Methodology for the evaluation and comparison of benefits and impacts of green infrastructure practices using a life cycle approach*. ASCE: 1663–1672.

Flyvbjerg B (2007) *Policy and planning for large-infrastructure projects: Problems, causes, cures*. Environment and Planning B: Planning and Design 34(4): 578–597.

Food and Agriculture Organization of the United Nations (2018) *FAOLEX Database*. See < http://www.fao.org/faolex/en/> (accessed 05/03/2018).

Frantzeskakis J. & Giannopoulos AG (2005) *Transport design and traffic engineering* (3rd edition). Thessaloniki, Greece: Epikentro.

Freeman E, Martin K & Parmar B (2007) *Stakeholder capitalism*. Journal of Business Ethics 74 (4): 303-314.

Freudenthal H (1983) *Didactical Phenomenology of Mathematical Structures*, Reidel, Dordrecht.

Friedman M (1970) *The social responsibility of business to increase its profi*ts. The New York Times Magazine. <http://umich.edu/~thecore/doc/Friedman.pdf> (accessed 15/06/2019).

Frischmann BM (2012) *Infrastructure: The Social Value of Shared Resources.* New York: Oxford University Press.

George G & Bock AJ (2011) *The business model in practice and its implications for entrepreneurship research*. Entrepreneurship Theory and Practice 35(1): 83-111.

Ghauri PN & Grønhaug K (2010) *Research Methods in Business Studies* (4th edition). London: Prentice Hall.

Giannopoulos AG (2002) *Forecast of Demand of Transportation in Transportation Design*. Thessaloniki: Paratiritis.

Giddens A (1987) *Social Theory and Modern Sociology*. Cambridge: Polity Press: 20-21.

Gilmore JG & Pine JB II (1997) *The Four Faces of Mass Customization*. Harvard Business Review 75(1): 91-101.

Gkargkavouzi A, Paraskevopoulos S & Matsiori S (2018) *Who cares about the environment?* Journal of Human Behavior in the Social Environment 28(6): 746–757.

Gómez-Baggethun E & Ruiz-Pérez M (2011) *Economic valuation and the commodification of ecosystem services*. Progress in Physical Geography: Earth and Environment 35(5): 613-628.

Gómez Ortega A, Delgado Jalón ML & Rivero Menéndez JÁ (2014) *A strategic analysis of collective urban transport in Spain using the Five Forces Model*. Investigaciones Europeas de Dirección y Economía de la Empresa 20(1): 5–15.

Gompers P, Ishii J & Metrick A (2003) *Corporate governance and equity prices*. The Quarterly Journal of Economics 118(1): 107-155.

Grant A & Ries R (2013) *Impact of building service life models on life cycle assessment*. Building Research and Information 41(2): 168–186.

Grimsey D & Lewis MK (2002) *Evaluating the risks of public private partnerships for infrastructure projects.* International Journal of Project Management 20(2): 107–118.

Gullone E (2000) *The development of normal fear: a century of research*. Clinical Psychology Review 20: 429-451.

Gutowski TG (2018) *A Critique of Life Cycle Assessment; Where Are the People?* Procedia CIRP 69:11–15.

Hagerty MR (1999) *Testing Maslow's hierarchy of needs: national quality-of-life across time.* Social Indicators Research 46(3): 249-271.

Hall GS (1897) *A study of fears*. American Journal of Psychology 8: 147–249.

Hall JW, Tran M, Hickford AJ & Nicholls RJ (2016) *The future of national infrastructure: A System-of-Systems Approach*. Cambridge University Press.

Hardin G (1968) *The Tragedy of the Commons*. Science 162: 1243-1248.

Harrigan WJ & Commons ML (2015) *Replacing Maslow's needs hierarchy with an account based on stage and value*. Behavioral Development Bulletin 20(1): 24-31.

Harrington C & Estes CL (2004) *Health Policy: Crisis and Reform in the U.S. Health Care Delivery System* (4th edition). MA: Jones & Bartlett Publishers.

Hay A (2016) *After the flood: Exploring operational resilience*. Victoria, British Columbia: Friesen Press.

Hayashi Y & Morisugi H (2000) *International comparison of background concept and methodology of transportation project appraisal*. Transport Policy 7(1): 73-88.

Heaton J (2000) *Secondary data analysis of qualitative data: A review of the literature*. Social Policy Research Unit (SPRU), University of York, York.

Henry BC (2013) *The Philosophy of Meaning and Value.* ARPN Journal of Science and Tecnology 3(6): 6.

Herling RW Weinberger L & Harris L (2000) *Case study research: Defined for application in the field of HRD.* St. Paul: University in Minnesota, Human Resource Development Research Center.

Hickford AJ, Nicholls RJ, Otto A, Hall JW, Blainey SP, Tran M & Baruah P (2015) *Creating an ensemble of future strategies for national infrastructure provision*. Futures 66: 13-24.

Hill MR (1993) *Archival Strategies and techniques* (Qualitative research methods series 31). Sage.

Hillar SP (2012) *Mind mapping with FreeMind*. Birmingham Eng.: Packt Publishing

Hirschman AO (1958) *The Strategy of Economic Development.* Yale University Press, New Haven, Conn.

Hodková J, Lupíšek A, Mančík VL & Žd'Ára T (2012) *National platform for LCA data on building elements in the context of the Czech Republic*. International Journal of Sustainable Building Technology and Urban Development 3(4): 277–284.

Hoffman K & Kunze R (1971) *Linear Algebra* (2nd edition). Englewood Cliffs, New York: Prentice-Hall.

Holgate, STT (2017) *Every Breath We Take: The Lifelong Impact of Air Pollution' - A Call for Action*. Clinical Medicine, Journal of the Royal College of Physicians of London 1: 8-12.

Hong WK, Park SC, Kim JM, Kim SIl, Lee, SG, Yune DY, Yoon TH & Boong YR

(2010) *Development of structural composite hybrid systems and their application with regard to the reduction of co2 emissions*. Indoor and Built Environment 19(1): 151–162.

Hoogmartens R, Passel S, Van Acker K & Dubois M (2014) *Bridging the gap between LCA, LCC and CBA as sustainability assessment tools.* Environmental Impact Assessment Review 48: 27–33.

Huang PCC & Gao Y (2015) *Should Social Science and Jurisprudence Imitate Natural Science?* Modern China 41(2): 131– 167.

Hudson LA & Ozanne JL (1988) *Alternative Ways of Seeking Knowledge in Consumer Research.* Journal of Consumer Research 14(4): 508-521.

IBM (2018) *IBM SPSS software*. See < https://www.ibm.com/analytics/spss-statistics-software> (accessed 8/11/2018).

iBUILD (2017) *Infrastructure BUsiness models, valuation and Innovation for Local Delivery.* See <https://research.ncl.ac.uk/ibuild/> (accessed 21/11/2017).

Ingerson M, Donaldson T, Harris J, Keevil A, Phillips R, Agle B, Godfrey PC, Harrison JS & Mitchell R (2015) *Normative Stakeholder Capitalism: Getting from Here to There*. Business & Professional Ethics Journal 34(3): 377-406.

ISO (1997) *ISO 14040:1997 Environmental management — Life cycle assessment — Principles and framework (Vol. 1)*. Geneve.

Jessen K (1984) *The Infrastructure and the Civil Engineer*. Journal of Professional Issues in Engineering Education and Practice 110(4): 151–156.

Jones H, Moura F & Domingos T (2017) *Life cycle assessment of high-speed rail: a case study in Portugal.* International Journal of Life Cycle Assessment 22: 410–22.

Jun WK, Lee M-K & Choi JY (2018*) Impact of the smart port industry on the Korean national economy using input-output analysis*. Transportation Research Part A 118: 480-493.

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2018a) *Defining the Social Value of Transport Infrastructure*. Proceedings of the Institution of Civil Engineers journal Infrastructure Asset Management, Issue: Themed issue on

Understanding the value of infrastructure systems (DOI: 10.1680/jinam.18.00005).

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2018b) *Infrastructure Management: Development of a Business Model for Transport Infrastructure Interdependencies Management.* RELAND: International Journal of Real Estate & Land Planning 1: 234-252.

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2018c) *The Environmental Value of Sustainable Transport Infrastructure*. RELAND: International Journal of Real Estate & Land Planning 1: 42-57.

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2017a) *Transport infrastructure interdependencies with energy, water, waste and communication infrastructure in the United Kingdom*. 64th Annual North American Meetings of the Regional Science Association International, 8–11 November, Vancouver, Canada: 96.

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2017b) *Next Generation Infrastructure Interdependencies: An economic deterministic model of transport interdependencies in the United Kingdom*. International Symposium for Next Generation Infrastructure, 11–13 September, London, United Kingdom: 210-218.

Kalyviotis N, Rogers CDF, Tight MR, Hewings GJD & Doloi H (2017c) *The individual as the key-stakeholder of Next Generation Infrastructure projects: Defining the social value of transport infrastructure in the United Kingdom*. International Symposium for Next Generation Infrastructure, 11–13 September, London, United Kingdom: 219-227.

Kalyviotis N (2015) *Project Control Body of Strategic Knowledge for Complex Construction Projects*. Eighth International Conference on Construction in the 21st Century (CITC-8) "Changing the Field: Recent Developments for the Future of Engineering and Construction", May 27-30, 2015, Thessaloniki, Greece: 31-38.

Kalyviotis N (2013) *Risk Management in Major Construction Joint Venture Projects.* Umeå School of Businesss, Umeå, Sweden.

Kalyviotis N, Kitsios D & Naniopoulos A (2010) *Construction contracts, project delivery methods and roles of the project stakeholders. The case of Khalifa port project in Abu Dhabi*. PM-05 - Advancing Project Management for the 21st Century "Concepts, Tools & Techniques for Managing Successful Projects" 29-31 May, Heraklion, Crete, Greece: 312-319.

Kambil A, Ginsberg A & Bloch M (1996) *Re-inventing value propositions*. Working Paper. New York: Leonard N. Stern School of Business.

Kang G, Kim T, Kim YW, ChoH & Kang KI (2015) *Statistical analysis of embodied carbon emission for building construction*. Energy and Buildings 105: 326–333.

Kessides C (1993) *The contributions of infrastructure to economic development: a review of experience and policy implications.* World Bank Discussion Papers 213.

Khatri N & Tyagi S (2014) *Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas*. Frontiers in Life Science 8(1): 1-17.

Kikuchi Y, Kanematsu Y, Sato R & Nakagaki T (2016) *Distributed Cogeneration of Power and Heat within an Energy Management Strategy for Mitigating Fossil Fuel Consumption.* Journal of Industrial Ecology 20(2): 289-303.

Kim J (2015) Cities Today Need to Up Their Game, Starting with Innovatively Financing Their Infrastructure. Stanford Global Projects Center, Stanford University.

Kjaer LL, Host-Madsen NK, Schmidt JH & McAloone TC (2015) *Application of environmental input-output analysis for corporate and product environmental footprints-learnings from three cases.* Sustainability 7(9): 11438–11461.

Korytárová J & Vaňková L (2017) *Analysis of extreme values of the economic efficiency indicators of transport infrastructure projects.* IOP Conference Series: Materials Science and Engineering 251(1).

Koutitas CG (1994) *Introduction to Coastal Engineering and Port Projects*. Thessaloniki, Greece: Zitis.

Lagaros ND (2018) *The environmental and economic impact of structural optimization*. Structural and Multidisciplinary Optimization 58(4): 1751–1768.

Lakshmanan TR (1989) *Infrastructure and Economic Transformation* in A. Andersson, D.F. Batten, B. Johansson, and P. Nijkamp (eds). Advances in Spatial Theory, Amsterdam: North-Holland: 241-261.

Landrigan, PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, Baldé, AB, Bertollini R, Bose-O'Reilly S, Boufford JI, Breysse PN, Chiles T, Mahidol C, Coll-Seck A, Cropper ML, Fobil J, Fuster V, Greenstone M, Haines A, Hanrahan D, Hunter D, Khare M, Krupnick A, Lanphear B, Lohani B, Martin K, Mathiasen KV, Mcteer MA, Murray CJL, Ndahimananjara JD, Perera F, Potočnik J, Preker AS, Ramesh J, Rockström J, Salinas C, Samson LD, Sandilya Karti, Sly PD, Smith KR, Steiner A, Stewart RB, Suk WA, van Schayck OCP, Yadama GN, Yumkella K, & Zhong M. (2018) *The Lancet Commission on pollution and health*. The Lancet 391(10119): 462–512.

Landrum NE (2018) *Stages of Corporate Sustainability: Integrating the Strong Sustainability Worldview.* Organization & Environment 31(4): 287-313.

Langston C, Chan EHW & Yung EHK (2018) *Hybrid input-output analysis of embodied carbon and construction cost differences between new-build and refurbished projects*. Sustainability 10(9).

Laou E (2013*) GHG emissions from road transport in Cyprus by 2030*. Student Thesis, Cyprus University of Technology.

Lawer ET (2019) *Examining stakeholder participation and conflicts associated with large scale infrastructure projects: the case of Tema port expansion project, Ghana*, Maritime Policy & Management. Routledge 46(6): 735–756.

Le ABD, Whyte A, & Biswas WK (2019) *Carbon footprint and embodied energy assessment of roof-covering materials.* Clean Technologies and Environmental Policy 21(10): 1913–1923.

Le HQ & Hsiung BCB (2014) *A novel mobile information system for risk management of adjacent buildings in urban underground construction*. Geotechnical Engineering 45(3): 52–63.

Lederman J & Wachs M (2014) *Habitat conservation plans*. Transportation Research Record 2403: 9–16.

Lee K-M & Inaba A (2004) *Life Cycle Assessment - Best Practices of ISO 14040 Series*. (APEC) Asia-Pacific Economic Cooperation: 1–4.

Lemma MS, Gervásio H, Pedro JO, Rigueiro C & da Silva LS (2020). *Enhancement of the life-cycle performance of bridges using high-strength steel*. Structure and Infrastructure Engineering 16(4): 772–786.

Levasseur M, Généreux M, Bruneau J-F, Vanasse A, Chabot É, Beaulac C & Bédard M-M (20015) *Importance of proximity to resources, social support, transportation and neighborhood security for mobility and social participation in older adults: results from a scoping study*. BMC Public Health 15:503.

Linder JC (2004) *Outsourcing for Radical Change: A Bold Approach to Enterprise Transformation.* New York: AMACOM.

Liveable Cities (2015) *PhD Studentships in Sustainability and Resilience Infrastructures for the Future*. See < http://liveablecities.org.uk/updates/phd-studentships-sustainability-and-resilience-infrastructures-future> (accessed 3/8/2015).

Liveable Cities (2017) *Transforming the Engineering of Cities for Global and Societal Wellbeing.* See <http://liveablecities.org.uk/> (accessed 21/11/2017).

Lolli N, Fufa SM, & Kjendseth WM (2019) *An assessment of greenhouse gas emissions from CLT and glulam in two residential nearly zero energy buildings*. Wood Material Science and Engineering 14(5): 342–354.

Long R, White MC, Friedman WH & Brazeal DV (2000) *The 'Qualitative' versus 'Quantitative' research rebate: a question of metaphorical assumptions?* International Journal of Value-Based Management 13: 189–197.

Luce RD & Raiffa H (1957) *Games and Decisions.* New York: John Wiley and Sons.

Lyubimov A (2015) *Critical realism theory*. See <http://istheory.byu.edu/wiki/Critical_realism_theory> (accessed: 03/08/2015).

Ma H, Zhang Z, Zhao X & Wu S (2019) *A comparative life cycle assessment (LCA) of warm mix asphalt (WMA) and hot mix asphalt (HMA) pavement: A case study in China*. Advances in Civil Engineering 12.

Magretta J (2002a) *What Management Is: How it works and why it's everyone's* *business.* New York: The Free Press.

Magretta J (2002b) *Why Business Models Matter*. Harvard Business Review 80(5): 3-8.

Malterud K (2001) *Qualitative research: standards, challenges, and guidelines*. The Lancet 358(9280): 483 – 488.

Manda BMK, Bosch H & Worrell E (2015) *Sustainable Value Creation with Life Cycle Management*. In Sonnemann G & Margni M (ed.) *Life Cycle Management*. Springer: Dordrecht, The Netherlands: 129–146.

Marcus M & Minc H (1988) *Introduction to Linear Algebra*. New York: Dover.

Markides C & Geroski P (2005) *Fast Second*: *How Smart Companies Bypass Radical Innovation to Enter and Dominate New Markets*. San Francisco: Jossy-Bass.

Martini CA & Lee DQ (1996) *Difficulties in Infrastructure Financing.* Journal of Applied Scienceand Investment 1(1): 24-27.

Maslow A (1954) *Motivation and personality.* New York, NY: Harper.

May T (2011) *Social Research; Issues, Methods and Process*. 4th edition. Maidenhead: Open University Press, McGraw Hill.

McCann D & Berry C (2017) *Shareholder capitalism A system in crisis*. <https://neweconomics.org/uploads/files/NEF_SHAREHOLDER-CAPITALISM_E_latest. pdf > (accessed 03/08/2019).

McKibbin W & Henckel T (2017) *The economics of infrastructure in a globalized world: Issues, lessons and future challenges*. Journal of Infrastructure, Policy and Development 1 (2): 254-271.

McKenzie RB & Lee DR (2006) *Microeconomics for MBAs: The Economic Way of Thinking for Managers.* Cambridge University Press.

Meadows DH, Meadows DL, Randers J & Behrens WWIII (1972) *The Limits to Growth.* Universe Books. (Club of Rome)

Meil J, Lucuik M, O'Connor J & Dangerfield J (2006) *A life cycle environmental and economic assessment of optimum value engineering in houses*. Forest Products Journal 56(9): 19–25.

Menéndez (1991) *Access to Basic Infrastructure by the Urban Poor.* Washington

D.C.: The World Bank.

Merciai S & Schmidt J (2017) *Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database*. Journal of Industrial Ecology 22(3): 516–531.

Mill JS (1848) *Principles of Political Economy.* London; Longmans, Green and Co.

Miller D, Hope Q, Eisenstat R, Foote N & Galbraith J (2002) *The problem of solutions: Balancing clients and capabilities.* Business Horizons, 45(2), 3-12.

Mokhtarian PL (2002) *Telecommunications and travel: The case for complementarity*. Journal of Industrial Ecology 6(2): 43–57.

Moll DM, McElroy RH, Sabogal R, Corrales LF & Gelting RJ (2007) *Health impact of water and sanitation infrastructure reconstruction programmes in eight Central American communities affected by Hurricane Mitch.* Journal of Water and Health, 5(1): 51–65.

Monteiro A & Poças Martins J (2013) *A survey on modeling guidelines for quantity takeoff-oriented BIM-based design*. Automation in Construction 35: 238–253.

Mooney JE, Ismail HS & Shahidipour SMM (2000) *Mass Customisation: A Methodology and Support Tools for Low Risk Porter Implementation in Small and Medium Enterprises*. 7th ISPE International conference on concurrent engineering: Research and applications, July 17 –20, Lyon Claude Bernard University, France.

Morgan G & Smircich L (1980) *The Case for Qualitative Research.* Academy of Management Review 5(4): 491-500.

Mouter N (2014) *Cost-Benefit Analysis in Practice: A study of the way Cost-Benefit Analysis isperceived by key individuals in the Dutch CBA practice for spatial-infrastructure projects*. TRAIL Thesis Series T2014/2, the Netherlands TRAIL Research School.

Myers MD (2009) *Qualitative Research in Business & Management*. Trowbridge, Wilshire: The Cromwell Press Ltd.

Myers R (1990) *Classical and modern regression with applications* (2nd edition). Boston, MA: Duxbury.

National Infrastructure Plan (2013) *National Infrastructure Plan 2013* <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263159/national_infrastructure_plan_2013.pdf> (accessed 01/12/2015).

National Rail (2009) *Comparing environmental impact of conventional and high speed rail.* Network Rail UK <http://www.networkrail.co.uk/aspx/5892.aspx> (accessed 12/07/2019).

National Science Foundation (2017) *Critical Resilient Interdependent Infrastructure Systems and Processes 2.0 FY18 (CRISP 2.0).* Alexandria, Virginia, USA.

Nikolaidis AF (2000) *Airport Planning and Construction*. Thessaloniki, Greece

Niu Y & Fink G (2019) *Life Cycle Assessment on modern timber bridges*. Wood Material Science and Engineering 14(4): 212–225.

Nussbaum M (1988) *Nature, Functioning and Capability: Aristotle on Political Distribution.* Oxford Studies in Ancient Philosophy (Supplementary Volume) 6: 145-84.

Nussbaum M (2004*) Promoting women's capabilities* in: Benería L & Bisnath S (eds.) Global tensions: challenges and opportunities in the world economy. New York: Routledge: 200-214.

Office for National Statistics (2015). *Guide to Gross Value Added (GVA).* See <http://www.ons.gov.uk/> (accessed 21/11/2017).

Office of Rail and Road (2017). *Rail regulation.* See < http://orr.gov.uk/rail> (accessed 21/11/2017).

Olson M (2010) *Document analysis.* In A. Mills, G. Durepos, & E. Wiebe (Eds.), Encyclopedia of case study research. Thousand Oaks, CA: SAGE Publications: 319-321.

Olugbenga O, Kalyviotis N & Saxe S (2019a) *Embodied emissions in rail infrastructure: a critical literature review*, Environmental Research Letters 14(12): 123002.

Olugbenga O, Kalyviotis N & Saxe S (2019b) *Embodied Emissions in Rail Infrastructure: A Literature Review*, Transportation Research Board 98th Annual Meeting Transportation Research Board 19-06088: 01698381.

Orlikowski WJ & Baroudi JJ (1991) *Studying Information Technology in Organizations: Research Approaches and Assumptions*, Information Systems Research (2): 1-28.

Osterwalder A (2004) *The Business Model Ontology - A Proposition In A Design Science* Approach. Ph.D. Thesis, Ecole des Hautes Etudes Commerciales de l'Université de Lausanne.

Oughton EJ, Usher W, Tyler P & Hall JW (2018) *Infrastructure as a Complex Adaptive System.* Complexity 2018: 3427826.

Park SC, Hong WK & Kim JT (2014) *Application of Smart Frames to tall buildings with dual systems and with building frame systems.* Indoor and Built Environment 23(1): 161–170.

Payne A & Frow P (2014) *Developing superior value propositions: A strategic marketing imperative*. Journal of Service Management 25(2): 213-227.

Pearlstein S (2014) *When shareholder capitalism came to town*. The American Prospect 25, 40.

Pepper D & Rogers M (2004) *Managing Customer Relationships: A Strategic Framework.* New Jersey: John Wiley & Sons Inc.

Perkins J & Suh S (2019) *Uncertainty Implications of Hybrid Approach in LCA: Precision versus Accuracy*. Environmental Science and Technology 53(7): 3681–3688.

Pine JB II (1993) *Mass Customization: The New Frontier in Business Competition. Boston*. Massachusetts: Harvard Business School Press

Ploszaj A, Celińska-Janowicz D, Rok J & Zawalinska K (2015*) Regional Input-Output Studies: A Systematic Literature Review*. 18th Annual Conference on Global Economic Analysis "Information for the Policy Maker: Practical Economic Modelling for Tomorrow", Melbourne, Australia.

Pollock JL & Cruz J (1999) *Contemporary Theories of Knowledge* (2nd edition). Rowman-Littlefield.

Porter ME (1985) *The Competitive Advantage: Creating and Sustaining Superior Performance*. NY: Free Press.

Poudelet V, Chayer JA, Margni M, Pellerin R & Samson R (2012) *A process-based approach to operationalize life cycle assessment through the development of an eco-design decision-support system*. Journal of Cleaner Production 33: 192–201.

Prud'homme R (2005) *Infrastructure and Development* in Bourguignon F & Pleskovic B (eds) *Lessons of Experience, Proceedings of the 2004 Annual Bank conference on Development Economics*. Washington: The World Bank and Oxford University Press: 153-181.

Puskas A & Moga LM (2015) *Sustainability of reinforced concrete frame structures - A case study*. International Journal of Sustainable Development and Planning, 10(2): 165–176.

Ragnarsdóttir KV, Sverdrup HU & Koca D (2012) *Assessing Long Term Sustainability of Global Supply of Natural Resources and Materials*. In book: Sustainable Development - Energy, Engineering and Technologies - Manufacturing and Environment Edited by Chaouki Ghenai IntechOpen

Rebitzer G, Ekvall T, Frischknecht R., Hunkeler D, Norris G, Rydberg T, Schmidt W-P, Suh S, Weidema BP & Pennington DW (2004) *Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications*. Environment International 30(5): 701–720.

Rempelos G, Preston J & Blainey S (2020) *A carbon footprint analysis of railway sleepers in the United Kingdom*. Transportation Research Part D: Transport and Environment 81: 102285.

Reser J P & Bentrupperbäumer JM (2005) *What and where are environmental values? Assessing the impacts of current diversity of use of "environmental" and "World Heritage" values.* Journal of Environmental Psychology 25(2): 125–146.

Riffat S, Powell R & Aydin D (2016) *Future cities and environmental sustainability*. Future Cities and Environment 2(1): 1-23.

Robati M, Daly D & Kokogiannakis G (2019) *A method of uncertainty analysis for whole-life embodied carbon emissions (CO 2 -e) of building materials of a net-zero energy building in Australia*. Journal of Cleaner Production, 225: 541–553.

Robertson AB, Lam FCF & Cole R J (2012) *A comparative cradle-to-gate life cycle* *assessment of mid-rise office building construction alternatives: Laminated timber or reinforced concrete*. Buildings 2(3): 245–270.

Robson C (2002) *Real World Research* (2nd Edition). Oxford: Blackwell.

Rodrigue J-P (2017) *The Geography of Transport Systems* (4th Edition). New York: Routledge.

Rodríguez-Pose A (2015). *Government quality and the economic returns of transport infrastructure investment in European regions.* Papers in Evolutionary Economic Geography (PEEG) 1535.

Rogers CDF (2018a) *Engineering future liveable, resilient, sustainable cities using foresight*. Proceedings of the Institution of Civil Engineers journal Civil Engineering 171(6): 3-9 (DOI: 10.1680/jcien.17.00031).

Rose A (2005) *Tracing Infrastructure Interdependence through Economic Interdependence*. Center for Advanced Engineering, Workshop on Interdependent Infrastructure, Christchurch, New Zealand.

Roser T, Defillippi R & Samson A (2013) *Managing your co-creation mix: co-creation ventures in distinctive contexts*. European Business Review 25(1): 20-41.

Ruist E (1990) *Modellbygge för empirisk analys: att se vad som sker i det som synes ske (Model building for Empirical Analysis: To See What Is Happening in What Appears to Be Happening).* Lund: Studentlitteratur.

Saad D & Hegazy T (2015) *Enhanced benefit–cost analysis for infrastructure fund allocation*. Canadian Journal of Civil Engineering 42(2): 89-97.

Said H & El-Rayes K (2014) *Automated multi-objective construction logistics optimization system*. Automation in Construction 43: 110–122.

Said IM & Al-Qadi IL (2019) *Iterative Framework for Performance and Environmental Impacts of Airfields.* Transportation Research Record 2673(9): 179–187.

Sandberg J & Alvesson M (2011) *Ways of constructing research questions: gap-spotting or problematization?* Organization 18(1): 23–44.

Sanjuan-Delmás D, Hernando-Canovas E, Pujadas P, de la Fuente A, Gabarrell X, Rieradevall, J & Josa A (2015) *Environmental and geometric optimisation of* *cylindrical drinking water storage tanks*. International Journal of Life Cycle Assessment 20(12): 1612–1624.

Sariatli F (2017) *Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability.* Visegrad Journal on Bioeconomy and Sustainable Development 6(1): 31–34.

Saunders M, Lewis P & Thornhill (2009) *A Research methods for business students* (5th edition). London: Pearson Education Limited.

Sausen R, Isaksen I, Grewe V, Hauglustaine D, Lee Ds, Myhre G, Kohler Mo, Pitari G, Schumann U, Stordal F & Zerefos C (2005) *Aviation radiative forcing in 2000: An update on IPCC (1999)*. Meteorologische Zeitschrift 14(4): 555–561.

Saxe S, Guven G, Pereira L, Arrigoni A, Opher T, Roy A, Arceo A, Sampedro S, Duhamel M, McCabe B, Panesa DK, MacLean H & Posen ID (2020). *Taxonomy of uncertainty in environmental life cycle assessment of infrastructure projects*. Environmental Research Letters 15(8): 083003.

Saylor Academy (2012) *Risk Management for Enterprises and Individuals* (v1.0). See < https://saylordotorg.github.io/text_risk-management-for-enterprises-and-individuals/index.html> (accessed 23/05/2018)

Schumacher EF (1973) *Small Is Beautiful: A Study of Economics As If People Mattered*. Blond & Briggs.

Schwab K (2019). *Davos manifesto 2020: The universal purpose of a company in the fourth industrial revolution.* Cologny, Switzerland: <https://www.weforum.org/agenda/2019/12/davos-manifesto-2020-the-universal-purpos e-of-a-company-in-the-fourth-industrial-revolution/> (accessed 03/01/2021)

Selvanathan EA & Selvanathan S (1994) *The demand for transport and communication in the United Kingdom and Australia*. Transportation Research Part B: Methodological 28(1): 1-9.

Sen A (1993) *Capability and Well-being* in: Nussbaum M and Sen A (eds.) The Quality of Life. Oxford: Clarendon Press: 30–53.

Shafiq N, Nurrudin MF, Gardezi SSS & Kamaruzzaman AB (2015). *Carbon footprint* *assessment of a typical low rise office building in Malaysia using building information modelling (BIM).* International Journal of Sustainable Building Technology and Urban Development 6(3): 157–172.

Shiklomanov I A (2000*) Appraisal and Assessment of World Water Resources.* Water International 25(1): 11-32.

Silverman D (2011) *Interpreting Qualitative Data* (4th Edition). London UK: SAGE Publications Ltd.

Smith A (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations.* The Glasgow Edition. New York: Oxford University Press.

Simonen K (2015) *Testing Whole Building LCA: Research and Practice*. <https://www.acsa-arch.org/proceedings/Intersections Proceedings/ACSA.AIA.Inter.15%0A/ACSA.AIA.Inter.15.6.pdf%0A> (accessed 23/12/2020)

Stadler K, Wood R, Bulavskaya T, Södersten CJ, Simas M, Schmidt S, Usubiaga A, Acosta-Fernández J, Kuenen J, Bruckner M, Giljum S, Lutter S, Merciai S, Schmidt J-H, Theurl M-C, Plutzar C, Kastner T, Eisenmenger N, Erb K-H, de Koning A, & Tukker A (2018) *EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables: EXIOBASE 3*. Journal of Industrial Ecology: 1-14.

Stahel W (2012) *The business angle of a circular economy –higher competitiveness, higher resource security and material efficiency*. Geneva.

Stahel WR & MacArthur DE (2019) *The circular economy A user's guide*. New York City: Routledge.

Steinmueller WE (1996) *Technological Infrastructure in Information Technology Industries.* Technological Infrastructure Policy, Volume 7 of the series Economics of Science, Technology and Innovation: 117-139.

Stephan A & Crawford RH (2014) *A comprehensive life cycle water analysis framework for residential buildings*. Building Research & Information 42(6): 685–695.

Sturgis S (2019) *Targeting Zero: Whole Life and Embodied Carbon Strategies for*

Design Professionals. Riba publishing.

Subcommittee on Health and Environment of the Committee on Interstate Commerce, U.S. House of Representatives (1976) *A discursive dictionary of health care.* Washington D: U.S. Government Printing Office.

Suh S & Nakamura S (2007) *Five years in the area of input-output and hybrid LCA.* International Journal of Life Cycle Assessment 12(6): 351–352.

Summers JK, Smith LM, Case JL & Linthurst RA (2012) *A review of the elements of human well-being with an emphasis on the contribution of ecosystem services.* Ambio 41: 327–340.

Sussman J, Dodder R, McConnell J, Mostashari A & Sgouridis S (2009) *The CLIOS Process: A User's Guide.* Massachusetts Institute of Technology, Cambridge, MA, USA

Szmigielski S (1996) *Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation*. Science of the Total Environment, 180(1): 9-17.

Tapio P, Banister D, Luukkanen J Vehmas J & Willamo R (2007) *Energy and transport in comparison: Immaterialisation, dematerialisation and decarbonisation in the EU15 between 1970 and 2000*. Energy Policy 35(1): 433-451.

Tecchio P, Gregory J, Ghattas R & Kirchain R (2019) *Structured Under-Specification of Life Cycle Impact Assessment Data for Building Assemblies*. Journal of Industrial Ecology, 23(2): 319–334.

Tecchio P, Gregory J, Olivetti E, Ghattas R & Kirchain R (2019) *Streamlining the Life Cycle Assessment of Buildings by Structured Under-Specification and Probabilistic Triage*. Journal of Industrial Ecology 23(1): 268–279.

The Public Policy Cycle Web Site (2001) *Defining Public Policy*. See <http://profwork.org/pp/study/define.html> (accessed 31/05/2018).

Thiebault V, Du G & Karoumi R (2013) *Design of railway bridges considering LCA.* Journal of ICE Bridge Engineering 166(4): 240–251.

Thorpe D (2019) *One Planet' Cities: Sustaining Humanity within Planetary Limits*.

Routledge.

Timmer MP, Dietzenbacher E, Los B, Stehrer R & de Vries G J (2015) *An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production*, Review of International Economics 23: 575–605.

Timmer MP, Los B, Stehrer R & de Vries G J (2016) *An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release*, GGDC research memorandum number 162, University of Groningen.

Tjandraatmadja GF, Burn S, McLaughlin M & Biswas T (2005) *Rethinking urban water systems – revisiting concepts in urban wastewater collection and treatment to ensure infrastructure sustainability*. Water Science & Technology: Water Supply 5(2):145-154.

Tran M, Byers EA, Blainey SP, Baruah P, Chaudry M, Qadrdan M & Eyre NJ (2016) *Quantifying interdependencies: the energy–transport and water–energy nexus.* The Future of National Infrastructure: 227-240 (Book referred before separately). Cambridge University Press

Trunzo G, Moretti L, & D'Andrea A (2019) *Life cycle analysis of road construction and use*. Sustainability 11(377): 1–13.

Tukker A, Giljum S & Wood R (2018) *Recent Progress in Assessment of Resource Efficiency and Environmental Impacts Embodied in Trade: An Introduction to this Special Issue*. Journal of Industrial Ecology 22(3) :489–501.

Turley R, Saith R, Bhan N, Rehfuess E & Carter B (2013) *Slum upgrading strategies involving physical environment and infrastructure interventions and their effects on health and socioeconomic outcomes*. Cochrane Public Health Group, Cochrane Database of Systematic Reviews, 1(1).

Tversky A & Kahneman D (1991) *Loss Aversion in Riskless Choice: A Reference-Dependent Model.* Quarterly Journal of Economics, 106(4): 1039-1061.

UK government (2017) *Energy Consumption in the UK: Information for overall energy consumption in the UK with details of the transport, domestic, industry and services sectors*. See < https://www.gov.uk/> (accessed 19/03/2018)

United States Environmental Protection Agency (2016) *Transportation Sector*

Emissions. See <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation> (accessed 31/05/2018).

Vaccaro V & Cohn D (2004) *The Evolution of Business Models and Marketing Strategies in the Music Industry*. International Journal on Media Management 6(1-2): 46-58.

van Roekel R , Walker AN & Graveland C (2017) *Feasibility study on linking ownership information to Exiobase*. <https://www.cbs.nl/en-gb/background/2017/06/feasibility-study-on-linking-ownership-info-to-exiobase> (accessed 15/06/2020)

Van Wee B (2007) *Rail Infrastructure: Challenges for Cost-Benefit Analysis and Other ex ante evaluations*. Transportation Planning and Technology 30 (1): 31-48.

VisitBritain (2018) *Family friendly Britain*. See <https://www.visitbritainshop.com/world/articles/family-travel-guide/> (accessed 31/05/2018).

Vickerman R (2007) *Cost - benefit analysis and large-scale infrastructure projects: State of the art and challenges*. Environment and Planning B: Planning and Design 34(4): 598–610.

Wainwright SP & Forbes A (2000) *Philosophical problems with social research on health inequalities*. Health Care Analysis 8(3): 259 – 277.

Walker A, Zult D, Hoekstra R, van der Berg M, & Dingena G (n.d.) *Footprint calculations using a Dutch national accounts consistent Exiobase*. <https://www.cbs.nl/en-gb/custom/2017/36/footprint-calculations-using-snac-exiobase> (accessed 22/05/2020).

Wang Y, Pang B, Zhang X, Wang J, Liu Y, Shi C & Zhou S (2020). *Life cycle environmental costs of buildings*. Energies 16(3).

Westin J & Kågeson P (2012) *Can high speed rail offset its embedded emissions?* Transportation Research Part D: Transport and Environment 17(1): 1–7.

Whetten DA (1989) *What constitutes a theoretical contribution?* Academy of Management Review 14(4): 490-495.

Weng L, Boedhihartono AK, Dirks PHGM, Dixon J, Lubis MI & Sayer JA (2013)

Mineral industries, growth corridors and agricultural development in Africa. Global Food Security 2(3): 195–202.

Wilson A (1969) *The Use of Entropy Maximising Models*. Journal of Transport Economics and Policy 3(1): 108-126.

Wikipedia (2018). *Maslow's hierarchy of needs*. See <https://en.wikipedia.org/wiki/Maslow%27s_hierarchy_of_needs/> (accessed 8/11/2018).

Winters PL, Cleland F, Mierzejewski E & Tucker L (2001) *Assessing Level of Service Equally Across Modes.* A report for the Florida Department of Transportation and NCTR: 1-53.

Wong THF (2006) *Water sensitive urban design - the journey thus far*. Australian Journal of Water Resources 10(3): 213-222.

World Input-Output Database (2018) See < http://www.wiod.org/> (accessed 08/02/2018).

Yang Y, Heijungs R, & Brandão M (2017) *Hybrid life cycle assessment (LCA) does not necessarily yield more accurate results than process-based LCA*. Journal of Cleaner Production 150: 237–242.

Yin R (1989) *Case Study Research*. United States: Sage Publications.

Yin RK (2002) *Case study research – design and methods* (3rd edition). SAGE, Newbury Park.

Yin RK (2009) *Case Study Research: Design and Method*s (4th edition). Thousand Oaks, California: Sage Publications.

Zhang X & Wang F (2016) *Assessment of embodied carbon emissions for building construction in China: Comparative case studies using alternative methods*. Energy and Buildings 130: 330–340.

Zhuang J, Liang Z, Lin T & De Guzman FD (2007) *Theory and practice in the choice of social discount rate for cost-benefit analysis: A survey.* ERD Working Paper Series (94): 1–45.

Zingales L (2012) *Capitalism for the people*. Boulder, USA: Basic Books.

Appendix

Appendix A: Principal component analysis factors

Table A1 Component Matrix

Component Matrix[a]

	Component			
	1	2	3	4
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	.984			
Administrative and support service activities	.984			
Computer programming, consultancy and related activities; information service activities	.984			
Accommodation and food service activities	.981			
Architectural and engineering activities; technical testing and analysis	.979			
Telecommunications **(Communication)**	.975			
Legal and accounting activities; activities of head offices; management consultancy activities	.975	-.205		
Public administration and defence; compulsory social security	.967			
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	.966			
Human health and social work activities	.960	-.224		
Advertising and market research	.959			
Education	.958	-.250		
Other professional, scientific and technical activities; veterinary activities	.957			
Other service activities	.956	-.258		
Construction	.955	.206		
Manufacture of furniture; other manufacturing	.954		-.214	
Water collection, treatment and supply **(Water)**	.946	-.200		
Scientific research and development	.932			
Fishing and aquaculture	.925			
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services **(Waste)**	.917		.303	
Postal and courier activities	.914		.282	
Insurance, reinsurance and pension funding, except compulsory social security	.908		-.247	

Manufacture of fabricated metal products, except machinery and equipment	.906	.339		
Real estate activities	.894	-.344	-.210	
Manufacture of paper and paper products	.892			
Financial service activities, except insurance and pension funding	.890		.352	
Activities auxiliary to financial services and insurance activities	.881	-.438		
Manufacture of food products, beverages and tobacco products	.859			-.438
Manufacture of basic pharmaceutical products and pharmaceutical preparations	.820	-.500		
Mining and quarrying	.792		.336	.440
Manufacture of rubber and plastic products	.789	.322	-.346	-.333
Crop and animal production, hunting and related service activities	.784			
Electricity, gas, steam and air conditioning supply **(Energy)**	.768	-.329	-.265	-.221
Manufacture of machinery and equipment n.e.c.	.761	.397	-.301	
Repair and installation of machinery and equipment	.646	.270	-.328	.304
Printing and reproduction of recorded media		.882	.394	
Manufacture of chemicals and chemical products	.239	.867	.266	-.204
Manufacture of other non-metallic mineral products	.351	.849	.293	
Manufacture of electrical equipment	.440	.691	-.341	
Manufacture of basic metals	.420	.683	-.385	.348
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	.594	.679	.383	
Publishing activities	.635	.647	.391	
Manufacture of coke and refined petroleum products	.465	-.644	.466	
Forestry and logging	.294	.381	.834	
Manufacture of textiles, wearing apparel and leather products	.295	.438	-.808	
Manufacture of computer, electronic and optical products	.501		-.684	.256

Extraction Method: Principal Component Analysis.   a. 4 components extracted.

Table A2 Rotated Component Matrix

Rotated Component Matrix[a]

	Component			
	1	2	3	4
Education	.990			
Human health and social work activities	.986			
Legal and accounting activities; activities of head offices; management consultancy activities	.976			
Activities auxiliary to financial services and insurance activities	.974			
Public administration and defence; compulsory social security	.974			
Other service activities	.968		.208	
Computer programming, consultancy and related activities; information service activities	.965			
Administrative and support service activities	.962		.235	
Manufacture of basic pharmaceutical products and pharmaceutical preparations	.949			
Postal and courier activities	.948	.210		
Architectural and engineering activities; technical testing and analysis	.948		.264	
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	.936	.225	.212	
Other professional, scientific and technical activities; veterinary activities	.930		.295	
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services **(Waste)**	.930	.267		
Water collection, treatment and supply **(Water)**	.929		.311	
Financial service activities, except insurance and pension funding	.928	.251		
Real estate activities	.925		.278	
Telecommunications **(Communication)**	.916	.322		
Fishing and aquaculture	.897		.235	
Accommodation and food service activities	.896	.202	.317	.226
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	.893	.312		.216
Advertising and market research	.849	.257	.349	.204
Insurance, reinsurance and pension funding, except compulsory social security	.847		.360	.267

Manufacture of furniture; other manufacturing	.845		.456	
Scientific research and development	.845	.387	.225	
Construction	.828	.495	.233	
Electricity, gas, steam and air conditioning supply **(Energy)**	.805		.202	.300
Manufacture of food products, beverages and tobacco products	.764	.314		.477
Manufacture of paper and paper products	.757	.300	.369	.234
Manufacture of coke and refined petroleum products	.714		-.470	-.337
Mining and quarrying	.706	.449		-.470
Manufacture of fabricated metal products, except machinery and equipment	.691	.394	.566	
Crop and animal production, hunting and related service activities	.662	.224	.366	.219
Manufacture of rubber and plastic products	.580	.297	.535	.496
Printing and reproduction of recorded media		.947		
Manufacture of other non-metallic mineral products		.928	.258	
Manufacture of chemicals and chemical products		.916		
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	.349	.905		
Publishing activities	.399	.889		
Forestry and logging	.227	.811	-.329	-.364
Manufacture of textiles, wearing apparel and leather products			.954	
Manufacture of basic metals		.412	.851	
Manufacture of computer, electronic and optical products	.324		.820	
Manufacture of electrical equipment		.464	.762	
Manufacture of machinery and equipment n.e.c.	.517	.325	.702	
Repair and installation of machinery and equipment	.450		.666	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Table A3 Featured model with Printing and reproduction of recorded media

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	4973.328	28255.160		.176	.864		
	Energy	-.093	1.107	-.012	-.084	.935	.159	6.293
	Waste	-2.566	2.421	-.190	-1.060	.317	.097	10.266
	Communication	-4.051	2.529	-.442	-1.602	.144	.041	24.301
	Water	-14.841	7.606	-.366	-1.951	.083	.089	11.204
	Printing	-3.784	2.808	-.123	-1.347	.211	.376	2.658

a. Dependent Variable: Transport

Table A4 Featured model with mining and quarrying

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	14967.266	29029.375		.516	.619		
	Energy	1.371	1.253	.174	1.094	.302	.138	7.263
	Waste	-1.866	2.443	-.138	-.764	.464	.106	9.414
	Communication	-7.021	1.939	-.766	-3.621	.006	.078	12.860
	Water	-13.973	8.263	-.344	-1.691	.125	.084	11.906
	Mining	.734	.854	.124	.859	.413	.168	5.969

a. Dependent Variable: Transport

Table A5 Featured model with manufacture of textiles, wearing apparel and leather products

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	-28072.640	28439.978		-.987	.349		
	Energy	.114	.820	.014	.139	.893	.204	4.891
	Waste	-4.445	2.252	-.329	-1.974	.080	.079	12.592
	Communication	-5.589	1.515	-.610	-3.689	.005	.081	12.369
	Water	-2.191	6.751	-.054	-.324	.753	.080	12.516
	Manufacturetextiles	-7.961	3.163	-.152	-2.517	.033	.605	1.654

a. Dependent Variable: Transport

Table A6 Featured model with forestry and logging

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	18227.478	28754.995		.634	.542		
	Energy	1.208	1.076	.153	1.122	.291	.180	5.566
	Waste	-1.936	2.389	-.143	-.810	.439	.107	9.360
	Communication	-7.619	2.091	-.832	-3.645	.005	.064	15.543
	Water	-7.526	7.790	-.186	-.966	.359	.091	11.003
	Forestry	46.564	43.918	.102	1.060	.317	.365	2.737

a. Dependent Variable: Transport

Table A7 Featured model with crop and animal production, hunting and related service activities

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	5100.290	28778.923		.177	.863		
	Energy	.336	.996	.043	.337	.744	.202	4.943
	Waste	-2.125	2.368	-.157	-.897	.393	.105	9.537
	Communication	-5.195	2.076	-.567	-2.502	.034	.063	15.897
	Water	-9.208	7.165	-.227	-1.285	.231	.104	9.656
	Cropandanimal	-3.374	2.753	-.117	-1.225	.252	.355	2.818

a. Dependent Variable: Transport

Table A8 PCA factors

Year	Factor 1	Factor 2	Factor 3	Factor 4
2000	1.89519	0.62214	-1.53692	1.06314
2001	1.7509	0.53455	-0.04186	0.21844
2002	1.32761	0.07721	0.61799	-0.48905
2003	0.9125	-0.58656	0.69675	-1.11872
2004	0.24945	-1.13264	0.45255	-1.10992
2005	0.00398	-1.12396	0.50073	-0.84183
2006	-0.21703	-1.10668	-0.19214	0.4976
2007	-0.89818	-1.73713	-0.6789	0.68832
2008	-0.74144	-1.03344	-0.68964	1.15648
2009	-0.68278	0.90452	2.26303	-0.03892
2010	-0.44936	0.80228	0.79911	1.21411
2011	-0.64514	0.80439	0.26034	1.30379
2012	-0.72285	0.8372	0.1312	0.15848
2013	-0.68474	1.18106	-1.00753	-0.86053
2014	-1.09814	0.95707	-1.57473	-1.84141

Table A8 PCA analysis

Component Score Coefficient Matrix

	Component			
	1	2	3	4
Energy	.039	-.052	-.023	.175
Waste	.041	.023	-.033	-.092
Communication	.034	.031	-.033	.044
Water	.033	-.040	.046	-.076
VAR00001	.015	.011	.013	.105
Forestry	.008	.145	-.085	-.167
VAR00003	.031	-.013	.038	-.139
Mining	.015	.036	.068	-.339
VAR00005	.029	.046	-.089	.320
Manufacturetextiles	-.041	-.058	.216	-.027
VAR00007	-.007	.143	-.041	.049
VAR00008	.018	.023	.002	.118
Printing	-.034	.160	-.016	.002
VAR00010	.059	-.026	-.087	-.155
VAR00011	-.028	.156	-.038	.139
VAR00012	.052	-.049	-.016	-.106
VAR00013	.004	.025	.009	.272
VAR00014	-.027	.146	-.001	.019
VAR00015	-.044	.012	.211	-.209
VAR00016	.003	.024	.069	.013
VAR00017	-.018	-.085	.205	-.127
VAR00018	-.038	.033	.155	-.074
VAR00019	-.012	.002	.140	-.109
VAR00022	.021	-.016	.050	.020
VAR00023	-.012	-.026	.162	-.187
VAR00027	.023	.057	-.014	.005
VAR00035	.045	.016	-.045	-.058
VAR00036	.030	.006	-.010	.119
VAR00037	-.005	.137	-.032	.012
VAR00038	.033	.033	-.049	.139
VAR00041	.045	.024	-.048	-.089

VAR00042	.029	-.024	.007	.134
VAR00043	.049	-.050	.003	-.102
VAR00044	.039	-.065	.034	-.019
VAR00045	.041	-.016	-.004	-.014
VAR00046	.036	-.016	-.001	.051
VAR00047	.024	.030	.025	-.138
VAR00048	.024	.014	.001	.100
VAR00049	.036	-.028	.002	.086
VAR00050	.038	-.014	-.001	.020
VAR00051	.043	.010	-.033	-.018
Education	.045	-.009	-.024	-.037
VAR00053	.045	-.001	-.031	-.028
VAR00054	.042	-.031	-.009	.052
Activitiesofhouseholds	.035	.010	-.012	.020
Computerprogramming	.039	-.004	-.012	.011

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Component Scores.

Appendix B: Accessibility to transport modes by the survey participants

User/Postcode	Car	Cycling	Walking	Rail	Bus	Taxi
1. N19L	✗	✓	✓	✓	✓	✓
2. N52N	✓	(✓)	✓	✓	✓	✓
3. EC1Y1B	✗	(✓)	✓	✓	✓	✓
4. EC1V1J	✗	(✓)	✓	✓	✓	✓
5. E11B	✓	(✓)	✓	✓	✓	✓
6. EC1V9H	✓	(✓)	✓	✓	✓	✓
7. SE17S	✗	(✓)	✓	✓	✓	✓
8. SE17S	✗	(✓)	✓	✓	✓	✓
9. E1W3D	✓	(✓)	✓	✓	✓	✓
10. W1T5D	✓	(✓)	✓	✓	✓	✓
11. BR34S	✗	✗	✓	✓	✓	✓
12. W21H	✓	(✓)	✓	✓	✓	✓
13. SW81A	✗	✗	✓	✓	✓	✓
14. E112A	✓	(✓)	✓	✓	✓	✓
15. W128N	✓	(✓)	✓	✓	✓	✓
16. E147L	✗	✗	✓	✓	✓	✓
17. SW178R	✓	(✓)	✓	✓	✓	✓
18. W1W6N	✓	(✓)	✓	✓	✓	✓
19. SW111J	✓	(✓)	✓	✓	✓	✓
20. E143N	✓	(✓)	✓	✓	✓	✓
21. EC1M5Q	✓	(✓)	✓	✓	✓	✓
22. SW181S	✓	(✓)	✓	✓	✓	✓
23. W60T	✓	(✓)	✓	✓	✓	✓
24. SW67N	✗	✓	✓	✓	✓	✓
25. W1U8E	✗	✗	✓	✓	✓	✓
26. N78G	✗	(✓)	✓	✓	✓	✓
27. NW71Q	✓	(✓)	✓	✓	✓	✓
28. W44P	✓	(✓)	✓	✓	✓	✓
29. SE17Q	✗	✗	✓	✓	✓	✓
30. SE16Q	✗	(✓)	✓	✓	✓	✓
31. SW84R	✓	(✓)	✓	✓	✓	✓
32. SW84R	✓	(✓)	✓	✓	✓	✓
33. SW66L	✓	(✓)	✓	✓	✓	✓
34. NW33N	✗	✓	✓	✓	✓	✓
35. W111E	✗	(✓)	✓	✓	✓	✓
36. N76R	✓	(✓)	✓	✓	✓	✓
37. SE30A	✓	(✓)	✓	✓	✓	✓
38. W24S	✗	(✓)	✓	✓	✓	✓

39. W113T	✓	✓	✓	✓	✓	✓
40. W93H	✗	(✓)	✓	✓	✓	✓
41. SW130D	✗	(✓)	✓	✓	✓	✓
42. SW36H	✗	✗	✓	✓	✓	✓
43. SW115E	✗	✓	✓	✓	✓	✓
44. SW195E	✓	✗	✓	✓	✓	✓
45. NW22H	✗	(✓)	✓	✓	✓	✓
46. SW182J	✓	(✓)	✓	✓	✓	✓
47. N87N	✗	✓	✓	✓	✓	✓
48. SW111P	✗	✗	✓	✓	✓	✓
49. NW80D	✓	(✓)	✓	✓	✓	✓
50. NW35Q	✗	✓	✓	✓	✓	✓
51. SE137S	✗	✗	✓	✓	✓	✓
52. SW33D	✗	✓	✓	✓	✓	✓
53. W114J	✓	(✓)	✓	✓	✓	✓
54. WC1H9E	✗	(✓)	✓	✓	✓	✓
55. W43J	✓	(✓)	✓	✓	✓	✓
56. NW105B	✗	(✓)	✓	✓	✓	✓
57. SW178Q	✓	(✓)	✓	✓	✓	✓
58. SW178Q	✓	(✓)	✓	✓	✓	✓
59. W113R	✗	(✓)	✓	✓	✓	✓
60. SE85P	✗	(✓)	✓	✓	✓	✓
61. W53P	✓	(✓)	✓	✓	✓	✓
62. W25D	✓	(✓)	✓	✓	✓	✓
63. SW194Q	✓	(✓)	✓	✓	✓	✓
64. NW17E	✓	✓	✓	✓	✓	✓
65. N78H	✗	✗	✓	✓	✓	✓
66. N134E	✗	(✓)	✓	✓	✓	✓
67. N102A	✓	(✓)	✓	✓	✓	✓
68. E148B	✗	(✓)	✓	✓	✓	✓
69. N42S	✓	(✓)	✓	✓	✓	✓
70. SE228D	✗	(✓)	✓	✓	✓	✓
71. SW179A	✓	(✓)	✓	✓	✓	✓
72. SE173E	✗	(✓)	✓	✓	✓	✓
73. NW64N	✗	(✓)	✓	✓	✓	✓
74. SE12L	✗	✗	✓	✓	✓	✓
75. W1T5L	✗	(✓)	✓	✓	✓	✓
76. N70E	✗	✗	✓	✓	✓	✓
77. SE270L	✓	(✓)	✓	✓	✓	✓
78. SE77A	✗	(✓)	✓	✓	✓	✓
79. SE163D	✗	(✓)	✓	✓	✓	✓
80. W43R	✓	(✓)	✓	✓	✓	✓

81. NW119A	✗	(✓)	✓	✓	✓	✓
82. SW84B	✗	(✓)	✓	✓	✓	✓
83. W105U	✓	(✓)	✓	✓	✓	✓
84. SW83Q	✓	(✓)	✓	✓	✓	✓
85. NW51U	✓	(✓)	✓	✓	✓	✓
86. W24N	✓	(✓)	✓	✓	✓	✓
87. NW117Q	✓	(✓)	✓	✓	✓	✓
88. SW1P4D	✓	(✓)	✓	✓	✓	✓
89. W1J0D	✓	(✓)	✓	✓	✓	✓
90. W1S2Q	✓	(✓)	✓	✓	✓	✓
91. W24J	✓	(✓)	✓	✓	✓	✓
92. SW85D	✓	(✓)	✓	✓	✓	✓
93. W1H1P	✓	(✓)	✓	✓	✓	✓
94. W111B	✓	(✓)	✓	✓	✓	✓
95. W23N	✓	(✓)	✓	✓	✓	✓
96. W149S	✓	(✓)	✓	✓	✓	✓
97. SW67S	✗	(✓)	✓	✓	✓	✓
98. SE135R	✓	(✓)	✓	✓	✓	✓
99. W1H1N	✓	(✓)	✓	✓	✓	✓
100. NW54P	✗	(✓)	✓	✓	✓	✓
101. NW22T	✓	(✓)	✓	✓	✓	✓
102. SW109H	✓	(✓)	✓	✓	✓	✓
103. W43H	✗	(✓)	✓	✓	✓	✓
104. W85D	✓	(✓)	✓	✓	✓	✓
105. N193Q	✓	(✓)	✓	✓	✓	✓
106. W87Q	✗	✗	✓	✓	✓	✓
107. SW1P4H	✓	(✓)	✓	✓	✓	✓
108. W1H5N	✓	(✓)	✓	✓	✓	✓
109. W1U6A	✗	(✓)	✓	✓	✓	✓
110. W1H2A	✗	(✓)	✓	✓	✓	✓
111. WC2R1H	✓	(✓)	✓	✓	✓	✓
112. N13N	✓	(✓)	✓	✓	✓	✓
113. SW84P	✓	(✓)	✓	✓	✓	✓
114. NW41Q	✗	(✓)	✓	✓	✓	✓
115. SE171U	✓	(✓)	✓	✓	✓	✓
116. E12A	✗	✗	✓	✓	✓	✓
117. E1W1N	✓	(✓)	✓	✓	✓	✓
118. NW52J	✓	(✓)	✓	✓	✓	✓
119. W111J	✓	(✓)	✓	✓	✓	✓
120. NW52N	✗	✓	✓	✓	✓	✓
121. NW52N	((✓))	(✓)	✓	✓	✓	✓
122. EC1V4P	✓	(✓)	✓	✓	✓	✓

123. SE58T	✓	(✓)	✓	✓	✓	✓
124. SE58J	✓	(✓)	✓	✓	✓	✓
125. NW86E	✓	(✓)	✓	✓	✓	✓
126. SW50L	✓	(✓)	✓	✓	✓	✓
127. SW50D	✓	(✓)	✓	✓	✓	✓
128. SW72R	✓	(✓)	✓	✓	✓	✓
129. E26J	✓	(✓)	✓	✓	✓	✓
130. BT119L	✓	(✓)	✓	✓	✓	✓
131. BT96N	✓	(✓)	✓	✓	✓	✓
132. BT147P	✓	(✓)	✓	✓	✓	✓
133. B191L	✗	(✓)	✓	✓	✓	✓
134. B450N	✗	✓	✓	✓	✓	✓
135. B152D	✗	✓	✓	✓	✓	✓
136. B152D	✗	(✓)	✓	✓	✓	✓
137. B31U	✗	(✓)	✓	✓	✓	✓
138. B312Y	✗	(✓)	✓	✓	✓	✓
139. B144D	✓	(✓)	✓	✓	✓	✓
140. B449R	✓	(✓)	✓	✓	✓	✓
141. B95W	✓	(✓)	✓	✓	✓	✓
142. B169J	✗	✓	✓	✓	✓	✓
143. B903D	✓	(✓)	✓	✓	✓	✓
144. B240L	✓	(✓)	✓	✓	✓	✓
145. B261L	✗	(✓)	✓	✓	✓	✓
146. B302D	✗	✓	✓	✓	✓	✓
147. B179H	✓	(✓)	✓	✓	✓	✓
148. B57Q	✓	(✓)	✓	✓	✓	✓
149. B664D	✗	✗	✓	✓	✓	✓
150. B160R	✗	(✓)	✓	✓	✓	✓
151. B301P	✓	(✓)	✓	✓	✓	✓
152. B31F	✓	(✓)	✓	✓	✓	✓
153. B153S	✗	(✓)	✓	✓	✓	✓
154. B31Q	✗	✓	✓	✓	✓	✓
155. B151U	✓	(✓)	✓	✓	✓	✓
156. B11S	✓	(✓)	✓	✓	✓	✓
157. B186H	✓	(✓)	✓	✓	✓	✓
158. B13A	✓	(✓)	✓	✓	✓	✓
159. B11B	✓	(✓)	✓	✓	✓	✓
160. B12D	✗	✗	✓	✓	✓	✓
161. B56N	✓	(✓)	✓	✓	✓	✓
162. B120N	✓	(✓)	✓	✓	✓	✓
163. B168A	✗	✓	✓	✓	✓	✓
164. B168E	✓	(✓)	✓	✓	✓	✓

165. B12P	✓	(✓)	✓	✓	✓	✓
166. B168A	✓	(✓)	✓	✓	✓	✓
167. B186B	✓	(✓)	✓	✓	✓	✓
168. B152B	✓	(✓)	✓	✓	✓	✓
169. BS78N	✓	✓	✓	✓	✓	✓
170. BS35Q	✓	(✓)	✓	✓	✓	✓
171. BS66A	✓	(✓)	✓	✓	✓	✓
172. BS15L	✗	✗	✓	✓	✓	✓
173. BS31R	✗	(✓)	✓	✓	✓	✓
174. BS151B	✗	(✓)	✓	✓	✓	✓
175. BS16X	✗	(✓)	✓	✓	✓	✓
176. BS20E	✓	(✓)	✓	✓	✓	✓
177. BS13Q	✗	✗	✓	✓	✓	✓
178. CF119E	✓	(✓)	✓	✓	✓	✓
179. CF243L	✓	(✓)	✓	✓	✓	✓
180. CF110J	✓	✓	✓	✓	✓	✓
181. CF110A	✗	✗	✓	✓	✓	✓
182. CF239J	✓	(✓)	✓	✓	✓	✓
183. CF239H	✓	(✓)	✓	✓	✓	✓
184. CF119Q	✓	(✓)	✓	✓	✓	✓
185. CF110S	✓	(✓)	✓	✓	✓	✓
186. CF102D	✓	(✓)	✓	✓	✓	✓
187. EH74B	✓	(✓)	✓	✓	✓	✓
188. EH66B	✓	(✓)	✓	✓	✓	✓
189. EH68Q	✗	(✓)	✓	✓	✓	✓
190. EH39P	✓	✓	✓	✓	✓	✓
191. EH111B	✗	(✓)	✓	✓	✓	✓
192. EH75Y	✓	(✓)	✓	✓	✓	✓
193. EH91H	✓	(✓)	✓	✓	✓	✓
194. EH75S	✓	(✓)	✓	✓	✓	✓
195. EH66E	✓	(✓)	✓	✓	✓	✓
196. EH41N	✗	(✓)	✓	✓	✓	✓
197. EH92L	✓	(✓)	✓	✓	✓	✓
198. EH112H	✓	(✓)	✓	✓	✓	✓
199. G36L	✗	(✓)	✓	✓	✓	✓
200. G58D	✓	(✓)	✓	✓	✓	✓
201. G58A	✓	(✓)	✓	✓	✓	✓
202. G14E	✓	(✓)	✓	✓	✓	✓
203. G37X	✓	(✓)	✓	✓	✓	✓
204. G11H	✓	(✓)	✓	✓	✓	✓
205. G27A	✗	(✓)	✓	✓	✓	✓
206. G38H	✓	✓	✓	✓	✓	✓

207. G38H	✓	(✓)	✓	✓	✓	✓
208. G24L	✓	(✓)	✓	✓	✓	✓
209. G38H	✓	(✓)	✓	✓	✓	✓
210. G37A	✓	(✓)	✓	✓	✓	✓
211. G38E	✓	(✓)	✓	✓	✓	✓
212. G40S	✗	✓	✓	✓	✓	✓
213. G36A	✗	(✓)	✓	✓	✓	✓
214. G36A	✗	(✓)	✓	✓	✓	✓
215. G36N	✗	✗	✓	✓	✓	✓
216. G36L	✓	(✓)	✓	✓	✓	✓
217. LS31J	✗	✓	✓	✓	✓	✓
218. LS15P	✗	✓	✓	✓	✓	✓
219. LS27H	✗	(✓)	✓	✓	✓	✓
220. LS42R	✓	✓	✓	✓	✓	✓
221. LS101H	✓	(✓)	✓	✓	✓	✓
222. LS119B	✓	✓	✓	✓	✓	✓
223. LS64A	✓	(✓)	✓	✓	✓	✓
224. LS61B	✓	(✓)	✓	✓	✓	✓
225. LS31D	✗	(✓)	✓	✓	✓	✓
226. LS184P	✓	(✓)	✓	✓	✓	✓
227. LS61Q	✗	(✓)	✓	✓	✓	✓
228. LS74S	✗	✓	✓	✓	✓	✓
229. LS101T	✓	✓	✓	✓	✓	✓
230. LS12T	((✓))	✓	✓	✓	✓	✓
231. LS27Q	✗	✓	✓	✓	✓	✓
232. LS63E	✓	✓	✓	✓	✓	✓
233. LS27P	✓	✓	✓	✓	✓	✓
234. LS101B	✗	(✓)	✓	✓	✓	✓
235. LS42N	✗	✓	✓	✓	✓	✓
236. LS31E	✗	✓	✓	✓	✓	✓
237. LS61B	✓	(✓)	✓	✓	✓	✓
238. L10B	✓	(✓)	✓	✓	✓	✓
239. L15B	✗	(✓)	✓	✓	✓	✓
240. L31D	✓	(✓)	✓	✓	✓	✓
241. L52A	✗	✗	✓	✓	✓	✓
242. CH448B	✓	(✓)	✓	✓	✓	✓
243. L77E	✗	✓	✓	✓	✓	✓
244. L31B	✓	(✓)	✓	✓	✓	✓
245. L276W	✓	(✓)	✓	✓	✓	✓
246. L15A	✓	✓	✓	✓	✓	✓
247. L36J	✓	✓	✓	✓	✓	✓
248. L85R	✓	✓	✓	✓	✓	✓

249. L85R	✓	✓	✓	✓	✓	✓
250. L32B	✗	✗	✓	✓	✓	✓
251. L34E	✓	(✓)	✓	✓	✓	✓
252. L14A	✗	(✓)	✓	✓	✓	✓
253. L39P	✓	(✓)	✓	✓	✓	✓
254. L22H	✓	(✓)	✓	✓	✓	✓
255. L40R	✓	(✓)	✓	✓	✓	✓
256. L16D	✓	(✓)	✓	✓	✓	✓
257. L15F	✓	(✓)	✓	✓	✓	✓
258. L62PF	✗	✗	✓	✓	✓	✓
259. M34N	✓	(✓)	✓	✓	✓	✓
260. M47B	✓	(✓)	✓	✓	✓	✓
261. M44T	✓	(✓)	✓	✓	✓	✓
262. M154Q	✓	(✓)	✓	✓	✓	✓
263. M12D	✓	(✓)	✓	✓	✓	✓
264. M12T	✓	(✓)	✓	✓	✓	✓
265. M167H	✗	✗	✓	✓	✓	✓
266. M206S	✗	✓	✓	✓	✓	✓
267. M74S	✗	(✓)	✓	✓	✓	✓
268. M44A	✓	(✓)	✓	✓	✓	✓
269. M47A	✓	(✓)	✓	✓	✓	✓
270. M155P	✗	✓	✓	✓	✓	✓
271. M168B	✓	(✓)	✓	✓	✓	✓
272. M228H	✓	(✓)	✓	✓	✓	✓
273. M113F	✓	(✓)	✓	✓	✓	✓
274. M74Z	✓	(✓)	✓	✓	✓	✓
275. M36F	✓	(✓)	✓	✓	✓	✓
276. M34N	✓	(✓)	✓	✓	✓	✓
277. M279T	✓	(✓)	✓	✓	✓	✓
278. M202X	✓	(✓)	✓	✓	✓	✓
279. M34N	✓	(✓)	✓	✓	✓	✓
280. M219P	✓	(✓)	✓	✓	✓	✓
281. M501D	✓	(✓)	✓	✓	✓	✓
282. M146B	✓	(✓)	✓	✓	✓	✓
283. M335P	✓	(✓)	✓	✓	✓	✓
284. M17H	✓	(✓)	✓	✓	✓	✓
285. M503T	✓	(✓)	✓	✓	✓	✓
286. NE82D	✓	(✓)	✓	✓	✓	✓
287. NE236P	✓	(✓)	✓	✓	✓	✓
288. NE12A	✓	✓	✓	✓	✓	✓
289. NE13R	✓	(✓)	✓	✓	✓	✓
290. NE31A	✓	(✓)	✓	✓	✓	✓

291. NE32J	✓	(✓)	✓	✓	✓	✓
292. NE65A	✓	(✓)	✓	✓	✓	✓
293. NE21Q	✓	(✓)	✓	✓	✓	✓
294. NE12A	✗	✗	✓	✓	✓	✓
295. NE14A	✓	(✓)	✓	✓	✓	✓
296. NE15J	✓	(✓)	✓	✓	✓	✓
297. NE12J	✗	✗	✓	✓	✓	✓
298. NE15J	✓	(✓)	✓	✓	✓	✓
299. NE16B	✓	✓	✓	✓	✓	✓
300. NE83Q	✓	(✓)	✓	✓	✓	✓

✓	The participants have directly access to transport mode
✗	The participants do not have access to transport mode at all
(✓)	The participants probably have the ability to buy a bicycle (e.g. car owner or not low income <10000)
((✓))	The participants do not have a car in their house, but they have indirectly access to it

Appendix C: Social infrastructure interdependencies

The individuals were asked to evaluate the dependency with an integer between 0 and 5 and the mean, the median and the mode were calculated for the following transport modes:

- Walking with energy (Table C.1 & Figure C.1), water (Table C.2 & Figure C.2), waste (Table C.3 & Figure C.3) and communication (Table C.4 & Figure C.4) infrastructure
- Cycling with energy (Table C.5 & Figure C.5), water (Table C.6 & Figure C.6), waste (Table C.7 & Figure C.7) and communication (Table C.8 & Figure C.8) infrastructure
- Rail with energy (Table C.9 & Figure C.9), water (Table C.10 & Figure C.10), waste (Table C.11 & Figure C.11) and communication (Table C.12 & Figure C.12) infrastructure
- Bus with energy (Table C.13 & Figure C.13), water (Table C.14 & Figure C.14), waste (Table C.15 & Figure C.15) and communication (Table C.16 & Figure C.16) infrastructure
- Car with energy (Table C.17 & Figure C.17), water (Table C.18 & Figure C.18), waste (Table C.19 & Figure C.19) and communication (Table C.20 & Figure C.20) infrastructure
- Taxi with energy (Table C.21 & Figure C.21), water (Table C.22 & Figure C.22), waste (Table C.23 & Figure C.23) and communication (Table C.24 & Figure C.24) infrastructure
- Air transport with energy (Table C.25 & Figure C.25), water (Table C.26 & Figure C.26), waste (Table C.27 & Figure C.27) and communication (Table C.28 & Figure C.28) infrastructure
- Water transport with energy (Table C.29 & Figure C.29), water (Table C.30 & Figure C.30), waste (Table C.31 & Figure C.31) and communication (Table C.32 & Figure C.32) infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	281	93.7	93.7	93.7
	1	6	2.0	2.0	95.7
	2	5	1.7	1.7	97.3
	3	4	1.3	1.3	98.7
	4	1	.3	.3	99.0
	5	3	1.0	1.0	100.0
	Total	300	100.0	100.0	

Table C.1 Walking dependency with energy infrastructure

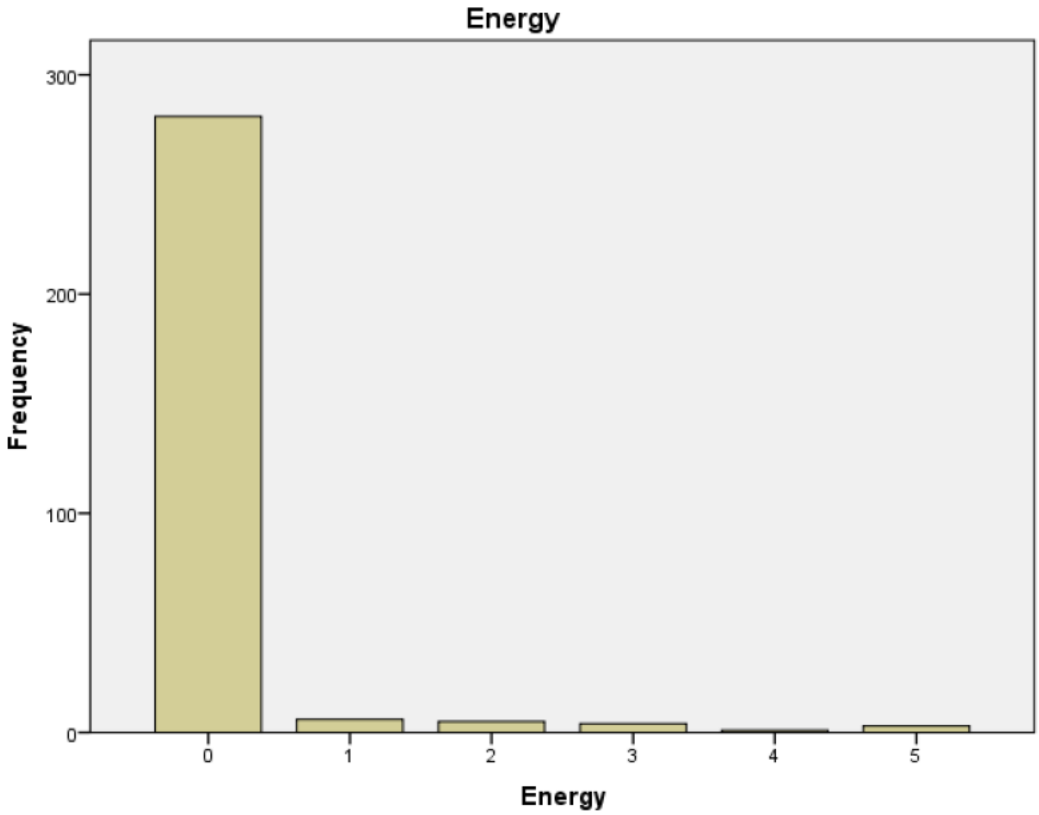


Figure C.1 Walking dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	247	82.3	82.3	82.3
	1	15	5.0	5.0	87.3
	2	15	5.0	5.0	92.3
	3	7	2.3	2.3	94.7
	4	6	2.0	2.0	96.7
	5	10	3.3	3.3	100.0
	Total	300	100.0	100.0	

Table C.2 Walking dependency with water infrastructure

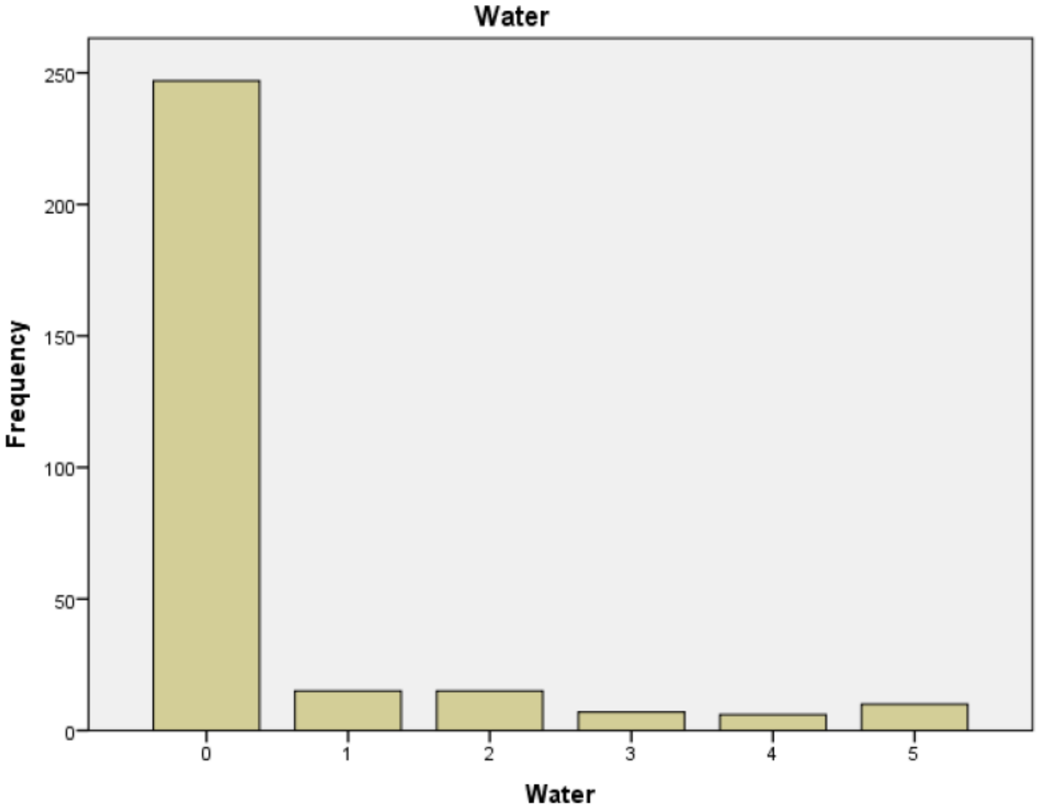


Figure C.2 Walking dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	216	72.0	72.0	72.0
	1	33	11.0	11.0	83.0
	2	14	4.7	4.7	87.7
	3	9	3.0	3.0	90.7
	4	3	1.0	1.0	91.7
	5	25	8.3	8.3	100.0
	Total	300	100.0	100.0	

Table C.3 Walking dependency with waste infrastructure

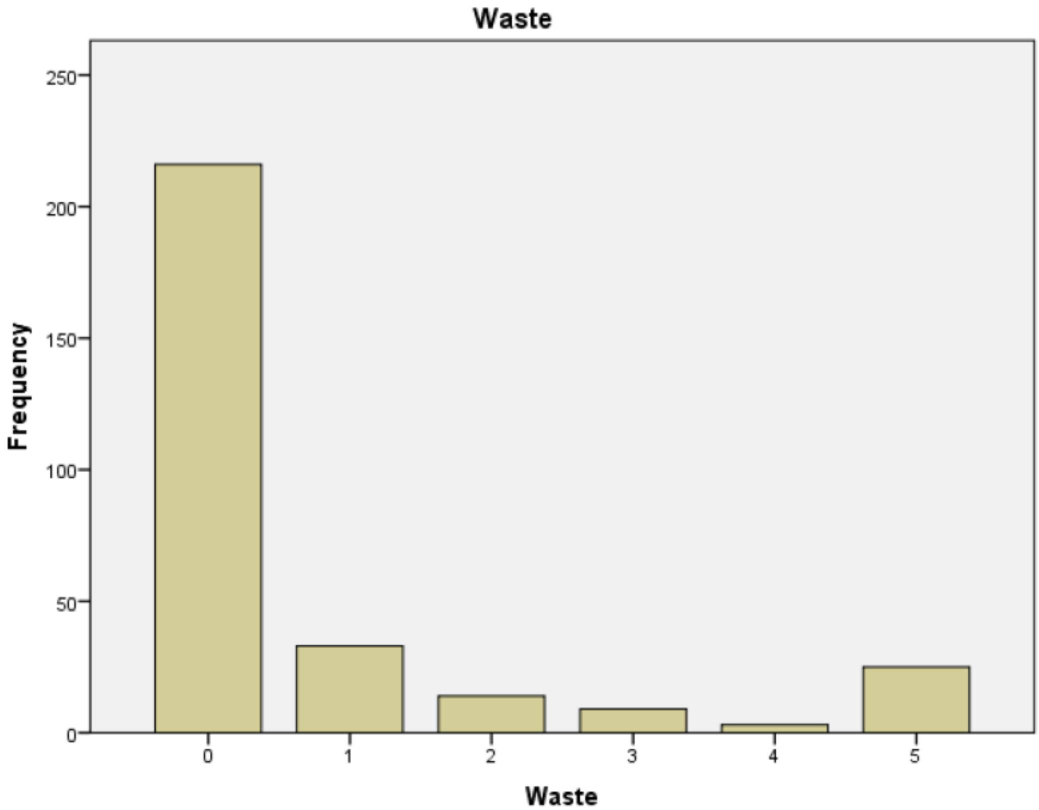


Figure C.3 Walking dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	188	62.7	62.7	62.7
	1	36	12.0	12.0	74.7
	2	50	16.7	16.7	91.3
	3	13	4.3	4.3	95.7
	4	2	.7	.7	96.3
	5	11	3.7	3.7	100.0
	Total	300	100.0	100.0	

Table C.4 Walking dependency with communication infrastructure

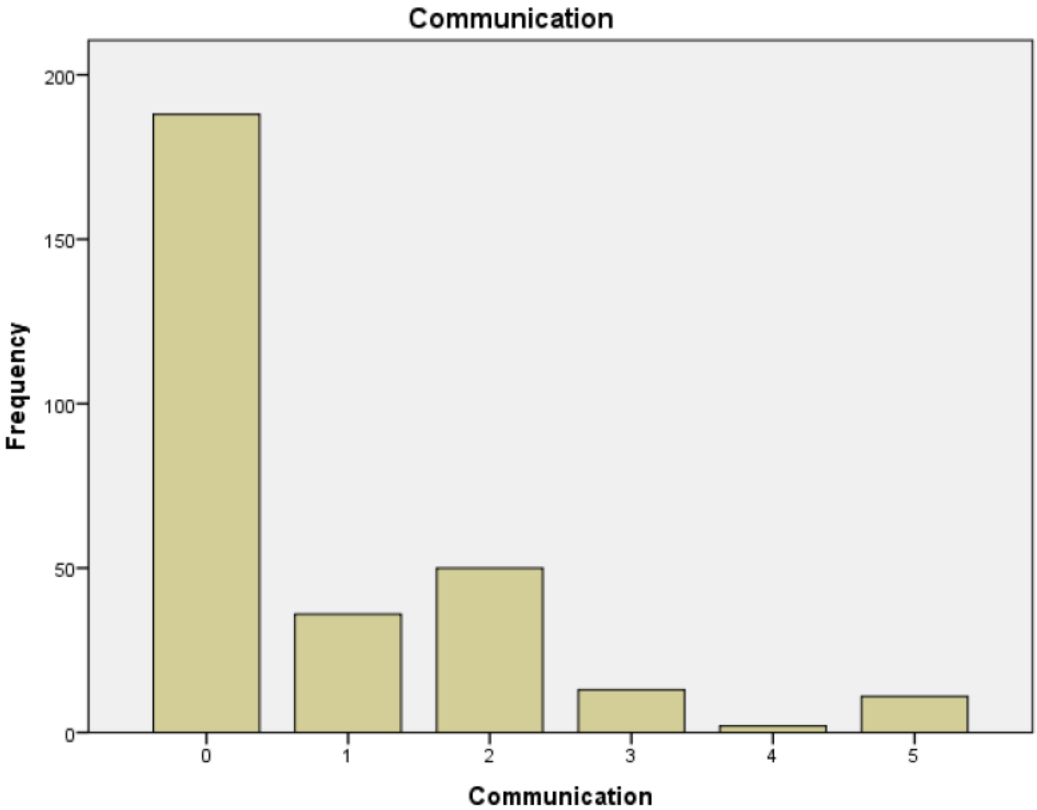


Figure C.4 Walking dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	279	93.0	93.0	93.0
	1	7	2.3	2.3	95.3
	2	7	2.3	2.3	97.7
	3	1	.3	.3	98.0
	4	2	.7	.7	98.7
	5	4	1.3	1.3	100.0
	Total	300	100.0	100.0	

Table C.5 Cycling dependency with energy infrastructure

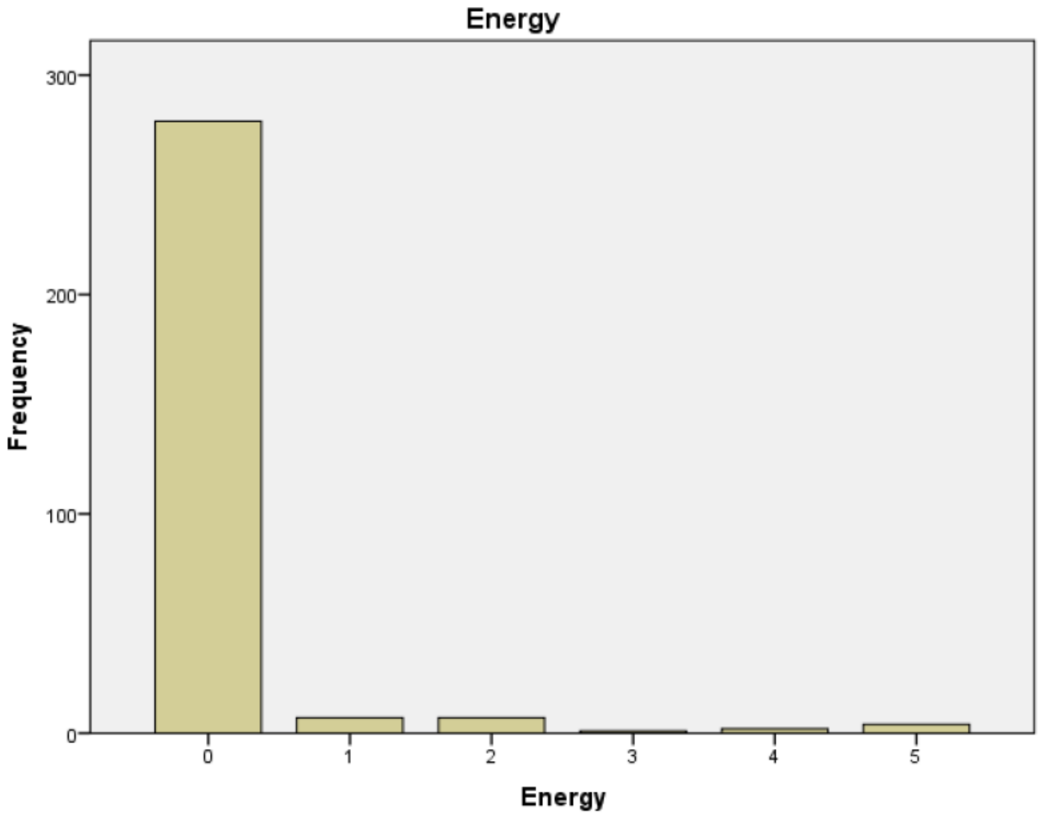


Figure C.5 Cycling dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	245	81.7	81.7	81.7
	1	19	6.3	6.3	88.0
	2	9	3.0	3.0	91.0
	3	5	1.7	1.7	92.7
	4	8	2.7	2.7	95.3
	5	14	4.7	4.7	100.0
	Total	300	100.0	100.0	

Table C.6 Cycling dependency with water infrastructure

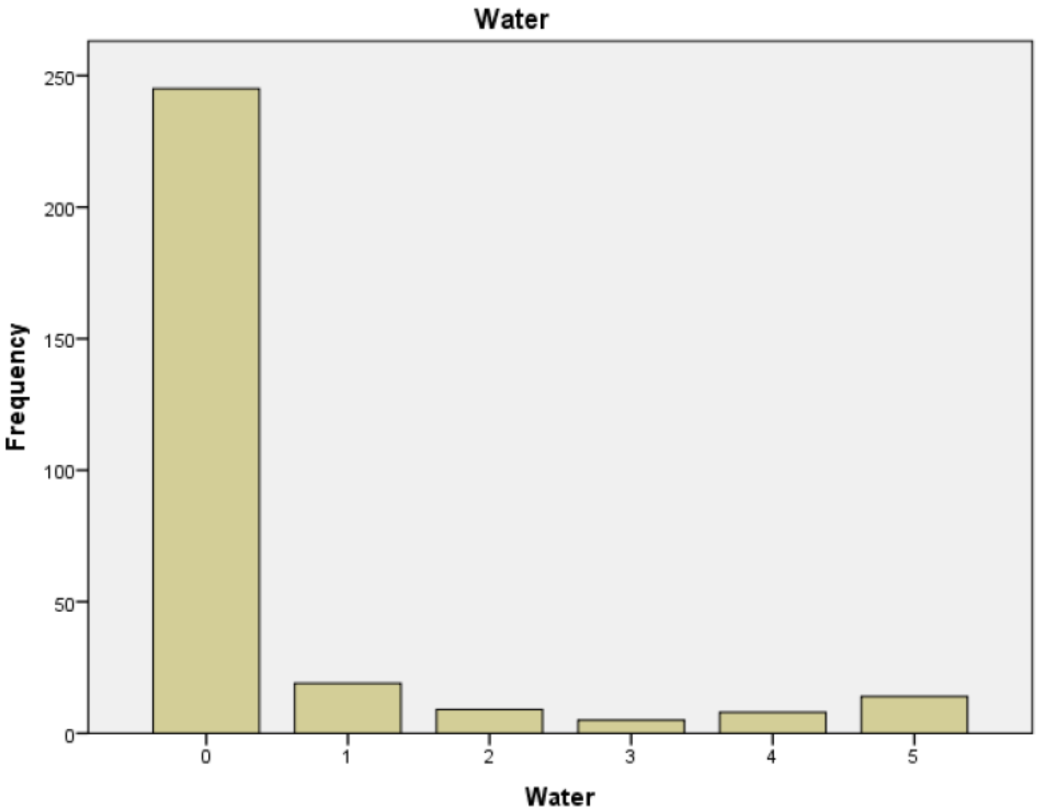


Figure C.6 Cycling dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	213	71.0	71.0	71.0
	1	33	11.0	11.0	82.0
	2	16	5.3	5.3	87.3
	3	12	4.0	4.0	91.3
	4	2	.7	.7	92.0
	5	24	8.0	8.0	100.0
	Total	300	100.0	100.0	

Table C.7 Cycling dependency with waste infrastructure

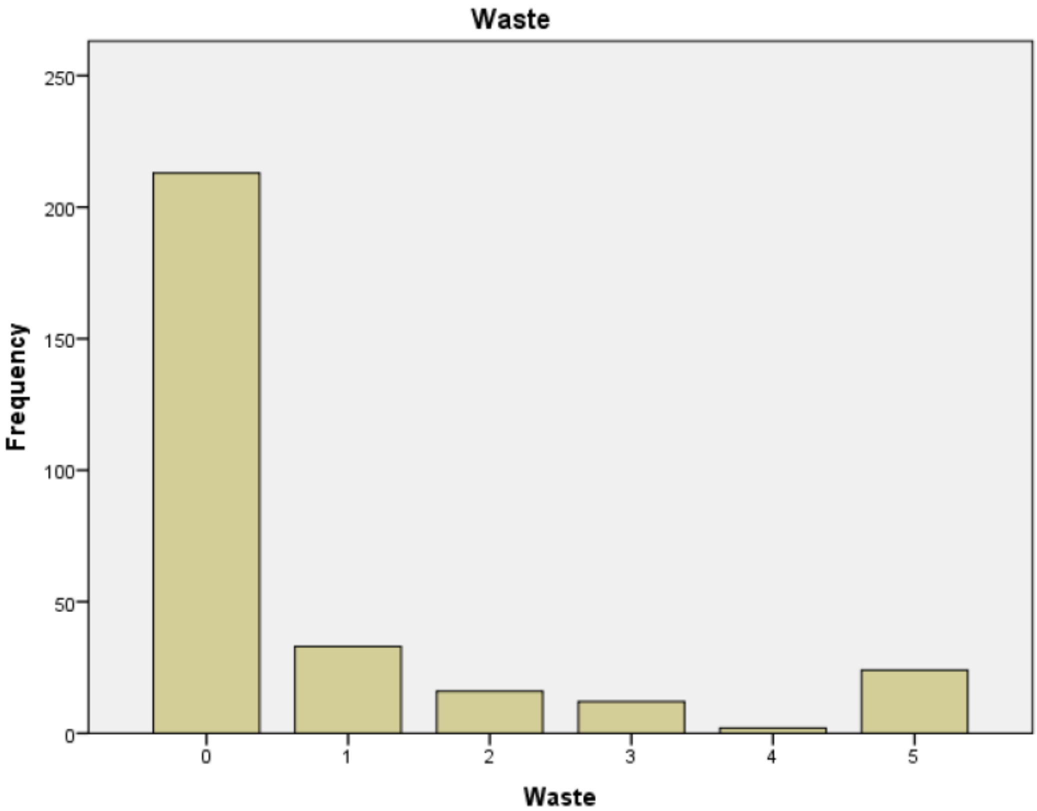


Figure C.7 Cycling dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	189	63.0	63.0	63.0
	1	52	17.3	17.3	80.3
	2	32	10.7	10.7	91.0
	3	13	4.3	4.3	95.3
	4	3	1.0	1.0	96.3
	5	11	3.7	3.7	100.0
	Total	300	100.0	100.0	

Table C.8 Cycling dependency with communication infrastructure

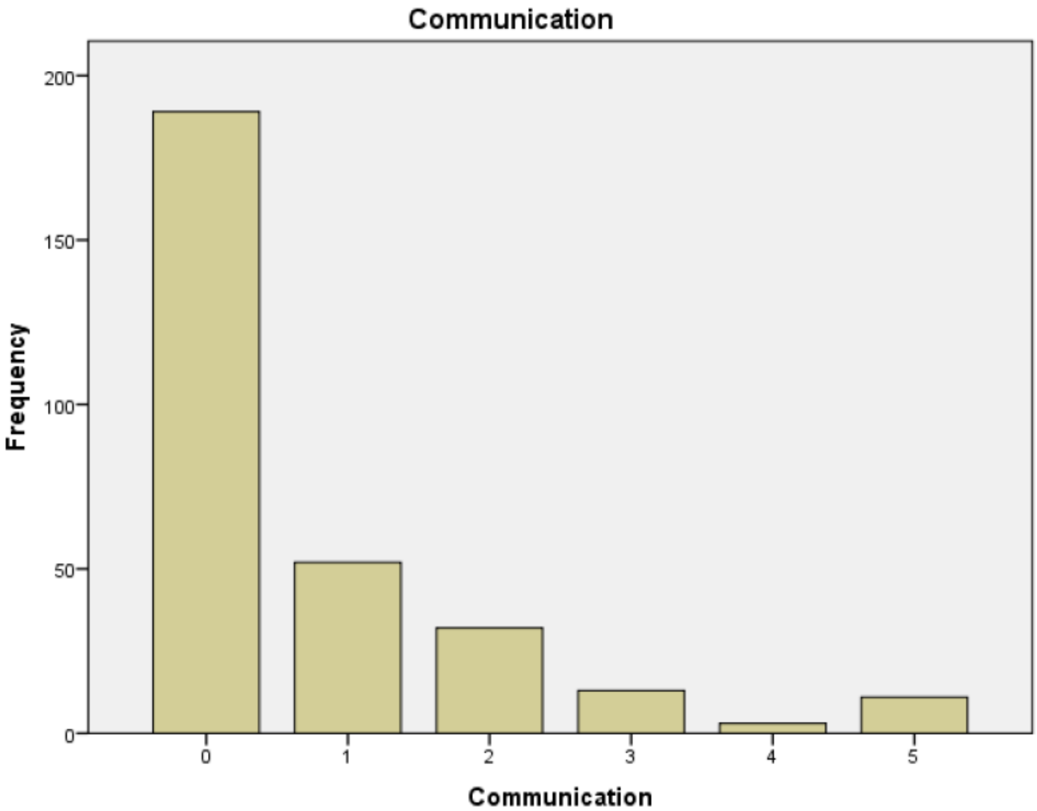


Figure C.8 Cycling dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	8	2.7	2.7	2.7
	1	5	1.7	1.7	4.3
	2	8	2.7	2.7	7.0
	3	19	6.3	6.3	13.3
	4	12	4.0	4.0	17.3
	5	248	82.7	82.7	100.0
	Total	300	100.0	100.0	

Table C.9 Rail dependency with energy infrastructure

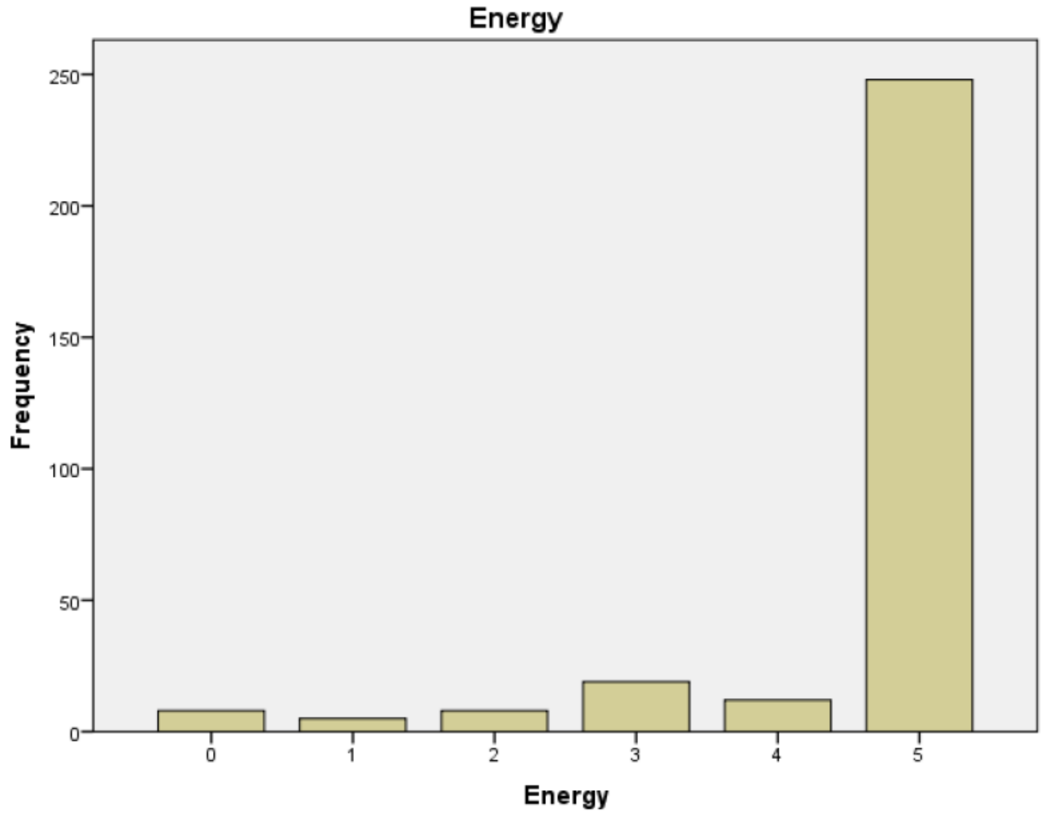


Figure C.9 Rail dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	247	82.3	82.3	82.3
	1	11	3.7	3.7	86.0
	2	11	3.7	3.7	89.7
	3	7	2.3	2.3	92.0
	4	8	2.7	2.7	94.7
	5	16	5.3	5.3	100.0
	Total	300	100.0	100.0	

Table C.10 Rail dependency with water infrastructure

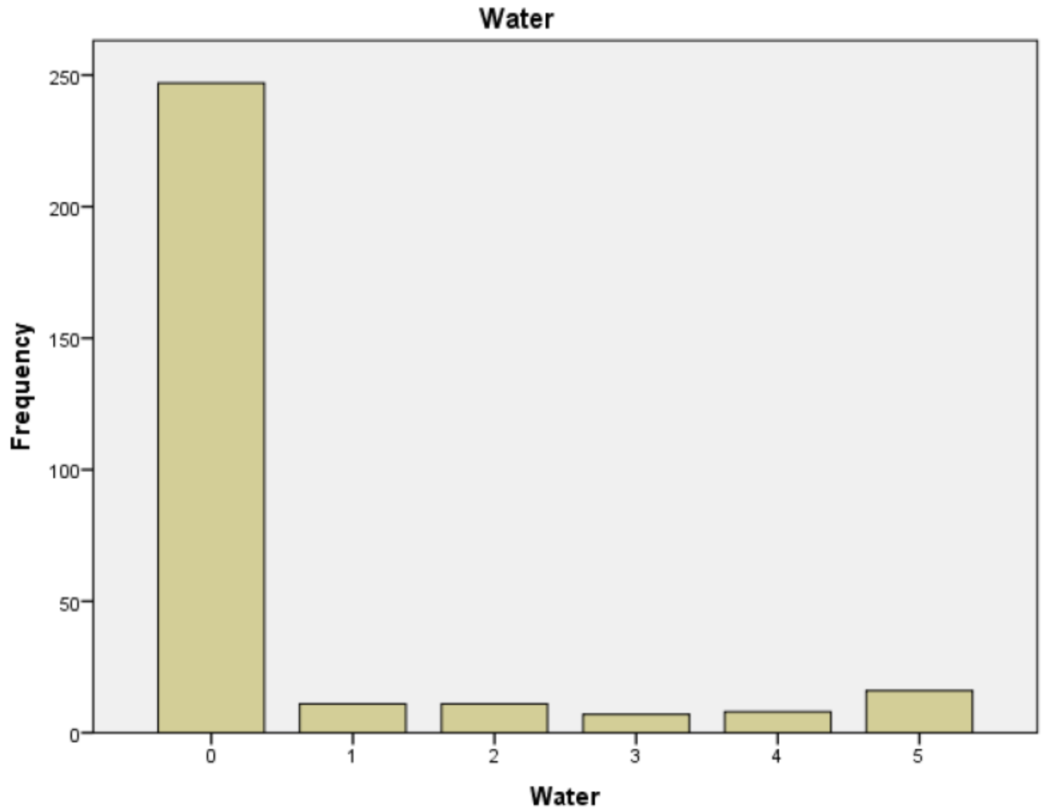


Figure C.10 Rail dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	208	69.3	69.3	69.3
	1	30	10.0	10.0	79.3
	2	19	6.3	6.3	85.7
	3	17	5.7	5.7	91.3
	4	9	3.0	3.0	94.3
	5	17	5.7	5.7	100.0
	Total	300	100.0	100.0	

Table C.11 Rail dependency with waste infrastructure

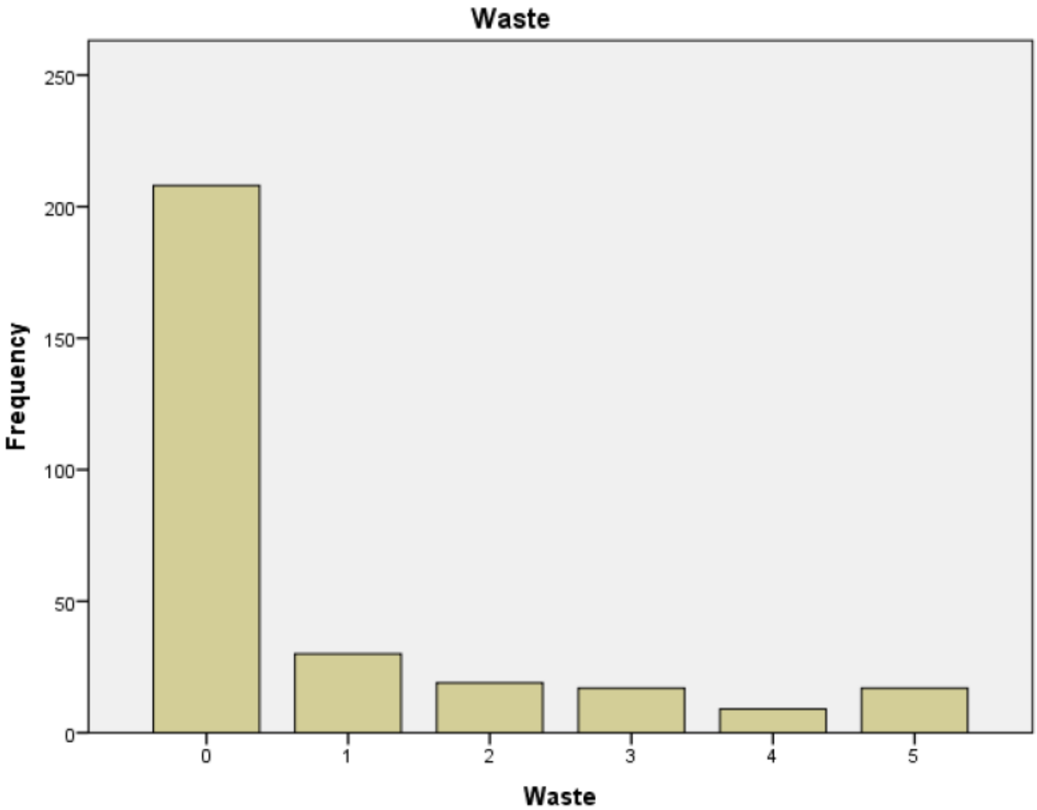


Figure C.11 Rail dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	34	11.3	11.3	11.3
	1	35	11.7	11.7	23.0
	2	27	9.0	9.0	32.0
	3	43	14.3	14.3	46.3
	4	32	10.7	10.7	57.0
	5	129	43.0	43.0	100.0
	Total	300	100.0	100.0	

Table C.12 Rail dependency with communication infrastructure

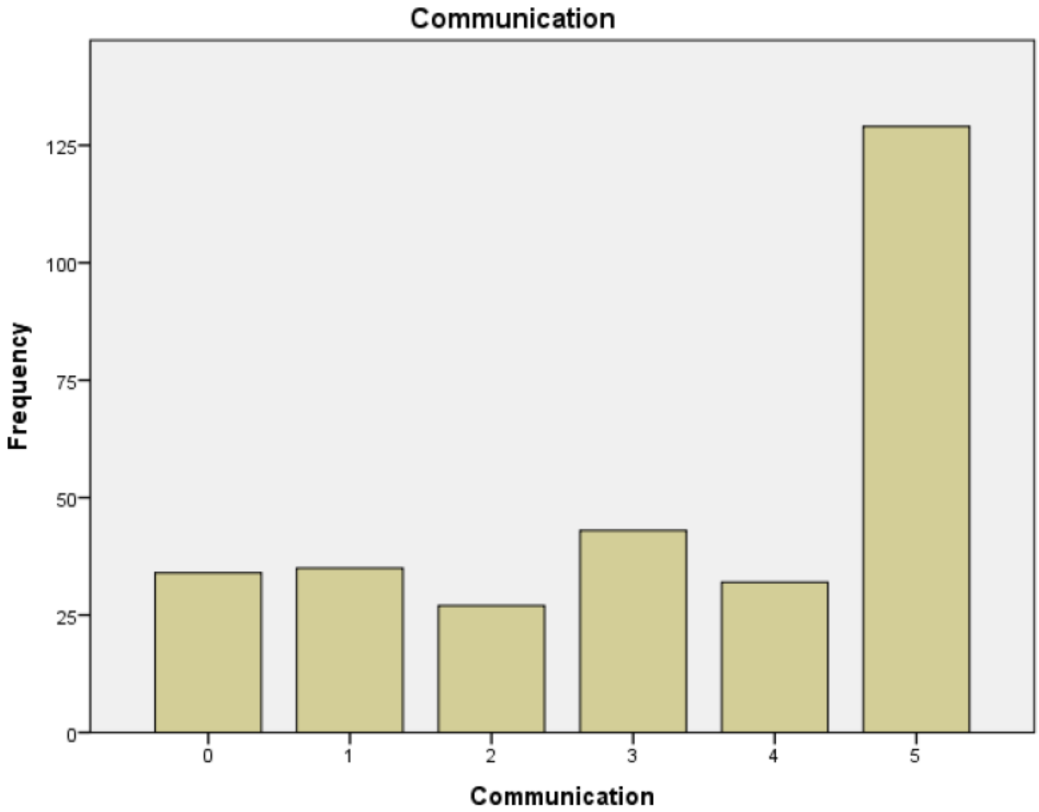


Figure C.12 Rail dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	6	2.0	2.0	2.0
	1	2	.7	.7	2.7
	2	5	1.7	1.7	4.3
	3	17	5.7	5.7	10.0
	4	12	4.0	4.0	14.0
	5	258	86.0	86.0	100.0
	Total	300	100.0	100.0	

Table C.13 Bus dependency with energy infrastructure

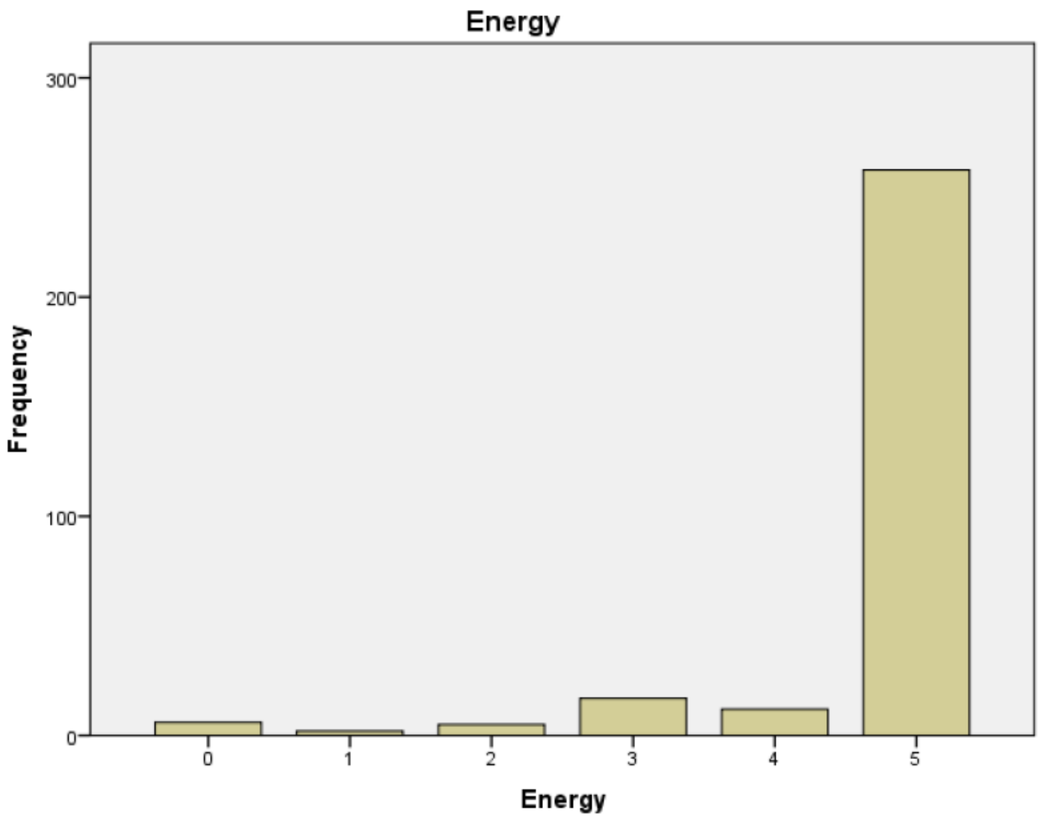


Figure C.13 Bus dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	261	87.0	87.0	87.0
	1	15	5.0	5.0	92.0
	2	7	2.3	2.3	94.3
	3	2	.7	.7	95.0
	4	5	1.7	1.7	96.7
	5	10	3.3	3.3	100.0
	Total	300	100.0	100.0	

Table C.14 Bus dependency with water infrastructure

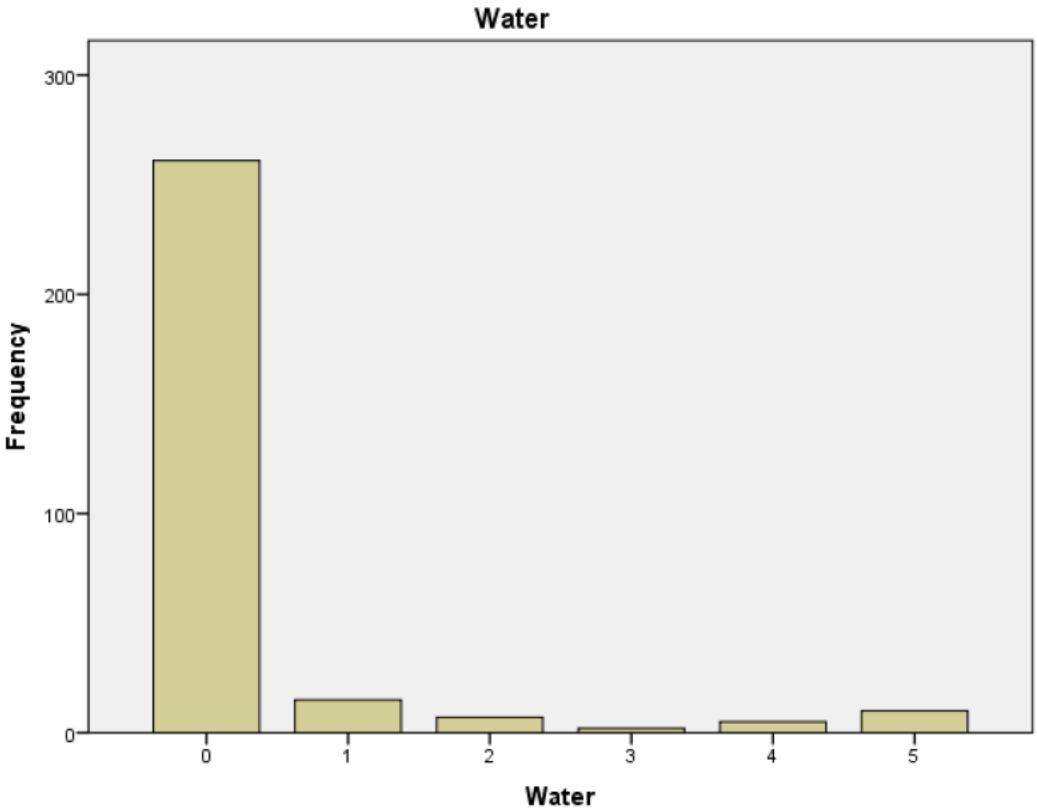


Figure C.14 Bus dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	214	71.3	71.3	71.3
	1	35	11.7	11.7	83.0
	2	11	3.7	3.7	86.7
	3	9	3.0	3.0	89.7
	4	11	3.7	3.7	93.3
	5	20	6.7	6.7	100.0
	Total	300	100.0	100.0	

Table C.15 Bus dependency with waste infrastructure

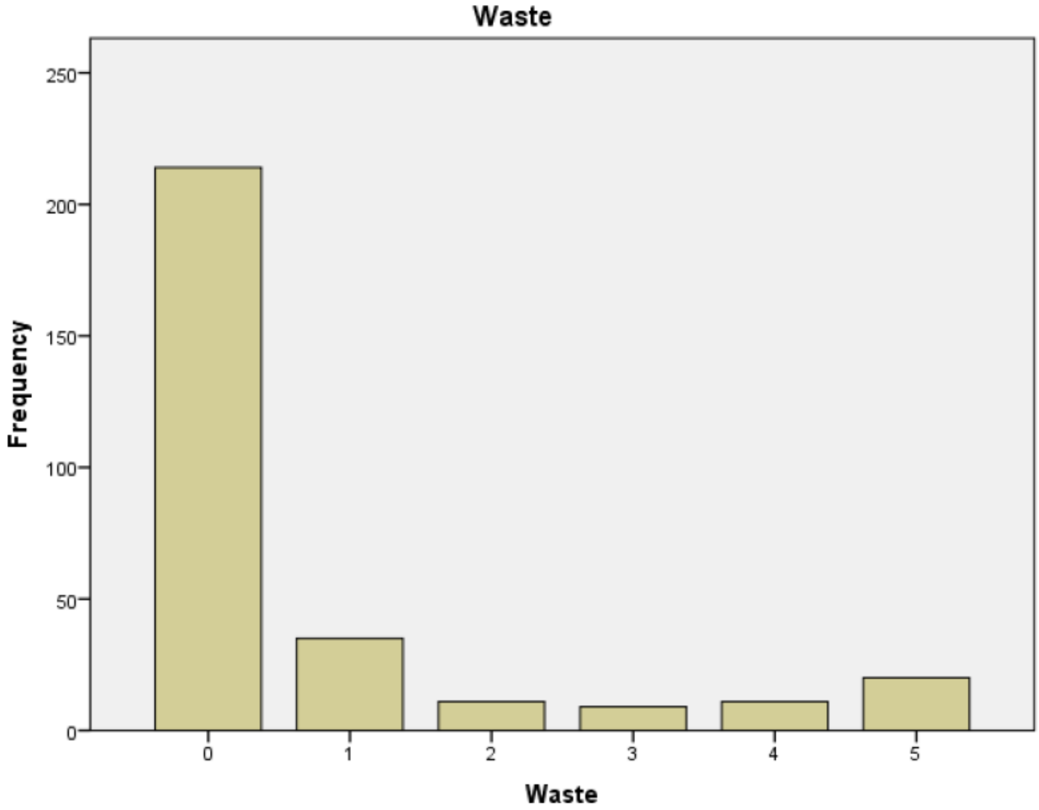


Figure C.15 Bus dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	45	15.0	15.0	15.0
	1	52	17.3	17.3	32.3
	2	39	13.0	13.0	45.3
	3	61	20.3	20.3	65.7
	4	31	10.3	10.3	76.0
	5	72	24.0	24.0	100.0
	Total	300	100.0	100.0	

Table C.16 Bus dependency with communication infrastructure

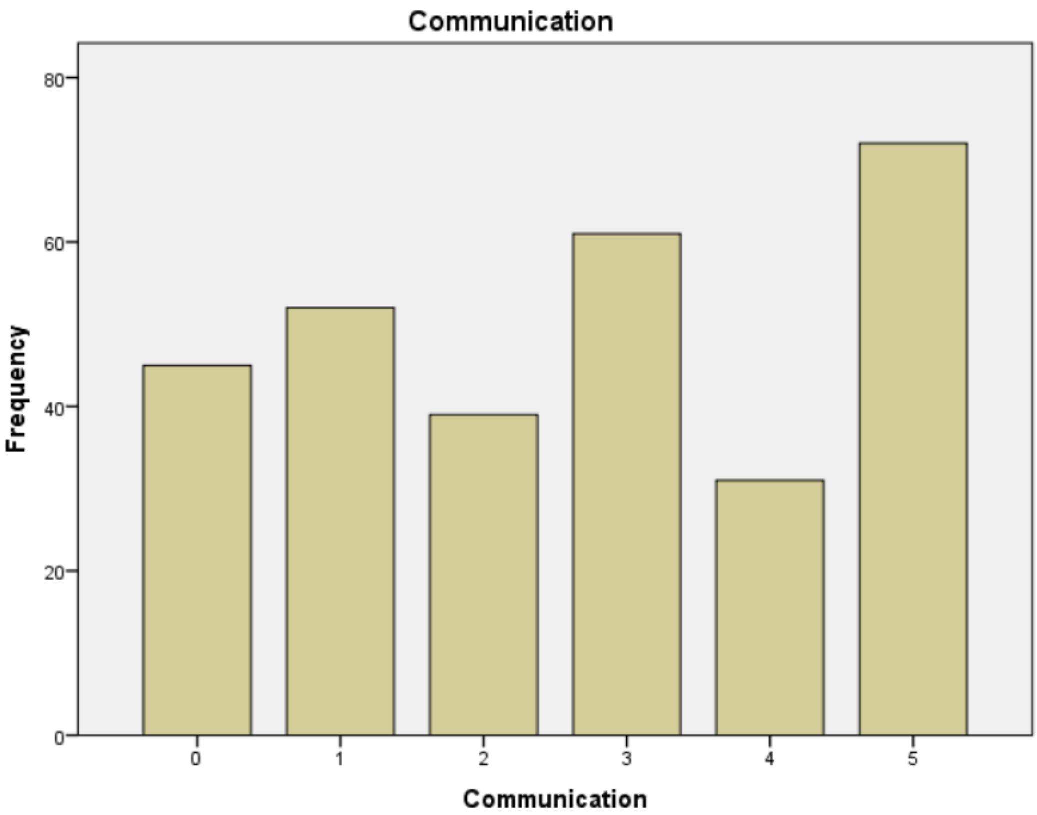


Figure C.16 Bus dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	7	2.3	2.3	2.3
	1	3	1.0	1.0	3.3
	2	6	2.0	2.0	5.3
	3	12	4.0	4.0	9.3
	4	10	3.3	3.3	12.7
	5	262	87.3	87.3	100.0
	Total	300	100.0	100.0	

Table C.17 Car dependency with energy infrastructure

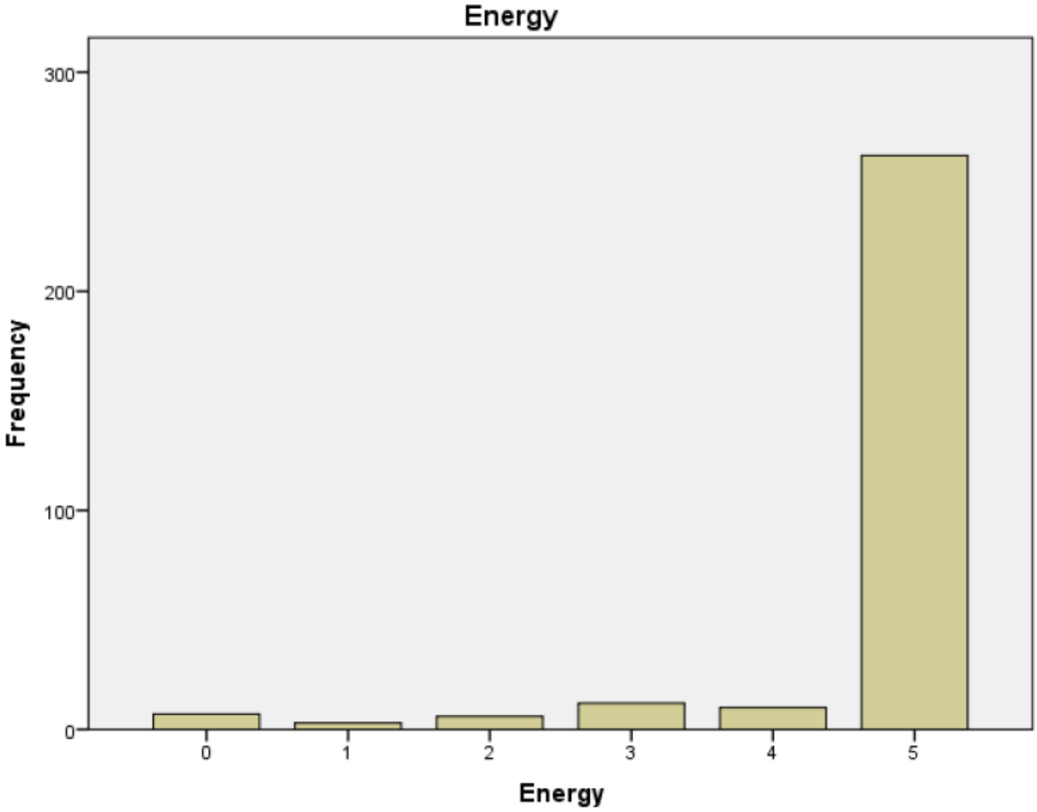


Figure C.17 Car dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	264	88.0	88.0	88.0
	1	11	3.7	3.7	91.7
	2	4	1.3	1.3	93.0
	3	5	1.7	1.7	94.7
	4	6	2.0	2.0	96.7
	5	10	3.3	3.3	100.0
	Total	300	100.0	100.0	

Table C.18 Car dependency with water infrastructure

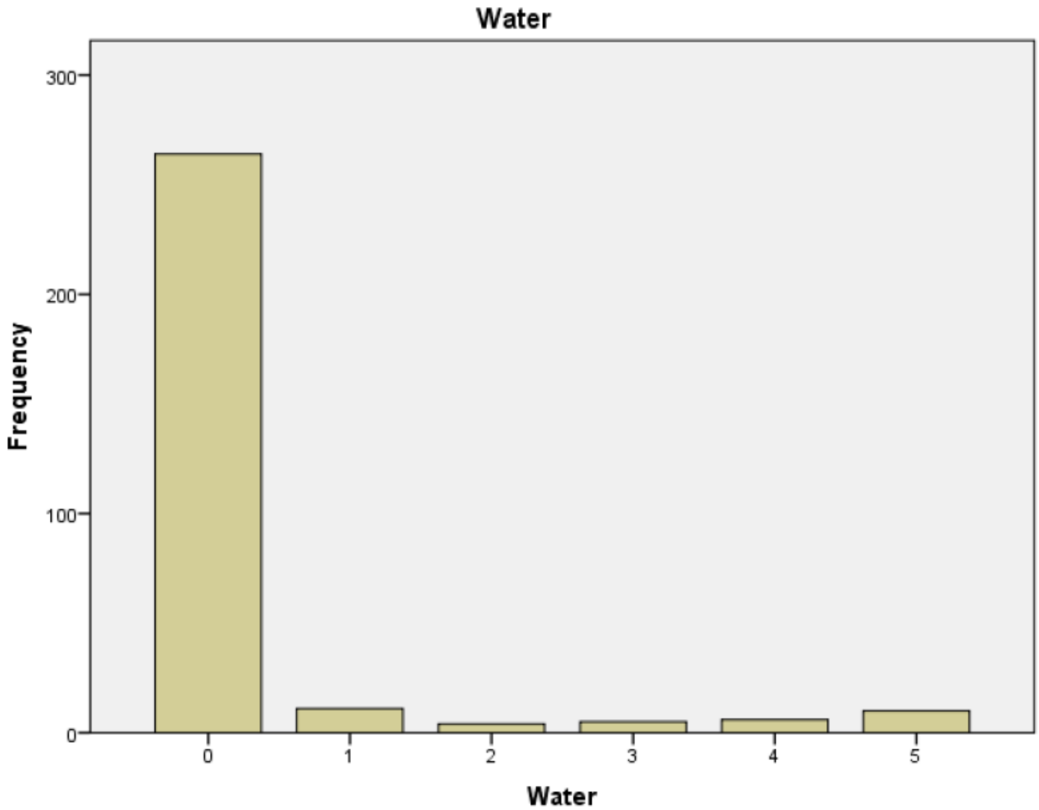


Figure C.18 Car dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	261	87.0	87.0	87.0
	1	7	2.3	2.3	89.3
	2	9	3.0	3.0	92.3
	3	5	1.7	1.7	94.0
	4	8	2.7	2.7	96.7
	5	10	3.3	3.3	100.0
	Total	300	100.0	100.0	

Table C.19 Car dependency with waste infrastructure

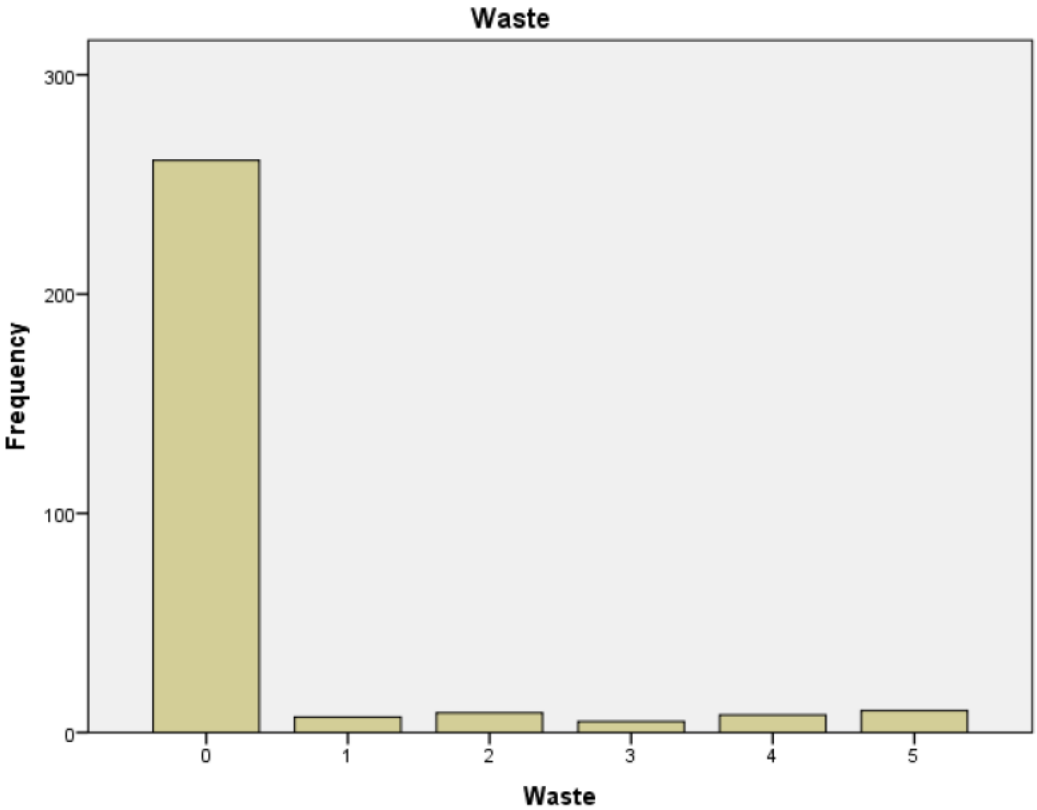


Figure C.19 Car dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	132	44.0	44.0	44.0
	1	42	14.0	14.0	58.0
	2	33	11.0	11.0	69.0
	3	35	11.7	11.7	80.7
	4	25	8.3	8.3	89.0
	5	33	11.0	11.0	100.0
	Total	300	100.0	100.0	

Table C.20 Car dependency with communication infrastructure

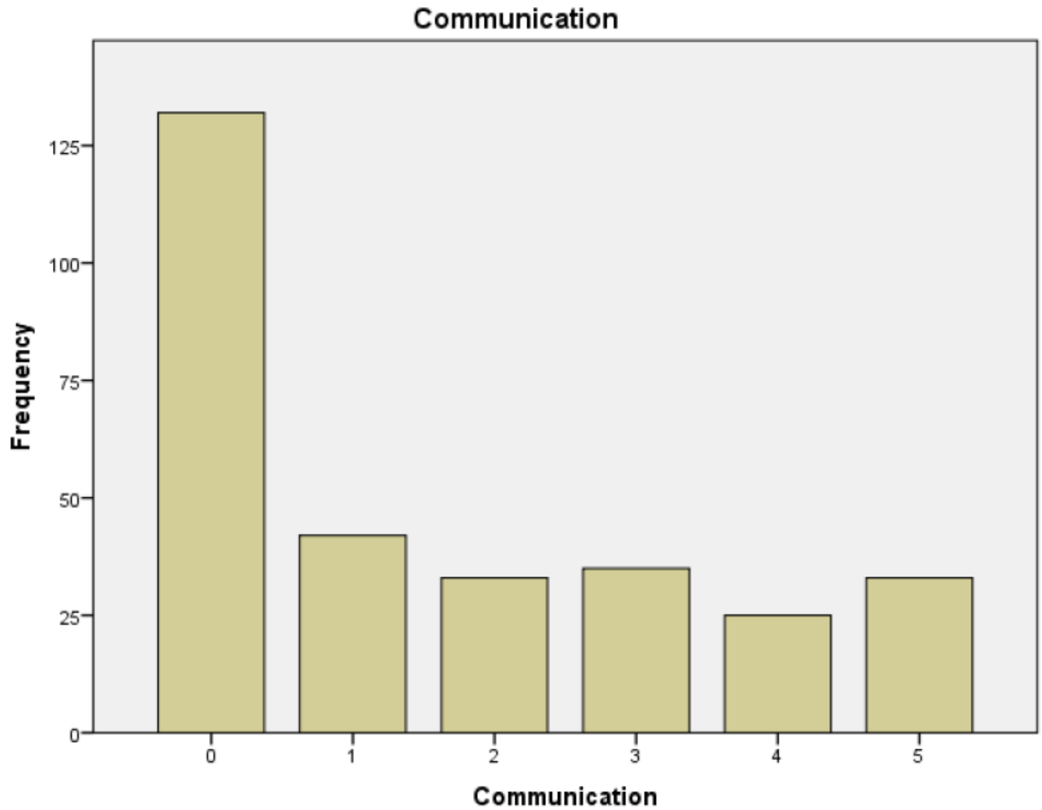


Figure C.20 Car dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	3.0	3.0	3.0
	1	2	.7	.7	3.7
	2	6	2.0	2.0	5.7
	3	7	2.3	2.3	8.0
	4	13	4.3	4.3	12.3
	5	263	87.7	87.7	100.0
	Total	300	100.0	100.0	

Table C.21 Taxi dependency with energy infrastructure

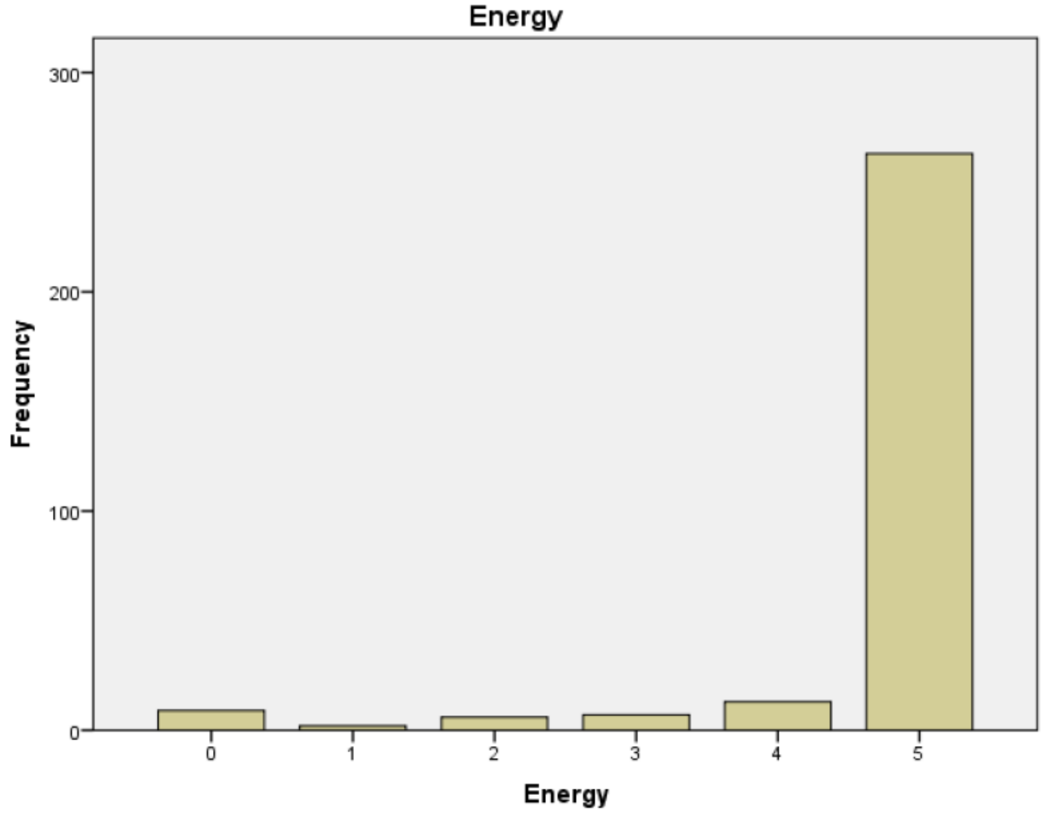


Figure C.21 Taxi dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	269	89.7	89.7	89.7
	1	12	4.0	4.0	93.7
	2	2	.7	.7	94.3
	3	1	.3	.3	94.7
	4	7	2.3	2.3	97.0
	5	9	3.0	3.0	100.0
	Total	300	100.0	100.0	

Table C.22 Taxi dependency with water infrastructure

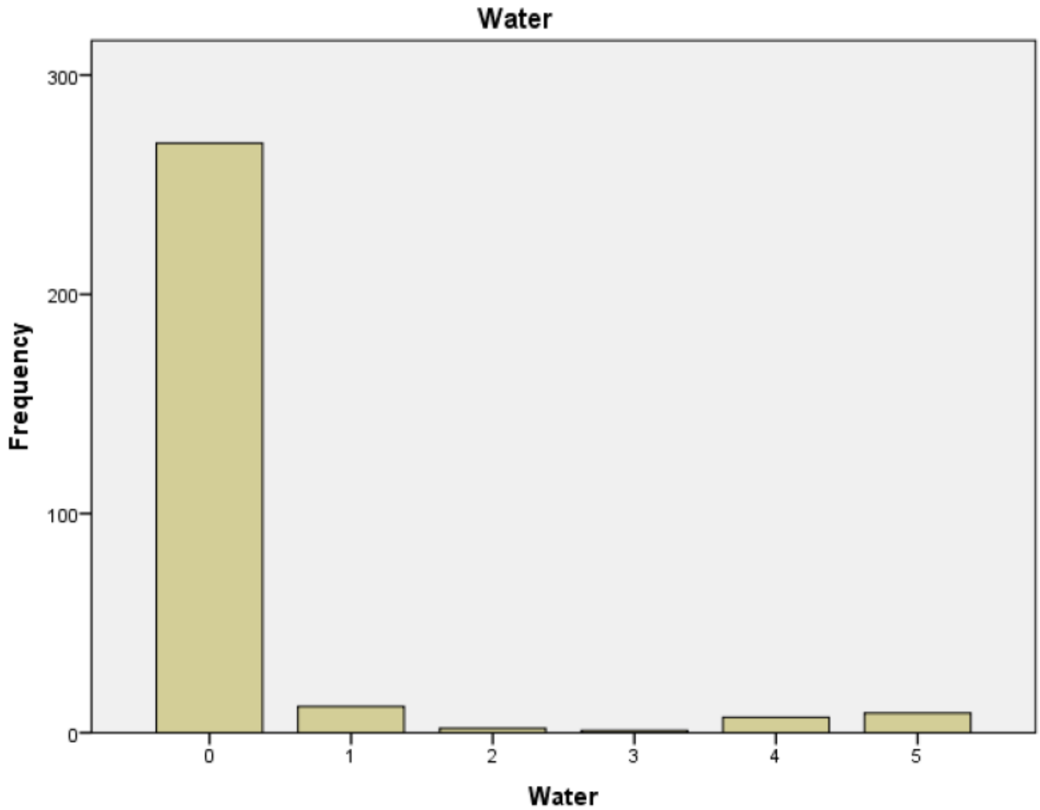


Figure C.22 Taxi dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	256	85.3	85.3	85.3
	1	9	3.0	3.0	88.3
	2	6	2.0	2.0	90.3
	3	7	2.3	2.3	92.7
	4	10	3.3	3.3	96.0
	5	12	4.0	4.0	100.0
	Total	300	100.0	100.0	

Table C.23 Taxi dependency with waste infrastructure

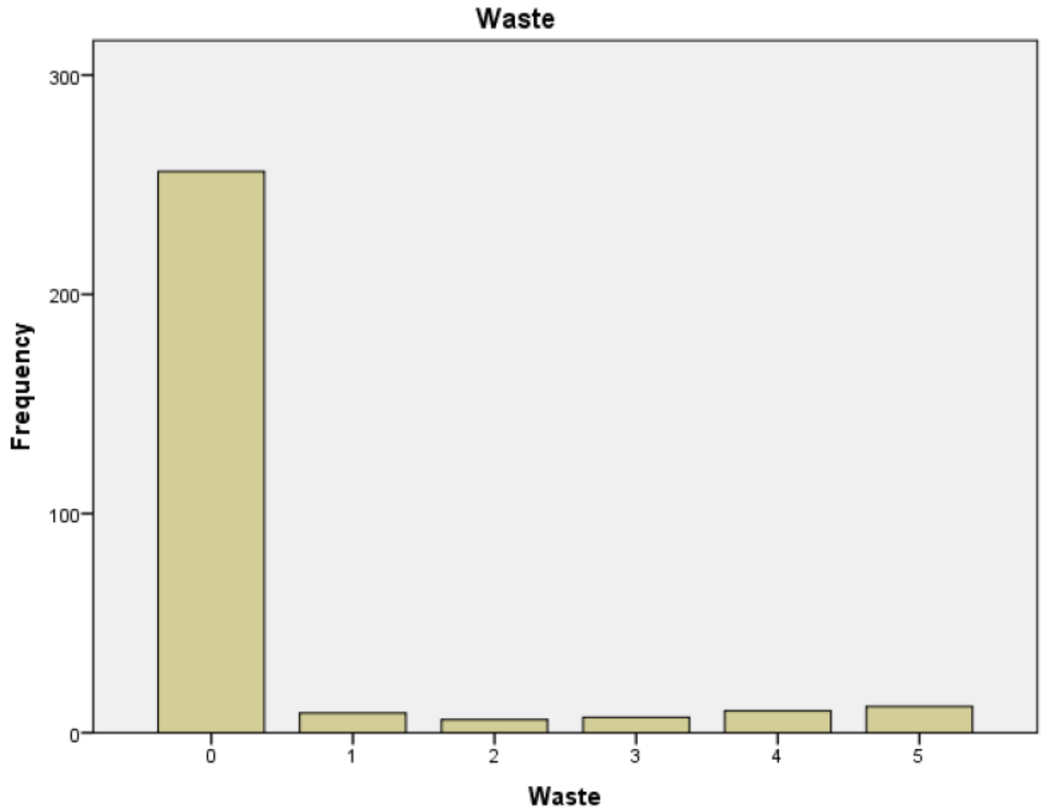


Figure C.23 Taxi dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	42	14.0	14.0	14.0
	1	29	9.7	9.7	23.7
	2	42	14.0	14.0	37.7
	3	49	16.3	16.3	54.0
	4	40	13.3	13.3	67.3
	5	98	32.7	32.7	100.0
	Total	300	100.0	100.0	

Table C.24 Taxi dependency with communication infrastructure

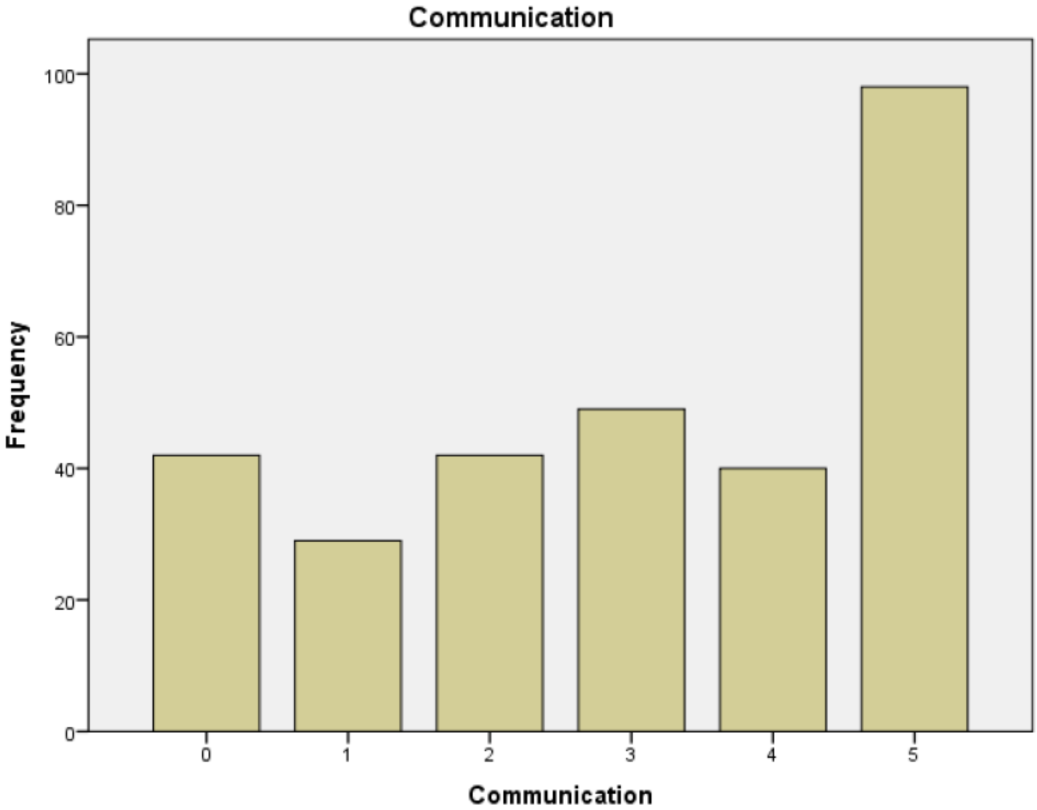


Figure C.24 Taxi dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	3.3	3.3	3.3
	1	1	.3	.3	3.7
	2	4	1.3	1.3	5.0
	3	4	1.3	1.3	6.3
	4	10	3.3	3.3	9.7
	5	271	90.3	90.3	100.0
	Total	300	100.0	100.0	

Table C.25 Air transport dependency with energy infrastructure

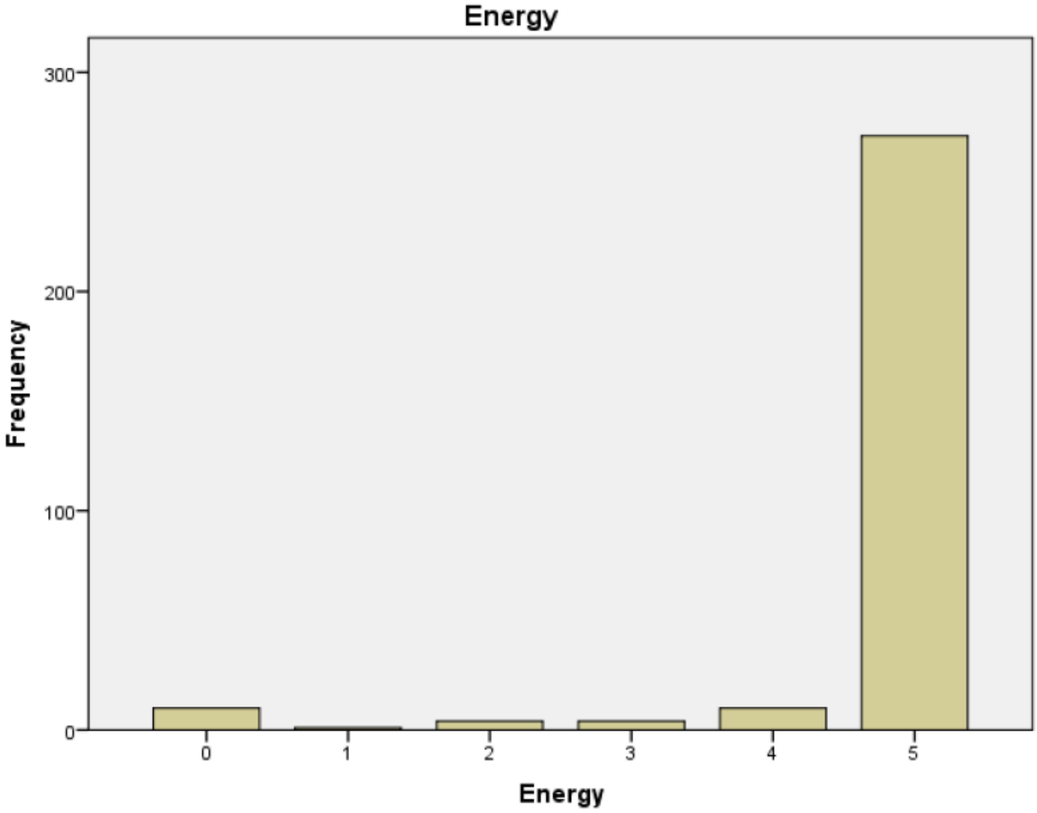


Figure C.25 Air transport dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	246	82.0	82.0	82.0
	1	13	4.3	4.3	86.3
	2	12	4.0	4.0	90.3
	3	10	3.3	3.3	93.7
	4	7	2.3	2.3	96.0
	5	12	4.0	4.0	100.0
	Total	300	100.0	100.0	

Table C.26 Air transport dependency with water infrastructure

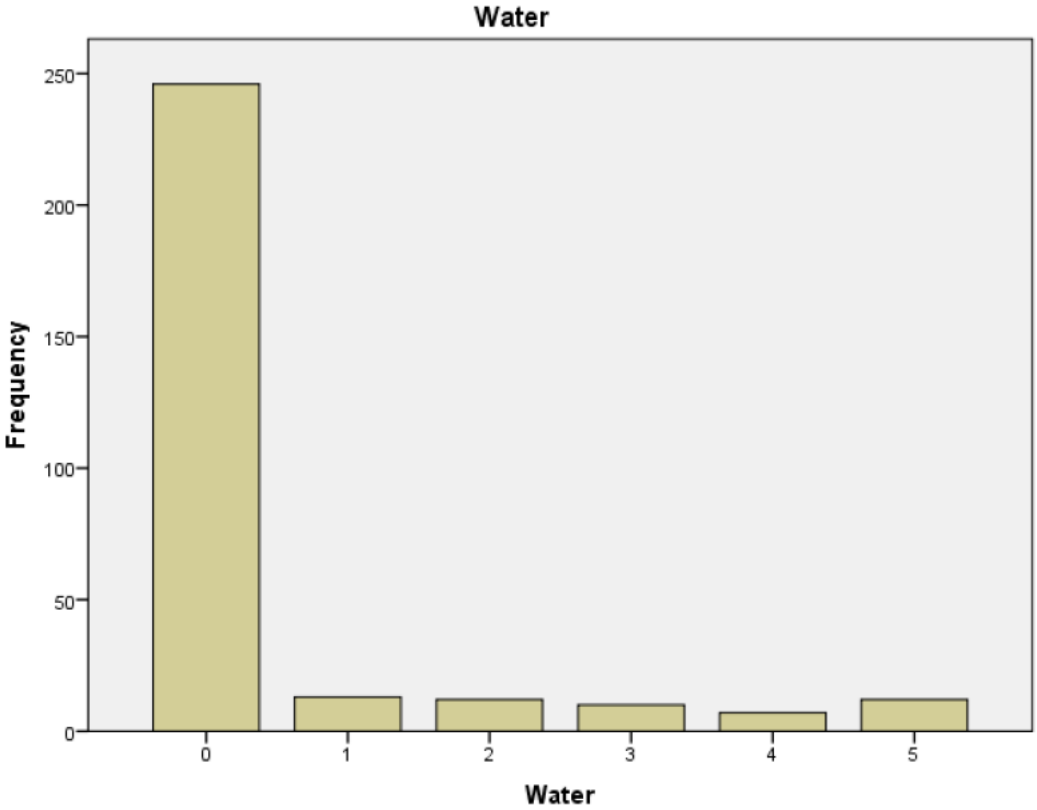


Figure C.26 Air transport dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	232	77.3	77.3	77.3
	1	21	7.0	7.0	84.3
	2	16	5.3	5.3	89.7
	3	10	3.3	3.3	93.0
	4	3	1.0	1.0	94.0
	5	18	6.0	6.0	100.0
	Total	300	100.0	100.0	

Table C.27 Air transport dependency with waste infrastructure

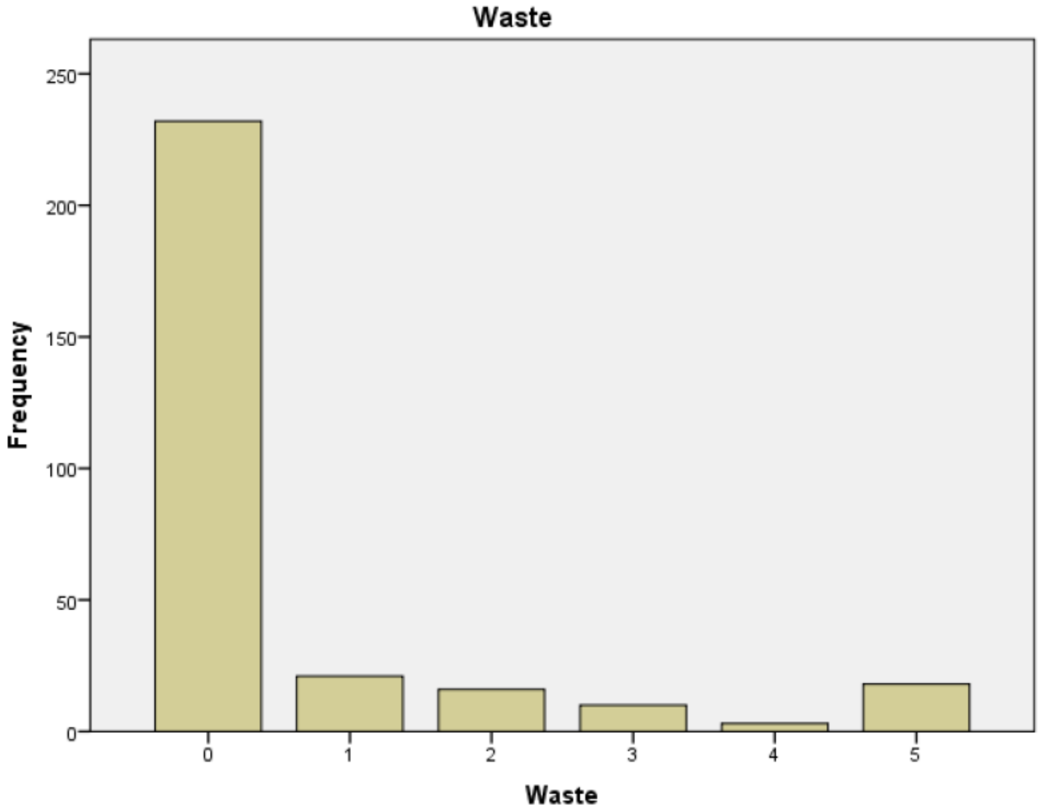


Figure C.27 Air transport dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	37	12.3	12.3	12.3
	1	7	2.3	2.3	14.7
	2	19	6.3	6.3	21.0
	3	19	6.3	6.3	27.3
	4	28	9.3	9.3	36.7
	5	190	63.3	63.3	100.0
	Total	300	100.0	100.0	

Table C.28 Air transport dependency with communication infrastructure

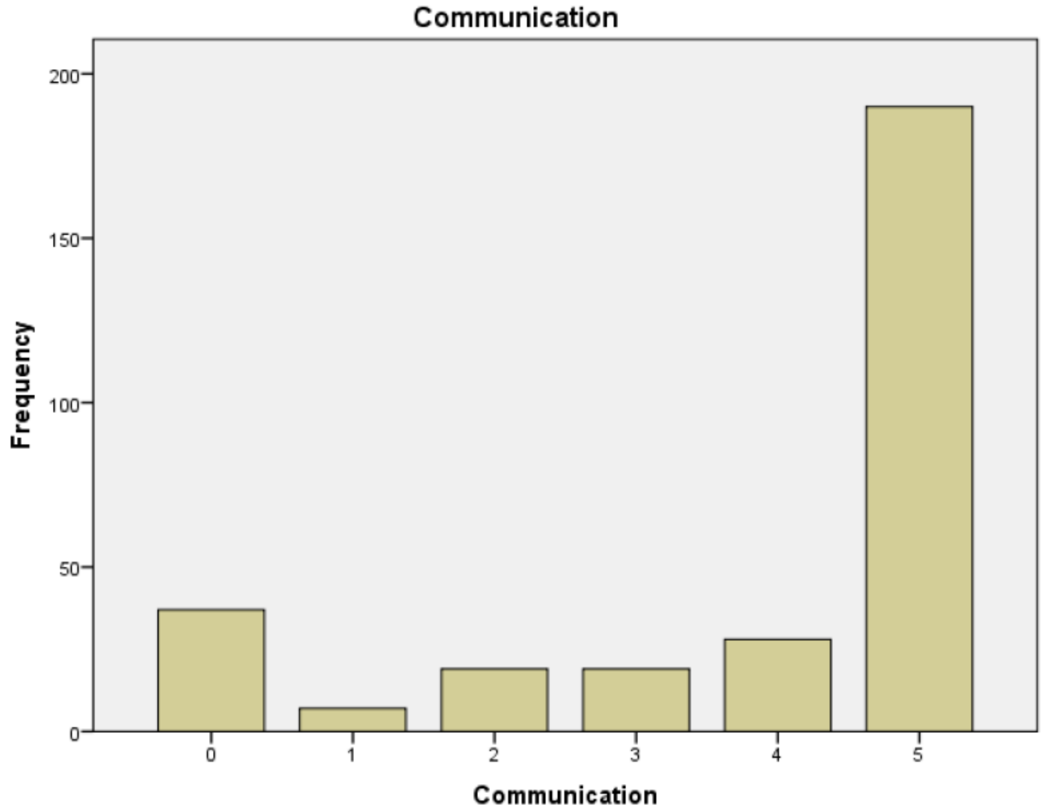


Figure C.28 Air transport dependency with communication infrastructure

Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	19	6.3	6.3	6.3
	1	7	2.3	2.3	8.7
	2	12	4.0	4.0	12.7
	3	12	4.0	4.0	16.7
	4	13	4.3	4.3	21.0
	5	237	79.0	79.0	100.0
	Total	300	100.0	100.0	

Table C.29 Water transport dependency with energy infrastructure

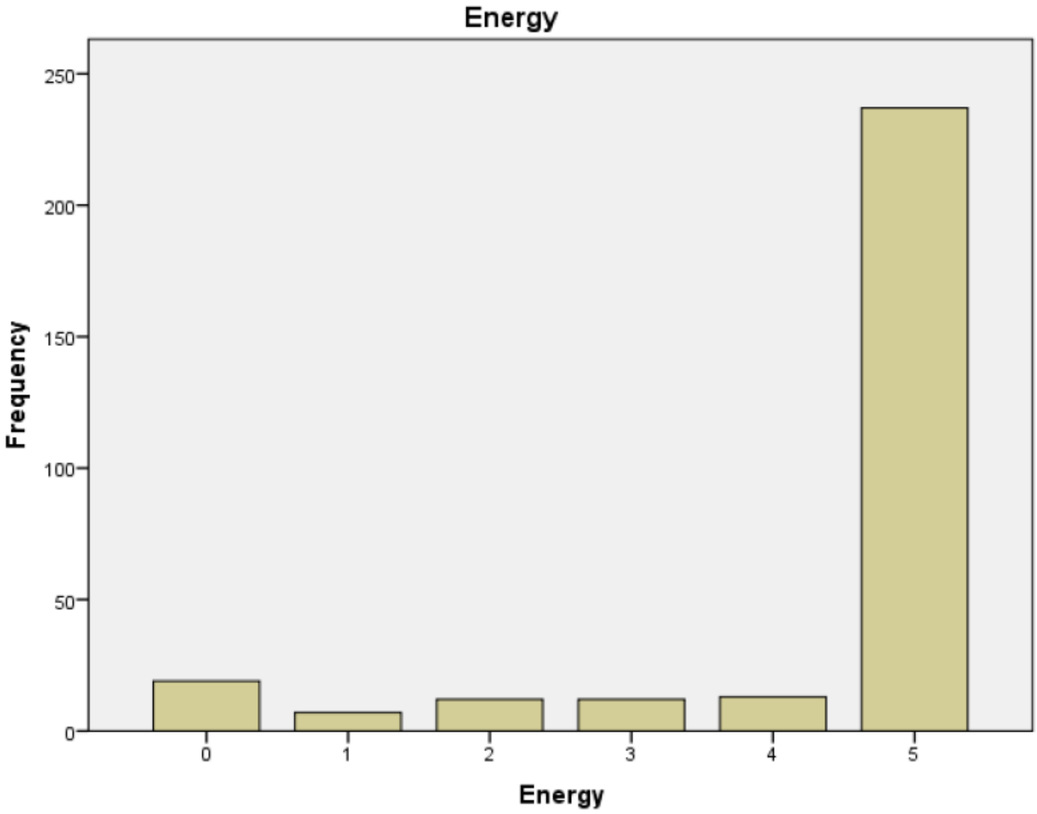


Figure C.29 Water transport dependency with energy infrastructure

Water

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	30	10.0	10.0	10.0
	1	4	1.3	1.3	11.3
	3	1	.3	.3	11.7
	4	8	2.7	2.7	14.3
	5	257	85.7	85.7	100.0
	Total	300	100.0	100.0	

Table C.30 Water transport dependency with water infrastructure

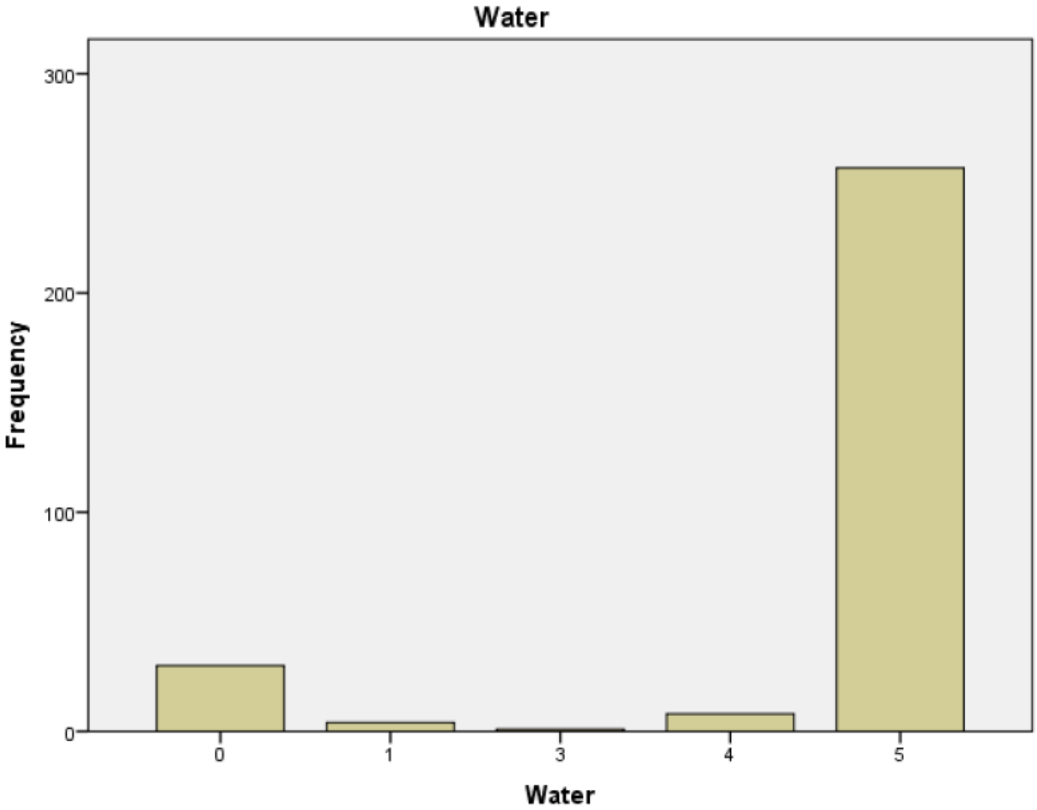


Figure C.30 Water transport dependency with water infrastructure

Waste

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	233	77.7	77.7	77.7
	1	18	6.0	6.0	83.7
	2	14	4.7	4.7	88.3
	3	9	3.0	3.0	91.3
	4	5	1.7	1.7	93.0
	5	21	7.0	7.0	100.0
	Total	300	100.0	100.0	

Table C.31 Water transport dependency with waste infrastructure

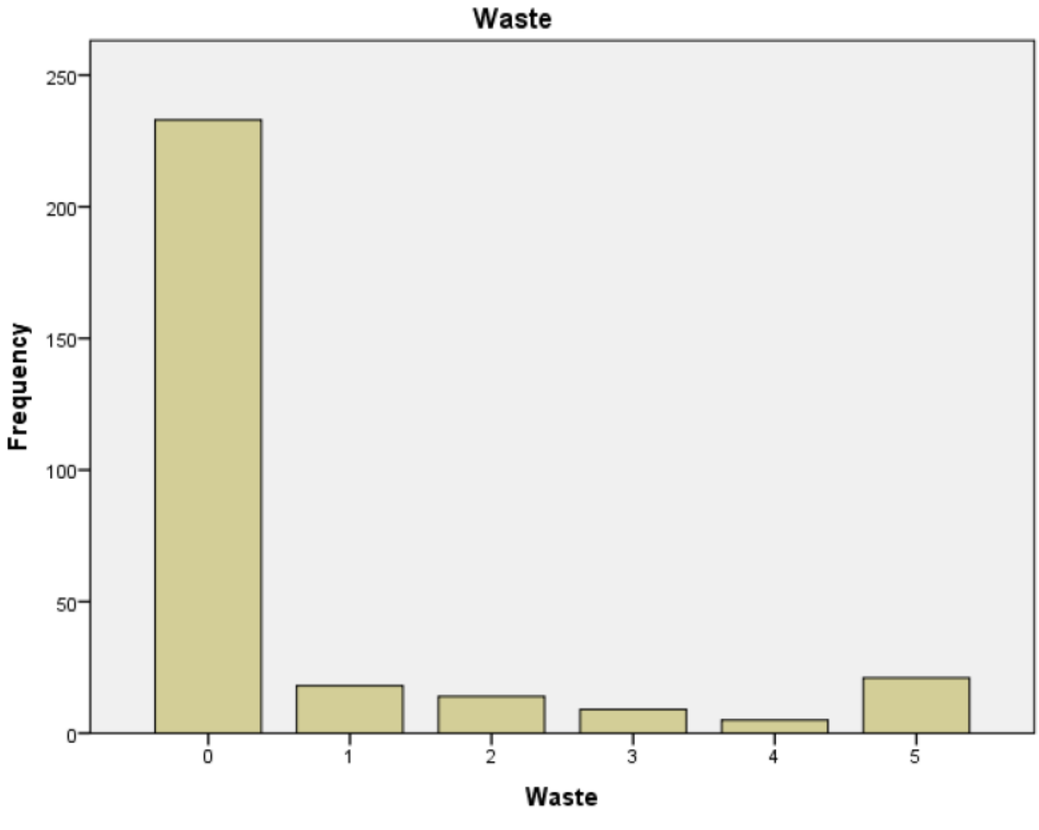


Figure C.31 Water transport dependency with waste infrastructure

Communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	57	19.0	19.0	19.0
	1	52	17.3	17.3	36.3
	2	42	14.0	14.0	50.3
	3	33	11.0	11.0	61.3
	4	27	9.0	9.0	70.3
	5	89	29.7	29.7	100.0
	Total	300	100.0	100.0	

Table C.32 Water transport dependency with communication infrastructure

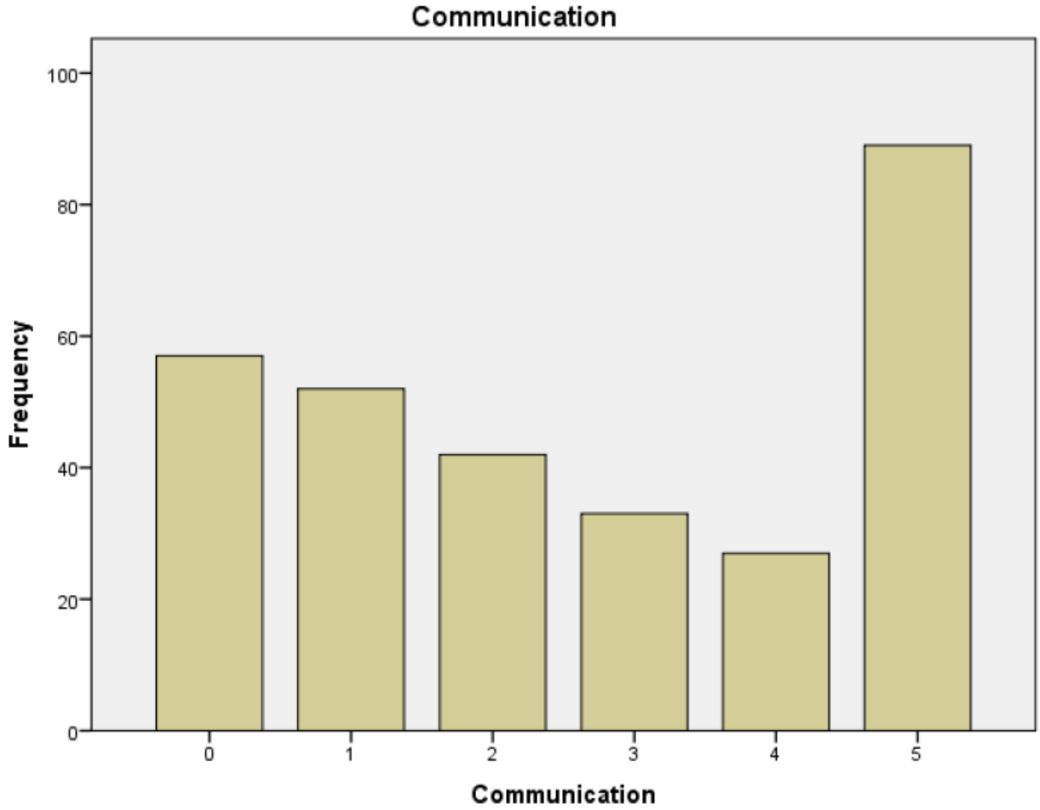


Figure C.32 Water transport dependency with communication infrastructure

Appendix D: Infrastructure/sectors emissions per millions of euros

The numbers represent raw data that in many cases represent artificial precision. The numbers used in the main body of the thesis have been adjusted to represent the confidence in each value.

Combustion	/M.EUR	Transport via railways	Other land transport	Transport via pipelines	Sea and coastal water transport	Inland water transport	Air transport
CO_2	kg	111343.9	75817.3	71681.49	1108655.203	1.83E+07	1862350.55
CH_4	kg	6.238257	4.54647	4.298415	78.72147886	1256.948296	14.3246283
N_2O	kg	42.21357	28.65806	27.09408	73.19358565	4603.169686	53.2051471
SO_x	kg	17.04783	1.969464	1.861975	17143.43579	152268.3867	568.83487
NO_x	kg	1811.144	519.2538	490.9285	25327.8992	408003.4647	6118.75415
NH_3	kg	0.270514	1.05822	1.000488	0.05264327	0.047646388	0.17962125
CO	kg	371.9159	178.2455	168.5243	2609.062487	41939.39313	11860.3205
Benzo(a)-pyrene	kg	0.001062	0.00117	0.001106	6.13E-05	5.55E-05	0.0020887
Benzo(b)-fluoranthene	kg	0.001836	0.004233	0.004003	0.007221654	0.113501983	0.00240859
Benzo(k)-fluoranthen	kg	9.78E-04	6.61E-04	6.25E-04	2.80E-05	2.54E-05	1.22E-04

Indeno(1,2,3-cd)pyrene	kg	6.25E-04	4.27E-04	4.04E-04	0.003532855	0.056681484	6.18E-05
PCDD_F	kg I-TEQ	2.70E-09	2.46E-09	2.33E-09	1.13E-10	1.02E-10	4.57E-10
NMVOC	kg	160.2165	28.55117	26.99358	844.7898495	13600.89201	435.243209
PM_{10}	kg	50.23377	30.27385	28.62203	2122.43322	18402.08881	12.4706341
$PM_{2 5}$	kg	47.76662	27.92559	26.40159	2122.333157	18402.00751	57.8458301
TSP	kg	53.38177	44.33343	41.91496	2123.055043	18402.64132	14.1566342
As	kg	0	0	0	154.8712546	1086.557878	0
Cd	kg	3.51E-04	2.74E-04	2.59E-04	9.292351941	65.21871018	9.31E-05
Cr	kg	0.001817	0.003572	0.003377	0.063771562	0.574430091	7.68E-04
Cu	kg	0.06095	0.092727	0.087669	154.87521	1086.561458	0.02219303
Hg	kg	0	0	0	6.197080476	43.62924232	0
Ni	kg	0.002449	0.001726	0.001632	9.294917712	65.42838692	6.47E-04
Pb	kg	0.009344	0.006423	0.006072	0.066397099	0.784160389	0.00138649
Se	kg	3.51E-04	3.02E-04	2.85E-04	0.132253666	1.567866517	9.63E-05
Zn	kg	0.035647	0.047423	0.044836	0.301652597	3.70419127	0.01178429
NMVOC (NC)	Kg	94.03963	117.3346	1.142945	11.18485141	22.71792767	44.9018179

Transport		GB	GB	GB	GB	GB	GB	GB	GB	GB	GB
Combustion	/M.EUR	Manufacture of motor vehicles, trailers and semi-trailers	Manufacture of other transport equipment	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	Retail sale of automotive fuel	Transport via railways	Other land transport	Transport via pipelines	Sea and coastal water transport	Inland water transport	Air transport
CO2	kg	20189.56423	30835.96883	15337.77805	70140.17465	111343.9	75817.3	71681.49	1108655.203	1.83E+07	1862350.55
CH4	kg	0.556520143	0.797515374	0.700365474	1.511312079	6.238257	4.54647	4.298415	78.72147886	1256.948296	14.3246283
N2O	kg	1.793773793	1.443605764	3.619895089	2.258851783	42.21357	28.65806	27.09408	73.19358565	4603.169686	53.2051471
SOx	kg	25.35766668	11.13914083	7.107112811	2.008445598	17.04783	1.969464	1.861975	17143.43579	152268.3867	568.83487
NOx	kg	35.05666252	48.0562249	52.95923313	115.6997005	1811.144	519.2538	490.9285	25327.8992	408003.4647	6118.75415
NH3	kg	0.090620189	0.092836237	0.209112791	0.168105969	0.270514	1.05822	1.000488	0.05264327	0.047646388	0.17962125
CO	kg	35.92423416	23.1431504	29.63364197	49.30823167	371.9159	178.2455	168.5243	2609.062487	41939.39313	11860.3205
Benzo(a)-pyrene	kg	0.001306613	5.33E-04	5.65E-04	2.84E-04	0.001062	0.00117	0.001106	6.13E-05	5.55E-05	0.0020887
Benzo(b)-fluoranthene	kg	0.001696551	6.83E-04	8.91E-04	5.15E-04	0.001836	0.004233	0.004003	0.007221654	0.113501983	0.00240859
Benzo(k)-fluoranthen	kg	6.91E-04	3.24E-04	2.73E-04	8.88E-05	9.78E-04	6.61E-04	6.25E-04	2.80E-05	2.54E-05	1.22E-04
Indeno(1,2,3-cd)pyrene	kg	4.92E-04	1.80E-04	1.67E-04	5.78E-05	6.25E-04	4.27E-04	4.04E-04	0.003532855	0.056681484	6.18E-05
PCBs	kg	3.45E-06	1.37E-13	7.08E-08	2.45E-08	0	0	0	0	0	0
PCDD_F	kg I-TEQ	5.17E-09	1.71E-09	1.38E-09	2.77E-09	2.70E-09	2.46E-09	2.33E-09	1.13E-10	1.02E-10	4.57E-10
HCB	kg	1.26E-08	5.00E-16	7.08E-09	2.45E-09	0	0	0	0	0	0
NMVOC	kg	4.072347261	3.06257864	4.173452966	5.766210781	160.2165	28.55117	26.99358	844.7898495	13600.89201	435.243209
PM10	kg	4.172759822	2.531522459	3.681548587	2.855817406	50.23377	30.27385	28.62203	2122.43322	18402.08881	12.4706341
PM2.5	kg	3.691298413	2.089490563	3.244762362	2.648756852	47.76662	27.92559	26.40159	2122.333157	18402.00751	57.8458301

TSP	kg	5.12282366	3.527125556	5.460148646	4.158320362	53.38177	44.33343	41.91496	2123.055043	18402.64132	14.1566342
As	kg	1.52E-04	1.16E-04	5.90E-05	1.16E-04	0	0	0	154.8712546	1086.557878	0
Cd	kg	1.76E-04	2.45E-04	8.95E-05	6.12E-04	3.51E-04	2.74E-04	2.59E-04	9.292351941	65.21871018	9.31E-05
Cr	kg	0.001134407	0.001347338	9.84E-04	0.001111952	0.001817	0.003572	0.003377	0.063771562	0.574430091	7.68E-04
Cu	kg	0.002891158	0.00291766	0.008072978	0.006990713	0.06095	0.092727	0.087669	154.87521	1086.561458	0.02219303
H	kg	2.19E-04	1.05E-04	2.84E-05	2.69E-04	0	0	0	6.197080476	43.62924232	0
Ni	kg	0.013316142	0.020543016	0.012768938	0.003467215	0.002449	0.001726	0.001632	9.294917712	65.42838692	6.47E-04
Pb	kg	0.003648871	0.001388648	0.001428402	0.001721463	0.009344	0.006423	0.006072	0.066397099	0.784160389	0.00138649
Se	kg	4.59E-05	1.18E-05	3.77E-05	3.61E-05	3.51E-04	3.02E-04	2.85E-04	0.132253666	1.567866517	9.63E-05
Zn	kg	0.00864587	0.00742023	0.00578031	0.018996759	0.035647	0.047423	0.044836	0.301652597	3.70419127	0.01178429

		GB	GB	GB	GB	GB	GB	GB	GB	GB	GB	GB
Combustion	/M.EUR	Production of electricity by coal	Production of electricity by gas	Production of electricity by nuclear	Production of electricity by hydro	Production of electricity by wind	Production of electricity by petroleum and other oil derivatives	Production of electricity by biomass and waste	Production of electricity by solar photovoltaic	Production of electricity nec	Transmission of electricity	Distribution and trade of electricity
CO2	kg	1.94E+07	3780831.664	1899.914863	2181.197429	2118.984322	5596856.643	5274146.357	1302.524097	7819.780309	1285.376624	1286.147137
CH4	kg	204.8112172	61.45113027	0.121790857	0.139548043	0.13529369	185.541027	5661.669744	0.085076256	0.191020158	0.083956298	0.084007857
N2O	kg	307.5467479	6.333976042	0.621493764	0.71153843	0.689358806	100.8301484	749.6507383	0.437194504	0.376886774	0.43143204	0.43169373
SOx	kg	41966.22665	17.29237671	0.115498717	0.13226784	0.128162196	24972.45515	2778.245343	0.081084275	0.101402984	0.080021062	0.080069819
NOx	kg	63469.30713	5573.409544	11.49587202	13.17154323	12.76897615	14922.6485	76022.90073	8.03396983	17.38571787	7.927994368	7.932813138
NH3	kg	0.073710353	1.807267777	0.095864458	0.109757717	0.106331079	24.26030974	0.106895747	0.067442602	0.056293057	0.066559258	0.0666008
CO	kg	30714.53782	2356.696838	9.957790985	11.40490885	11.05290391	569.1799934	92953.13657	6.981439656	10.54367991	6.889813652	6.894011665
Benzo(a)-pyrene	kg	2.56E-04	7.65E-05	1.35E-04	1.55E-04	1.50E-04	7.15E-05	0.403623591	9.53E-05	7.96E-05	9.40E-05	9.41E-05
Benzo(b)-fluoranthene	kg	1.61E-04	1.17E-04	2.10E-04	2.40E-04	2.33E-04	1.10E-04	0.015724314	1.48E-04	1.23E-04	1.46E-04	1.46E-04
Benzo(k)-fluoranthen	kg	1.12E-05	5.63E-05	1.45E-05	1.67E-05	1.61E-05	2.96E-05	0.005599959	1.02E-05	8.64E-06	1.01E-05	1.01E-05
Indeno(1,2,3-cd)pyrene	kg	2.49E-04	5.48E-05	9.69E-06	1.11E-05	1.07E-05	3.85E-04	0.134741513	6.82E-06	5.79E-06	6.73E-06	6.73E-06
PCBs	kg	0.034800308	0	0	0	0	0	0.021614472	0	0	0	0
PCDD_F	kg I-TEQ	2.05E-06	3.06E-08	1.33E-10	1.53E-10	1.48E-10	1.35E-07	1.80E-05	9.35E-11	1.12E-10	9.23E-11	9.24E-11
HCB	kg	1.27E-04	0	0	0	0	0	0.002161432	0	0	0	0
NMVOC	kg	246.6405723	94.56192347	1.286223378	1.47283538	1.426923095	111.5916495	2634.805514	0.903993891	0.934529649	0.892127004	0.892658882
PM10	kg	2047.700933	63.26467112	0.679884937	0.778547876	0.754312601	1030.110233	11080.27181	0.477811091	0.505580101	0.471510947	0.471787242

PM2.5	kg	1842.829349	63.24695611	0.622741871	0.713081792	0.690900418	781.660284	11888.72057	0.437584793	0.472016996	0.431820252	0.432087981
TSP	kg	6142.32219	63.43450917	1.227784928	1.405875468	1.361991939	1377.178615	18373.7729	0.863269176	0.827320456	0.851925265	0.852427778
As	kg	1.627485697	0.005527329	7.80E-08	9.87E-08	1.05E-07	0.216954025	3.407875965	1.18E-12	1.08E-05	0	0
Cd	kg	0.202668645	0.031629704	7.14E-06	8.23E-06	8.03E-06	0.081127386	0.634021471	4.71E-06	6.57E-05	4.65E-06	4.65E-06
Cr	kg	1.031811672	0.040313691	8.74E-05	1.00E-04	9.70E-05	0.155964355	3.253091134	6.11E-05	1.30E-04	6.03E-05	6.03E-05
Cu	kg	0.992544643	0.025141145	0.002255495	0.002582415	0.002501768	0.298537759	7.603533315	0.001586641	0.001372012	0.001565737	0.001566695
H	kg	0.329590588	0.006186314	8.66E-08	1.10E-07	1.17E-07	0.024861525	0.543966434	1.31E-12	1.20E-05	0	0
Ni	kg	1.11162213	0.060445101	4.24E-05	4.86E-05	4.72E-05	13.46461872	5.115479957	2.92E-05	1.42E-04	2.88E-05	2.89E-05
Pb	kg	1.666501303	0.014418918	1.57E-04	1.79E-04	1.74E-04	0.256445377	7.42124398	1.10E-04	1.20E-04	1.09E-04	1.09E-04
Se	kg	5.158807428	6.90E-04	7.38E-06	8.45E-06	8.19E-06	0.125270921	0.43229908	5.18E-06	5.67E-06	5.12E-06	5.12E-06
Zn	kg	3.972293731	0.835547389	0.001170318	0.001341379	0.001300937	5.015501823	65.20482522	8.15E-04	0.002312473	8.04E-04	8.05E-04

		Energy Gas	Water		Communication
		GB	GB	GB	GB
Combustion	/M.EUR	Manufacture of gas; distribution of gaseous fuels through mains	Steam and hot water supply	Collection, purification and distribution of water	Post and telecommunications
CO2	kg	366327.7281	1.46E+08	47314.74491	45411.69693
CH4	kg	2.332397863	2437.782866	0.987505279	2.538001118
N2O	kg	0.30146303	844.9906687	0.853605473	15.48511883
SOx	kg	0.970598446	92211.0313	3.097732961	2.806228961
NOx	kg	181.10858	282742.4629	68.20585493	282.557602
NH3	kg	0.01086207	46.38039478	0.117254099	0.53956045
CO	kg	72.2722034	120714.1786	42.50981121	96.41057099
Benzo(a)pyrene	kg	1.67E-05	0.001326313	5.77E-04	6.89E-04
Benzo(b)fluoranthene	kg	2.57E-05	0.001653368	8.28E-04	0.002346685
Benzo(k)fluoranthene	kg	3.58E-06	0.001640279	2.74E-04	4.24E-04
Indeno(1,2,3-cd)pyrene	kg	3.04E-06	0.002420652	2.32E-04	2.77E-04
PCBs	kg	0	0.05155358	5.02E-07	6.22E-08
PCDD_F	kg I-TEQ	3.15E-09	4.08E-06	4.59E-09	1.89E-09
HCB	kg	0	1.88E-04	5.02E-08	6.22E-09
NMVOC	kg	5.020437044	3383.280455	4.484639678	15.37600453
PM10	kg	1.594956685	5991.581698	2.588196703	16.53271152

PM2.5	kg	1.588544218	5405.413998	2.449038919	15.22605053
TSP	kg	1.656732304	12450.35438	3.21222998	23.98836601
As	kg	2.14E-04	2.832869374	1.02E-04	2.08E-05
Cd	kg	0.001194952	1.380931868	4.34E-04	1.90E-04
Cr	kg	0.001530925	2.963157178	8.58E-04	0.002107405
Cu	kg	0.001175852	2.57274714	0.002419099	0.049298324
Hg	kg	4.19E-04	0.712113873	1.93E-04	1.98E-05
Ni	kg	0.002286435	18.70216227	0.005065713	0.004168288
Pb	kg	2.33E-04	3.217180095	0.001383092	0.003702149
Se	kg	2.68E-05	7.824859379	2.15E-05	1.63E-04
Zn	kg	0.03166618	37.55756586	0.012863616	0.026401454
NMVOC (non combustion)	kg	1.135929462	0.974871154	33.16723689	5.980380744

Incineration of waste		GB	GB	GB	GB	GB	GB	GB
Combustion	/M.EUR	Incineration of waste: Food	Incineration of waste: Paper	Incineration of waste: Plastic	Incineration of waste: Metals and Inert materials	Incineration of waste: Textiles	Incineration of waste: Wood	Incineration of waste: Oil/Hazardous waste
CO2	kg	548998.0057	548349.5631	2334123.837	430446.7857	2446796.322	2101889.435	559686.1386
CH4	kg	10.76111084	10.79064513	43.22625631	10.69078878	45.26375832	39.12830427	10.89642179
N2O	kg	2.979737233	3.689862366	11.3714733	18.33052819	11.9592751	11.44888518	2.940708059
SOx	kg	8.288632616	7.87314853	23.43770175	8.104155748	24.98700941	21.90277975	7.61912646
NOx	kg	712.2764554	722.3161945	3018.664846	796.2034267	3164.183801	2735.413172	725.68537
NH3	kg	0.265810091	0.329908813	0.793629648	1.841865382	0.824884795	0.835648297	0.25691305
CO	kg	303.0553603	305.5477697	1149.873357	413.2822562	1202.338421	1049.703442	303.2485979
Benzo(a)pyrene	kg	0.001479883	0.001430001	0.002085139	0.003661942	0.002117991	0.002127359	0.001323521
Benzo(b)fluoranthene	kg	0.002217608	0.002188437	0.00339127	0.006219358	0.00345147	0.003470727	0.001998218
Benzo(k)fluoranthene	kg	7.23E-04	6.57E-04	7.89E-04	0.001104288	7.96E-04	7.92E-04	6.34E-04
Indeno(1,2,3-cd)pyrene	kg	6.52E-04	5.88E-04	6.93E-04	9.17E-04	6.92E-04	6.87E-04	5.74E-04
PCBs	kg	1.57E-06	1.38E-06	1.44E-06	1.68E-06	1.40E-06	1.39E-06	1.39E-06
PCDD_F	kg I-TEQ	2.83E-08	2.72E-08	9.14E-08	2.54E-08	9.52E-08	8.29E-08	2.76E-08
HCB	kg	1.57E-07	1.38E-07	1.44E-07	1.68E-07	1.40E-07	1.39E-07	1.39E-07
NMVOC	kg	30.73662866	31.33953318	117.6867839	48.39625405	123.1115778	107.8937237	30.78505917
PM10	kg	10.87711847	11.14972199	31.93143007	26.49055687	33.2571409	30.28992434	10.45083805
PM2.5	kg	10.62729403	10.84950634	31.25864776	24.89645836	32.53586577	29.56051787	10.22455439
TSP	kg	12.28376768	13.0567081	37.03844714	38.88304504	38.61964363	35.72819015	11.83436227

As	kg	9.58E-04	9.47E-04	0.003903773	6.83E-04	0.004092711	0.003515949	9.68E-04
Cd	kg	0.005047078	0.005025037	0.021350088	0.003716834	0.022376454	0.019208457	0.005141476
Cr	kg	0.006934374	0.006951551	0.028224374	0.007052751	0.029617027	0.025592748	0.006987693
Cu	kg	0.009761582	0.012344825	0.040790509	0.062774456	0.042773037	0.040699092	0.009907041
Hg	kg	0.002281947	0.00226885	0.00966522	0.001604532	0.010129953	0.00869	0.002325215
Ni	kg	0.013817073	0.013122538	0.0428807	0.010355084	0.045860467	0.039773862	0.012791082
Pb	kg	0.010810322	0.010827914	0.042956187	0.011661962	0.045034767	0.039002737	0.010860445
Se	kg	1.42E-04	1.48E-04	5.54E-04	2.87E-04	5.80E-04	5.12E-04	1.42E-04
Zn	kg	0.137491773	0.137846066	0.575932261	0.126032764	0.603493124	0.519994286	0.139830575
NMVOC (non combustion)	kg	105.3730349	96.25115798	55.86210071	53.49143998	81.186503	81.32248101	84.81524789

Other waste		GB	GB	GB	GB	GB	GB	GB
Combustion	/M.EUR	Biogasification of food waste, incl. land application	Biogasification of paper, incl. land application	Biogasification of sewage slugde, incl. land application	Composting of food waste, incl. land application	Composting of paper and wood, incl. land application	Waste water treatment, food	Waste water treatment, other
CO2	kg	5824038.981	4.87E+07	119825.357	65934.70278	0	641669.9357	320927.5509
CH4	kg	107.4482085	905.2902562	2.855912185	2.016531729	0	19.94004079	10.37011892
N2O	kg	33.30907646	366.1420417	0.321264082	1.704590868	0	62.00161122	31.33581578
SOx	kg	55.86389802	465.905964	2.11515994	8.425943316	0	20.73013112	13.66126996
NOx	kg	7607.191128	64949.06238	152.2342639	88.26766291	0	1682.754685	840.5655528
NH3	kg	2.376837767	28.09021636	0.095356552	0.125879557	0	6.065764808	3.069469075
CO	kg	2866.484242	24615.26278	93.14435897	72.83954268	0	936.9196344	488.0452613
Benzo(a)pyrene	kg	0.004252845	0.039684137	0.001122881	0.001439783	0	0.009595635	0.005474207
Benzo(b)fluoranthene	kg	0.007376388	0.072350949	0.0016331	0.002037773	0	0.016990933	0.009443271
Benzo(k)fluoranthene	kg	0.001195058	0.007847758	5.91E-04	8.09E-04	0	0.002248919	0.001513232
Indeno(1,2,3-cd)pyrene	kg	9.78E-04	0.005573123	5.62E-04	6.91E-04	0	0.001644628	0.001161503
PCBs	kg	1.43E-06	1.49E-06	1.50E-06	1.56E-06	0	1.63E-06	1.62E-06
PCDD_F	kg I-TEQ	2.17E-07	1.76E-06	1.24E-08	1.11E-08	0	3.53E-08	2.21E-08
HCB	kg	1.43E-07	1.49E-07	1.50E-07	1.56E-07	0	1.63E-07	1.62E-07
NMVOC	kg	296.0990084	2580.704335	8.967359359	7.29302795	0	119.0513398	61.34523845
PM10	kg	79.63776713	732.9553703	4.835194167	5.695031696	0	73.60156838	39.03811883
PM2.5	kg	77.59138456	708.4070745	4.806811904	5.407863651	0	68.0921713	36.18380736
TSP	kg	95.84256549	929.5337462	4.989572749	6.274713395	0	115.8577928	60.24628785

As	kg	0.009655412	0.080118376	2.34E-04	1.87E-04	0	8.75E-04	4.74E-04
Cd	kg	0.053139236	0.443041954	0.001137173	6.23E-04	0	0.004973264	0.002502532
Cr	kg	0.07058438	0.598087127	0.001562188	0.001533773	0	0.014269391	0.007440534
Cu	kg	0.119925525	1.306985401	9.64E-04	0.001543518	0	0.20941122	0.104309362
Hg	kg	0.024035815	0.200001749	5.14E-04	2.77E-04	0	0.00197769	9.95E-04
Ni	kg	0.103658371	0.860388788	0.002307745	0.013873581	0	0.026339468	0.018395982
Pb	kg	0.107134646	0.908667508	0.002718534	0.002542407	0	0.024013714	0.012594761
Se	kg	0.001419381	0.012737648	3.64E-05	3.80E-05	0	7.89E-04	4.03E-04
Zn	kg	1.439176203	12.12146114	0.031696891	0.018464879	0	0.222453777	0.112277471
NMVOC (non combustion)	kg	24.87532361	30.12867686	30.30895086	67.92892874	0	132.694917	150.1340979

Landfill of waste		GB	GB	GB	GB	GB	GB
Combustion	/M.EUR	Landfill of waste: Food	Landfill of waste: Paper	Landfill of waste: Plastic	Landfill of waste: Inert/metal/hazardous	Landfill of waste: Textiles	Landfill of waste: Wood
CO2	kg	119968.9476	144729.0141	245746.5876	132704.0589	829949.0863	468588.5731
CH4	kg	3.015278924	3.437056608	5.216642936	3.215689666	15.61550583	9.174575972
N2O	kg	1.378444477	1.147844829	1.084700348	1.036000823	1.939694616	1.306921319
SOx	kg	7.843567406	6.658105931	6.383501499	6.086215676	10.68907466	7.522189025
NOx	kg	152.8244307	183.6326554	309.6286842	168.6114829	1038.558812	587.6548076
NH3	kg	0.106978429	0.10516757	0.103960717	0.104866896	0.103213255	0.103203422
CO	kg	95.43732673	106.3970581	151.5137387	101.1378661	412.0036622	250.9383862
Benzo(a)pyrene	kg	0.001389832	0.001337657	0.001299143	0.001323532	0.001276742	0.00127417
Benzo(b)fluoranthene	kg	0.001965846	0.001903668	0.00185931	0.001887744	0.001835842	0.001831405
Benzo(k)fluoranthene	kg	7.83E-04	7.43E-04	7.13E-04	7.31E-04	6.99E-04	6.94E-04
Indeno(1,2,3-cd)pyrene	kg	6.80E-04	6.58E-04	6.43E-04	6.52E-04	6.40E-04	6.35E-04
PCBs	kg	1.58E-06	1.58E-06	1.58E-06	1.58E-06	1.59E-06	1.59E-06
PCDD_F	kg I-TEQ	1.31E-08	1.39E-08	1.75E-08	1.35E-08	3.83E-08	2.54E-08
HCB	kg	1.58E-07	1.58E-07	1.58E-07	1.58E-07	1.59E-07	1.59E-07
NMVOC	kg	9.423978654	10.45940901	14.91891881	9.912257496	40.92716309	24.82327996
PM10	kg	5.870453005	5.880763181	6.619970705	5.715257615	11.70988507	8.494072107
PM2.5	kg	5.637018367	5.697813437	6.479108349	5.548981893	11.60151663	8.383798852
TSP	kg	6.276818249	6.226643095	6.91555846	6.04143871	11.96730085	8.753603179
As	kg	2.72E-04	3.04E-04	4.66E-04	2.82E-04	0.001436164	8.33E-04

Cd	kg	0.001124612	0.001355666	0.002286384	0.001246672	0.007652095	0.004334577
Cr	kg	0.002057607	0.002226624	0.003307516	0.00204642	0.010062047	0.005841027
Cu	kg	0.001242191	0.001350445	0.002011082	0.001243063	0.006112856	0.003551705
Hg	kg	5.06E-04	6.12E-04	0.00103493	5.62E-04	0.003473191	0.001965786
Ni	kg	0.012857922	0.010681842	0.0102649	0.009602234	0.018829845	0.012593097
Pb	kg	0.003349765	0.003635606	0.005285538	0.003377208	0.015440075	0.009106928
Se	kg	4.51E-05	4.79E-05	6.63E-05	4.48E-05	1.82E-04	1.09E-04
Zn	kg	0.031450389	0.03755126	0.062135622	0.034677806	0.2038406	0.116230434
NMVOC (non Combustion)	kg	103.461661	81.7620119	75.75536389	75.92137941	67.34720987	68.84362404

Appendix E: SPSS results

Age Factor

Descriptives

Overall Evaluation

	N	Mean	Std. Deviation	Std. Error
1	184	0,04	3,376	0,249
2	400	0,78	3,323	0,166
3	384	0,85	3,439	0,176
4	424	0,23	3,405	0,165
5	352	-0,33	3,195	0,17
6	176	-0,25	3,259	0,246
7	480	0,3	3,224	0,147

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Car	1	23	2,35	2,461	0,513
	2	50	1,16	3,633	0,514
	3	48	1,63	3,443	0,497
	4	53	2,26	2,949	0,405
	5	44	1,05	3,348	0,505
	6	22	2,41	2,789	0,595
	7	60	1,50	3,213	0,415

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Air	1	23	1,13	3,584	0,747
	2	50	2,50	2,613	0,370
	3	48	2,88	2,606	0,376
	4	53	1,89	2,722	0,374
	5	44	-0,23	2,744	0,414
	6	22	1,23	3,624	0,773
	7	60	0,92	2,948	0,381

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Walking	1	23	0,48	3,409	0,711
	2	50	1,86	3,245	0,459
	3	48	1,27	3,279	0,473
	4	53	0,68	3,338	0,459
	5	44	1,48	3,008	0,453
	6	22	0,41	3,050	0,650
	7	60	1,22	3,147	0,406

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Taxi	1	23	0,26	2,880	0,600
	2	50	0,48	3,196	0,452
	3	48	1,31	3,054	0,441
	4	53	-0,11	3,042	0,418
	5	44	-0,93	2,748	0,414
	6	22	-0,14	2,900	0,618
	7	60	0,17	3,104	0,401

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Water	1	23	-1,00	2,985	0,622
	2	50	0,22	2,772	0,392
	3	48	0,83	2,716	0,392
	4	53	-0,79	2,951	0,405
	5	44	-0,61	2,554	0,385
	6	22	-0,73	2,931	0,625
	7	60	-0,08	3,060	0,395

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Rail	1	23	-0,48	4,032	0,841
	2	50	0,16	3,548	0,502
	3	48	-1,02	3,699	0,534
	4	53	-0,66	4,028	0,553
	5	44	-0,82	3,737	0,563
	6	22	-1,68	3,030	0,646
	7	60	0,35	3,635	0,469

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Cycling	1	23	-0,65	3,242	0,676
	2	50	0,84	3,605	0,510
	3	48	0,08	3,758	0,542
	4	53	-0,60	3,307	0,454
	5	44	-0,93	3,165	0,477
	6	22	-2,45	2,324	0,496
	7	60	-1,20	2,851	0,368

Descriptives

Evaluation

Mode		N	Mean	Std. Deviation	Std. Error
Bus	1	23	-1,74	2,832	0,590
	2	50	-0,96	2,762	0,391
	3	48	-0,21	3,458	0,499
	4	53	-0,85	3,290	0,452
	5	44	-1,66	3,050	0,460
	6	22	-1,05	2,903	0,619
	7	60	-0,45	3,067	0,396

Gender Factor

Descriptives

Evaluation

	N	Mean	Std. Deviation	Std. Error
Male	1176	0,33	3,348	0,098
Female	1224	0,28	3,333	0,095

Travel time

Descriptives

TravelTime

	N	Mean	Std. Deviation	Std. Error
Walking	300	-0,70	3,294	0,190
Cycling	300	-0,55	3,242	0,187
Rail	300	0,45	3,501	0,202
Bus	300	-0,36	3,277	0,189
Car	300	2,93	2,867	0,166
Taxi	300	2,25	2,890	0,167
Air	300	2,68	2,732	0,158
Water	300	-0,94	2,828	0,163

Excess time

Descriptives

ExcessTime

	N	Mean	Std. Deviation	Std. Error
Walking	300	1,62	3,344	0,193
Cycling	300	0,41	3,299	0,190
Rail	300	-0,99	3,147	0,182
Bus	300	-1,61	2,833	0,164
Car	300	1,40	3,357	0,194
Taxi	300	-0,99	3,274	0,189
Air	300	0,19	3,099	0,179
Water	300	-0,09	2,667	0,154

Travel cost

Descriptives

TravelCost

	N	Mean	Std. Deviation	Std. Error
Walking	300	2,65	2,529	0,146
Cycling	300	1,40	2,874	0,166
Rail	300	-1,30	2,897	0,167
Bus	300	-1,31	2,898	0,167
Car	300	-1,44	3,262	0,188
Taxi	300	-3,68	2,156	0,124
Air	300	-0,52	3,184	0,184
Water	300	-0,69	2,489	0,144

Comfort

Descriptives

Comfort

	N	Mean	Std. Deviation	Std. Error
Walking	300	0,65	3,448	0,199
Cycling	300	-1,85	3,098	0,179
Rail	300	-0,09	3,687	0,213
Bus	300	-0,66	3,176	0,183
Car	300	3,03	2,626	0,152
Taxi	300	2,44	2,742	0,158
Air	300	0,76	3,050	0,176
Water	300	1,00	2,946	0,170

Safety

Descriptives

Safety

	N	Mean	Std. Deviation	Std. Error
Walking	300	0,22	3,176	0,183
Cycling	300	-1,61	2,856	0,165
Rail	300	0,73	3,125	0,180
Bus	300	0,18	2,914	0,168
Car	300	2,40	2,715	0,157
Taxi	300	1,81	2,639	0,152
Air	300	0,47	3,170	0,183
Water	300	-0,33	2,711	0,157

Appendix F: Analysis of each benefits and need by transport mode

Table F1 Descriptive statistics of the evaluations of air transport

Air Transport

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		1.5367	2.6833	.1900	-.5167	.7600	.4667	-2.4733	.9100	-3.3367	3.3267	.7500
Median		2.0000	4.0000	.0000	.0000	1.0000	.0000	-4.0000	1.0000	-5.0000	4.0000	.0000
Mode		5.00	5.00	.00	.00	.00	.00	-5.00	.00	-5.00	5.00	.00

Table F2 Descriptive statistics of the evaluations of water transport

Water Transport

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		-.2067	-.9433	-.0900	-.6867	1.0033	-.3267	-1.8167	.9033	-2.4500	3.0133	.3167
Median		.0000	.0000	.0000	.0000	1.0000	.0000	-2.0000	.0000	-3.0000	4.0000	.0000
Mode		.00	.00	.00	.00	.00	.00	-5.00	.00	-5.00	5.00	.00

Table F3 Descriptive statistics of the evaluations of walking

Walking

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		1.1600	-.7033	1.6167	2.6467	.6500	.2233	3.9100	1.5300	3.7100	-.1200	2.9700
Median		2.0000	-1.0000	3.0000	3.0000	1.0000	.0000	5.0000	2.0000	5.0000	.0000	5.0000
Mode		5.00	-5.00	5.00	5.00	5.00	2.00	5.00	5.00	5.00	.00	5.00

Table F4 Descriptive statistics of the evaluations of cycling

Cycling

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		-.5600	-.5533	.4100	1.4000	-1.8533	-1.6133	3.8500	-.0967	3.4033	.2200	1.8333
Median		-.5000	.0000	.0000	1.0000	-3.0000	-2.0000	5.0000	.0000	5.0000	.0000	2.5000
Mode		-5.00	-5.00[a]	.00	.00	-5.00	-5.00	5.00	-5.00	5.00	.00	5.00

a. Multiple modes exist. The smallest value is shown

Table F5 Descriptive statistics of the evaluations of bus

Bus

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		-.8867	-.3567	-1.6067	-1.3067	-.6600	.1767	-2.5900	-1.0267	-2.9367	2.9433	-.3533
Median		-1.0000	.0000	-2.0000	-2.0000	-1.0000	1.0000	-4.0000	-1.0000	-4.0000	3.0000	.0000
Mode		-5.00	-5.00	-5.00	-5.00	-5.00	1.00[a]	-5.00	.00	-5.00	5.00	-5.00

a. Multiple modes exist. The smallest value is shown

Table F6 Descriptive statistics of the evaluations of rail transport

Rail

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		-.4633	.4500	-.9933	-1.3033	-.0933	.7300	-2.4333	-.3133	-1.5900	3.2367	1.0233
Median		.0000	1.0000	-1.0000	-2.0000	.0000	1.0000	-3.5000	.0000	-2.0000	4.0000	2.0000
Mode		-5.00	5.00	-5.00	-5.00	-5.00	5.00	-5.00	.00	-5.00	5.00	5.00

Table F7 Descriptive statistics of the evaluations of car

Car

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		1.6633	2.9300	1.3967	-1.4400	3.0267	2.4033	-2.8233	1.6033	-3.9133	3.1800	-3.0100
Median		3.0000	4.0000	2.0000	-2.0000	4.0000	3.0000	-5.0000	2.0000	-5.0000	4.0000	-5.0000
Mode		5.00	5.00	5.00	-5.00	5.00	5.00	-5.00	5.00	-5.00	5.00	-5.00

Table F8 Descriptive statistics of the evaluations of taxi

Taxi

		Evaluation	TravelTime	ExcessTime	Cost	Comfort	Safety	Health	Recreation	Environment	Industrial	Congestion
N	Valid	300	300	300	300	300	300	300	300	300	300	300
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		.1767	2.2467	-.9867	-3.6800	2.4367	1.8067	-2.6000	.5567	-3.6700	2.6233	-2.6600
Median		.0000	3.0000	-1.0000	-5.0000	3.0000	2.0000	-4.0000	.0000	-5.0000	3.0000	-4.0000
Mode		1.00	5.00	-5.00	-5.00	5.00	5.00	-5.00	.00	-5.00	5.00	-5.00

Appendix G: Interview proforma/ survey

Valuing Transport Infrastructure

Welcome to this survey. Completing this questionnaire will require approximately 20 minutes of your time. **Any information you provide is strictly confidential.**
This survey explores contemporary times and societal trends and their influence on transport infrastructure and on its value. It is conducted in the framework of the research project "iBUILD – Infrastructure BUsiness models, valuation and Innovation for Local Delivery" (https://research.ncl.ac.uk/ibuild/). The results will be used to advance current knowledge and research about Transport systems in United Kingdom.

Questions

In which age group do you belong to?

15-19 ☐ **20-29** ☐ **30-39** ☐ **40-49** ☐ **50-59** ☐ **60-65** ☐ **65+** ☐

In which ethnic group do you belong to?

White ☐ **Asian** ☐ Black ☐ **Other: ___________** **Prefer not to say** ☐

Household description

Number of individuals per household:_____(number of people)

Number of cars per household:_____(number of cars)

Household income in thousands of pounds £ (x10,000) per year:

0-10 ☐ 10-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐

60-70 ☐ 70-80 ☐ 80-90 ☐ 90-100 ☐ >100 ☐

In which area do you leave (the first 5 digitals of your postcode): _ _ _ _ _

Average distance travelled per day (i.e. from where to where)?

____.

Do you adjust your mode of Transport to society?

Yes ☐ No ☐

If Yes what exactly do you do?

____.

If No what would it take to change it?

____.

Tick the ones that apply and fill in the percentage of distance covered of the multimodal transport (DAILY) and evaluate the following dependencies:

Transport	Which do you use	Percentage of distance covered	Transport of goods (tick)	Evaluate your Travel Dependency from (rate from 0 to 5)			
				Energy Infra-structure	Water Infra-structure	Waste Infra-structure	Commu-nications Infra-structure
Walking	☐	%	☐				
Cycling	☐	%	☐				
Rail	☐	%	☐				
Bus	☐	%	☐				
Car	☐	%	☐				
Taxi	☐	%	☐				

Rate how the following transport means affect your MAIN mode of Transport on a day

- **Rate from -5 to -1 if you think that affect negatively your daily travel overall**
- **Rate from 0 if you think that does not affect your daily travel overall**
- **Rate from 1 to 5 if you think that affect positively your daily travel overall**

Walking: -5 -4 -3 -2 -1 0 1 2 3 4 5

Cycling: -5 -4 -3 -2 -1 0 1 2 3 4 5

Rail: -5 -4 -3 -2 -1 0 1 2 3 4 5

Bus: -5 -4 -3 -2 -1 0 1 2 3 4 5

Car: -5 -4 -3 -2 -1 0 1 2 3 4 5

Taxi: -5 -4 -3 -2 -1 0 1 2 3 4 5

Transport	**Number of trips last year**	**From (i.e London)**	**To (i.e Athens)**	**Evaluate your Travel Dependency from (rate from 0 to 5)**			
				Energy Infra-structure	**Water Infra-structure**	**Waste Infra-structure**	**Commu-nications Infra-structure**
Air transport							
Water transp.							

Rate how the following transport means affect YOUR way of Transport in general:

Air transport: -5 -4 -3 -2 -1 0 1 2 3 4 5

Water transport: -5 -4 -3 -2 -1 0 1 2 3 4 5

Rate the following factors of each transport mean from -5 to 5 based on your personal experience (choose -5 if the particular transport mean does not fulfill, at all, the specific factor, choose 5 if the particular transport mean fulfills at maximum the specific factor)					
	Travel Time	**Excess Travel Time**	**Travel Cost**	**Comfort and Convenience**	**Safety and Security**
Walking					
Cycling					
Rail					
Bus					
Car					
Taxi					
Air transport					
Water transp.					

Rate the following benefits of each transport mean from -5 to 5 based on your personal experience					
	Health benefits	**Recreation benefits**	**Environmental benefits**	**Industrial benefits**	**Congestion benefits**
Walking					
Cycling					
Rail					
Bus					
Car					
Taxi					
Air transport					
Water transp.					

Which are the main reasons for choosing your transport mean (e.g. time, cost, comfort etc.)?

____

Should you have any questions about the current survey or the study in general, you may contact Mr Nikolaos Kalyviotis of the University of Birmingham (by email at [redacted] or by phone at [redacted] or [redacted] who will be happy to respond to any questions.