Driving in the Wrong Lane:

Towards a Change in Paradigm for Optimal Passenger Car Lifespans

Alexandre Rodrigues

A thesis submitted in partial fulfilment of the requirements of Nottingham Trent University for the degree of Dr of Philosophy

September 2018

“The day the cars will lay in heaps

Their wheels turning in vain

We'll run along the empty highways

Shouting, screaming, singing

Loud, loud, loud, loud”

Ferris, C., Vangelis, 1972. Loud, Loud, Loud. *In: Aphrodite’s Child*

COPYRIGHT STATEMENT

ABSTRACT

Passenger cars are responsible for high demands of energy and materials, both from manufacturing and use stage; raw material resource extraction, transformation, use and disposal. Their energy and material efficiencies are far from perfect, despite the car, and its incumbent industry, being present and influential in society for almost a century and half. The premise of car design, manufacturing process, business model and use have scarcely evolved or changed drastically. Nations have been producing and consuming this product unsustainably. The surge of developing nations and their consumption demands is adding further pressure on resources and energy use. This PhD is focused on how to reduce passenger car impacts through two alternative consumption models; longer lifespans (extensive) and car share (intensive). These may contribute towards a necessary transition of the overall incumbent car regime and its different elements – business models, design, manufacturing, sales, usage and disposal – towards more sustainable use of materials and energy by reducing their demand and consumption. It aims to understand the role of some of its different actors but also to understand why alternative - and less impactful - forms of car use have not succeeded and how a transition to a different car regime can be triggered.

The literature review looked critically into the automotive industry's failure to become more sustainable. It compared extensive and intensive use, the desirable design aspects of the former and impacts of the latter. It looked into transition models, car cultures, their influence in car consumption and use. Finally, it discussed how personal behaviour can have a role in changing norms and attitudes in societies. Two different sets of research interviews, three informative interviews and a consumer survey were undertaken to collect data to help fulfil the aims and objectives of this research. The three interviews aimed to understand the different business models, incumbent car industry, start-up car manufacturers and car sharing business models respectively. The first set of - exploratory - interviews with car designers and engineers helped to explain the barriers and opportunities of car design for extensive and intensive use. It raised questions about society's readiness for such alternative forms of consumption. The second set of interviews looked into the systemic barriers of car sharing; the role of policy, society, technology and the shift from ownership to shared use. It also explored the service-life of shared

cars. Finally, the consumer survey helped to explain the attitudes, norms and behaviour of car users and verify some assumptions made throughout the different interview sets.

There are substantially more obstacles to purposely designed cars to have an extensive lifespan than for an intensive one. Nonetheless, some aspects of design for longevity can be adopted by designers to optimise the lifespan of cars. Consumer behaviour may also be of key importance in extending passenger car lifespans. The set of interviews with car sharing experts and the consumer survey explored and analysed reasons behind the low uptake of and readiness towards car sharing in order to understand barriers and opportunities. Interview and survey data were thematically and systematically analysed. If the vision of less unsustainable, socio-technical transition of car usage is taking place, from a top-down technological approach, there is no equivalent change in the social, bottom-up car ownership culture. Given that policy makers are systemically compromised - by the relevant stakeholders - where they operate, changes in ownership culture could stimulate and mandate the necessary policy action where relevant. It is also debatable if the promised lower impact of car sharing is occurring. Car share has a lower uptake, cars are driven low annual mileages and have a short service life.

This research contributes to the understanding of how the social facet of socio-technical transitions can help replace the car culture status-quo and provide opportunities for nudge policy action using Cultural Theory and the Theory of Interpersonal Behaviour. The research reports on consumer mindfulness of car sharing and barriers and drivers for social transitions towards different cultures of car ownership and use. The data brings new insights into UK car consumers, addressing calls for understanding car user behaviour, and creating mechanisms to overtake the car culture status quo.

ACKNOWLEDGEMENTS

This research was funded by Nottingham Trent University with support from the RCUK Energy Programme's funding for the Centre for Industrial Energy, Materials and Products (CIE-MAP), grant reference EP/N022645/1.

I would like to thank those who, in one form or another, helped, supported and provided me with unique opportunities throughout the unforgettable and life-changing journey that has been this PhD.

First and foremost, I would like to thank my director of studies, Professor Tim Cooper, who gave me the opportunity of conducting this research, provided invaluable feedback and guidance and opened the doors to a number of great researchers with whom I have had the pleasure and privilege of working. I also would like to thank my second supervisor, Dr Matthew Watkins, for all his countless support, feedback and guidance throughout these years. A big thank you to my external adviser, Dr Paul Nieuwenhuis, who has been a source of inspiration, both as a person but also as an academic. His writings have been very stimulating and thought provoking. A great thank you to Professor Peter Wells, whose work I most admire and also has been a great source of inspiration and thought.

I am most indebted to all UKINDEMAND and CIE-MAP colleagues for all their support, friendship, intellectual stimulation, discussions and laughs. At Nottingham Trent University; Dr Giuseppe Salvia, Dr Mariale Moreno, Dr Naomi Braithwaite, Dr Laura Piscicelli, Dr Kyungeun Sung, Dr Alexander Gnanapragasam, Dr Christine Cole, Dr Ana Mestre and Dr Jagdeep Singh. My PhD colleagues, Deepti Mahajan, Tung Dao, Patrick Keen and Filipa Calado. Also, my office colleagues, Angharad McLaren, Katherine West and especially Matt Shapley for all his invaluable help and feedback with statistics. Elsewhere from UKINDEMAND and CIE-MAP in Cambridge, Leeds, Bath and Cardiff universities and the Green Alliance: Professor Julian Allwood, Professor John Barrett, Professor Geoff Hammond, Professor Nick Pidgeon and Dustin Benton. A big thank you to Dr John Rogers for inviting me to write several journal articles and conference papers with him, Dr Danielle Densley-Tingley, Dr Jannik Giesekam, Dr Jonathan Norman, Dr Marco Sakai, Dr Catherine Cherry, Dr Samuel Cooper, Dr Simone Cooper-Searle, Dr Jon Cullen, Dr Paul Brockway, Dr Anne Owen, Dr Katharine Rietig, Dr Katy Roelich, Dr Sally Russell, Dr Kate Scott, Dr

André Serrenho, Dr. Katharine Steentjes, Suzana Matoh, Kirsten Saward, Fran Sergent and Robin Styles. It has been a privilege and an honour to work and share ideas with all of them.

All the inspirational academics from the End Use Energy Demand centres I had the privilege to meet and share ideas with, especially the teams from DEMAND, led by Professor Elizabeth Shove, and CIED, led by Professors Benjamin Sovacool, Frank Geels, Steven Sorrell and Dr Tim Schwanen who have been so inspirational and intellectually stimulating in their writings.

All NTU staff in the different departments for their support, patience and help, particularly the librarians who are so knowledgeable and helpful and the ITS team who are very quick to respond to computer 'crisis'.

My friends in Nottingham, especially Claire Maskery who was the best neighbour and friend anyone can have. My friends in Manchester, especially Dr Neil Pye for all his friendship and support.

All my family and friends in Portugal who I miss so much and have been so supportive throughout this journey. My parents José and Isabel, my in-laws Rosália, Sebastião and family. My siblings Ana, Tiago, their spouses Vitor and Estela and my beautiful nephews, João and Eva.

And last, but not least to my wife Sofia who has provided strength, support and immense care, who has always believed in and encouraged me to aim higher. And for Daniel, our son, to whom this PhD is dedicated, in the hope that he may reap the fruits of this very modest contribution to improve our fragile world.

TABLE OF CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

AUTHOR'S DECLARATION AND PUBLICATIONS

This thesis includes content that has been published during the course of this research. I declare that the information in this thesis is original work by the author, Alexandre Rodrigues. The following is a list of publications by the author related to this thesis. Three of the five conference papers were initiated by the author; the initiation, key ideas, development and writing up of these papers were the sole responsibility of the candidate, under the supervision of Prof Tim Cooper and Dr Matthew Watkins. The other conference papers were collaborations between partner academic institutions members of CIE-MAP and formerly UKINDEMAND research centres of which the author was an active member through his academic institution.

Rodrigues, A., Cooper, T., Watkins, M., 2016 'Car sharing in the UK. Paving the Way to Cleaner and Smarter Transport'. Proceedings of the International Sustainable Innovation Conference. International Sustainable Innovation Conference 2016. November 7-8, 2016, Epsom, University of The Creative Arts, UK

Rodrigues, A., Cooper, T., Watkins, M., 2015. 'User-intensive Cars; Design Contributions for More Sustainable Approaches to Personal Transportation'. Proceedings of the International Sustainable Innovation Conference. November 9-10, 2015, Epsom, University of The Creative Arts, UK

Rogers, J. G., Cooper, S.J.G., Cooper S., Densley-Tingley D., Braithwaite, N., Moreno M., Rodrigues, A., Salvia G., 2015. 'Product longevity and shared ownership: Sustainable routes to satisfying the world's growing demand for goods'. AIMS Energy, 3(4): 547-561. DOI: 10.3439/energy.2015.4.547

Rogers. J., Cooper, S. J. G., Braithwaite, N., Moreno, M., Rodrigues, A., Salvia G., Cooper, S., Densley-Tingley, D., 2015. 'Product Renovation and shared ownership: sustainable routes to satisfying the World's growing demand for goods'. Proceedings of the Global Conference on Energy and Sustainable Development GCESD2015, February 24-26, 2015, Technology Park, Coventry University, Coventry, UK

Rogers, J., Rodrigues, A., 2015. 'Product Leasing - A strategy to allow manufactures and customers to benefit from elongation of life products'. Proceedings of the International

Conference on Product Lifetime and the Environment PLATE 2015. June 17-19, 2015 Nottingham Trent University, UK

Rodrigues, A., Cooper, T., Watkins, M., 2015. 'Driving in the Wrong Lane: Towards a Longer Lifespan of Cars'. Proceedings of the International Conference on Product Lifetime and the Environment PLATE 2015. June 17-19, 2015 Nottingham Trent University, UK

1 INTRODUCTION

1.1 Background

The current demand for the main engineering materials - cement, steel, plastic, aluminium and paper - has quadrupled in the last 50 years (Allwood, et al. 2011). One of the reasons is the growth of the world's population, which, according to some forecasts, is predicted to increase by 30% to 9 billion people by 2050 (European Commission 2011). In the future "people in developing and emerging economies will legitimately aspire to the welfare and consumption levels of developed countries" (ibid, p 2), placing increasing pressure on natural resource extraction. Such unsustainable consumption needs to be addressed through more efficient manufacturing, use and disposal of products and materials (Rogers, et al. 2015). As GDP rises, so does resources and energy demand (Dobbs, et al. 2011). According to the OECD (2002 p 11), this refers to "the relative growth rates of a pressure on the environment of an economically relevant variable to which is causally linked". In other words, a partition between "environmental bads" and "economic goods" (ibid p 11).

The United Nations has been proposing the development of decoupling integrated approaches to resource management and resource productivity such as decoupling natural resource use and environmental impacts from economic growth (UNEP 2011). Examples of governmental action in decoupling have been tried but with limited scope (Dobbs, et al. 2011). The UNEP concludes that such decoupling has been occurring, nonetheless at a slow rate of 1-2% per year in industrialised countries and is not yet enough to reduce negative environmental impacts produced by mass production and unsustainable consumption (UNEP 2011).

The discussion about unsustainable production and consumption is not recent. Packard (1960) points out excessive production and consumption, especially after the end of World War II, when mass consumption started to be incentivised by large businesses through advertisements that focused on fashion and constant minor changes to products every year (Slade 2006). According to Packard (1960), the automotive industry was an active promoter of such consumption and Alfred Sloan was its main mentor (Slade 2006). Alfred Sloan, managing director of General Motors during the 1920s, defended the automotive industry position as a need to increase market share against rival companies (Sloan 1990 [1964]). Packard argued that business strategies such as planned obsolescence or advertisement efforts to stimulate mass-consumption in society are responsible for the world's vanishing resources at one end, and the accumulation of waste at the other (cf. Figure 1 for steel use and its application in the automotive industry).

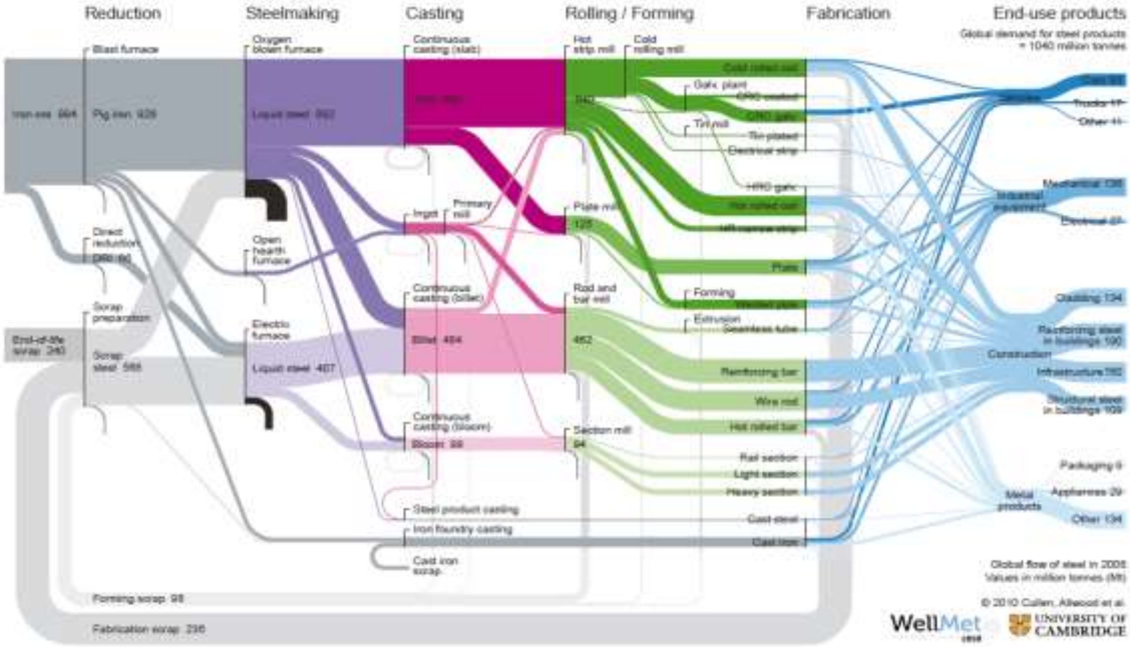


Figure 1. Sankey diagram of global flow of steel use. Cullen, Allwood, et al. (2011).

The OECD (1982) recognised that increasing the lifespan of products can be a way to incentivise consumers to keep their products for longer, postponing an eventual scrappage before the end of their potential useful life. Stahel (1982) and, later, Cooper (1994) also suggested longer lifespans for household goods in order to create more sustainable patterns of production and consumption but also delaying recycling and eventual waste. Both authors suggested the introduction of policy, manufacturing and consumption intervention, to reduce throughput and product demand, and the negative impacts these have on the environment. They also set the ground for an impactful societal change, contributing to closing the loop of a circular economy through strategies such as reduction, reuse and, perhaps, less recycling of materials. More recently the Ellen MacArthur Foundation has taken a lead in developing solutions and polices for the circular economy with circular business models at its heart, although only one car manufacturer has joined this organisation (Ellen MacArthur Foundation 2014, Ellen MacArthur Foundation 2018).

1.2 Historical Perspective

What once used to be the consumer norm of buying a product and using it until it broke beyond repair changed in the 1920s (Slade 2006, Bakker, et al. 2014). Since the beginning of the consumerist age, after World War I, and especially after World War II, western societies have been nudged, through advertisement, to own and consume as many goods as possible and replace them once a new version of the product is made available (Packard 1960, Slade 2006). After the end of World War 2, mass consumption was incentivised through aggressive marketing campaigns and by the growing economies following the end of that war. Mass-produced cars - like any other mass-produced product - create environmental impacts in the ecosystem. OICA, the world's automotive manufacturers organisation, reported a growth in demand of passenger vehicles from 2007-2017 (Organisation Internationale des Constructeurs d'Automobiles 2018), despite the credit crunch that affected many world markets. There are nearly 950 million passenger cars in circulation around the world (ibid) contributing to negative impacts through congestion, pollution and end-of-life disposal.

This overconsumption norm arrived in the automotive industry shortly after mass production was introduced in car manufacturing (Slade 2006). Firstly, on the production side, by Henry Ford – the engineer who first introduced mass-produced cars – secondly, on the consumer side by Alfred Sloan, an MIT business graduate, who started the cycle of annual model change, planned obsolescence and market segmentation at General Motors (Freund and Martin 1993). One of the tools used by the automotive industry was advertising as a strategy to increase demand (ibid). Despite his organisational skills, Sloan was not able to provide technologically superior products to those of Ford, namely the T model that dominated the North American market until the early 1920s (Slade 2006). Sloan soon realised that only by selling fashionable products would General Motors overtake Ford Motor Corporation (Sloan 1990 [1964]). To this end, Sloan hired a stylist called Harley Earl, who, up until then, had designed bespoke cars for Hollywood celebrities (Slade 2006, ibid, Gartman 1994). Freund and Martin (1993) and Nieuwenhuis and Wells (2007) provide further arguments for the rapid expansion of the car in the United States; the former, an insufficient railway system and a fast-growing population, the latter, the advancement in steel body construction. This rapid growth and demand also enabled the American auto makers to become transnational before the advent of World War 2. The first, perhaps unintended, step was to open the market to women through one of GM's automotive inventions; the starter motor (Slade 2006). This innovation soon replaced the starter crank, a difficult and dangerous device to operate. Realising that by opening up the market to women, cars would have to become more comfortable, easier to drive and above all, fashionable. GM soon started to propose a broader range of colour options, interior fabrics and other accessories that were aimed at a broad public in contrast to Ford's narrow product offerings. Women at the time were key in convincing men to buy these desirable cars (Slade 2006). Sloan, however, provided a different technical argument for such strategy; the advent of the closed steel bodied car (Sloan 1990 [1964]). Sloan wanted to make changes to both accepted styling and engineering principles; reducing the height of vehicles to lower their centre of gravity and so improve their safety at higher speeds (ibid). Such innovations meant radical and costly changes into the car's structure. To avoid such costs in the future, he sought incremental evolution in each car model's overall design leading to the annual car model change. All these technological innovations and manufacturing techniques, and extensive advertisement, aligned with a deficient offer of public transport in some countries, contributed to the first advent of the car in becoming the dominant mode of transport.

After World War 2, a growing middle class, mainly in the USA, Western Europe and Japan, was keen, and becoming wealthy enough, to access cars that up to that point were the privilege of the upper classes (Sachs 1992). With an imperative need to rebuild war-torn nations, cars also became essential to that reconstruction (Freund and Martin 1993). Mass-production techniques were soon adopted by the majority of European and Japanese car manufacturers, mirroring the United States (Wells and Nieuwenhuis 2012). The beginning of the successive oil and energy crises, however, did very little to destabilise the automotive industry (ibid) both at a product level, with the need for more fuel-efficient cars, and at a manufacturing level through reduction in resource waste (Hawken, Lovins and Lovins 1999).

The automotive industry was built historically under the principle of 'cradle to grave', where environmental sustainability was not naturally considered, (McDonough and Braungart 2002). Those principles remain largely unchanged, because continuity in design and business principles have been dominant (Wells and Nieuwenhuis 2012). Its business, design and manufacturing process principles have not changed considerably for more than 80 years, despite small evolutionary gains in material and energy efficiency and slow evolutionary processes (ibid).

1.3 Sustainability and Product Longevity in Car Design

1.3.1 Sustainability in Car Design

The extraction of raw materials and the energy to transport and transform them into mass-produced products and their consumption and disposal create important social and environmental impacts in the ecosystem (OECD 1982, van Nes and Cramer 2006, Rivera and Lallmahomed 2016). Despite the advances in sustainable design and the many avenues created; green design, eco-design, cradle to cradle, design for sustainability, design for sustainable behaviour and design for product attachment (McDonough and Braungart 2002, Mackenzie 1997, Charter and Tischner 2001, Bhamra and Lofthouse 2007, Vezzoli and Manzini 2008, Lilley 2009, Chapman 2009), the mainstream automotive industry has resolutely failed to transition from such advances and kept its business, manufacturing and design approaches under a continuous improvement method focusing on fighting, adapting to its interests or, at best, following environmental policies (Wells 2010). Sustainability in car design has been restricted by the current automotive business regime which was created without sustainability at its core (Wells 2004). The attempts to make the incumbent car regime less unsustainable seem to be rather more reactive than preventive due to its fundamental premises (ibid).

The passenger car constitutes an ubiquitous product of our society and, arguably, the most impactful form of personal transportation. The choice of car longevity is due to the fact that there is evidence that extending the lifespan of a car can constitute an alternative to the current norm of using a car for less time than its life potential ({{513 Kagawa, Shigemi 2013; 287 Kagawa,Shigemi 2006}}. On the other hand, car sharing has been promised to reduce the negative environmental – and financial - impact of cars by dividing its use by as many users as possible ({{793 Duncan, Michael 2011; 997 Shaheen, Susan 2012; 870 Martin, Elliot W 2011; 791 Rodier, Caroline 2003}}. Other alternative mobility modes are the use of bicycles, public transport (train, bus, tram, etc.) or walking (check literature on this). However, given the current public transport limitations, city planning around motor vehicles and suburban sprawl, and political and technological vision frames {{952 Bergman, Noam 2017}}it is difficult to see these alternatives, in the short to medium-term, as viable, despite desirable.

Nonetheless, Henderson {{1227 Henderson, Jason 2009/a;}} suggests society needs to de-essentialising cars, despite its resistance, in Atlanta where his study took place, to adopt public transport, due to cocooning, social and racial secessioninsm, urban-rural perceptions and relatively poor planning. Soron {{1201 Soron, Dennis 2009/a;}}, on the other hand, sees the car as the archetype of an over-consumerist society, with hard to break social structures around the former. The car nature, its physical size demands large amounts of land for manufacturing, roads, motorways, and other related infrastructures. It is this need for energy and material demand within the car regime {{304 Allwood, J. 2012}} that needs to be holistically reduced.

1.3.2 Lifecycle Assessments

During a passenger car model development stage, a life cycle analysis (LCA) is produced to optimise resources and energy during lifecycle (e.g. Kim, et al. 2003, Cooper 2005, Nemry, et al. 2008, Arena, Azzone and Conte 2013, Danilecki, Mrozik and Smurawski 2017). LCAs are internationally standardised by the ISO 14040: 2006 norm {{1226 International Organization for Standardization 2016}}. For example, LCAs can help designers to understand how long, in years, it takes user stage emissions to meet manufacturing emissions. In LCAs these emissions are expressed as $CO2_{eq}$, a measure to describe how much CO_2 contributes to global warming, and how this period of time can be reduced through the usage of less energy demanding materials (Danilecki, Mrozik and Smurawski 2017). However, despite covering life cycle assessment (LCA) studies and life cycle inventory (LCI) studies, LCAs do not describe the LCA procedure in detail, nor does it specify methodologies for the individual phases of the LCA {{1226 International Organization for Standardization 2016}}.

Trade flows, indispensable to all stages of car manufacturing, likewise, generate important emissions which become embodied in the final product (Wiedmann, et al. 2007, Skelton and Allwood 2013). It is these embodied emissions (Figure 2) that need to be minimised, either by prolonging the life of products (Cooper 2005) or through a shorter but more intensive usage (van Nes and Cramer 2006, Vezzoli and Manzini 2008). In sum, optimising the product lifespan (Danilecki, Mrozik and Smurawski 2017, Skelton and Allwood 2013).

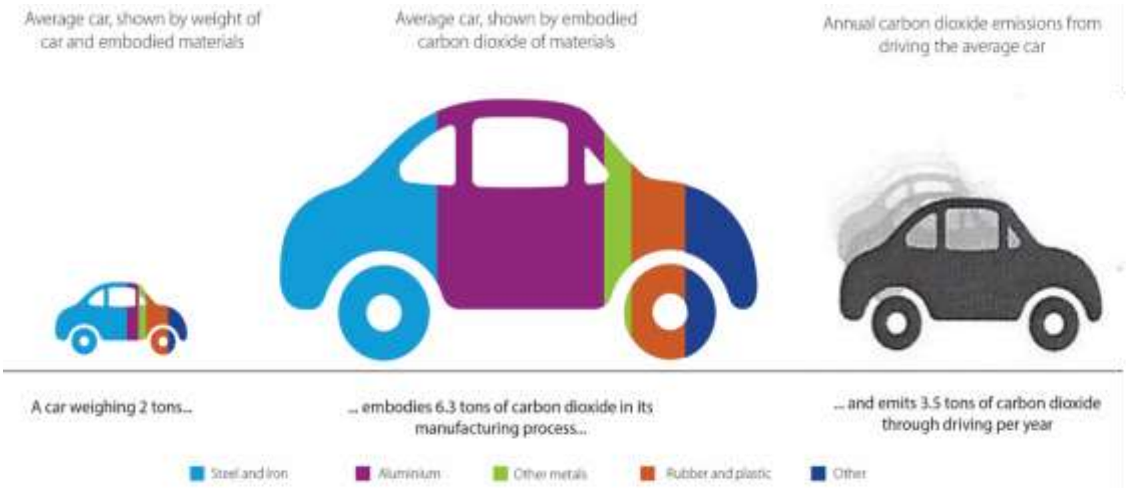


Figure 2. Passenger Car Lifecycle Embodied Emissions. UKINDEMAND (2014)

However, LCAs are not exempt of critique. Despite covering life cycle assessment (LCA) studies and life cycle inventory (LCI) studies, LCAs do not describe the LCA procedure in detail, nor does it specify methodologies for the individual phases of the LCA {{1226 International Organization for Standardization 2016}}. Ayres (1995) criticizes LCAs for their failure to attribute reliable sources for process data or using market-based valuation instead of implicit energy. The challenges LCAs face are diverse such as methodological choices, lacking of measurement points (e.g. electricity consumption), sensitive information, multidisciplinary activities within the LCA, different measurement units, organisational communication, consistency (Rebitzer, et al. 2004) and information updates (Schweimer and Levin 2002). Grant and Macdonald (2009) assert that successful LCAs depend upon the correct question being asked, the context and the outcome. Environmental solutions for products depend upon cultural, economic, legal and political systems. LCAs increase the knowledge but do not provide solutions (ibid). Contrastingly, there are public and industry databases available offer aggregated resource consumption, waste, emissions per kilogram of material produced but also disaggregated Life Cycle Impact (LCI) of unit process level (Rebitzer, et al. 2004). Nonetheless, trying to undertake a passenger car LCA outside the automotive industry faces many challenges (Nemry, et al. 2008, Arena, Azzone and Conte 2013, Danilecki, Mrozik and Smurawski 2017, Schweimer and Levin 2002, Yuan, et al. 2009)(Danilecki, Mrozik and Smurawski 2017). LCAs are confidential for each new car model, mainly due to competitiveness reasons. Supplier choice may have an effect on the overall LCA, for example, component transport costs and emissions, country of origin or energy source, irrespectively of price paid for that component (Wiedmann, et al. 2007). Schweimer asserts that a ‘good deal of uncertain data’ information may be outdated leading to ‘erroneous values’. LCA’s built upon Schweimer’s lifecycle impacts (LCI) have been undertaken (Yuan, et al. 2009) and may not be completely accurate. Arena, Azzone and Conte (2013) acknowledged that social and economic scope levels should be added to LCA environmental models to embrace all pillars of sustainability and concluded that LCA models for passenger cars cannot be empirically tested due the high confidentiality surrounding the data for car manufacturers. Danilecki, Mrozi and Smurawski (2017) had make a large number of simplifying assumptions to reach their results. Nonetheless, LCAs are a helpful tool to provide – outside the automotive industry – an indication of passenger cars’ impact in the environment.

Currently a typical European passenger car (e.g. a VW Golf) will take 21 years of use to meet the same CO_{2eq} emissions used for its manufacturing (Danilecki, Mrozik and Smurawski 2017) (Figure 3). Given that use stage is responsible for nearly 80% of total primary energy consumption (Mildenberger and Khare 2000), design has an important role in reducing those emissions. For example, a reduction of energy and material input through the use of lightweight or recycled materials, such as aluminium and plastics, and different designs may contribute to reduce emissions (Danilecki, Mrozik and Smurawski 2017, Allwood and Cullen 2012). This, in turn, enables an optimised lifespan of cars, which is the period of usage necessary to meet $CO2_{eq}$ emissions from manufacturing and usage. The use of materials and energy at the manufacturing stage can also be reduced by using more efficient manufacturing processes, for example, less waste material (Allwood and Cullen 2012).

[redacted]

The gains in extending the lifespan of a car may have limitations. After the CO_{2eq} emissions threshold from manufacturing and use are met, emissions from user stage will surpass those of manufacturing. At this point, maintaining a car may be less efficient than buying a newer model. Nonetheless, this measurement of CO_{2eq} emissions is potentially necessary to define an optimal lifespan of a car (Danilecki, Mrozik and Smurawski 2017). LCAs on cars, outside the automotive industry, have to make simplified assumptions upon a series of factors which, will determine the overall lifecycle impact (Kim, et al. 2003, Danilecki, Mrozik and Smurawski 2017). Such assumptions may reduce the precision of LCA calculations. In order to produce accurate lifespan forecasting, the information should be made accessible from manufacturers (Hsu 2016).

1.3.3 Longevity in Car Design

After the 1973 oil crisis, the pressures over fuel efficiency, safety and longevity were starting to be addressed by the automotive industry. Fuhrmann (1979) calculated that a longer-life car driven in excess of 300,000 km (185,500 miles) would require less material, to achieve such use, than three equivalent cars doing 100,000 km each (62,000 miles) in a time when most cars could not achieve such mileage before rusting away or breaking down completely (ibid). This view reflects that design and advances in technology, such as corrosion protection, are key to ensure a longer life of vehicles (Andrews, Nieuwenhuis and Ewing 2006). In the early 1980s, the OECD reported that the car was one of the products for which lifespans needed to be addressed (OECD 1982). Anecdotally, Ware (1982), from an automotive engineering viewpoint, already envisaged a maintenance plan to keep used cars running for longer. Ware's research resulted in a dedicated centre to extend the life of Morris Minor cars. Car lifespans have also been addressed by scholars who provide examples of how longer lifespans can address economic, energy, material and environmental impacts (Nieuwenhuis 1994, Kagawa, Tasaki and Moriguchi 2006, Kagawa, et al. 2011, Allwood and Cullen 2012, Kagawa, et al. 2013, Skelton and Allwood 2013).

1.3.4 Alternative Forms of Car Usage and Consumption

For products with high energy demand during their user stage, such as cars, longevity may not be the adequate strategy and an early replacement may be desirable (van Nes and Cramer 2006). More durable products may require additional material to make them more robust, hardwearing and meet user's changing needs, thus increasing embodied emissions, however, emission savings are highly sensitive to user stage rates (Skelton and Allwood 2013). For example, increasing the use rate from 0.1% to 5% annually, increases potential savings from 5% to 50% of initial emissions (ibid). Other forms of car usage have been tried with more or less degrees of success (Williams 2007). Taxis are intensively used passenger cars and usually accumulate very high annual mileages in a very short period of time. Some experiments using product service systems (Mont 2002) – involving the sale of use of a product instead of the product itself (Section 2.5.1) – have been tested with differing degrees of success, e.g. CityCarShare, ZipCar, Uber or Lyft {{10 Williams,Andrew 2007; 1228 Andreassen, Tor Wallin 2018}}. Car sharing schemes, in their various iterations, can be included in this approach {{10 Williams,Andrew 2007}}. The advantage of such schemes is that the capital asset – the shared car – can be used by different users, thus reducing user and product environmental impact due to a reduction in demand for new products (Vezzoli and Manzini 2008). For products with high energy demand during user stage there is, thus, a desired - and expected - intensification of usage of the product, enabling this to wear rapidly and to be replaced by a more efficient unit (ibid). In car sharing schemes, there is potential to reduce individual user emissions by 60% as long as cars are used throughout their design life of around 150,000 km (Skelton and Allwood

2013). So far, more sustainable forms of car usage (e.g. Riversimple) have had limited uptake by society {{1229 Wells, Peter 2018}} which is rooted in ownership or very limited forms of car product-oriented service, e.g. leasing or contract-hire (Williams 2007).

1.4 The Challenging Consumer Norms, Attitudes and Behaviours towards Cars

Contrary to most household products, a car can reflect its user's personality and approach to personal transportation (Freund and Martin 1993, Verplanken, Aarts and Van Knippenberg 1997, Steg, Vlek and Slotegraaf 2001, Gärling, et al. 2002, Sheller 2012). It represents, in many markets, segments and societies, a symbolic and cultural product (e.g. Sheller 2012) projecting a desired image and *status* (Prettenthaler and Steininger 1999, Johansson-Stenman and Martinsson 2006). In others, it is one of the few reliable sources of transportation because the infrastructure has been purposely made to favour this mode of transport (Freund and Martin 1993). The different cultures of car ownership have been extensively studied (e.g. Sachs 1992, Freund and Martin 1993, Steg, Vlek and Slotegraaf 2001, Miller 2001, Steg 2005, Sheller 2012, Wells and Xenias 2015). Its ownership and use outcomes are due to personal and external circumstances, not always a reasoned choice, unless adaptations to lifestyles are needed. Car ownership may be grounded in, and shaped by, all kinds of pre-discursive and pre-cognitive stimuli (Schwanen and Lucas 2011). Once regular use of the car becomes established travel choices become 'locked-in'; they reinforce the 'car-system' and undermine other travel solutions (ibid). The external circumstances of car ownership are provided both by manufacturers through high degrees of variety and 'customisation' but also by infrastructures and government policies that reinforce car usage (Wells and Xenias 2015). The car, Freunde and Martin (1993) postulate, becomes an ideology. The challenge of diverting as many consumers as possible away from unsustainable levels of car use may require deep changes in cultural norms (Sheller 2012), in practices (Spurling, et al. 2013) as well as policies to support or reinforce those changes (Schwanen and Lucas 2011). Consumers are often unaware of the environmental and social impact of their consumption (Murphy and Cohen 2001). Murphy and Cohen suggest that there is a physical relationship between the material demands of groups of consumers and consequences to other social groups, sometimes in remote areas.

1.5 Research Gaps in Passenger Car lifespans

There is evidence that increasing the lifespan of cars can bring advantages at many levels (Section 1.3.3). But there is also evidence that energy-demanding products such as cars, at the user stage, may benefit from reduced lifespans achieved through an intensity of usage (Section 1.3.4). Irrespectively, there is neither evidence that consumers are changing their car consumption norms, attitudes and behaviours towards less impactful usages, nor which strategy is the most correct for each approach. The car sharing sector is, still, a niche and the lifespan of cars is little over a decade in many countries, with lifespans varying from country to country (Oguchi and Fuse 2014). Nonetheless, whichever strategy is in the best interest of car users, and the environment, needs to be economically feasible. There will be a need to intervene at design level either to increase the lifespan of cars or to make them more intensively used. However, design and technological interventions may not be sufficient to stimulate a different, more sustainable, usage of cars (Wells and Xenias 2015). The car sharing sector remains a niche market and to upscale it and increase its positive environmental and social impacts, a change in consumer attitudes (e.g. Evans and Cooper 2010) may be as crucial as the technologies potentially enabling such change (Geels and Kemp 2012). Likewise, creating the necessary conditions for the acceptance of a longer lifespan of cars may have to come from interventions at consumer behaviour level (e.g. Evans and Cooper 2010), given that the car industry's relative persistence in continually pursuing growth in car manufacturing will not initiate such changes, preferring a *status quo* strategy (Wells and Nieuwenhuis 2012). However, changes in consumer attitudes and behaviour could, in turn, create pressure in the mainstream industry to start a transition towards a more sustainable design, manufacture and supply of cars, that will meet the needs of this changing consumer society and the environmental challenges faced.

1.6 Aims and Objectives

The aim of this research is to develop policy options nudging societal behaviour changes towards more sustainable passenger car use, contributing thus to the increase of energy and material efficiency by reducing passenger car output.

The main research questions for this doctoral thesis are as follows:

- How a behavioural and cultural change towards passenger cars can influence the demand for energy and materials used for the production and optimal usage of passenger cars?
- How can optimal passenger car lifespans influence car design and, ultimately, bring about a paradigmatic change of the incumbent car regime towards sustainability?
- What type of policy options could be devised to enable more sustainable and efficient use of passenger cars leading to a change in the incumbent car regime?

The objectives are to understand how design can contribute to optimise the lifespan of cars, the systemic barriers for alternative car usage and the norms, attitudes and behaviour of car users and devise policy options that, on one hand, nudge society towards a more sustainable behavioural in relation to car consumption and usage and, on the other hand, incentivise manufacturers to design cars with an optimal lifespan reducing at the same time energy and material demands.

1.7 Overview of this Thesis

Chapter 1, conveys the motivations behind this research, rationalises the topics by describing their choice, describes the aims and objectives and the overview of the thesis chapters.

Chapter 2 reviews the literature by discussing three strategies for material and energy demand reduction, industrial throughput and the overconsumption of passenger cars: car longevity, use-intensive cars through product sharing and behavioural changes. It also critically analyses the automotive industry and the many reasons for its apparent lethargy in becoming more sustainable.

Chapter 3 discusses the research methodology undertaken with an overview and purpose. The research methodology section also presents and discusses the methods chosen, their applicability to the different components of this research and the sampling strategies for each method. It presents the analysis strategies for each study and its justification.

Chapter 4 presents the findings from the three studies; two semi-structured interview sets and one survey. The first exploratory study concerns automotive designers and engineers and their view on car longevity and intensive use of cars (e.g. car sharing). The second set of interviews explores the systemic barriers towards car sharing, acquisition and usage of shared cars. The third study, a survey, to understand car user’s norms attitudes and behaviours towards car consumption but also their knowledge and openness to alternative forms of car consumption.

Chapter 5 discusses how this research meets its aims and objectives, draws conclusions from the findings and how these converge or diverge with the literature reviewed, and describes the different policy options towards a more sustainable consumption and use of passenger cars. It also reflects upon the overall research limitations. The section finishes by presenting the contributions to knowledge from this research and recommendations for future research.

2 THEORETICAL AND EMPIRICAL BACKGROUND

This chapter discusses the overarching foundations of this thesis, the automotive industry, the use and lifetimes of cars, cultural norms and the processes for achieving behavioural change. towards more sustainable forms of car usage.

2.1 Circular Economy, Materials and Energy Demand

Circular economy advocates suggest that switching from a linear type economy would save more than $1T in materials (Ellen MacArthur Foundation 2014). The circular economy concept can be traced back to “The Limits to Growth” (Meadows, et al. 1972) which forecasted an exponential growth in future world population competing for the same limited resources. Over the last decades, rapid population and economic growth in developing nations accelerated these limits; governments and industry show concern in accessing resources in an increasingly competitive and populated world, (European Commission 2011, UNEP 2011, Eatherley and Morley 2008, Engineering Employers' Federation 2014). However, some criticism of the circular economy has surfaced (e.g. Allwood 2014), arguing that there are material and energy losses during the lifetime of products and these will have to be topped up by extracting, possibly less, virgin materials using energy to transform them nonetheless. Those who are favourable to this type of economy acknowledge that there is, thus far, no perfectly closed-circle economy (Mathews and Tan 2011).

One of the main circular economy strategies adopted by the automotive industry is remanufacturing. Remanufacturing is a process of restoring non-functioning, discarded or traded-in products or components to the same degree of performance of a new similar product or component (Lund and Hauser 2010). Remanufacturing enables important material and energy savings and diverts end-of-life products from scrap (Oakdene-Hollins 2008). Remanufactured products can be sold for a fraction of the price of a similar new product (ibid). Renault, for example, has a dedicated remanufacturing unit in France since 1949, where components are remanufactured and sold as spare parts. This enables that plant savings of 80% in energy use, 88% in water, 92% in chemical products and 70% less waste production (Ellen MacArthur Foundation 2013). However, the real motivations behind remanufacturing seem to be more mundane; spare parts security, warranty issues, market share, brand protection and customer orientation (Seitz 2007). Automotive component remanufacturing has been a long established, if discreet, activity and only during this decade has been associated with the circular economy. The UK Society of Motor Manufacturers and Traders has recently started to introduce the term ‘circular economy’ and ‘remanufacturing’ as part of their sustainability discourse; the 2014 ‘Sustainability Report’(Society of Motor Manufacturers and Traders 2014) does not address this and in 2015 (Society of Motor Manufacturers and Traders 2015a), both terms appear only once. Currently, only four members of this industry body are considered remanufacturers (Society of Motor Manufacturers and Traders 2018).

A typical European medium-sized car uses 60.6% steel, 14.9% plastics (ABS, PP, PE, PA, etc.), 14.4 % other materials (electronics, engine oil, coolants, etc.), 8% aluminium, and 2.1 % non-ferrous metals (Cu, Zn, Sn, Mg, Pb, etc.) (Danilecki, Mrozik and Smurawski 2017). The 950 million passenger cars circulating around the world (Organisation Internationale des Constructeurs d’Automobiles 2018) and their manufacturing process contribute to between 5-6% of global greenhouse gas emissions (GHG) (Carbon Trust 2011). Of these, 1% or 0.4 $GtCO_{2eq,}$ were used for the production of 66 million cars in 2008 (Ibid). In 2017, the industry produced 73.5 million passenger cars (Organisation Internationale des Constructeurs d’Automobiles 2018) and 40% of those GHG emissions move across international borders between production and consumption (Carbon Trust 2011) (Figure 4).

[redacted]

2.2 The Automotive Industry

The mass-manufacturing automotive industry is rooted in a century old 'locked-in' business model which has evolved slowly, making large manufacturers dominant actors, with all their, often as powerful, supply chain in a submissive situation. This makes any break away towards alternative business and design models very difficult (Wells and Nieuwenhuis 2012). The incumbent business model, with strategies such as annual small changes to the product, multiplication of models, credit acquisition, part-exchange for a newer vehicle, and its value network, was established years after Ford's developed the mass production process (Slack 2007). Technical developments such as the all-steel body *Budd system* (Nieuwenhuis and Wells 2007), management and marketing techniques initiated by Alfred Sloan of General Motors (G.M.) (Slade 2006), all contributed to build the current automotive regime landscape (Geels, et al. 2012). The high capital investment costs and relentless consolidation - the merging of smaller manufacturers into large multinationals - have made alternative socio-technical propositions, new designs and new entrants into market very challenging (Wells and Nieuwenhuis 2012). This model was enabled in part by consumer credit (ibid) and planned obsolescence strategies (Slade

2006, Burns 2010). These strategies were initiated during the Great Depression and strongly pursued after World War 2 (Packard 1960). Sloan's business model, with annual style changes, incited consumers to buy the latest product version, contributing to an early obsolescence, a higher throughput of cars and excessive consumerism.

Wells and Nieuwenhuis (2012) argue that this 90-year old automotive industry paradigm has barely changed, with improvements seen in manufacturing efficiencies and product design, usually under unforeseen new constraints, at least to the incumbent business model (e.g. energy prices and environmental laws). The mainstream automotive industry is, thus, typically slow in accepting new socio-technical developments and appears to be incapable of transitioning to different and sustainable business models (ibid).

2.2.1 Passenger Car Design and Development

Passenger car design reflects the paradigm of the automotive industry (Wells and Nieuwenhuis 2012). Design and development accounts for a substantial part of decision making during a car project; car projects take between 27 to 48 months from concept to production (Mildenberger and Khare 2000, Razavi, Densmore and Martin 2002). Passenger car vehicle development is divided into the following stages (Happian-Smith 2001):

- Material selection
- Body design
  - Styling
  - Aerodynamics
- Chassis design & analysis
- Crashworthiness
- Noise, vibration and harshness
- Occupant accommodation and ergonomics
- Suspension systems
- Control systems
- Engine design
- Transmission and driveline
- Braking systems

- Testing and failure prevention
- Manufacturing

These stages are often undertaken in tandem and in a constant exchange of ideas between the different stakeholders responsible for each stage of the project (ibid). Lifecycle assessments (LCAs), performance targets, new technology, safety and legislation and market differentiation requirements are set during the early stages of development (ibid). Legislation plays an important role in defining car safety, End-of-Life (EoL) options and material choice (Mildenberger and Khare 2000, McAuley 2003). Contrastingly, LCAs have been criticised for not taking into account social, economic and technical impacts (Section 1.3.2).

Some considerations are made during the development stage and before starting production; budgetary (cost-saving decisions in design and manufacturing), technological and physical (rolling resistance, friction, aerodynamics, weight and its effects on energy consumption and emissions) to gain competitive edge (McAuley 2003). During this stage, design compromises often arise and create conflicts between internal stakeholders, as the anecdotal evidence from Wise (1996) shows. These conflicts illustrate how often the final product is compromised and how such compromises may carry inadequacies in other areas such as reparability, maintenance and disassembly. It is not clear to what extent and in what ways longevity is incorporated into the design of today's new cars. Designing cars to last longer may have adverse effects if impacts from lifecycle are considered such as fuel consumption from an older less fuel-efficient engine (Mayyas, et al. 2012), or from additional material, increasing further embodied emissions (Skelton and Allwood 2013). Nonetheless, they are designed to be repaired and maintained, using consumables such as brake pads, tyres, engine oil, etc., potentially furthering their lifespan.

2.3 Extensive vs. Intensive Use

This part of the literature review assesses how product longevity has been addressed purposefully, or indirectly by the automotive industry. This assessment uses strategies suggested by Bakker et al. (Bakker, et al. 2014) to classify design approaches to product longevity within circular design. Circular design evolved from the traditional linear model design process of take-make-dispose (Moreno, et al. 2016). By considering the product systemically, including its lifecycle, manufacturer business model, consumers, etc, designers can make informed decisions about which circular strategies to use. The circular design strategy used in this assessment is design for long life use of products (Bakker, et al. 2014, Moreno, et al. 2016). This strategy focuses on the technical cycle to extend the lifespan of products. It includes the following sub-strategies (Bakker, et al. 2014):

- Design for attachment and trust
- Design for adaptability and upgradability
- Design for standardisation and compatibility
- Design for ease of maintenance and repair
- Design for durability
- Design for disassembly and reassembly

These strategies adopt and expand upon the principles of design for sustainability described by (Bhamra and Lofthouse 2007). Bakker, et al. (2014) argue that design for sustainability should include detailed sub-strategies for product longevity; the former lacks perspective in maintaining value over time, whilst the latter seeks to maximise product retention instead of high throughput and product replacement (den Hollander, Bakker and Hultink 2017). Product longevity fosters repair and reuse contributing thus to the circular economy, where closed loops of materials, parts and products feed into manufacturing and repair (Oguchi, et al. 2016).

2.4 Passenger Car Lifetimes

Designing a car to last longer has been open to debate; on one hand, scholars like Nieuwenhuis (1994) have noted that doubling the lifespan of cars from 10 to 20 years could potentially decrease the volume of vehicles produced and dismantled, thus reducing their environmental costs. On the other hand, these products may have constraints that limit this vision (Fuhrmann 1979, Mayyas, et al. 2012).

In the UK, cars have a lifespan of between 13 and 14 years (Skelton and Allwood 2013, Oguchi and Fuse 2014, Dun, Horton and Kollamthodi 2015). However, as Nieuwenhuis (2008) asserts, it is possible, from a consumer perspective, to prolong the life of passenger cars beyond their intended lifespan. Design for product longevity needs to be attained in conjunction with, if not before, consumption (Cooper 2004).

In the case of cars, Cooper et al. (2014) foresee a potential 21-year lifespan for car structures. They also break down the potential lifespan of the main car systems in the following manner (ibid):

- Suspension - 4 years
- Transmission - 12 years
- Engine - 13 years
- Interior and trim - 13 years
- Other - 8 years

This does not include maintenance items such as oil, widescreen wipers or tyres, which due to their nature and expected performance are considered wear and tear components.

Cooper, et al. (2014) concluded that engine wear often leads to car replacement, given how expensive this repair can be against the value of the car at this age, hindering the realisation of the 21-year lifespan potential.

Nonetheless, a shift in consumer behaviour should also be encouraged (Evans and Cooper 2010, Cox, et al. 2013). Mass-produced consumer goods can be made relatively cheap due to low price of materials (UNEP 2011). In some countries, government subsidisation of certain energy resources, such as fossil fuels, is contributing to the depletion of natural resources (Dobbs, et al. 2011). Such affordability enables products to become disposable and quickly replaced, creating different types of obsolescence (Packard 1960, OECD 1982, Bakker, et al. 2014, Cooper 2005, Burns 2010). Barbirolli (2008) has shown how certain durable goods such as cars, electrical appliances and computers are used with a utilisation rate of between I0% and 20% of their true lifespan potential. Consumers actively trying to keep their products for longer often encounter barriers such as ease of affordability of new products or the social pressure to update to a more efficient and safe product (Cox, et al. 2013).

Durability is not the main motivator for new household goods purchases despite an interest from consumers to know how much products last (Brook Lyndhurst 2011). Passenger cars change hands quite often and, at the end of their lifetime, may have been exchanged three to four times (Cooke 2013). Reports from the Royal Automotive Club Foundation (RAC 2011) and British Car Auctions (Cooke 2013) found that between 1997 and 2003 the majority of new UK cars were traded in within 4 years, with a minority keeping their cars for more than 7 years. The complex relationship of consumers with their purchases goes beyond functionality and durability; Cooper (2005) suggests that this may be a signal to others of dissociation with a product that is perceived as out of date or, in the case of many cars, a symbol of status (Johansson-Stenman and Martinsson 2006, Whiteley 1987).

It has been argued that cars, like other consumer goods, have planned obsolescence built in (Packard 1960, Slade 2006). Obsolescence can take many forms and can vary from product to product (Packard 1960, OECD 1982, Cooper 2005, Burns 2010, Chapman 2010). Burns (2010) classified obsolescence in four modes: aesthetic, social, technological and economic suggesting that when designing a product, it should be assessed against these four modes. This obsolescence assessment may be more complex; recent studies show not a deliberate decision but one that is affected by innovation cycles, product complexity and development costs (Longmuss and Poppe 2017).

Meijkamp (1998), Vezzoli and Manzini (2008) and Skelton and Allwood (2013) argue that for intensively used shared-use products, such as shared cars, early obsolescence and a shorter optimised lifespan may be beneficial. This obsolescence is more technological and economical, rather than aesthetic or social. Shared cars can potentially wear faster and be replaced with more efficient units. This approach challenges some of the strategies of design for product longevity, including design for obsolescence (e.g. Burns 2010, Park 2010). In fact, it may accelerate obsolescence (Vezzoli and Manzini 2008). Looking at Burns' four modes of obsolescence from an intensely used product approach, two assessment modes will be removed by intensive use; technological and economic obsolescence (Burns 2010).

It has been argued that a product with environmental impact during usage (i.e. energy or water consumption), such as a passenger car, should be replaced before it is broken, but only with a less impactful product. This depends upon three variables (van Nes and Cramer 2006 p 1317):

> "(1) the initial environmental impact of the replacement product,

> (2) the decrease in the environmental impact of the replacement product during usage compared to the product in possession, and
>
> (3) the lifetime of the replacement product, or rather, the expected usage time of this product."

Conversely, Kagawa et al. (2011), looking into vehicle lifetime and its impact in the environment, concluded that there are overall CO_2 emission savings, from cradle to grave, and extending the lifespan of cars by a year from a baseline lifetime of 11.36 years to 12.36 years, concluded that there is a decrease in combined CO_2 emissions from reducing manufacturing output, due to lifespan extension, which in turn will affect fossil fuel refining processes and other services related to manufacturing and sales. Kagawa et al. (ibid) also compared CO_2 emissions savings to a car with a decrease in lifespan of a year from the baseline. Early car replacement could lead to more fuel-efficient vehicles on the road. However, the reductions in CO_2 emissions would be less significant when compared to the emissions associated with the manufacture of new vehicles (ibid). Skelton and Allwood (2013), evaluating the trade-off between increasing product lifetimes and increasing frequency of use, argue that increasing a passenger car use frequency, e.g. car club cars, emissions are reduced by 60%. "Emissions can be saved across the board regardless of the relative position of actual and optimal life. If the vehicles are assumed to fail at their design life ([…] 150,000km – 32.4 years for a privately owned, occasionally used car, and 2.16 years for the car club car) emissions are reduced by approximately 60% in the car-sharing scheme" (ibid pp.1726,1727). Skelton and Allwood reached a similar conclusion to Kagawa et al. (2011) concluding that emissions cost of early car replacement is at least as great as that of and extended car lifespan.

Durable consumer goods, such as passenger cars, may be worth repair as long as their commercial value is higher than the cost of repair (van Nes and Cramer 2006, Kim, et al. 2003, Nieuwenhuis 2008). By the end of a few years or very high mileage, depreciation and high repair costs lead consumers to replace their vehicles (Engers, Hartmann and Stern 2009, Gilmore and Lave 2013). Depreciation, the decreasing value of a product during time (Storchmann 2004), is the highest hidden cost consumers meet after buying a car (RAC 2011). According to trade publications and organisations for car buyers such as Parkers (2008) and WhatCar? (Holder 2016) at the end of three years from new, a car may be worth 40% of its initial value while a 10-

year-old car is only worth 10% (Storchmann 2004, Rogers and Rodrigues 2015). This depreciation rate starts to flatten after 10 years and remains almost flat (Storchman 2004). However, Storchmann limited his chronological study to three representative car models in the UK market (VW Golf, Toyota Corolla/Auris, BMW 318). Car depreciation in the market, unlike asset depreciation in financial accounts (Ryan 2008), depends upon many different variables such as mileage, reliability, condition, age, brand and desirability (Engers, Hartmann and Stern 2009, Gilmore and Lave 2013). Depreciation rates depend upon type of car, average annual mileage and fuel efficiency (Gilmore and Lave 2013). Rogers and Rodrigues (2015), on a sample of 560 cars calculated depreciation rates for eight car models using dealers' asking prices at different car ages and mileage from online multi-dealer car sales websites. A geographic search was set so that 70 cars of each model were included in the data. The results show all models depreciate at an average exponential rate of 19.6% per year (figure 4) in line with those of Parkers and WhatCar? (Parkers 2008, Holder 2016).

model	exponent	R2	average annual mileage
Golf	-0.184	0.939	8135
Beetle	-0.188	0.937	7995
Fabia	-0.175	0.919	6812
BMW 3	-0.207	0.899	9401
Mercedes E	-0.215	0.919	11465
Mondeo	-0.223	0.909	13878
Focus	-0.181	0.926	8558
Rio	-0.192	0.833	7587
average	-0.196		9229

Figure 5. Car price depreciation. Rogers, Rodrigues (2015).

2.4.1 Design for Product Attachment

Product attachment is the emotional bond consumers experience with their products (Schifferstein and Zwartkruis-Pelgrim 2008). Products are seen as valuable by their users even if their market value is low or inexistent (ibid). Such bond is created due to a series of experiences, but most products do not evolve, as opposed to users who evolve throughout life creating an imbalance (Chapman 2015). When this dissymmetry happens the relationship between object and subject declines and replacement follows (ibid). Objects that fulfil the changing needs of users are more powerful in achieving profounder levels of attachment (ibid), thus kept by their users for longer. The disparity between object and subject is, likewise, a by-product of technological development or “streamlined efficiency” (ibid p 80). Conversely, Wells and Xenias (2015) argue that current manufacturing technology enables product personalisation and therefore a bonding with the product. (Govers and Mugge 2004) assert that people become attached to products with similar ‘personality’ to theirs. This could, perhaps, be transposed to many users of cars who choose a model that conveys an image - real or not - of themselves to others (Johansson-Stenman and Martinsson 2006, Whiteley 1987). Material possessions, Chapman (2015) asserts, are shown as signifiers of status, concurring with Johansson-Stenman and Martinsson (2006) and Whiteley (1987) who classified the car as the status product *sans pareil*. Govers and Mugge (2004) suggest that products may incorporate meanings of self-expression, affiliation, pleasure and memories. Johansson-Stenman and Martinsson (2006) argue that car consumers are more concerned with status than environmental impacts, despite signalling otherwise in public.

Govers and Mugge (2004) and Wells and Xenias (2015) argue that product attachment through personalisation may lead to product longevity. However, Govers and Mugge (2004) also acknowledge that attachment may decline due to fashion changes, leading to early disposal. Nonetheless, Nieuwenhuis (2008) asserted that some cars, due to their particular history or rarity, are kept for indefinite periods of time or passed over through generations entering the realm of classic cars, usually attracting relatively high prices when traded in the market, thus having had a financial reason for being kept.

Chapman (2010 p.72) envisages strategies and frameworks that need to be developed, engaging users “on deeper and more profound levels, delivering intense and sophisticated experiences that slowly penetrate the user psyche over longer, more rewarding periods of time.” People have a peculiar relationship with cars (Whiteley 1987). Brand desire, image, function but also ease to part with, make this an intriguing product to be analysed from a product attachment perspective. For cars to evolve with their user’s needs, thus extending their lifespan, they would have to be modular (Nieuwenhuis 2008), insomuch as the evolving needs of the user could be accommodated by the car’s structure and equipment.

2.4.2 Design for Adaptability and Variability

Adaptability is a design feature, enabling, in a dynamic environment, a product to be changed to fulfil the needs of that same environment (Mackenzie, Cooper and Garnett 2010). In order to achieve this adaptability, products should be designed to be modular, flexible and with dynamic dimensions (Vezzoli and Manzini 2008). Adaptability has been used by automotive manufacturers to a limited extent. Cars are designed and tested to be used in disparate environmental conditions during their lifespans (Mildenberger and Khare 2000). Adaptability is common in commercial vehicles (Salvador, Forza and Rungtusanatham 2002). Trucks and lorries can, due to their modular construction, be adapted to carry various types of bodies. The 'General Purpose Vehicle' or Jeep is an example of a modular vehicle adapted to be used in various conditions (Buckley and Rees 2006).

Design for variability, like adaptability, is also closely related with modularity. Variability is the possibility a product has to offer changes to its use benefiting the user; e.g. stereo modules that can be bought separately and then stacked or arranged side-by-side (van Nes 2010). This variability should, like adaptability, be facilitated by modularity, disassembly and repair. Variability, enables changes to the product without the need for additional parts, unlike adaptability, broadly retaining its original physical appearance (ibid).

[redacted]

Variability has been used mainly in car interiors. A pioneer example is the Citroën *2CV* with removable seats (Figure 6) that could double as picnic chairs (Reynolds 2005). The Renault *16* could be configured into different solutions (Figure 7). Its seats were designed to adapt to different uses: child seat, rest position or a couchette for two passengers (Groupe Renault 2016). Finally, the Renault *Espace* (Figure 8), had six fully independent seats that could swivel, tumble and also be used as tables, creating different interior configurations (Groupe Renault 2016).

[redacted]

[redacted]

Despite this variability, mass-produced passenger cars, in general, are unable to evolve with users' needs and expectations and do not have variable dimensions, (cf. Vezzoli and Manzini (2008). The main limitation of mass-manufacturing is a negative correlation between high volume and product variety (Salvador, Forza and Rungtusanatham 2002). Such limitation is exacerbated by the design and construction methods of cars (Nieuwenhuis and Wells 2007), which in turn influence negatively the automotive industry's capability to change and adapt to sustainable design and paradigms (Wells and Nieuwenhuis 2012, Orsato and Wells 2007).

2.4.3 Design for Standardisation and Compatibility

The incumbent automotive industry was built upon the principles of mass production, made possible with standardisation of components and vehicles (Wells 2004). Ford's principles of mass production relied on those to increase productivity and throughput, thus reducing cost. According to (Stahel 2010b), standardisation has advantages over bespoke components during the main product stages:

- In manufacturing
  - avoids design duplication
  - makes production cheaper
  - reduces quality control in production
  - reduces handling costs
  - prevents surplus of spares and out-of-production service parts
  - improves product information to customers
- During user-stage
  - reduces operating costs (training, stock and spare parts management)
  - facilitates repair (reducing their cost)
  - reduces maintenance mistakes
  - enables adaptation (e.g. upgradability
- At End-of-Life
  - remarketing of components
  - economy of scale in remanufacturing
  - parts cannibalisation
  - avoids out-of-production spare parts

Nonetheless, despite this 'endogenous' standardisation, i.e. parts that only fit one car model or at best several multinational's subsidiaries' models. 'Exogenous' standards do exist, but are limited in the automotive industry to a few components (Blume and Walther 2013). A lack of open, industry-wide standards is undermining modularity (Section 2.4.4) and increasing costs to the value chain (Blume and Walther 2013, Sturgeon, et al. 2009). A notable exception is the microelectronics industry supplying automotive manufacturers; with well-defined core competencies, standardised interfaces, modular architectures and clear positions of power meeting "the automotive OEMs more at eye level than 'classical' suppliers and preventing their dominance (Blume and Walther 2013). Conversely, the automotive industry has been facing, since the early 21st century, an increase in customised products that use standardised parts such as coloured trimming components in dashboards, reducing thus, the margins to standardised parts, and increases costs (Ahmadjian and Lincoln 2001). The lack of open standards throughout the industry undermines value chain modularity, limits economies of scale and of scope in production and design respectively (Sturgeon, et al. 2009).

Standardisation of parts is also made difficult because legal requirements (e.g. safety, end-of-life) and incentive policies vary from country to country, despite this being a global industry (Sturgeon, et al. 2009). Sturgeon and associates (ibid) maintain that a concentration of powers at the top of the value chain means that each automotive company or group will have its own standards, providing little room for innovation from smaller entrants, concurring with Wells and Nieuwenhuis's (2012) assertions about systemic continuity, such as those of product and process technology and business model. There are nonetheless, limits to standardisation (Sturgeon, et al. 2009); visible components need to be stylistically distinct from those of competitors, and specific performance goals for standardised parts may be difficult to achieve in different vehicles or are deliberately avoided (Blume and Walther 2013), forcing suppliers to work closely with manufacturers, often in a submissive role.

2.4.4 Upgradability and Modularity

Upgradability is the ability of a product to evolve with, and adapt to consumer needs, be up-to-date with the latest technology, regulation and fashion trends, enabling longer product lifespans (van Nes 2010) and can be applied to reduce product obsolescence through replacement of old parts or components for newer, more up-to-date units (Vezzoli and Manzini 2008). Upgradability can be facilitated by using easier to replace and upgrade modular sub-assemblies (Park 2010).

To decrease the environmental impact of a product, a considerable part of it has to remain unchanged (Vezzoli and Manzini 2008). This approach enables product update without sacrificing components that do not need to be replaced. Replacement components should be accessible to consumers (van Nes 2010) in order to ‘future proof’ products against increasing uncertainty of future technological, regulatory and fashion requirements (Umeda, et al. 2008). Nieuwenhuis (2008) concludes that a modular approach to car construction could, conceptually, enable the car to evolve with the user’s needs, offer a higher degree of customisation and regular cosmetic changes, contributing thus to a longer lifespan. Elements of the structure, once their lifetime ends, or user needs change, would be replaced by more up-to-date parts.

Modularity enables reparability and upgradability through easy replacement and addition of new modules (2010). Vezzoli and Manzini (2008 p142) set out guidelines to “design modular and dynamically configured products to facilitate their adaptability.” Cars are, to a limited extent, modular (Pandremenos, et al. 2009, Paralikas, et al. 2011, Pandremenos, et al. 2011, Christensen 2011, McDuffie 2013) but this modularity is restricted to the manufacturer’s capability of using modules - subassemblies - during design and assembly phases (Pandremenos, et al. 2009). In some cases, vehicles use common architectures, but display different styles. These modules are not upgradable during the car’s service life because the inflexible manufacturing process is not designed to accommodate this. Nonetheless, Nieuwenhuis (2008) provides the example of upgraded classic cars. The process is often very expensive and only worthwhile if there is an emotional relationship with the car, if the car’s market value is higher than the upgrade process or if its market value increases with such upgrades.

In the early days of motoring, manufacturers would often build cars as modules that could be personalised (Nieuwenhuis and Wells 2007). Before mass production, chassis and engines were assembled and customers would take these to their coachbuilders of choice to ascribe a bespoke body - another module - suiting their needs. This slow and expensive process led to Ford’s mass production process (Nieuwenhuis and Wells 2007). Nonetheless, truck and bus industries were still using it at the beginning of this century (Salvador, Forza and Rungtusanatham 2002). On one hand, this approach enables flexibility and high variability to fit different needs, on the other hand, limits production capability. The higher production cost, high maintenance and overall weight led mass-manufacturers to slowly abandon this approach in favour of unitary construction, the *Budd process,* laying the foundations of the mainstream passenger car industry (Nieuwenhuis and Wells 2007). Structural modularity was eliminated by design to improve manufacturing efficiency, sacrificing flexibility.

The *Budd process* premise, despite improvements, remains the same to this day; stamping sheets of metal into different shapes and profiles, welding them in jigs and chemically protecting the resulting structure from operating environments. This process is the cornerstone of continuity in the car industry (Wells and Nieuwenhuis (2012), which is averse to innovative design solutions and manufacturing concepts, e.g. Micro Factory Retailing, perceiving them as too risky to take into production, despite the high capital costs of the current approach (Wells (2010).

Few examples of limited mass-produced modular vehicles can be found in manufacturers such as Rover, Citroën and Land-Rover. The latter could have external modules attached to perform disparate tasks: to plough a field or to be driven on rails for rail track repairs, etc. (Chapman 2013). The Citroën *ID/DS* and the Rover *P6*, built by means of a modified *Budd process,* offered detachable external panels, which, in the event of a small collision, were relatively easy to repair or replace (Pressnell 1999) (Figure 9).

[redacted]

Modular concept-cars were proposed by FIAT in 1981 (Figure 10 and Figure 11), Opel in 1983 (Figure 12 and Figure 13) and Mercedes in 1995 (Figure 14). The FIAT *VSS*, designed by the architect Renzo Piano, had a spaceframe structure upon which non-loadbearing plastic panels were fastened. These panels could be replaced by different ones to form an estate, a saloon, etc. (Bellu 2002).

[redacted]

[redacted]

The Opel *Junior* had modularity limited to its interior, where different functional blocks could be secured or removed from the dashboard (Figure 12 and Figure 13).

[redacted]

[redacted]

The Mercedes-Benz *VRC* concept (Figure 14) proposed different top bodies that could be fastened to a single main structure (Kolarevic 2003). None of these solutions went into production. Attempts to improve upgradability of car components have been tried in electronics (Razavi, Densmore and Martin 2002), structures (Dower 2006) and engine and powertrain (Moura and Viegas 2009). Some of these have, so far, been applied to passenger car manufacturing in limited applications. After the VSS experiment, FIAT started to use pre-assembled modules - cockpit and doors - and interchangeable parts such as suspension, steering and braking systems that could be assembled in other cars from its group brands - ALFA and Lancia (Pandremenos, et al. 2009).

[redacted]

Umemori et al. (2001) argue that designers should take into consideration some factors, such as socio-technological trends and competing products, before embarking on design for upgradability. They also suggest that the further in the future new generations of products are, the harder it will be to predict functionality and performance trends. Manufacturers designing modular products, using operational definitions of product modularity such as standardisation, transferability, separateness, specificity, inter-changeability, reusability and decomposability, can improve customer service, flexibility and delivery by enabling modular product ranges, which in turn can improve product performance. (Antonio, Yam and Tang 2007). In-use modules should be easily replaceable by newer, more efficient ones, enabling product durability, functionality and increasing their overall performance (Stahel 2010a). Concurrently, Antonio, Yam and Tang (2007), through a survey of plastic, microelectronics and toy industries, maintain that manufacturers can provide better customer service, flexibility and delivery, which in turn improves product performance. Conversely, manufacturers cannot improve their capability for low price and product quality by modular product design (ibid). This may create important barriers to consumer satisfaction.

2.4.5 Design for Disassembly (DfD) and Product Disassembly

Design for Disassembly (DfD) enables maintenance and repair during usage and disassembly at end-of-life (Vezzoli and Manzini 2008). Design for disassembly is a design strategy to help designers incorporate disassembly in a new product (Bogue 2007). This strategy also helps designers to gather feedback in order to improve future model generations and consumer expectations (Go, et al. 2011), and in line with EU Directives 2000/53/EC on end-of-life vehicles, paragraph 13 and Directive 2005/32/EC on eco-design requirements for energy-using products (European Commission 2000, European Commission 2005). DfD should be introduced at the early stages of design, nevertheless, many designers still have little knowledge of DfD principles (Bogue 2007). Contrastingly, (Stahel 2010b) acknowledges that cars are designed to be disassembled, in line with eco-design guidelines, but in fact end up shredded due to cost constraints, resulting thus, in a smaller impact derived from the EU's Directive for end-of-life vehicles (European Commission 2000, European Commission 2005). This shows that some degree of unawareness and mismatch between design intention and end-of-life practice regarding DfD occurs in car design and manufacturing.

Product disassembly is labour-intensive and costly (Westkämper, et al. 1999) and needs to produce financial returns from materials and parts recovered (Go, et al. 2011). Product disassembly can be classified into two types: destructive and non-destructive (Desai and Mital 2003). Destructive disassembly destroys the component and render it useless for reuse or other recovery activity, except recycling of its basic materials or incineration (ibid). For non-destructive disassembly, two further types can be classified: total and selective disassembly. With total disassembly, the product is disassembled to its constituent parts (ibid). This can be a time-consuming process due to complexity and the number of sub-assemblies, parts, materials and fastening technologies applied during manufacturing. Selective disassembly dismantles selected components into valuable sub-assemblies or single parts, allowing a faster process. Giudice and Kassem (2009) call this the “evaluation of disassembly depth effectiveness” which make use of a quantifiable measure able to assess the efficiency of the design solution.

The European Directives 2000/53/EC on end-of-life vehicles and 2005/32/EC on eco-design (European Commission 2000), foresee a role for easier disassembly as facilitator of all other eco-design approaches. Westkämper, et al. (1999 p564) assert that “the integration of assembly and disassembly seems to be advantageous for the activation of higher value for repair, maintenance and reuse of parts and components.” Conversely, Chapman (2010) criticises DfD as a symptomatic measure that does very little towards reducing current consumer - and industrial - demand.

2.4.6 Design for Durability/Robustness

A working legal definition for durability can be found in Ervine (2010); goods must be able to be fit for purpose and retain non-functional capabilities for a reasonable time. The automotive industry has been testing passenger cars, and their components, for integrity, safety and durability for many decades due to consumer pressure (Nader 2011 [1965]), business competitiveness (Happian-Smith 2001), product differentiation (Kotler and Keller 2009) and legal frameworks (Happian-Smith 2001).

A general lack of durability in American new cars was reported during the 1950s and 1960s, both with squeaks, rattles, missing bolts or corrosion (Packard 1960). Japanese car manufacturers, during and after the oil crisis of 1974, started to challenge western car manufacturers by offering smaller engines and strong vehicle reliability (Holweg 2007). Barbiroli (2008) notes that reliability enables durability of products, ensuring their functionality for longer. However, reliability may not be sufficient to enable such durability. Cooper (2002) argues that increased durability may demand an element of redesign to a product; internal component quality but also shape and surface and, ultimately, attention to detail in its construction. It is difficult to make projections of product failure towards the end of expected life (e.g. automotive components) due to lack of data beyond warranty time; the cost model inputs are random variables and optimisation of cost model is an interaction of random factors (Kleyner and Sandborn 2008). Reliability, although important, may not be a decisive factor for longevity. The anecdotal

Japanese car reliability has been achieved through lean manufacturing, a process developed by Toyota Motor Company during the 1930s and slowly adopted by many other global car manufacturers (Liker 2006). The process envisages the elimination of time and material waste by acting on defective components in real time during all assembly stages (Liker 2006, Wells Wynn-Williams 2009, 2010).

Corrosion, a major problem affecting most cars until the end of the 1970s, is now reduced through better steel treatment, despite some anecdotal evidence of relatively recent cars still being affected by this problem due to poor anti-corrosion protection during manufacturing (Evans 2016). Seaside or harsher winter environments, where salt is spread on the roads, may accelerate corrosion (Fuhrmann 1979). Corrosion can attack welding and parts of the structure (Happian-Smith 2001) leading to structural failure, reduce longevity and threatening safety (Fuhrmann 1979). Corrosion protection technology leapt forward after the 1980s, with steel galvanisation and electrochemical processes before and during the painting stage - e.g. cataphoretic protection - enabling a longer structural lifespan (Andrews, Nieuwenhuis and Ewing 2006). Anticipating structural load and the operational environment can lead to a more durable car (Allwood and Cullen 2012). It is not uncommon nowadays for automotive manufacturers to guarantee corrosion protection against perforation for 6 to 12 years.

Regarding the average lifespans of cars, the literature consulted suggests different figures throughout time and in different countries:

- Nieuwenhuis (1994), 11-12 years in Western Europe.
- Kim, et al (2003) - 16.9 years in 1990 in the U.S.
- Barbirolli (2008) - 5-6 years in the 1990s, down from 15-16 years in 1960 and 1970s. No specific country.
- Vezzolli and Manzini (2008), 5-15 years. No specific country.
- Skelton, Allwood (2013), 14 years in the UK.
- Oguchi, Fuse (2014), 13.5 years in the UK.
- Dun, Horton and Kollamthodi (2015), 14.4 (petrol cars), 14,0 (diesel cars) in UK.

Barbirolli’s (2008) assertions however, compared with the other authors, seems incongruous. The author does not provide clear evidence for such a conclusion. Lifespans may be related to the different contextual environment cars operate in during their lifespan (Nieuwenhuis 1994), rendering car longevity labelling quite difficult. Cooper's (2010) suggestion of labelling optimal lifespans has not yet been translated to the auto industry. Oguchi and Fuse (2014) have indirectly shed some light about how challenging car lifespan labelling may be. In their study of 17 countries, they found a disparity between average lifespan of cars, from 11 years in Belgium to 22.6 in Australia. For Stahel (2010b), in developing countries, such as India and Philippines, cars are kept for longer and their components often remanufactured concurring with Nieuwenhuis (1994), who implied country development and component scarcity contribute to longevity. Nevertheless, average lifespan does not seem to be related with country development alone nor, for example, local climate conditions. In Australia and Finland – both developed countries with, contrasting harsh climates – cars have around 23 years lifespan on average (Oguchi and Fuse 2014); South Korea passenger car average lifespan raised from just under 9 years in 2000 to 13 in 2010 (ibid). Design, thus, may not be the only contributor to such disparate numbers, and more research is needed. This partially contradicts Stahel's (2010a) assertion that in industrialised countries fashion and social pressure are the main determinants for lower product durability. However, Oguchi and Fuse ((2014) show that the lifespan of cars has increased or stabilised in many countries. Nonetheless, consumers seem to be divided about satisfaction with their products' lifetimes (Cooper 2004, Cooper and Mayers 2000).

2.4.7 Maintenance and Reparability

Most cars are designed to be maintained and repaired during their lifespans; they incorporate consumables that have to be replaced regularly at mileage or year intervals (Graham and Thrift 2007). These include brake pads, tyres, coolants, lubricants, windscreen wipers, etc. However, at later stages of a car's life, usually when their market value drops, due to age and/or mileage, some critical components may have worn (e.g. clutches, bearings, pistons), potentially creating uncertainty in consumers; whether to keep their cars and repair them or buy a newer model (Kim, et al. 2003). Vezzoli and Manzini (2008) refer to labour costs as the main determinant of reparability. Nonetheless, careful maintenance through frequent servicing, and in case of breakdown or small damage, adequate repair action, may lead to longer lifespans (Stahel 2010a).

Gwilt et al. (2015) assert that care practices for products in general can be managed by service companies – which is already happening with cars – but warn that such practices create a duty of care disconnection between user and product. This disconnection is exacerbated by the relentless exclusion, by automotive companies, of car users' ability to maintain and repair their vehicles, especially after the advent of electronically controlled systems (Burns 2010). Nieuwenhuis (2008) explored car repair as a form of building emotional attachment and concluded that one of the many elements influencing this is a level of control achieved through mechanical simplicity allowing the owner to carry out their own maintenance and repair. This element has been lost during recent decades because passenger cars are increasingly complex to repair with simple tools (Graham and Thrift 2007). Such complexity requires mechanical, electrical and software knowledge that it is not within reach of the mainstream consumer (Burns 2010).

Different levels of preventive maintenance can be performed by users. They include checking fluid levels, tyre thread wear and small bodywork damage. The next level, changing oil, filters and brake pads can be performed if the user has some skills and basic tools (Automobile Association 2017). It is assumed that, during warranty periods, the vast majority of people may prefer to delegate this task to a service garage.

Also, important to car repair is market depreciation. Around the tenth year of a car's lifetime consumers, if confronted with major repairs, may face the decision to either repair or discard their car. (Kollmann 1992) suggests that consumers often overestimate repair costs. However, if an owner actively seeks to prolong the life of their car, the cost of doing so may be, in some cases, lower than buying a new or nearly-new car (Nieuwenhuis 1994).

2.5 Car Consumption

Unsustainable consumption became a symbol of a high standard of living and lock-in practices creating a sense of routine (Mont and Power 2010), even for large products such as cars. Sanne (2002) (2002) asserts that lock-in circumstances are often created by producers and business interests. But they are also created by socio-technical conditions such as available technologies, policies, infrastructure, user preferences, etc. (Geels 2011). This 'landscape' creates new habits that will, in time, become ingrained. Schwanen, Banister and Anable (2012) assert that car use habits are difficult to change - but not impossible - due to many actors in this landscape such as business and policy makers promoting its usage. Nonetheless, Sanne (2002) and Schwanen, Banister and Anable (2012) conclude that consumer habits can change with time, but that change must be generated by policies challenging dogmas of economic growth.

Economic growth discourse and policy has been promoting unsustainable levels of consumption, the construction of more car related infrastructures, whilst at the same time, incoherently - and with different levels of uncertainty - addressing low-carbon challenges (Barrett, et al. 2018). Cooper (2004), looking at household appliances, concludes that consumers have an important role in reversing consumerist trends, but are sometimes overwhelmed by technological advance, peer pressure, fashion and other socio-technical constraints. Consumers are tightly strapped in a capitalist, growth promoting economy and the unwillingness of governments to move away from this system.

Car consumption nowadays is facilitated by an unbridled access to credit in the form of personal loans, leasing, hire-purchase or personal contract plans, (Ramcharan, Van den Heuvel and Verani 2016, Cash 2017), making it relatively easy for people to buy, exchange and use cars. For example, a personal leasing with a fixed monthly cost; because the car is never owned by the user, depreciation is not a major issue, although the latter might be included in the monthly payment. Similarly, for a personal contract plan; at the end of the contract, no more than 36 months, the user can keep the car, exchange for a new one, or walk away.

Mont and Power (2010) and Power and Mont (2010) describe the role of consumers in finer detail and assert that it is needs, wants, desires, values and norms that dictate how people consume. Johansson-Stenman and Martinsson (2006), in a survey of 2,500 respondents in Sweden, conclude that many people are more concerned about status and less concerned about the environment, even if they admit the opposite publicly and criticise status as determinant when buying, for example, a car. There is a systematic observable pattern that describes discrepancies between respondent’s preferences for cars, and other people’s perception of respondent’s preferences for cars, e.g. “people in conversation give the impression that they are much more concerned about the environment than they actually are” (ibid p 143). Mont and Power (2010) and Schwanen and Lucas (2011), for example, do not disregard social and cultural norms, internal and external factors such as habits, perceptions, knowledge and transport alternatives that play a major role in motivating such levels of consumption and use of cars. Sheller (2012) ascertains the role of several cultural dimensions of automobility - emotional, sensory, aesthetic -, beyond the technical, political and socio-economic factors, are a broader setting to understand its ubiquitous persistence. Schwanen, Banister and Anable (2012) refer to contexts such as the school run, irregular working shifts or perhaps living where no other forms of mobility are reliable or available.

It must be acknowledged that not all areas and regions of a country are equal in access to health, wealth or social care, neither do all have the same access to wide transportation options to serve their needs. It has been known that car usage may increase poverty. In some instances, the lack of transport solutions, other than the car, strap poorer consumers in car ownership, increasing their financial burden (Lucas and Pangbourne 2012). Perhaps the most challenging regions to step from ownership to, for example, shared use are rural or small communities far away from larger cities (Wappelhorst, et al. 2014). Public funding and volunteerism could stimulate car sharing as part of wider mobility options (Liddle, McElwee and Disney 2012). In such cases, profit should not be the main incentive, but perhaps environmental sustainability (Ceschin and Vezzoli 2010) and social inclusion (Lucas 2006).

Mont and Power (2010) and Schwanen, Banister and Anable (2012) conclude that adopting sustainable consumption patterns and changing habits of car usage is important but not sufficient given the scale of change required, and, therefore, focusing on an individual level is unwise. They argue that change needs to take place at a system-level through policy interventions. However, Mont and Power (2010) advise that although some governments may be strongly inclined towards policy intervention, they may become inhibited to pursue such role due to lack of public support to car industry lobbying. Sheller (2012) concludes that a broad cultural perspective of holistic mobility offers a more realistic assessment about the role stakeholders, including, for example, anti-car advocacy groups, may play in car consumption and use.

Consumers have been nudged and nurtured to own products, cars being no exception. However, there are some indications society is changing and becoming open to shared use of products. Acknowledging and increasing the cost of motoring may provide a helping stimulus in that direction for some car users. Nevertheless, awareness and understanding concepts such as car sharing is necessary, together with viable public transport alternatives in order to allow higher numbers of car users to shift from ownership to shared use.

2.5.1 Product Service Systems (PSS) and Shared-use Cars

Baines, et al. (2007) define product service systems (PSS) as an integrated proposition that delivers value in use. It decouples economic achievement from material consumption, values asset performance rather than ownership by integrating product and service of value to the final user (ibid). The latter is released from ownership responsibilities. These lie with the service provider and potentially reducing the environmental impacts of economic activity. In a service economy, material products are treated as capital assets rather than as consumables, stimulating value-added services to prolong a product's life, minimising loss of resources, thus reducing material demand and environmental impacts (Mont 2002). Therefore, if products are shared as part of a service (e.g. transporting people from A to B), resources can be used more intensively and, therefore, efficiently (Mont 2004). The aim is to use product performance and attributes within a service 'offer' to obtain the desired result (Mont 2002). People consume a service and the product is shared by individuals.

PSS points toward an integrated approach with a new type of stakeholder relationship, convergence of new economic interests and resource optimisation (Manzini and Vezzoli 2003); in a classical business model, stakeholders work in isolation optimising their own share of the whole system and fail to reduce impacts elsewhere. A PSS approach can create a greater potential for eco-efficiency and influence strategic design for sustainability, including longevity, in an interconnected series of product and service lifecycles (ibid). In the context of PSS, strategic design is "the capability to create new stakeholder configurations and develop an integrated system of products, services and communication that is coherent with the medium-long term perspective of sustainability" (ibid p 856). In other words, designing and selling a system of products and services rather than designing and selling physical products.

Service system innovation transition starts with a vision and dynamism common to all stakeholders and, despite the uncertainties that same transition may bring, the process is held at three key stages, business sector long-term vision, the place where the transition is taking place and a dynamic stakeholder network (van den Bosch, Brezet and Vergragt 2005). Mont

(2002 p 239) argues that “when one is to integrate [the sale of a service rather than a product] into a system, sub-optimisation might occur and overall environmental impact might not necessarily be reduced”. The focus of PSS should be in providing consumer satisfaction but also an environmental sound service. Williams (2007) classifies car industry specific PSS into three categories. These are based upon Behrendt, et al. (2003), Brezet et al. (2001) and Zaring (2001):

1. Product-oriented services – Business which sells products plus some associated services (e.g. car dealership who offers a maintenance service contract)
2. Use oriented services – Products are central but owned by a service provider and available to users (e.g. car hire and car clubs)
3. Result-oriented services – Providers and users agree on a desired outcome (e.g traveling from A-to-B by bike and train, (cf. Olafsson, Nielsen and Carstensen 2016).

For Mont (2002) manufacturers, in general, might be interested in providing maintenance to help extend product lifetime if the operational cost of a product-service is absorbed by the service organisation, reducing the turnover of products that deliver that service and its environmental burden. Such maintenance can be an important cost for car sharing companies who usually acquire their vehicles for a relatively short period of time due to high utilisation and early replacement (Meijkamp 1998, Shaheen and Cohen 2012). Many automotive PSS initiatives, such as car leasing or car hire, may be flawed because they fail to address the sustainability elements, thus failing to deliver all the benefits of system innovation (Williams 2007). This is because changes will need to take place at system level, beyond product improvement and product re-design under environmental constraints or consumption. In parallel with other stakeholders, such as consumers and policymakers, the automotive industry itself needs to address its failure to deliver environmental sound solutions such as PSS innovation.

Ehrenfeld (2001) adds another stage in which institutional or infrastructural innovations, such as web apps or electric car charging stations produce beneficial outcomes (e.g. car clubs, lift share or car leasing). Car sharing has been relatively effective; consumers, consequently, increase their use of other modes of transport (e.g. rail, bus) and decrease the use of cars (Meijkamp 1998, Shaheen and Rodier 2005). Such reduced use of cars makes unclear how extensive the environmental impacts of shared cars (e.g. car hire, car share and lift share) are when compared to private cars and, seems to contradict the premises of PSS and asset intensive use.

Shared vehicles have the potential to increase and intensify the number of users per car, reducing car manufacturing demand and vehicles on the road (Shaheen and Rodier 2005, Baptista, Melo and Rolim 2014). In Austria, for example, 1.75 cars would be enough for 100 users (Steininger and Bachner 2014), in Switzerland potential users vary between 6.5% of the driving population in Geneva to 11.7% in Bern (Becker, Ciari and Axhausen 2017). The difference to the lifespan cars (Sections 2.3 and 2.4) is that the rate of replacement – either unit or generational - is liable to be much quicker and may enable newer, more efficient product's new generations, taking quicker advantage of technological improvements (Vezzoli and Manzini 2008, Meijkamp 1998). Such quicker replacement has the potential to frustrate users, or indeed service-providers who may have invested in interfaces to work with the superseded technology or the economies of repairing a short-lived product.

It is uncertain if, at their end-of-life, shared cars will be disposed quicker and potentially more effectively and efficiently than, for example, longer-lasting cars. Reflecting upon current car design, this quicker disposal would not be effective at EoL, as the recycling process is somewhat inefficient and time-consuming (Dalmijn and De Jong 2007). But, where the embodied GHG emissions are higher, the user stage, is where a prolonged intensity of use can potentially impact significantly.

2.5.2 Car Sharing Definitions

Steininger et al. (1996) define car sharing as an intermediate service between taxis and hire cars, although differences between the latter and car sharing are becoming ambiguous (Shaheen and Cohen 2012). Katzev (2003) defines a car sharing business as a cooperative or a for-profit organisation. Katzev's definition of car sharing also differentiates station cars from neighbourhood cars. The former, near train stations, airports and other transport hubs. The latter, near members' places of residence. For Loose, et al. (2006) car sharing is a sharing vehicle service between members which in turn promotes the use of sustainable modes of transport. Katzev (2003) makes a clearer - than Steininger's - differentiation between car clubs and car hire; car clubs charges are per minute or hour, and include fuel, whereas car hire charges are per day and do not include fuel. Shaheen and Cohen (2012) distinguish the usage rates per vehicle in car hire and car clubs; 78-82% per month and 25-40% per day respectively. Often car hire companies offer excess damage waiver for a daily fee and other options such as satnav and child booster seats. Recently, car clubs, acquired by larger car hire multinationals, are seeing their services being merged with car rental services, such as non-attended access to car hire or car club membership access to hire cars (ibid). Some companies include in their car club membership the option to hire cars and vice-versa (Enterprise Holdings 2016). Nonetheless, car clubs, lift share and car hire can be seen as different forms of car sharing. Another distinction made by Katzev (2003) is the difference between car clubs and ride sharing. In both cases a membership is required. The main distinction is that in ride sharing users going to the same destination share a vehicle, whereas in car clubs – like in car hire - each user will use the car for a particular, usually non-shared, journey.

The UK car sharing umbrella organisation's survey (Carplus 2015a, Carplus 2015b, Carplus 2015c), using Mosaic social categories, found that in England and Wales the main users of car sharing, are younger, urban, highly educated people (19%), followed by older singles leaving in leafy inner suburbs (14%). The third largest group are wealthy households in accessible suburban areas (11%), and the fourth largest group are inhabitants of the university fringe (10.3%), a total of nearly 54% of the main users. The remaining groups are other types within the 'middle class' cohort, with medium or high incomes living in city centres or suburban areas with access to good public transport.

2.5.3 Impacts of Car Sharing

Shared use cars enable the reduction of negative impacts such as congestion, pollution, energy and materials required to manufacture and use (Katzev 2003). Car sharing helps to reduce this impact in multiple ways: reductions of 33% in mileage by users (Meijkamp 1998), reductions in GHG emissions by households (Martin, Shaheen and Lidicker 2010) and reductions of up to 54% in CO2 emissions by individual car share users (Rydén and Morin 2005). There is evidence that people who join a car sharing scheme reduce their vehicle annual mileage (Shaheen and Cohen 2012, Carplus 2015a, Carplus 2015b, Carplus 2015c). Meijkamp´s (1998) study of Dutch car sharing, reported reductions in car usage rates from 3.5 to 2.0 times per week after engaging in this type of service. People who engage in car sharing tend to also use other modes of transport for daily activities such as commuting (Shaheen 2004). An increase in other modes of transport such as bicycle, train and city transport, was also reported by Meijkamp (1998). Meijkamp suggests, thus, a relationship between car sharing engagement and the use of alternative and public modes of transport. A potential benefit of car sharing is an intensive use of passenger cars. Meijkamp (ibid p 242) refers to an “enhanced service efficiency of the car” such as, the reduction in parking spaces needed, less materials and energy to manufacture the product and, a shorter lifespan of the car. According to Meijkamp (ibid p 242), “the extent to which cars are being used directly relates to the profitability of the investment in the car and of the company itself”. Car sharing users may reflect upon the reasons for using a car before travelling and may decide to drive only if there is no alternative to reach their intended destination. This is explained by the pay-per-use nature of car sharing (Shaheen and Cohen 2012).

One study concluded that 80% of the energy used by a car throughout its total lifespan is during use (Mildenberger and Khare 2000). The ratio of users to one car is directly proportional to the mileage travelled by that car annually. The higher the ratio of users per car, the higher the car’s potentially annual mileage (Meijkamp 1998). In Meijkamp’s study, 847 participants were using 71 cars, a ratio of 1 car per 12 users. Meijkamp reports an average of 5,660 km per year per user. For this reason, Meijkamp (ibid) suggests that shared cars will have a reduced lifespan, leading to a number of environmental benefits:

1. Faster turnover with newer, more efficient models.
2. Shorter economic payback period that presents smaller economic risks.
3. Cars are returned for disassembly faster, thus time between assembly and disassembly is shorter.

Such faster replacement could potentially increase reuse and remanufacturing of parts. Intensive usage can reduce up to 60% emissions when compared with a lower annual mileage car, (i.e. less than 5,000 miles per year), and “the magnitude of emissions savings is highly sensitive to the use-phase improvement rate. Increasing this rate from 0.1% to 5% per year increases the potential savings from 5% to over 50% of initial emissions” (Skelton and Allwood 2013 p 1727).

2.5.4 Upscale of Car Sharing

Loose, et al. (2006) assert that in order to upscale car sharing it is necessary to integrate this service with public transport. Furthermore, car sharing should be strategically partnered with car hire, petrol stations, car manufacturers, car dealers and places of employment (Shaheen 2004). Car sharing membership is only feasible if there are alternatives modes of transport to complement a lack of ownership of a privately-owned vehicle (Prettenthaler and Steininger 1999). Car ownership could then be replaced by mobility on-demand, with car sharing as option, without significant disadvantages to users. Katzev (2003), in his research of early car sharing adopters, found that what motivates people to join car sharing schemes is:

1. Occasional need of a car.
2. Financial savings (when compared with ownership).
3. Convenience of car availability (nearest car to home).
4. Length of membership (typically, annual).
5. Sale of, or avoidance of buying, a car.
6. Increase in use of multi modal transport.

Another advantage of car sharing is the increased cost-benefit of fewer cars on the road, mileage travelled, time spent travelling, fuel used, emissions and pollution levels (Fellows and Pitfield 2000). Users are also stimulated to be more cautious about each car journey because hourly rates are paid upfront and include all overhead costs (Katzev 2003).

Some strong psychological forces may, however, deter car owners to shift towards car sharing such as prestige and "waiting obedience" (Prettenthaler and Steininger 1999). Other reasons are what Katzev (2003 p 83) asserts as the negatives of car sharing such as:

> "1. The user has to plan his or her trips in advance, so in most cases spontaneity is lost.
>
> 2. The user has to remember, and take the time, to make a reservation.
>
> 3. The car is probably parked farther from the user's residence than his or her personal car would be.
>
> 4. The user has to leave the car clean, every time, even if he or she is in a hurry.
>
> 5. The user has to deal with some form of paperwork, personal identification

numbers (PINs), lockboxes, etc., for every trip.

6. The user has to worry about getting the car back on time—another loss of spontaneity."

It can be concluded that car sharing contrasts with both the accepted norm of car ownership and the status associated with it (Mont 2002, Prettenthaler and Steininger 1999, Johansson-Stenman and Martinsson 2006). People see utility in products both through their attributes and the status they provide to their self-image. Despite showing concern over the environment, many individuals will put their self-image above it, even if they do not assume such position in public (Johansson-Stenman and Martinsson 2006). This resistance to change from ownership towards services, like car sharing, by consumers, may also be influenced by wider societal factors such as moral, normative, emotional, social, facilitating conditions, and habits (Sheller 2012, Schwanen and Lucas 2011, Verplanken, et al. 1998, Nykvist and Whitmarsh 2008).

2.5.5 Shared Use and Car Ownership

Comprehensive shared use strategies may help car sharing service systems to fulfil their role in environmental, social and economic changes (Williams 2007, Tukker and Tischner 2006). They have to satisfy the needs of consumers, delivering integrated product service systems (Vezzoli, et al. 2012). It is also a way of reducing social and environmental pressures (Prettenthaler and Steininger 1999). Car sharing enables vehicle users to lower their annual vehicle fixed costs, inducing a shift to modal use of transport, (e.g. bus and rail) (Steininger, Vogl and Zettl 1996). The benefits of car sharing are more relevant to lower annual mileage drivers because it reduces their insurance, tax, servicing and depreciation costs compared to car ownership (Prettenthaler and Steininger 1999). Meijkamp (1998) argues that car sharing services encourage consumers to use cars more efficiently, and users of car sharing schemes changed their behaviour by increasing their use of public transport, thus reducing their annual car mileage.

Cars are, still, the preferred means of transportation, however, for Nykvist and Whitmarsh (2008), they have lost their iconic status. Contrastingly, Sheller (2012) argues that the culture of automobility is, still, dominant. Metz (2013), however, suggests that younger people, who cannot afford them and are adopting new telecommunication technologies that can replace social functions the car had in the past, are not interested in owning cars as much as previous generations were. To change the accepted norm of car ownership, a socio-technical change is needed (Schot and Geels 2008). On one hand, the technological change has occurred, for example, in car sharing, with the advent of the internet, smartphones, apps and constant online accessibility enabling a growth in car sharing activities (Shaheen and Cohen 2012). On the other hand, there is a slow uptake of alternative powertrain technologies (e.g. hybrids, electric, etc.) by consumers due to risk aversion and other societal issues such as status and performance (Wiedmann, et al. 2011). Shared passenger car use is still a niche activity, undermined by the overwhelming preferred norm of car ownership (Wells and Xenias 2015).

2.5.6 Transition from Ownership to Shared Use.

The transition between product ownership and service provision has been addressed from different perspectives (e.g. business and social sciences) by Steininger, et al (1996), Meijkamp (1998), Prettenhaler and Steininger (1999), Katzev (2003), Mont (2004) and Piscicelli, Cooper and Fisher (2015). On a systemic level Frank Geels and colleagues (Geels and Kemp 2012, Geels, et al. 2012, Schot and Geels 2008, Geels 2010) have been looking at paradigmatic transitions, from one socio-technical regime to another, through a multi-level perspective, (e.g. the train regime to the car regime). Socio-technical transitions are multi-dimensional phenomena encompassing changes in technology, markets, user practices, policy and culture and in response to environmental problems (Geels 2004). Steininger, Vogl and Zettl (1996) found financial reasons to be the most important factor for this transition, followed by environmental considerations. Pretenhaler and Steininger (1999) argue that policies to stimulate a shift from ownership to shared use need to be different from approaches to ownership; traditional transport policies impacting variable or fixed costs, (e.g. fuel and vehicle excise duty) can only increase the shifting potential when consumers are driven by annual vehicle mileage costs and by having a car as a convenience for every occasion. If, however, consumers are driven by more subtle incentives, such as prestige and status (e.g. sections 2.5, 2.5.4), then the lifestyle of product service use - as something prestigious - needs to be addressed as part of a policy option. The reasons for shared use transition amongst car sharing members reside mainly in the rising costs of motoring, time spent to access cars, public transport journey times and access to parking Meijkamp (1998). Katzev's (2003) study, based on the Portland, U.S.A., population, describes financial considerations as a reason for shifting. However, the most important factor was the need for an additional vehicle. Katzev (ibid) ascertains that car sharing users became more aware of travel costs after joining a car sharing scheme. This awareness was influenced positively by the likelihood of future use of car sharing vehicles and reduced impulsive car journeys. For Mont (2004), other indirect factors may lead to the use of car sharing, such as fuel prices, parking fees, efficient networks of public transport and restrictions to private car use. Piscicelli, Cooper and Fisher (2015), found important values such as tradition, security and power that may hinder the transition to shared economy services despite an increase in awareness of those, with potential implications for car sharing (see also section 2.5.4).

Schot and Geels (2008) ascertain that niches, clusters of niches and small-scale experiments are crucial for transition and regime change. In London, a case study in transitions, describes the efforts of a leading actor in the heavy vehicle industry to develop and commercialise, in large scale, hybrid-electric vehicles through field tests and subsidisation and a critical tension between niches and volume-oriented business (Sushandoyo and Magnusson 2014). Transitioning to more sustainable regimes is a normative goal and a collective problem (Geels 2010). The nature of shared consumption is disruptive and challenges the status quo (Piscicelli, Cooper and Fisher 2015). As such, there is no incentive for consumers or companies to change their habits and practises. The incentive, support and important penalising policies must come from public authorities and civil society, together with a narrative for sustainability that matches policy (Schwanen, Banister and Anable 2012, Geels 2010). However, barriers, such as systems of provision, policy and legislation frameworks may have negative impacts towards a transition to car share. Loose, et al. (2006) found nine steps for the uptake of car sharing:

1. Customer orientation; customer perception of car sharing.
2. Publicity; enhanced public awareness of the concept.
3. Target market alignment; marketing strategies and tools to attract new customers.
4. Compete with corporate vehicle fleets.
5. Technical innovation to be continuously improved.
6. Economic ratios; financial controls and flexibility.
7. Strategic alliances with public transport providers.
8. Boroughs and metropolitan authorities actively promoting car sharing.
9. Central government improving legal framework through road traffic regulations benefiting car share.

Nykvist and Whitmarsh (2008), and to some extent Geels (2010), assert that direct costs such as congestion charges are more effective than indirect penalties, (e.g. fuel duty), but only if supported by a good public transport network and comprehensive modal alternatives. Conversely, Prettenhaller and Steininger (1999) argue that such penalties are only effective if owners' concerns are related to mileage and convenience. For Katzev (2003) motoring costs and changes in personal situations are important considerations when shifting from ownership to a shared service.

Future individual behaviour change will have to act upon these influences through societal and technological changes (Geels, et al. 2012) initiated by third parties at higher or deeper levels (Jackson 2005). Government narratives for behaviour change also need to run parallel to tight policies for such changes (Schwanen, Banister and Anable 2012, Bergman 2017). Consumers need to be informed to understand the dimensions and possibilities of behaviour change but also recognise the role of collaborative consumption (Piscicelli, Cooper and Fisher 2015). Sheller (2012) argues that an automotive cultural shift is necessary and this may be influenced from outside the transport field, originated by other changes in communication, legitimacy, connectivity and spatiality.

2.5.7 Adaptation and Transition to Change

Culture is essential to understand how to mitigate, adapt to and, importantly, understand and framing phenomena such as climate change (Adger, et al. 2013 p 115). "Cultural factors shape how people support adaptation interventions, and their motivation to respond to them" (ibid p 115). The authors assert that [climate change] adaptation can put cultural elements of societal life at risk. Adger et al. (ibid) suggest that policy stemming from adaptation should be demanded at a local, community-based level. In that sense, it can be more plural and build upon accepted social norms, bringing cultural dimensions and policy making to a lower level. For Khalil (2011) short and longer-term policies should depend on countries' cultural profile. National culture and cultural values are better predictors of policy readiness than cultural practices. However, Khalil (2011) argues that culture can and should be manipulated in the right direction in order to develop policy. This concurs with Schwartz's (2014) assertion that cultures are not static and can be changed, either by policy (Khalil 2011) or by creating social structures enabling such changes, (e.g. consumption culture). Shove and Walker (2010), in their positioning paper criticising transitions and multi-level perspective (MLP) (e.g. Schot and Geels 2008), acknowledge that policies deliberately aimed at changing behaviours need to take into account the practices of those affected and how these can become dynamic and not stratified in hierarchies. As Geels initially proposed (cf. Geels and Schot 2007). Geels later acknowledged that levels, instead of hierarchies, refer to degrees of local practices (Geels 2011). These dynamic 'instabilities' from practices may undermine the crystallisation of the prevalent regime despite powerful interests deliberately trying to shape it (Shove and Walker 2010).

2.6 Cultural Influences upon Behaviour

Hofstede (1983), in his seminal work about national cultures in a business context, asserts that five dimensions exist in explaining how different national cultures are more or less open to changes in behaviour (Table 1). McSweeney (2002) argues that Hofstede's methodology is restricted to one company, I.B.M., and has questioned its generalizability. The structure of values that emerge at country level is an indirect indicator of the cultural orientations on which societies differ; this structure is best interpreted in terms of the value importance that guide and justify the functioning of societal institutions (Fischer, et al. 2010) and their reference groups. Triandis (2004) also criticised the limited number of dimensions, later addressed by Minkov and Hofstede (2010) (Table 1), but also criticises McSweeney (2002) for trying to be too perfect and perhaps missing Hofstede's national cultures insights, concluding that, despite the criticism, Hofstede is still influential in social sciences (Triandis 2004). Schwartz (2003) acknowledges that Hofstede's values for cultural insights discriminate among national and regional cultures but does not discriminate among individuals.

[redacted]

[redacted]

The macro level of cultural theory may provide a starting point to help understand general values of the UK population, and, specifically, car users. It could also be used to help understand the prevalent car regime (Geels, et al. 2012). Geels (2011) acknowledges that socio-technical transitions and the MLP are associated with “long-term macro-changes” (ibid p 38). Both Hofstede’s cultural dimensions and Geels’s MLP can be analogous to a country’s zoomed-out map, where only the main cities are shown and border lines provide a general idea of its geography. Hofstede’s “country-level dimensions cannot be applied to individuals and cannot be used for *inter-individual* comparisons” (Fischer, et al. 2010 p 136), neither can Geels’s MLP (Geels 2011). Fischer, et al. (2010) assess the degree of isomorphism (i.e. between individuals and between countries) on psychological values explained in terms of the same concepts or dimensions. Schwartz (2014) also asserts that the set of values, from his earlier work (Schwartz 1992), overlaps Hofstede’s more than, for instance, Inglehart and Baker’s (Inglehart and Baker 2000) (Table 2). Schwartz (2014) argues that cultures are never coherent nor totally integrated - more so nowadays -, with larger cross-cultural exchanges. Institutions and organisations emphasise orientations that are relevant to their functions (e.g. hierarchy, embeddedness or autonomy). Schwartz also concludes (ibid, p 580) that “the cultural value profiles of dominant cultural groups can characterize societies in a fruitful manner.” These descriptions of cultural dimensions in their various forms define how, in general, countries (or cultural regions) realise their social constructs, and this can shape, for example, how policy intervention is approached in different cultures.

Table 2. Relatedness of Schwartz, Hofstede and Inglehart and Baker’s cultural dimensions. Adapted from Schwartz (2014).

Hofstede 1980, Hofstede and Minkov (2011)	**Schwartz (1992, 2014)**	**Inglehart and Baker (2000)**
Individualism/Collectivism	Autonomy/Embeddedness	Secular-Rational/Traditional

Power Distance	Egalitarianism/Hierarchy	Self-Expression/Survival
Masculinity/Femininity	Mastery/Harmony	No equivalent

2.6.1 Individual Culture

Social relationships determine the content of individual values. It is meaningful to divide these values into vectors that express societal responses to the problems that all societies confront (Fischer, et al. 2010). From this perspective, the degree of similarity between values at individual and country levels is not critical (ibid). Hofstede (1983) made clear that national culture may not reflect individual culture. The reason for this dissimilarity is that statistics for one and the other stem from independent information (Fischer, et al. 2010 citing Dansereau, Alutto and Yammarino, 1984). Schwartz (1994) concurs to this affirming that individual-level value dimensions reflect the psychological subtleties of conflict and compatibility that people experience when pursuing different values in their lives, whereas culture-level dimensions are likely to reflect the different solutions to the problems of regulating human activities. Schwartz (ibid) noted Hofstede's dimensions of cultural variation as "ecological" or culture-level. Contrasting with individual-level dimensions, derived from analyses of numbers of individuals, culture-level dimensions are based on national statistical averages. Conversely, Fischer, et al. (2010) suggest that the relations between values at individual level reflect, despite not being totally homogenous between individuals, the logic of the requirements of functioning as psychological entities within interpersonal relationships. It can be concluded that such requirements originate, amongst other aspects, from social factors (Triandis 1979).

It is, therefore, important to understand how certain policies (e.g. environmental) meet, or not, the social constraints and expectations of the individual, for example car users. Policies are often triggers of cultural change both at societal level, for example, accepting recycling as beneficial to the environment, and also at individual level (e.g. waste separation for recycling as a positive personal contribution). The degree of reward, or penalty, seems to be related to the cultural insights described both by Hofstede (1983) and Schwartz (1994). If a policy is seen by the majority of the population of a country as beneficial for the common good, then it could facilitate behaviour change rapidly. However, attitudes, social factors, affects and habits towards car ownership can be so entrenched in a society that changing that society's behaviour, triggering a cultural shift, may need more than just mere rewarding or penalising policies. A subtler approach may, therefore, be required (Prettenthaler and Steininger 1999). In order to understand behaviour, it is vital to understand cultural values such as those found in Hofstede's (2011) individualism versus collectivism or Schwartz's (2014) autonomy versus embeddedness. These values are associated with 'contrasting openness' to changes by maintaining the status quo (Schwartz 2014).

Hofstede's (1983) 'uncertainty avoidance' dimension relates to the way society deals with future unpredictability. Some cultures feel more anxious than others when faced with ambiguous or unknown situations and, therefore, create mechanisms to avoid uncertainty. Hofstede's online dimension tool (Hofstede 2018), shows the UK's 'uncertainty avoidance' dimension with a value of 35 out of 100. 'Uncertainty Avoidance' relates to the way a society deals with the fact that the future can never be known (ibid). This means that, in general, the country scores low on this dimension; the UK as a nation is quite happy not to know what the future will bring, and, change plans as new information is gathered. Perhaps, in relation to car consumption, if a correct and comprehensive environmental information is available, people may change their values and behaviour accordingly. Nonetheless, the UK scores high in individualism, which means high levels of independence between people and individual fulfilment, for example purchasing a car as a hedonistic reward accessible due to increasing wealth. It is, however, low in 'power distance' despite the tensions between the deep-rooted class system and the belief in social mobility (Hofstede 2018).

2.7 Interpersonal Behaviour

As discussed in section 2.6, cultural dimensions and socio-technical transitions offer a 'birds-eye' view of the landscape and, whilst this can be important to define the whole, they do not offer insights of individuals (Fischer, et al. 2010), neither how their behaviour is influenced, and influences others. Behaviour is also influenced by culture. Triandis (1979) acknowledges national differences in conformity; as long as there is unanimity, the norm is clear. Such unanimity leads to 'groupthink' (Janis, 1972, cited by Triandis 1979). For Triandis (ibid), such reference groups support the structure of norms and determine fads, fashions, and social disseminations. Nonetheless, countries are made of the sum of all individuals and, as discussed previously, individual-level dimensions derive from analysing the numbers of individuals, and how their rapport with others influences their own behaviour, rather than statistical averages as in culture-level dimensions.

Habitual behaviours are an important characteristic of path dependency (Wells, Nieuwenhuis and Orsato 2011), perhaps typical of many car owners, which in turn undermine consumers' intentions to change behaviour (Jackson 2005). The Theory of Interpersonal Behaviour (TIB) (Triandis 1979) includes habits, but also social factors such as 'norms', 'roles' and 'self-concepts' together with emotions to drive intentions which, alongside habits, drive consumer behaviour. TIB acknowledges internal-external dichotomies of behaviour (Jackson 2005) such as facilitating conditions for certain behaviours (e.g. infrastructure, taxation, etc.) and social norms and roles (self-image, status, etc.). Triandis (1979) suggests the changes in behaviour occur when the value of consequences of a behaviour is altered; the consequences expected from individual behaviour changes through a change of habits. The high-living and materialistic behaviour, symbolised by consumerism, is deeply entrenched in today's society limiting changes in consumer habits (Sanne 2002). Habits are less important in the attribution of causes of behaviour than the affect associated with the behaviour and the perceived consequences (Triandis 1977). The combination of parameters determining behaviour are multiplied due to a proliferation of car subcultures in today's societies (ibid, Gartman 2004) (e.g. car tuning, customisation or classic cars).

[redacted]

The reasons for ubiquitous car ownership and frequent car exchange can be analysed under the light of TIB (Triandis 1979) (Figure 15). Car ownership behaviour can be conditioned by diverse social factors, starting with self-concept; the idea of the self (Jackson 2005), perhaps shaped in part by a culture of consumerism (Cooper 2005, e.g. Whiteley 1987) and, specifically, different car cultures (Sheller 2012). The role people give to themselves, and the corresponding behaviour is set by the position they hold in a particular group (Triandis 1979). This may influence the choice of car and the status image it portrays (Johansson-Stenman and Martinsson 2006, Whiteley 1987), together with the prevalent norm (i.e. whether the car's social function Is statutory or utilitarian). Emotions, in the TIB, have a role in forming intentions and act upon an axis in opposite directions of emotional responses (Jackson 2005). These could be translated as the reasons for and against owning a car; (e.g. 'waiting servant') versus limited availability of car sharing (Prettenthaler and Steininger 1999, Meijkamp 1998, Katzev 2003), or the idea of freedom of travel against congestion (Fellows and Pitfield 2000). Beliefs may also play an important role in the decision of owning a car. Likewise with cultural dimensions, such as individualism versus collectivism, different responses to environmental risks and consumption (Hofstede 1983, Hofstede 2011, Dake and Thompson 1999, respectively), social mobility and the belief that individuals through merit can access a higher social group (Jackson 2005, Hofstede

2018). Finally, the evaluation of outcomes can be related with emotions and rational choices; the dichotomy between voluntarist and behaviourist approaches which echo the ‘internalist’ individual attitudes, values habits and personal norms, and ‘externalist’ to the individual: fiscal, regulatory, social practices and constraints. All these are conceptions of ‘behaviour’, ‘attitudinal values’ and ‘context, derive from Stern’s ABC theory (Stern 2000).

Nonetheless, norms can change and group interaction can lead to behavioural change (Triandis 1979). Norms are often shaped by what large numbers of people do (ibid) and the importance individuals give to what others think of a particular behaviour (Fishbein and Ajzen 1975). This stimulates individuals to change their own behaviour and leads to conformity. Triandis (ibid) distinguishes normative social influence from informational social influence leading to behaviour change. The former is quicker to uptake, the latter slower. Normative social influence rewards or punishes individual behaviour (e.g. through rebates or taxes in products). This approach however, may have drawbacks; individuals acting for fear of sanctions and social factors conflicting with their behaviour (ibid). Contrastingly, informational social influence acts upon internalisation and acceptance of the views of others as long as the demands are consistent with personal values (Triandis 1979, Prettenthaler and Steininger 1999). Such internalisation can potentially take more time, due to slower changes in social factors and consequently behaviour towards, for example, non-ownership of cars (e.g. Geels 2012).

2.8 Nudge and Policy Making

Thaler and Sunstein suggest that people can, without any coercion or change in belief, shift their behaviour through ‘choice architecture’. ‘Choice architecture’, a facet of ‘Nudge’, is an organised context, with policies in place, where people are led to make decisions without being aware of them (Thaler and Sunstein 2009, Sunstein 2014). Consumer choices depend upon their starting point, in this case car ownership, and, therefore, consumers should not be asked what they would choose (Thaler and Sunstein 2003). This approach may lead to compliance, inasmuch as transparent information may lead to acceptance (ibid).

Critics of ‘Nudge’ theory argue that it is an imprecise philosophy of government, before being a policy approach, and subject to broad, and often incorrect, interpretations (Jones, Pykett and Whitehead 2010) and that is deeply troubling due to its paternalistic and manipulative nature

(Goodwin 2012). Jones, Pykett and Whitehead (2010) do not believe such theory is replacing neoliberalism, but rather a response to its failures. They suggest that it is a policy experiment deriving from economic theories that challenge neoliberal accepted belief, such as human capability in making rational choices. For 'Nudge' the human being is irreducibly irrational, and that irrationality derives from people's lack of anxiety, attention and self-control (ibid). If people were asked if they wished to change their behaviour, for example, towards non-ownership of cars, few would opt for the more cost-effective option (Thaler and Sunstein 2003). Goodwin (2012) does not believe in 'Nudge' effectiveness, nor in its notion of empowerment, because it sees as implicitly arbitrary and, arguably, manipulative.

For Jones, Pykett and Whitehead (2010), it is important to understand the rationalities that are used to justify particular forms and styles of governing; 'Nudge' has the same aims of neoliberalism, with the caveat that it does not assume human rational selection, thus the capacity of people to make rightful choices, which, in turn, Goodwin (2012) challenges. Jones, Pykkett and Whitehead (2010 p 498) conclude that "in effect, such policies seek to promote the notion of a post-Enlightenment citizen, who possesses little scope to determine the character of their own health, wealth and happiness." It is therefore important to check if those policies are coming from a benevolent and democratic origin, using them to improve people's lives, not the opposite. Nonetheless, for Goodwin (2012), such policies acting on individuals are not effective to challenge, for example, climate change. Goodwin argues that for such societal changes to happen and be impactful, society needs to act together rather than in isolation. Despite these strong criticisms about citizenship manipulation through choice architecture, reduced empowerment, and even semantics, or the state mimicking manipulative techniques used by private sector marketing (Goodwin 2012, Selinger and Whyte 2011, Leggett 2014), nudge can be characterised into two different types, more or less transparent in manipulating behaviour and choice. 'Type 1' nudges are aimed at influencing behaviour maintained by automatic thinking without involving reflectiveness, whilst 'type2' nudges are aiming at influencing the attention and principles of reflective thinking (Hansen and Jespersen 2013).

2.9 Summary

There is, apparently, contradiction between car longevity and car sharing. If, on the surface, their aim is similar, reducing the negative environmental impacts of vehicles, their methods differ. The former envisage a long lifespan, for as many years as possible, reducing throughput and postponing end-of-life (Section 2.4), the latter, envisages an intensive shared use, shortening its lifespan but replacing worn-out units with more efficient ones (Section 2.5.1). Both, in principle, help reduce the throughput of cars and, potentially, user stage impacts. There is scarce literature comparing the benefits and negative impacts of both and their design barriers and opportunities. This literature review, therefore, provides a starting point for this discussion (Section 2.3) and analyses the design opportunities and barriers for both concepts. There is also little knowledge to understand why passenger cars in the UK have an average lifespan of around 14 years (Section 1.3.3) and why car sharing is still a marginal sector in the UK, despite its potential to reduce car lifecycle emissions, manufacturing, usage and end-of-life impacts (Section 2.5.3). It is also not clear what the lifespan of the different type of shared cars is and if they are being used intensively until replaced by more efficient units, consequently what their real environmental impact is in the UK. Tukker (2004) questions the sustainability of many PSS businesses by asking which factors determine whether a PSS business model generates less material flow and emissions than the competing product-oriented model, and does it promote sustainable behaviour? For Williams (2007), the car industry fails at three stages identified as crucial for having PSS innovation:

1. Process improvement or redesign – LCAs have not contributed to changes in the design paradigm.
2. Function innovation – involves taking the original product function as the starting point for an investigation of innovative approaches to deliver this functionality (e.g. electric or hydrogen propulsion).
3. System changes – systemic changes (socio-technical) associated with the product (e.g. market dynamics, infrastructure, stakeholders and behavioural change).

It is also unclear what car users think about alternative forms of ownership, (e.g. cars that last longer or have a shared use (Section 2.3). The focus on car sharing has mostly been on technologies that enable more efficient car sharing, business models and studies of car share users (Section 2.5.1) rather than asking potential users what they think. The automotive industry is focused on technologies that could potentially enable car sharing, such as autonomous driving, but given its business model continuity it is most likely that this sector will still aim at those technologies to reinforce sales of product to individuals. Consumers are often overlooked and it is not clear if they are ready for a transition from ownership to shared use (Section 2.5.6). Such a transition could enable a cultural paradigm shift of society towards a different demand from consumers, changing both the automotive regime and the design of cars (Section 2.6). If consumers are prepared to shift, policies will need to overcome established interests and aim at creating the opportunity for such shift (Section 2.5.7). If, however, society is found to be oblivious or unprepared to make such a shift, policies may need to nudge consumers, and industry, towards different forms of car usage (Section 2.8).

No research has yet been undertaken to understand consumers' attitudes, values, behaviours and expectations towards passenger car longevity in different countries and how prepared these are to transition from ownership to other forms of car use. The relationship between users and their cars; what methods of purchase, the reasons to exchange cars, how they maintain them and for how long they keep them or how many people have scrapped a car are yet to be researched. For example, non-professionally sanctioned maintenance can render any warranty void and affect the value of the vehicle when traded in the second-hand market. It is not known how many people engage in DIY servicing and what is the relationship this has with car longevity. Consumer behaviour is essential to understand how sustainable policies can be shaped, and shape, consumers towards as lesser future energy and material demands.

3 RESEARCH METHODOLOGY

This chapter describes the methodology used outlining the research approach and design, the aims and objectives defined in Section 1, the methods used during the three stages of data collection, and subsequent analyses. The first two stages of data collection were through in-depth interviews and the third stage through a survey of car users.

This chapter identifies and supports the methodology undertaken in this research study, the primary and secondary data collection and their methodological analysis, reflecting upon the validity and reliability of the data acquired.

3.1 Research Undertaken

Social science in academic research may be motivated by societal advances and shifts, taking the 'real world' as the field of experiment (Robson 2002). This world, often complex, poorly controlled, and disordered, but nevertheless fascinating, is open to different interpretations and examples (Denscombe 2008). These elevate the motivations for doing social research. Reflecting upon modern life, academics and scholars raise questions stemming from gaps in knowledge (Bryman 2008) and from practical value for dealing with specific problems (Denscombe 2008). Henn, Weinstein et al. (2006) argue that social scientists test the appropriateness of existing theories, accounting for behaviours they are interested in developing and constructing new insights and new theories using different methodological approaches.

Positivism proposes research should be approached as in classical sciences, objectively; observing phenomena, quantify data and present solutions to change behaviour (Robson 2002). Contrastingly, interpretivism is associated with understanding the world from a human, therefore subjective, point of view; how people give meaning to phenomena surrounding them (Bryman 2008). Finally, critical social research focuses its position upon social, political and historical context to propose solutions to social problems (Henn, Weinstein and Foard 2006). Chosen methods are conditioned by the pragmatic standing (Denscombe 2008) of the research(er). In good social research, mixed methods are desirable to provide an adequate answer to phenomena (ibid). However, such differences in methodological approach are not always clear (Bryman 1988). Together, they can overcome bias in research through triangulation and also by encouraging to approach research from different angles (Denscombe 2008, Henn, Weinstein and Foard 2006). For this research, mixed methods (ibid) were used to address the research questions raised in the literature review, and throughout the research, actively responding to findings in the early research stages.

Mixed methods research approach combines quantitative and qualitative research in one single project. Instead of aligning with one ontology, positivism or constructivism, and from then conditioning all research to either approach, mixed methods enables research to be carried out, giving prominence to data collection and analysis with which the two approaches are associated, and results being fused (Bryman 2016). Two main definitions of a mixed methods researcher are 'qualitative dominant' constructivist-poststructuralist-critical view, while recognising the benefits of quantitative approaches, and 'quantitative dominant' postpositivist view recognising the benefits of qualitative data (Johnson, Onwuegbuzie and Turner 2007). A third emergent definition is 'pure mixed' researcher who believes both approaches, quantitative and qualitative, will add insights to most, or all, research questions (ibid). The four basic mixed methods design commonly used are (Creswell 2012):

- 'Convergent parallel design'
- 'Exploratory sequential design'
- 'Explanatory sequential design'
- 'Embedded design'

In 'convergent parallel design' both quantitative and qualitative data is collected in tandem and then compared or merged. In 'exploratory sequential design' qualitative data is gathered in preparation for quantitative data collection. The former opens the route to the findings obtained by the latter. In 'explanatory sequential design', the quantitative data is elaborated by qualitative data to reach the findings. Finally, in 'embedded design', quantitative data and qualitative data are embedded and integrated in each other producing a more holistic picture that leads to the findings (Creswell 2012). The initial exploratory nature of this research led to use an 'exploratory sequential design' approach. This is further discussed below (Section 3.2).

The methods for gathering primary data comprised of two sets of exploratory expert interviews and a nationwide consumer survey, with each method permitting triangulation in respect to the research questions. Qualitative methods were used to conduct the interviews and quantitative methods were employed for the survey. Quantitative and qualitative research have contrasting approaches to methodology. Bryman (2016) lists the difference between the two approaches (Table 3) and advises that these contrasts sensibly portray the differences between the two approaches, they should not be viewed as unambiguous. Qualitative research can be used to test theory and quantitative research can be exploratory (ibid).

The interviews were semi-structured and analysed using NVivo, whilst the survey was undertaken with a local market research organisation and analysed using SPSS. The survey was undertaken to confirm or dismiss some of the findings from the respective interviews and aspects found in the literature. Together these research stages considered design for longevity, shared product systems, interpersonal behaviour, and the role of culture in shaping behaviour and socio-technical transition models.

[redacted]

3.2 Research Methodology Overview and Purposes

The initial purpose of this research was to understand if the practical application of extended product longevity and use-intensive design strategies could be applied to passenger cars from a to address and reduce their material and energy demand (Section 2). Initial, exploratory, research investigated the barriers and opportunities for longer lifespan cars (LLC) and use-intensive cars (UIC) through interviews with car designers and development engineers (Figure 16). The interviews were intended to stimulate discussion with car designers and engineers by considering the above two concepts and describing design limitations and opportunities. The analysis of this set of interviews suggested that intensive use of cars raised less barriers than longer lifespan cars (Sections 4.1 and 4.2). There are practical applications of cars being used intensively in the form of car sharing (e.g. Autolib in Paris) that could be explored elsewhere. Furthermore, car sharing is a strategy enabling more efficient use of cars by reducing their negative environmental impact through the use of car clubs, car hire or lift share.

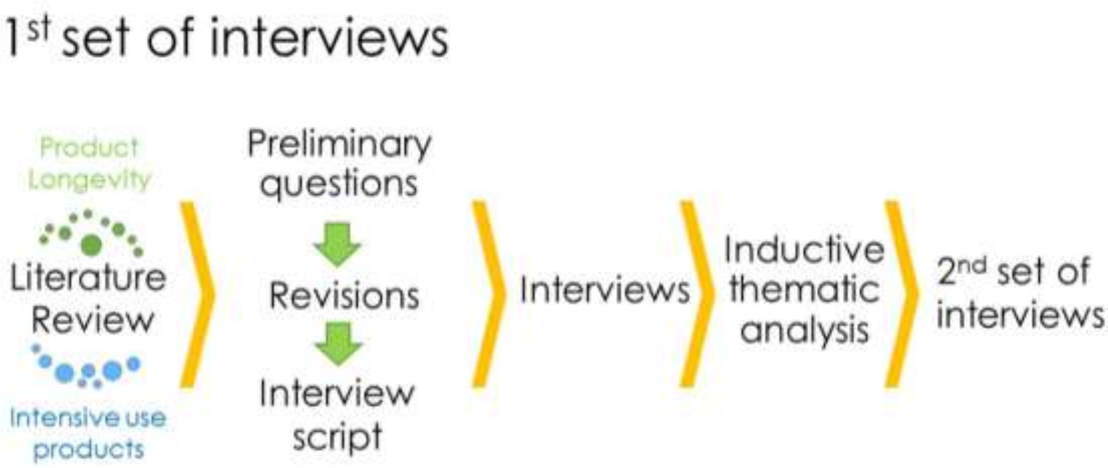


Figure 16. Methodology used for the 1st set of interviews

The second set of in-depth interviews used the same approach of the first, with the questions drawn from the literature review and also informed by analysis of the first set of interviews. It found to be beneficial to refer to and include some of the assumptions held by the first set of interviewees in the interview script (Figure 17).

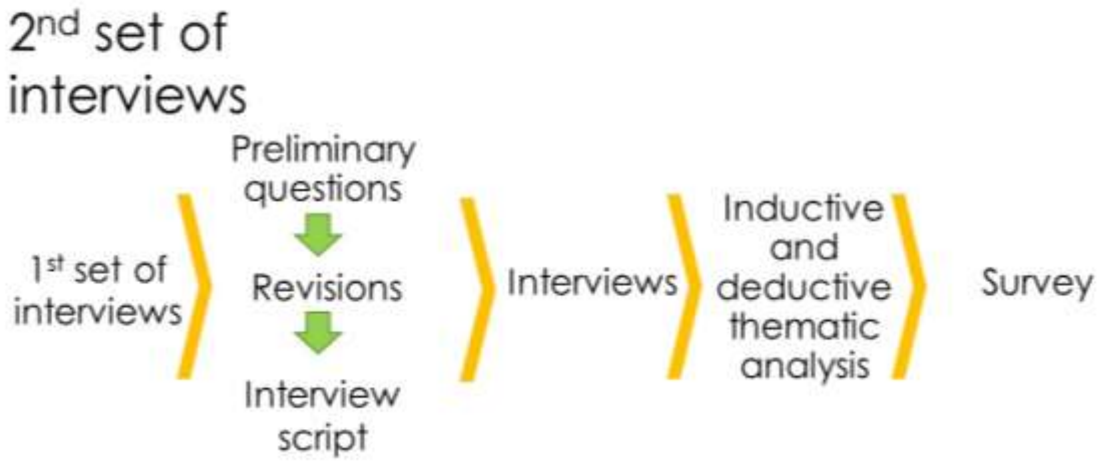


Figure 17. Methodology used for the 2nd set of interviews.

Finally, the survey was used to bring to light many questions unanswered by the qualitative analysis regarding consumer values, attitudes and behaviour and also to triangulate and validate some of the data from the two initial sets of interviews using quantitative statistical analysis (Figure 18).

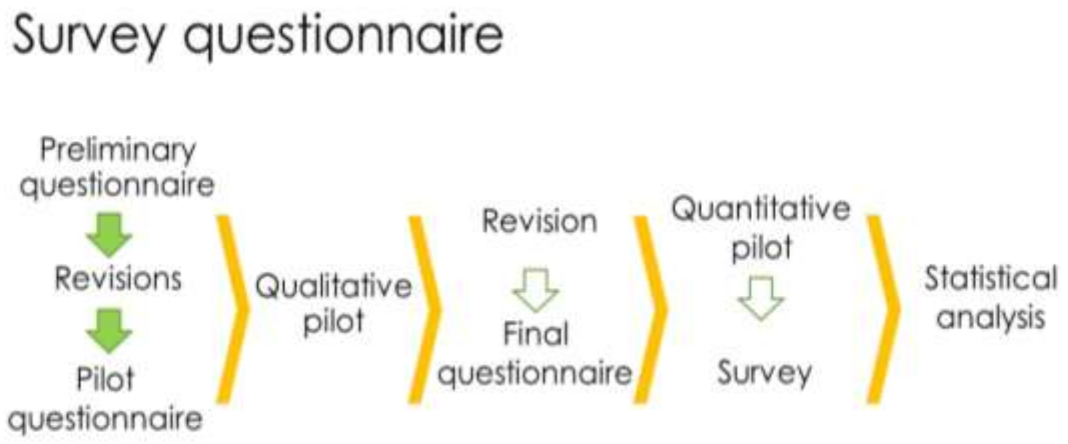


Figure 18. Survey questionnaire methodology

3.3 In-depth Interviews

In-depth interviews are used to gather information, such as personal accounts, by researchers, can be considered a valid form of research and are probably the most used method in qualitative research (Kvale 1996). The role of the interviewer has been debated and how far knowledge is constructed in interviews (Ritchie and Lewis 2003). Rapley (2001), argues that interviews are social meetings dependant of local, interactional and unforeseen circumstances in which both speakers draw from, and co-construct larger social norms. For Dworkin (2012), an in-depth interview is a method of deeply understanding phenomena, focusing on meaning and often centred on the ‘how’ and ‘why’ of a process, situation, social interaction or a particular issue. This means that in-depth semi-structured research interviews can have structured elements but also contingency, *ad-hoc,* questions.

The structure of the interview can be close to an everyday conversation, involving a specific approach and technique of questioning, conducted according to a guideline focusing on themes (Kvale 1996). These relate to the interviewee’s knowledge or perception of the topic, and the interviewer need to expand knowledge (Bryman 2008). The order of the questions can be rearranged in view of what, in the interviewer’s perception, is relevant and appropriate (Robson 2002, Legard, Keegan and Ward 2003), in the case of this research, understanding current design options and exploring new avenues (e.g. LLCs and UICs). Robson (2002) goes further, suggesting that questions can be omitted or added if relevant to the participant, as was the case in the second set of interviews, where some questions were not relevant to some of the interviewees.

This research used a set of semi-structured questions in which, responding directly to interviewee responses, were added *ad hoc* questions (Bryman 2008). This was necessary because the expertise of participants in both sets was disparate. Understanding the knowledge of the interviewee and being able to ask questions relevant to their expertise was key to gathering a rich set of data which helped to build a more comprehensive understanding.

The difference in how knowledge is constructed results in differing viewpoints about in-depth interviews (Legard, Keegan and Ward 2003); is the knowledge pre-existent, and how passive should interviewers be when conducting an interview? (Kvale 1996) distinguishes between two types of in-depth interviews:

- Miner metaphor: knowledge as something 'given'. The researcher needs to bring to the surface information in order to deepen knowledge. The transcribed information is then analysed and interpreted into a which is, in turn, correlated with and objective.
- Traveller metaphor: the interviewer is on a transformative wandering journey through a landscape and enters into conversation with the people encountered using a 'method' that will lead to new knowledge.

Legard, Keegan et al. (2003) argue that the first type will broadly fall into the modern social sciences research model and the second into the constructivist research model. However, Robson (2002 p 27) includes constructivism into the overall social research model - which includes post-positivism and feminism - and affirms that "the task of the [constructivist] researcher is to understand the multiple social constructions of meaning and knowledge". The feminist approach, on the other hand, takes a non-hierarchical stance where both interviewer and interviewee collaborate in the process of negotiating coverage, language and understanding (Legard, Keegan and Ward 2003). For feminists, the role of the researcher is to question accepted constructs and take a non-neutral view, creating a dialectical interview focusing on contradictions and enabling actions for change (Legard, Keegan and Ward 2003). Rapley (2001) concludes that whatever analytical position is framed, interviews should always be presented in the context in which they happened. Future readers can, therefore, understand how the discourse was co-constructed and assess its analytical reliability (Rapley (2001). This research reflects Legard, Keegan et al.'s (2003) miner metaphor and non-hierarchical stance together with a dialectical interview while taking Rapley's (2001) conclusions about contextualisation.

3.3.1 Interview Methods

For Henn, Weinstein et al. (2006), the qualitative researcher's focus is on the concept representativeness, whereas a quantitative researcher will be focused on obtaining statistically representative samples (see 3.3.2). The first is focused upon the representativeness of concepts and being able to access the selection of relevant respondents to obtain 'granular' data, whilst the second is focused on gathering large number of cases using narrower questionnaires without much scope for detailed analysis case by case, with the whole being more important than the component parts (ibid).

Two initial sets of semi-structured interviews were used in order to obtain the richest data possible from experts in the car manufacturing and car sharing sectors. Bryman (2008) argues that, in semi-structured interviews, focusing on the interviewee's point of view and going off on tangents is often encouraged to enrich data gathering. This method was chosen because it seeks to explore in detail both concepts (longevity and user-intensive), reflecting the reviewed literature, in order to bring to light their limitations and opportunities. Additional data was produced from *ad hoc* questions during the interviews to obtain more detailed insights contributing to the richness of data gathered.

All interviews were voice-recorded and transcribed. The analysis was performed by coding the themes chosen as appropriate and relevant (Bryman 2008) (Appendix M, Appendix F) (Sections 4.1 and 4.2). All interviewees signed an informed consent form (Appendix B, Appendix C) safeguarding any confidential information, their names and the companies they were working for at the time of the interview (Robson 2002).

To understand the role of both designers and vehicle engineers the first set covered ten exploratory interviews. Each interview was divided into four questions and conducted to assess the feasibility of longer lifespan cars and shared, use-intensive cars (Appendix E, Appendix L). This set of semi-structured interviews was undertaken between November 2014 and April 2015.

The exploratory interviews occurred on location where possible, or via video-call. The duration of the interviews ranged from forty minutes to one hour. An open-question approach was used (Robson 2002) in order to explore design approaches for longevity and intensity of use (e.g. Nieuwenhuis 1994, van Nes and Cramer 2006, Allwood and Cullen 2012). The questions set out to explore design barriers and opportunities for longer lifespan cars and shared, use-intensive cars and were based on the literature reviewed:

1. The process of vehicle design, and if designing for longevity and user-intensity would impact that process (Sections 2.2.1, 2.3, 2.5.1, 2.5.3 and 2.5.1).
2. The vehicles themselves; especially exploring features such as design for shared use, modularity, ease of repair, easy disassembly and upgrading (Sections 2.4.4, 2.4.5, 2.4.7, 2.5.5 and 2.5.1).
3. The feasibility of a 20-year lifespan car (Sections 2.2.1 and 2.4) and the designer/engineer approach to its design.
4. How the interviewees would design an optimal lifespan car with less material and energy (Sections 2.1, 2.2.1, 2.5, 2.5.1).

In addition to the first set of ten semi-structured interviews, two informative in-depth interviews were also undertaken with automotive business experts in opposite spectra of automotive manufacturing (Appendix D, Appendix K). One interviewee was from a traditional automotive company, the other from a start-up looking to sell the service of mobility but maintaining control of manufacture. Nine indicative questions were arranged and these interviews lasted between forty minutes and one and a half hours. The interviews occurred on location. An open-question approach was used (Robson 2002) in order to understand differences between the two business models and approaches to design, manufacture and sales.

After the analysis to the first set of exploratory in-depth interviews it was found that some of the physical barriers for longer lifespans, e.g. material and energy to produce a more durable vehicle, were deemed too challenging to overcome by most interviewees (Section 4.1), more than those found for a shared use car (Section 4.1.8). The acknowledgment of Oguchi and Fuse's (2014) work on disparate vehicle longevities found in a number of different countries also shaped the development of the second set of exploratory interviews.

The second set of exploratory in-depth interviews explored the main barriers for the upscaling of car sharing in the UK and some of the views relating to intensive use cars, uncovered during the previous set of exploratory interviews, (e.g. sharing a car with strangers). This set of in-depth interviews was comprised of ten exploratory interviews and one informative interview. The duration of each interview ranged from between forty minutes to one and a half hours. The interviews took place between February and May 2016. The questions drawn for this set of exploratory in-depth interviews were taken from the literature review and the thematic analysis of intensive use cars undertaken after the first set of interviews. The latter and subsequent thematic analysis of systemic barriers and opportunities for car sharing (Section 4.2) also provided guidance for the survey questions. The informative interview was undertaken with one of the pioneers of car clubs in the UK. The interviews occurred on location, where possible, or via phone or video call.

In principle, car sharing enables passenger cars to be replaced more rapidly, by new, more efficient and safer units due to intensive use, taking advantage of greater efficiencies and reduced environmental impacts of future models sooner than the longer life car option. Nevertheless, the questionnaire explored the systemic barriers encountered by this sector throughout the years reducing it to a fringe in the market for car use. The questionnaire was divided into five main themes:

1. Barriers for users
2. Barriers for the car sharing sector
3. Barriers to the integration of car sharing into public transport
4. The role of technology
5. Time in service and mileage of vehicles used in car sharing

This last question was devised to explore if car sharing organisations were indeed utilising their main asset – passenger cars – intensively and replacing them with more efficient products (e.g. Vezzoli and Manzini 2008, Prettenthaler and Steininger 1999).

3.3.2 Criticism of Interviews

Interviews are a specific form of conversation between two or more people, interviewer and interviewee, and, like other research methods, constructs knowledge through interaction (Kvale 1996). However, interviews, like other research methods, are not exempt from criticism. Rapley

(2001) advises about the focus given in interviews to the interviewee and less so the interviewer, despite acknowledging the notion of co-construction between the former and the latter. Hammersley (2003) advises that often interviewee accounts are affected by error and bias rather than by the researcher's observational reports. Hammersley suggests that verbal accounts are a mix of real and representations of the real, thus the interviewer needs discernment and care to ensure that bias and incorrect conclusions are eliminated as much as possible. This does not mean that all accounts are inaccurate or fictional. People have background assumptions, interests and preferences (ibid), potentially leading to obstructiveness and information withholding (Robson 2002). And these might, though not every time, encourage a different representation of the researcher's expectations (ibid). For Rapley (2001), the interviewee should remain in the centre of the interview analysis and within the objectives of the research. Rapley maintains that the interviewer is neither neutral nor facilitative. Robson (2002) refers to this as researcher assumptions and preconceptions. This is, Rapley argues, because the interview is always produced in negotiation with the interviewer and its outcome is the rapport between researcher and interviewee. It is therefore produced in a particular context and it is essential that one must understand that same context in order to effectively analyse the data. A correct methodological assessment, such as Ahern's reflexivity (Robson 2002 citing Ahern 1999), can detect and discount potential bias (Hammersley 2003). Ahern's reflexivity is the ability to set aside personal views and biases (Robson 2002 citing Ahern 1999). It is a function of how reflexive, rather than how objective, a researcher is.

The data collected during this research's interviews was collaboratively produced between the parties involved and it is, as Rapley (2001) concludes, one possible version, framed in a particular context. Therefore, the approach taken by this research is aligned with Rappley's (2001) stance on interview contextualisation and Hammersley (2003) advice on bias. This was checked during the in-depth exploratory interviews and also through the survey analysis. Rapley's stance is contrary to, for example, grounded theory. Grounded theory deconstructs the discourse into disconnected 'chunks' of data, thus eliminating the context (Bryman 2008). Likewise, with coding; there is a danger of fragmenting and decontextualizing data. However, Bryman (2008) advises that, when coding, the researcher should always look at the context of codes and states that coding is not analysis. In thematic analysis it is possible to keep the context and yet enable subdivisions of the theme or themes (ibid) and classify barriers and opportunities (Miles and Huberman 1994).

3.3.3 Planning and Recruiting Interview Participants

For Boyce and Neal (2006 p 4) “the process of conducting in-depth interviews follows the same general process as is followed for any other research: plan, develop instruments, collect data, analyse data, and disseminate findings.” McDougall and Fudge (2001) suggest that in planning and recruiting samples for qualitative methods, (e.g. in-depth interviews), the rationale is different from quantitative research. Samples are purposive, in order to produce rich datasets, in line with Robson (2002) and Bryman (2008); the former leaves judgement to the researcher as to what is relevant or of interest for the research, the latter argues that purposive sampling is relevant to the research questions being asked. In other words, the participants need to have some knowledge of what is asked from them or be able to relate to the context of that research. For this research, interviewees were carefully selected for their subject knowledge and experience of working in their respective sectors.

McDougall and Fudge (2001) suggest that researchers should consider the best time to contact potential research participants and the kind of event being studied, for example, if it is routine or special, if it relates to processes, ideas or concepts familiar to the participants, or if questions are exploring new ideas, concepts or processes (ibid). Robinson (2014) takes a more systematic approach for selecting participants, dividing the selection criteria into four stages (Table 4). For Robinson (2014) (2014), an inclusion and exclusion criteria should specify attributes to qualify or disqualify participants to take part in the research. Furthermore, homogeneity or heterogeneity of sample may influence the results. The more detailed the inclusion or exclusion attributes are, to define the sample, the more homogenous is the group sample (Robinson 2014). Bryman (2008) divides sampling into two levels; organisations and members of organisations. Boyce and Neal (2006) called them ‘stakeholder groups’ and ‘individuals within those groups’, respectively. Organisations or stakeholder groups should be different amongst the sampling group; this can be size, the volume of production, type of market, or any other criteria that differentiate them. For the recruiting process, McDougall and Fudge (2001) suggest researchers use informal networks, community organisations, agencies and advertising. The recruitment process should envisage personal communication (e.g. via post or email), followups and assurances to gatekeepers. The latter methodology and Robinson's (Robinson 2014) four-point approach was followed by the research to recruit interview samplings in both stages (Table 4).

Table 4. Robinson (2014) four-point approach to qualitative sampling adapted to the both set of interviews

1st set	Name	Definition	Key decisional issues
Point 1	Sample universe	Car designers and development engineers	Some heterogeneity. Responsible for all design aspects of a vehicle.
Point 2	Sample size	Between 10 and 15. Practical aspects were taken into account; availability of individuals was sparse, transcription time consuming, budgetary concerns.	Small sample
Point 3	Sampling strategy	People with direct influence in vehicle design and development.	Used all interviews in sample
Point 4	Source the sample	People directly contacted. Enough expertise to respond the questions.	No incentives.
2nd set	**Name**	**Definition**	**Key decisional issues**
Point 1	Sample universe	Car share experts; car share business managers, lift share business managers, car hire business managers, transportation authority policymakers and technology experts.	Very heterogenous. Systemic nature of car sharing demands different attributes
Point 2	Sample size	Between 10 and 15. Practical aspects were taken into account; availability of individuals was sparse, transcription time consuming, budgetary concerns	Small Sample
Point 3	Sample strategy	People with expertise in all important aspects of car share systems.	Stratified, cell, quota, theoretical strategies
Point 4	Source the sample	Snowball sample. People directly contacted.	No incentives

Both sets of interviews made use of formal and informal networks (MacDougall and Fudge 2001) and the second set of interview snowballing (Robinson 2014) to recruit interviewees. Through the informative interview with the pioneer and 'champion' (MacDougall and Fudge 2001) of car clubs in the UK, two key contacts within the umbrella organisation were established, who, in turn, provided another 12 potential contacts of stakeholders. A visit to the main exhibition of the mobility sector in the UK also helped to gather two more contacts, one of them interviewed in location.

From the formal networks, a list of contacts in the automotive sector and from a visit to a ‘low carbon vehicle’ exhibition provided interviewees. From the informal network, contacts were made through research colleagues’ recommendations. Robinson (2014 p 27) suggests, “any commonality found across a diverse group of cases is more likely to be a widely generalizable phenomenon than a commonality found in a homogenous group of cases”, concluding that heterogeneous sample groups can help establish whether a theory developed within one particular context is applicable in other contexts.

3.3.4 Interview Sample Size

Crouch and McKenzie (2006) accept that in small-scale qualitative studies - less than 20 participants - research is intentionally and conceptually indicative due to its exploratory nature. Robinson (2014), suggests that a sample between 3-16 participants is sufficient, with the caveat that the lower spectrum is for undergraduate studies and the higher end for larger projects. Kvale (1996) acknowledges that the numbers tend to be between 5-25 for reasons of time and resources available. It is reasonable to infer therefore that, for a PhD research, with time and budget limitations such as this, 9-10 participants is an acceptable number.

For Crouch and McKenzie (2006) ‘small sample size’ interviews tend to be exploratory, concurring with Kvale (1996), and tend to provide indications rather than conclusions. Crouch and McKenzie (2006) affirm that participants are not sampled from target groups but variants of a particular social setting. This standing contrasts with Robinson (2014) who classifies participants according to homogeneity or heterogeneity, to be chosen for, or excluded from, a research setting at the outset (see Table 4 and its application in Table 5 and Table 6). Baxter and Eyles (1997) classify them as purposeful sampling.

There were 16 individuals contacted for the first set, of which 10 agreed to be interviewed. The individuals were chosen for this interview due to their experience in developing passenger cars in their role as product designers or engineers. Each had more than ten years of experience in designing and developing cars and motorised vehicles. This experience and insight of the automotive industry and main product development process was fundamental for obtaining valuable insights in order to produce the richest qualitative dataset possible. Subjects came from three different countries, UK, Spain and Canada, and from a variety of different automotive companies ranging from mass-market, premium and high premium manufacturers (Table 5). The premium and high-premium manufacturer interviewees were from two companies, however, working in distinct departments. A large multinational tier-one supplier senior research and development representative and a vehicle testing consultancy senior manager with previous roles in engineering were also interviewed, reflecting suppliers' perspective, different company cultures and nationalities, approaches and areas of expertise in vehicle design. Interviewees were named D1 (Designer 1) E1, (Engineer 1) and so on (Table 5). A balance of four car designers and six engineers was achieved in order to provide a suitable breadth of opinions.

Table 5. List of interviewees set 1.

Reference	Job Title	Type of Company
Designer 1 (respondent D1)	Head of Concepts	High-Premium Manufacturer
Designer 2 (respondent D2)	Vehicle Interior Designer	High-Premium Manufacturer
Designer 3 (respondent D3)	Senior Interior Designer	Mass-market Manufacturer
Designer 4 (respondent D4)	Technical Specialist Whole Vehicle Sustainability	Premium Manufacturer
Engineer 1 (respondent E1)	Senior Manager Corporate Engineer R&D	Tier 1 Multinational Supplier
Engineer 2 (respondent E2)	Principal Materials Engineer	Sports Car Manufacturer
Engineer 3 (respondent E3)	Chief Engineer Body Complete	Premium Manufacturer
Engineer 4 (respondent E4)	Global Business Director - Former Technical Director	Vehicle Testing Consultancy
Engineer 5 (respondent E5)	Principal Development Engineer	Mass-market Manufacturer
Engineer 6 (respondent E6)	Materials Engineer and Group Leader in Sustainable Aluminium Strategies	Premium Manufacturer

For the second set of interviews, using the same type of confidentiality agreement approach of set 1, interviewees were assigned RESPONDENT CS1, RESPONDENT CS2 (Car Sharing) and so on. The individuals interviewed for this set ranged from car sharing and car hire organisation managers at a senior level to local transport authority experts in shared mobility and car sharing umbrella organisations, reflecting a broad range of stakeholders. The focus was on the systemic (socio-technical) nature of car sharing, hence the broader range of experts engaged for the interviewees (Table 6).

Table 6. List of Interviewees set 2

Reference	Job Title	Type of Company
Respondent CS1	Managing Director	Umbrella organisation
Respondent CS2	Assistant Director	Umbrella organisation
Respondent CS3	Policy and Planning Analyst	Local transport authority
Respondent CS4	Managing Director	Large car club
Respondent CS5	Senior Locations Manager	Large car club
Respondent CS6	Advanced Solutions Officer	Local transport authority
Respondent CS7	Head of Locations	Large car club
Respondent CS8	Managing Director	Small car club
Respondent CS9	Business Development Manager	Car hire multinational
Respondent CS10	Managing Director	Lift sharing organisation

3.4 Survey

The third stage of data collection aimed at understanding, from a car user perspective, the behaviour, beliefs, attitudes and habits towards passenger car ownership, and awareness and experience of car sharing and longer lifespan cars (UIC and LLC). Two pilot surveys (Section 3.4.1) were devised before the final survey in order to assess clarity, wording, format and interpretability and iron out any technical problems. As part of the Centre for Industrial Energy and Products (CIE-MAP) project, this research engaged with a market research survey company (J.R.A.), who provided the sample.

3.4.1 Pilot Survey

It is advisable to conduct a pilot study before a self-completion questionnaire (Bryman 2008). The role of the pilot survey is to ensure the research instrument, (i.e. the survey questionnaire), functions appropriately (Bryman 2008). The aim and objective of the first research pilot survey was to provide feedback about its readability, interpretability and flow, the second was to ensure questions operate well and the research instrument as a whole was functional (Bryman

2016). Van Teijlingen and Hundley (2002) advise about contamination of data in the final survey from the pilot if using the same respondents; they will not indicate response rates nor can have statistical foundation. Lancaster, Dodd, et al. (2004) state that pilot studies should have a well-defined set of aims and objectives to guarantee rigour and validity and those participating should be excluded from the main study.

The first sample for this survey was qualitatively assessed (Section 3.4.2) and did not take part in the final survey, equally with the second pilot. Johanson and Brooks (2009) note that literature on sample size in pilot studies is scarce and suggests different sample numbers according to the type of study; between 24 and 30 participants for quantitative pilots. This research used Hertzog's (2008) recommendation of a sample of 10, or less, participants for assessing clarity, wording, format acceptability and ease of administration, during the first pilot run. A quota sample of n = 122, for the pilot soft launch was also undertaken and analysed to test if the survey was operational and to iron out any potential mistakes and misinterpretations (Bryman 2008).

3.4.2 Pilot Survey Method

In the first pilot survey, three questions with Likert scale answers and a comments section (i.e. readability, interpretability and flow) were added to the end of the questionnaire. The objective was to assess its flow, readability and interpretability. Therefore, respondents (n = 10) were broadly representative of the UK population levels of education based upon the Office of National Statistics (ONS) (Office of National Statistics 2011), itself based upon Eurostat and UNESCO's International Standard Classification of Education, ISCED (Eurostat 2016) The respondents went through the same screening questions as the final survey sample (Section 3.4.4). The sample was taken from Prolific.ac database (Prolific 2016). This database has fewer number of education levels when compared to the ONS. For practical reasons, the different secondary school levels from ISCED/ONS were merged into Prolific.ac's 'Secondary school' level. Conversely, because the 2011 UK population census information, regarding level 4 education, includes all forms of higher education from undergraduate up to PhD in one level and Prolific.ac details higher education levels, these were also combined into one. Nonetheless, respondents had the opportunity, in the demographics section of the pilot survey, to declare to which of the detailed ONS levels they belonged. The pilot final educational levels were then classified into:

- No formal qualifications,

- Secondary school (College/GCSE/A levels)
- Higher Education degree (BA/BSc/MA, MSc/PhD)

The age distribution was: 18-24, *n* = 2; 24-34, *n* = 2; 35-44, *n* = 2; 45-54, *n* = 1; 55-64, *n* = 2; 65-74, *n* = 1

Gender: Women *n* = 7; Men *n* = 3

Postcode area: Urban *n* = 7; Rural *n* = 3

The results of this pilot show mostly positive responses in flow, readability and interpretability. However, the pilot also showed that careful consideration must be taken with the survey operationality and distribution of respondents (e.g. car owners and non-car owners) to the respective responses in the questionnaire. This recommendation was taken into consideration when finalising the survey questionnaire.

3.4.3 Survey Methods

Survey research can be used to gather data about behaviour, beliefs, attitudes and attributes using statistical information (Henn, Weinstein and Foard 2006). The aim of a survey is for something to be “viewed comprehensively and in detail” (Denscombe 2003 p 7). Survey questionnaires have to be designed on the premise of what is there to be observed, of the research strategy used to observe and to measure the data (Denscombe 2014). According to Denscombe, surveys should have a wide coverage at a specific point in time (ibid) and provide data about the distribution of a wide range of people characteristics, their relationships and causality (Robson 2002).

For this part of the research a self-completion questionnaire was designed to assess the behaviour, beliefs, attitudes and habits of passenger car drivers. The questionnaire aim was to help this research to understand if consumers are sceptical about, or open to, alternative forms of passenger car usage and, if so, their perceptions and expectations of current passenger cars in general, how these are typically acquired, and for how long they expect or intend to keep them. The questionnaire also enquired about consumer engagement in car maintenance and repair and the reasons behind replacing cars. Another area is the perception and expectation consumers have of passenger car longevity.

Bryman (2008) maintains that self-completion questionnaires should be easy to follow, and easy to answer with few open questions, easy-to-follow design and be shorter to reduce 'respondent fatigue'. However, such structural simplicity is open to criticism because it fails to capture depth of context, the respondent's understanding and interpretation of the questions as intended by researchers or the value content of the survey (Henn, Weinstein and Foard 2006). The emphasis of this survey is to search for possible associations of behaviour, beliefs, attitudes and habits (Bryman 2008) in passenger car consumption. The survey questionnaire (Appendix O) covered responses about three different forms of car sharing (car club, car hire and ride-share) and what would appeal owners to shift from ownership towards shared use, the number of cars each person owns, their brands, fuel type, the year, the price and age when bought, and their mileage. Respondents were asked questions about car ownership, demographics, frequency of driving, current ownership, annual mileage travelled, reasons for car usage, car sharing awareness, car sharing options, purchasing criteria, lifespan, car maintenance and repair, and how they discard their cars. A demographics section concluded the survey.

3.4.4 Survey Sampling

For a random probability sample to be obtained, using a random selective process (Blair and Blair 2015), all members of the population should have a nonzero chance of being selected (Bryman 2008). J.R.A.'s Research's UK panel, from which a sample was taken for this research, is formed of members recruited "using various methods including web-banners, website referrals, pay-per-click, natural search optimization, affiliate marketing, email, and online public relations activities" (Gallagher 2018, personal communication). These panel members are self-selected and only those who volunteer and have access to the internet will be captured, and for this reason the panel should be considered non-probability, with some members of the population having zero chance of being covered (Blair and Blair 2015). For the survey, this research used a sample randomly drawn from the panel. However, by nature of the first stage of recruitment, to the panel, this resulting sample should be considered non-probability.

Nonetheless, the panel represents a large sample of the total UK population. The sample, derived from the target population, for this survey was n=1,019 and was selected using three screening questions to identify eligible respondents (Dillman, Smyth and Christian 2014). J.R.A. research evaluated the project criteria, through the questionnaire's initial screening questions, to estimate the response rate; 3,333 people were randomly chosen from the panel to be part of the sample, with a target of n ~1,000 (Tillet 2018, personal communication). According to JRA (ibid), 40% of the target population was screened off through those initial screening questions in the survey, did not finish the survey or did not respond to the questionnaire leaving 1,019 completed surveys (ibid).

Bryman (2008) notes that the absolute size of a sample is more important than its relative size. Increasing the size of the sample decreases sampling error. A 3% margin of error (MOE) was calculated for the target sample (Rumsey 2011):

n = 1,019

$$\text{MOE} = 1 / \sqrt{1{,}019}$$

$$\text{MOE} = 0.03$$

The target sample was contacted during a week day starting a 9.00 am. Screening was necessary to exclude people under the age of 18 years old and to avoid potential respondents with conflicts of interest in the automotive industry or the car sharing sector distorting results. According to the Society of Motor Manufacturers and Traders (Society of Motor Manufacturers and Traders 2017) there are 814,000 people employed in the automotive sector. This represents 1.3% of the UK population (Office of National Statistics 2017). Another group screened out were people who do not hold a valid UK/EU driving licence or, if so, rarely drive (less than once per month). Such discrimination was necessary to avoid non-responses in relation to driving patterns. Contingency questions that generate variable relationships (Bryman 2008) were also asked to, for example, car owners; their purchase method, regular maintenance, ownership and disposal. The survey enabled a concise interpretation of its questions by all respondents but also answers the researcher's intended questions (Robson 2002).

The survey comprises a cross-sectional questionnaire design (Appendix O), filled in by respondents through a self-completion online website provided by JRA Research, at a point in time, between December 2017 and January 2018, and geographically limited to the UK and its residents, with quantitative and quantifiable data (Bryman 2008). The UK driving licence distribution is 54.1%/45.9% male/female (Figure 19). Distribution between age and gender were compared to UK's Department for Transport (DfT) own database (Department for Transport

2017) of UK drivers over 18 years of age and a proportion of 52.5%/47.5% male/female was found (Figure 19). DfT's database was chosen because it most closely matches the demographic variables and target population of interest.

Other characteristics, such as income, were not compared because DfT's database does not include information on income, education levels or frequency of car usage. Consequently, it is possible the sample was unrepresentative on demographic variables such as these. Geography distribution is acknowledged to be important because in different parts of the country norms, attitudes and behaviours may be different due to different social and infrastructural circumstances. However, the data from DfT only sates the number of drivers (male and female) in each postcode and does not divide them into, for example, regions or councils. There is no strong evidence of correlation between income and for example, a more environmentally conscious behaviour (Tanner and Kast 2003, Gilg, Barr and Ford 2005). Car ownership responds more strongly to rising income than to falling income (Dargay 2001). Representativeness is more important, because lack of representation may lead to results which do not reflect the target population Therefore, the target sample, *n* = 1,019, should perhaps only be considered representative of the target population in terms of gender.

It was assumed that the percentage of people with driving licences but driving less than once per month is quite low, therefore comparisons of the sample to the DfT data (representing the target population) could be omitted. There are no official numbers for car sharing workers in the UK, but, given this sector relatively small size, the numbers are assumed to be very low. The number of car sharing users in this survey was low, especially with those using car clubs and ride-share. Therefore, this research does not make any assumptions from those answers in isolation, as they may provide misleading information. Where relevant they were combined with all forms of car sharing (Section 2.5.2).

Patterns of association between variables were, for this research, only explored for gender response due to time and sample constraints. Because the sample was skewed towards older age drivers, it did not reflect the actual age distribution of UK driving licence holders (DfT 2017) therefore no analysis was performed for age distribution. A number of statistical options to reduce this skewedness was carefully reflected upon, including:

- a weighted sample for age distribution. However, this could skew other variables such as gender distribution (Wright 1997).
- Random deselection of a proportion of the sample that is over-represented on age. However, this would have reduced the sample size and increased the margin of error (Wright 1997, Lewis-Beck 1993).
- Boosting the sample to balance the age representation to match expected returns. Due to time constraints this was not viable and therefore this research was only able to be presented with an older age skewed sample.

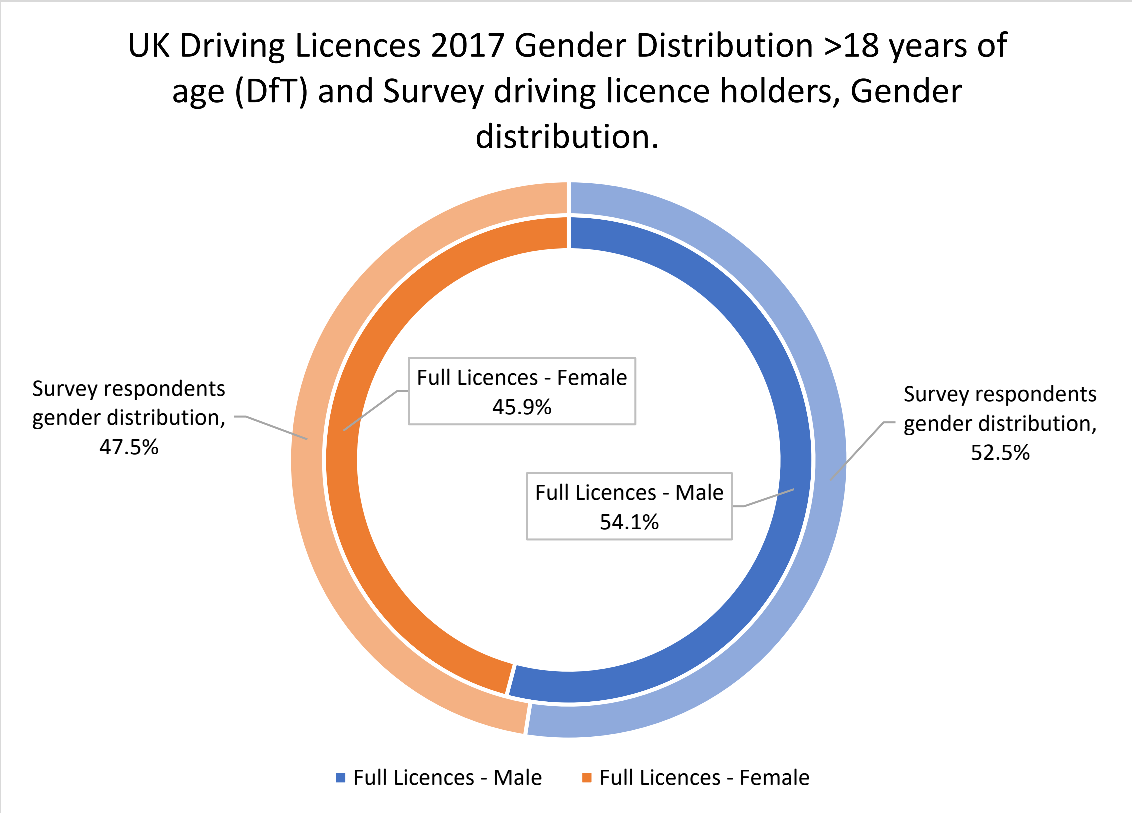


Figure 19. UK Driving Licence Gender distribution (DfT 2017) and survey sample gender distribution

3.4.5 Survey Design

A self-completion questionnaire (Bryman 2008) was designed to understand consumer behaviour, beliefs, attitudes and habits towards passenger car usage, including acquisition, engagement, disposal and car sharing (as defined in section 2.5.2). It was found during the first set of interviews with car designers that they were sceptical about consumer acceptance of car longevity and use-intensive cars, with a particular resistance to the former option. For the survey questionnaire, concept-by-intuition type questions (Saris and Gallhofer 2014) were formulated. Concept-by-intuition type questions can include judgments, feelings, evaluations, norms and behaviours (ibid). These questions are connected with assertions representing measurement instruments for cognitions, actions and feelings (ibid). These measurements are based upon Ajzen and Fishbein's Theory of Reasoned Action (Saris and Gallhofer 2014). This theory ascertains that attitudes are often defined on the basis of evaluations. Jackson (2005 p vii) suggests "these conceptual models are useful to understand the structure of some intentional behaviours" but leave out cognitive (habitual) dimensions.

Denscombe (2014) states that response burden - the time and effort to complete a survey - should be low, to increase completion rates. For Bryman (2008), the presentation layout is important to reduce low response rates, using an unobstructed arrangement and a clear presentation. Recruitment approach, financial incentives also affect response rates (ibid). Questionnaires can use both open and closed questions (Bryman 2008). The questionnaire used mainly closed questions, with a few exceptions where there was a need to assess precise information (e.g. questions about age and mileage of vehicles). Closed questions, such as age range, should be mutually exclusive and exhaustive, i.e. all response possibilities are provided (Henn, Weinstein and Foard 2006). In some of the questions a brief explanation of concepts, (e.g. car sharing), was deemed necessary; during the second set of interviews, lack of car sharing usage was one of the main barriers described by most interviewees. Good and Hardin (2012) suggest that questions should not reveal the study purpose, so that answers are not shaped by the respondents' perception of the same. Bryman (2008) recommends a cover letter explaining the reasons for the research to improve response rates. This survey used a brief introduction but without revealing the nature of the study, as suggested by Good and Hardin (2012). After the screening questions, respondents were divided into those who have a driving licence and a) own one or more cars and b) those who have a driving licence but do not own any car. The questionnaire was structured in the following form (Figure 20):

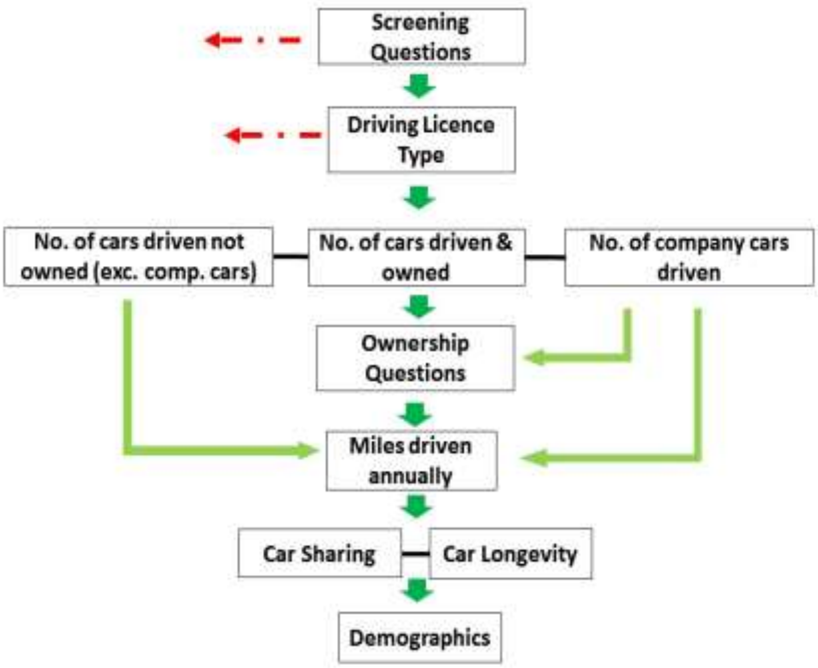


Figure 20. Survey flow schematic

3.5 Validity and Reliability

For Miles and Huberman (1994) validity is about the value of truth. Kvale (1996 pp 241 and 244) calls validity "quality of craftsmanship"; checking bias in the evidence, questioning "truth about what and why" (ibid p 244), quality of information and theorising through the generation of more questions. Validity, and reliability, are concepts born out of positivism in order to produce data that is repeatable and will have little variation under scrutiny (Ritchie and Lewis 2003). Crouch and McKenzie (2006) suggest that constructed validity is achieved when the mode of research (e.g. interviews), produces concepts and propositions, because they make sense as pivotal points in a hypothetical matrix where interview data produces crossovers with existing theoretical concepts, as was the case of this research.

Reliability is normally associated, in quantitative research, with formal tests and scales and, whilst necessary, it is not sufficient to ensure validity (Robson 2002). In qualitative research methods, such as interviews, questions of instrument validity and reliability depend upon the researcher as an instrument familiar with the field of research, with conceptual interest, multidisciplinary (Miles and Huberman 1994) and an observer (Robson 2002). However, such an approach is helping researchers to have a more holistic picture of society as opposed to using one single set of methods (Henn, Weinstein and Foard 2006).

The information gathered in this research was validated through triangulation methods in the form of two sets of interviews and one survey. Jick (1979), for example, used a mix of interviews, surveys and non-participant observations together with the archival material to triangulate his findings. Farmer, Robinson et al. (2006) used informant interviews and document analysis as part of their triangulation. Triangulation helps validation by enabling information to go through a series of independent confirmations, eradicating bias and therefore, its reliability. According to Miles and Huberman (1994), there are different methods of triangulation; data source (people, time, places, etc.), method (observation, interview, document), researcher (investigator A, B, etc.), theory (literature) and data type (qualitative texts/recording, quantitative data). The outcome may be corroboration and reliability but not always validity, especially if the triangulation outcome is a conflict of information or inconsistency.

3.5.1 Semi-structured Interviews Validity and Reliability

In qualitative research it is difficult to achieve the same notion of validity and reliability expected in quantitative research (Bryman 2008). Data validity for the two sets of interviews was attained by fully recorded spoken interviews. The threats to respondent bias, such as withholding information, were addressed through a confidentiality agreement that enabled interviewees to answer freely and anonymously. Researcher bias threat was also considered and during the interviews, questions challenging the responses given were asked when relevant. Using Ahern's reflexivity (Robson 2002 citing Ahern 1999), the researcher set aside personal views and biases towards passenger cars. This stance provided a deeper reflexion about the role of cars in society and the industry promoting them on one hand, and a critical reflection about the contradictory nature of some car sharing businesses (e.g. sustainability versus profitability), on the other.

It is important that reliability in qualitative approaches is thorough, careful and honest (Robson 2002). To ensure reliability for both interview stages, standardised research equipment was tested and used (ibid): a voice recorder and note taking. The interview environment was quiet to avoid background noise. Full verbatim transcriptions were written. Raw data and data analysis was also kept for audit purposes.

3.5.2 Survey Validity and Reliability

Reliability and validity were attained through the survey to validate some assumptions shared by interviewees during the two sets of interviews (Section 4), but also some assertions from the literature in both longer-lasting products and product-service systems (cf. use-intensive in section 2). Concurrent validity was used to measure survey responses, especially in sections D (car sharing) and E (car longevity) of the questionnaire (Appendix O). Concurrent validity compares a ‘criterion’ (e.g. people’s different attitudes) against a concept (e.g. sustainability) and measure its validity (Bryman 2008). For example, the responses from the first set of interviews were mostly sceptical of product longevity strategies but also of some car sharing principles.

3.6 Interview Thematic Analysis

The analysis of the two sets of interviews was similar in approach. By using thematic analysis (Bryman 2008, Braun and Clarke 2012), it was possible to categorise the themes into barriers and opportunities and codify them. Each code represented an approach in design for longevity or shared use. The approach for thematic analysis of the first set was a deductive approach (Bryman 2008, Braun and Clarke 2012), i.e. a ‘top-down’ approach where the researcher brings concepts, ideas or themes they want to explore (Figure 21) and then analyse the data through coding. For the second set, a mixed approach was taken; deductive and ‘bottom-up’ (inductive) approach, where the codes and themes derive from the data (Bryman 2008, Braun and Clarke 2012), which also led to inductive questions (Figure 22), such as “from a social perspective alone, what are the main barriers to upscaling the different forms of car-sharing?”. Bryman (2008) asserts that deductive and inductive approaches relate and complement each other, one may entail elements of the other, and they are iterative in the sense that the researcher may need to collect more data to establish the conditions in which a theory is or not valid and, if so, in which circumstances.

Codes are tags or labels for assigning meaning to descriptive or inferential information (Miles and Huberman 1994). For Miles and Huberman codes are attached to arguments, sentences or whole paragraphs, contextually or not. However, this organisation of words needs a meaning and context, condensed into clusters (ibid). In the first set of interviews, clustering of the codes was achieved by separating longer lasting cars from use-intensive shared cars and then grouping the similar sub-sections of each. Some of the codes were then subdivided into the sub-approaches related to each sub-code. For the second set, the code and clustering were simplified to codes and sub-codes (Appendix F, Appendix M). There is no prescription about how to segment the data when coding. It can be made in small or large chunks (Braun and Clarke 2012). The thematic analysis of the data collected in both interview sets derived from recurrent topics in the interviews (Bryman 2008). The first set was purely exploratory and aimed at determining if some of the concepts and strategies for longevity and intensive use were valid in car design (Section 2.4). For the second set, the codification was similar, with the questions deriving both from the first set of interviews use-intensive cars data analysis and product service systems and shared-use cars literature (Section 2.5). Both were analysed using Nvivo to help codify the responses; the codes were then classified into barriers and opportunities for each set of interviews.

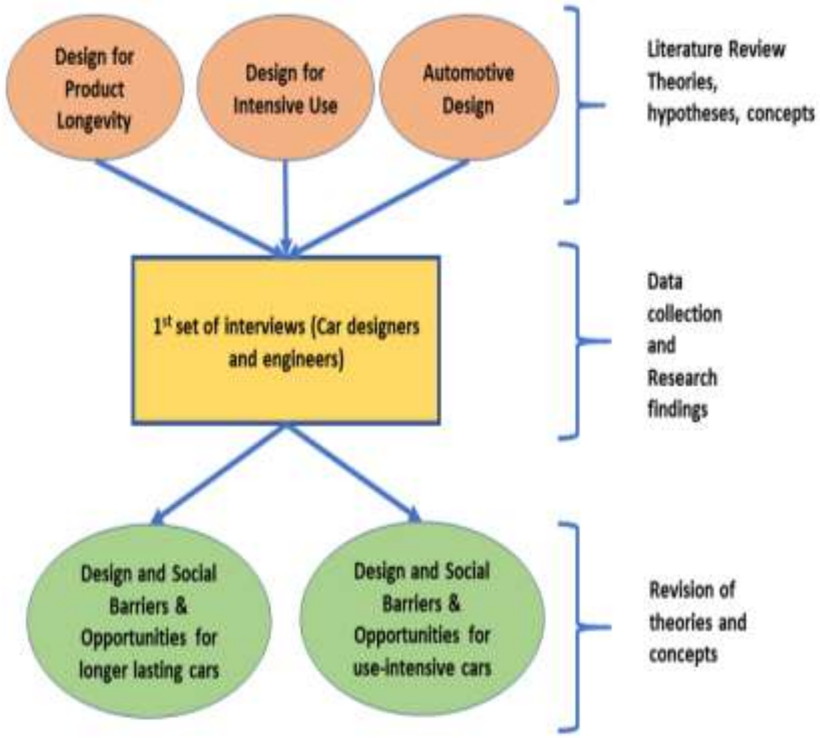


Figure 21. Deductive approach for the 1st set of interviews based upon Bryman (2008)

Pattern coding analysis could have been used. According to Miles and Huberman (1994), pattern codes are more explanatory and enable researchers to draw large quantities of data into smaller units of analysis; there is a degree of similarity with clustering. This type of analysis helps to identify the similarities between information provided by the interviewees (e.g., interviewees who had strong opinions about modular cars). Generally, these were in the 'development engineers' group, who were largely more reluctant to accept the possibility of longevity and intensive use than product designers. Engineers were very sceptical of accepting total vehicle modularity due to physical limitations and safety regulations. Contrastingly, designers seemed less unconvinced about modularity enabling more design freedom. However, the aim of the first set of interviews was to understand design practices and experience in the sector and the viability of longer lasting and use-intensive cars. The outcome highlighted the limitations of both concepts.

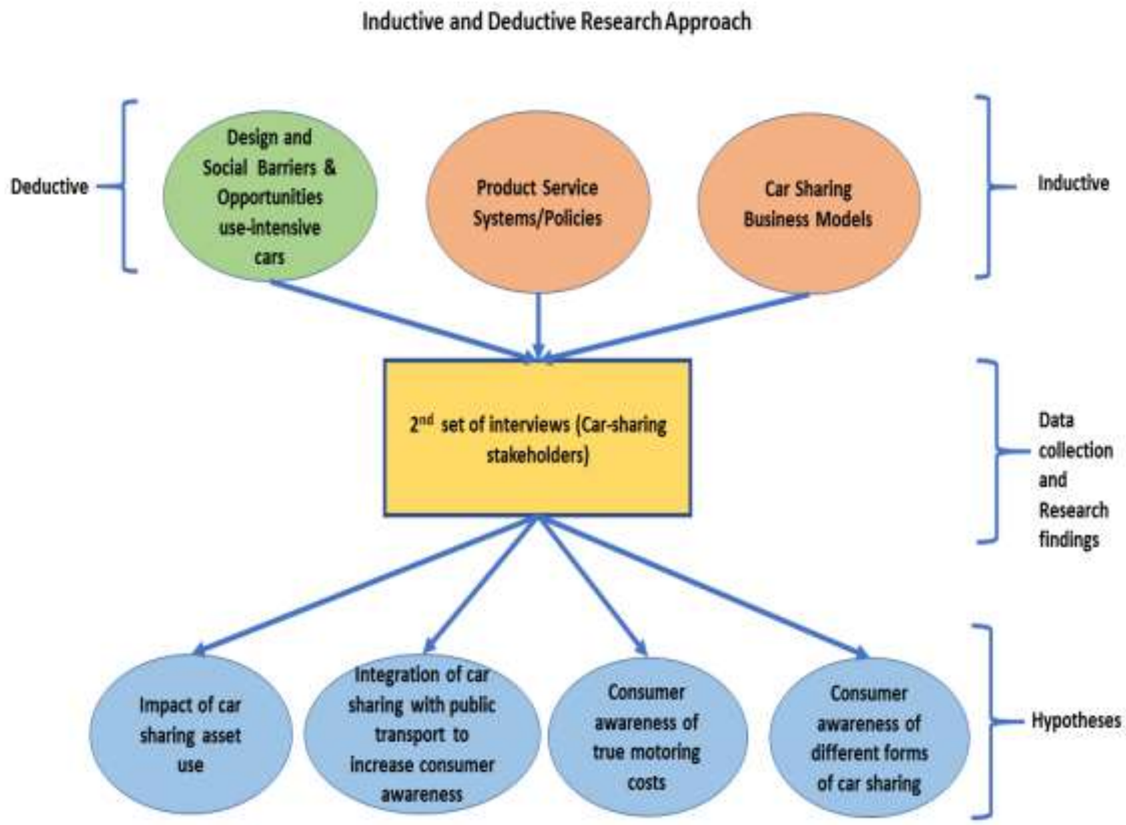


Figure 22. Mixed inductive and deductive approach to the 2nd set of interviews based upon Bryman (2008)

The aim of the second set was to understand the barriers to upscale car sharing. The deductive thematic analysis in the first set was deemed more appropriate for this type of analysis because the themes were set before the interviews (Bryman 2008) and there was no need to find new patterns from those. The answers to the themes were then classified more effectively. One important distinction must be made between the two sets. The first set was seeking interventions mainly at product design level, i.e. changes in the design of passenger cars. Contrastingly, in car sharing, interventions were sought at system level, despite some overlapping of systems and design in both. The themes for both sets are therefore different, and in most cases not comparable. However, some assertions made in both sets were explored in the survey (Figure 23).

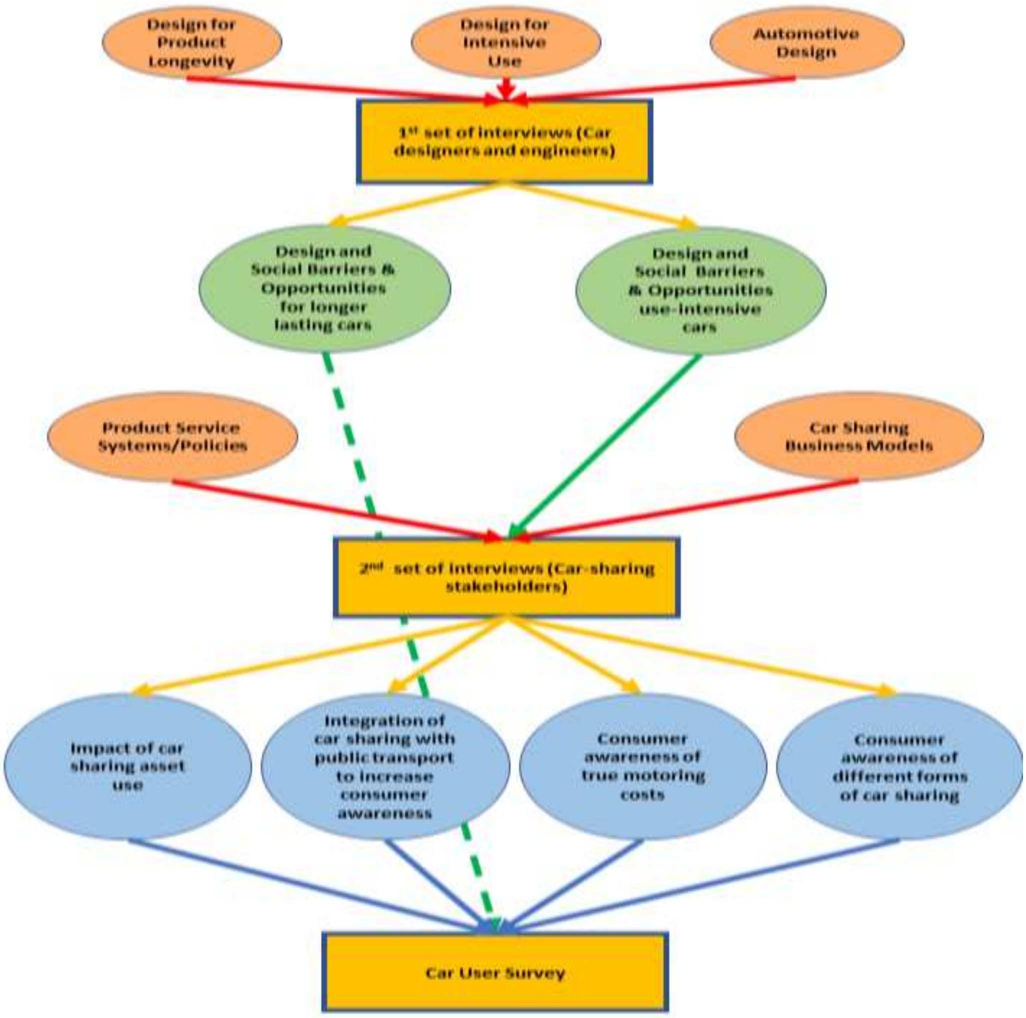


Figure 23. Schematic of the three research stages.

3.7 Survey Analysis

The survey was analysed through descriptive analysis methodology (Bryman 2016) using SPSS software. The data was tested for associations between gender and other variables, but no other demographic variables, due to due to the large set of data and time constraints. A number of different statistical tests were undertaken to assess ordinal and categorical data, and also means and relationships between variables (Section 3.7.1). Response outliers were also allocated a specific test (Section 3.7.2).

The survey discussion draws upon Jackson's (2005) policy options for sustainable consumption and Schwanen, Banister and Anable's (2012) assertions about consumer behavioural change. It looks at those from 'post-reflective habits' that open up the possibility of gradual behavioural change within individuals. In other words, by understanding norms and behaviours of car users, we can reflect upon ways of helping to change those behaviours (Thaler and Sunstein 2009, Thaler and Sunstein 2003). This can be achieved through a balance of policy incentives designed to internalise social and environmental externalities and information to ensure [car] users make informed and rational choices (Jackson 2005). This change may lead to a change in culture (Schwartz 2014, Hofstede 2011, Triandis 1977), where the car is not seen as a status symbol, rather a more utilitarian product.

3.7.1 Statistical Significance Tests

Statistical inference starts with an implicit or explicit 'null hypothesis' (H_0). Testing a 'hypothesis' or 'statistical significance' helps researchers to establish existing relationships between two groups and enables the researcher to accept or reject (H_1) the 'null hypothesis' (Wheelan 2013). A coefficient which suggests a relationship or causal link, the null hypothesis, is that this relationship most likely occurred from random chance, and that another sample and test would show no similar coefficient. In the latter case, an alternative hypothesis, usually a negative of the hypothesis, more consistent with the observed data, must be accepted (ibid). A *p* value below 0.05, indicates there's less than 5% chance this coefficient or relationship occurred by random chance, and that another sample would deliver the same conclusion. The following tests were used in the research survey:

Independent sample 'means' t test is used to compare two independent samples (e.g. male and female). According to Wright (1997), researchers assume that each person questioned is independent of all the others. Another assumption is that the dependent variables measured are interval or continuous, and the differences are normally distributed in a bell-shaped curve histogram (ibid). This is related to the central limit theorem. This theorem states that the larger the sample size, the mean will get closer to the normal distribution.

One sample T test if a normally distributed dependent interval or continuous variable differs significantly from a reference value (H_1). One sample T test is useful to test if a sample average differs significantly from a reference value (Blair and Blair 2015).

Pearson chi-square is used to find if a relationship between a categorical dependant variable and one independent variable with two independent groups (e.g. male and female) occurs (Blair and Blair 2015). Conversely, chi-square tests may bring interpretation problems; it is not directed at any specific alternative hypothesis. Nonetheless, it might be that the variables are related in a specific form (Wright 1997). Large samples frequently produce substantial 'chi-squares', even if the variables are weakly related (ibid). In order to test a hypothesis, there are two important assumptions to take into consideration; first, the two variables must be measured categorically, and second the two variables must be two or more categorical groups (e.g. males, females) (Wright 1997).

Fisher's exact test, similar to the ground for the Pearson Chi Square, is performed when, in a cross tabulation, more than 20% of the cells have an expected frequency of less than five and/or includes an expected value of less than 1 (Upton 1992). In other words, in some questions with categories, some of those categories were chosen by less than five respondents despite a large sample size.

Wilcoxon Mann-Whitney U test is a non-parametric test used to compare two sample means from the same population; when the assumptions for the group t test are dissimilar to the paired t test, and the groups do not have the same approximate standard deviation (Wright 1997). In other words, the discrepancies between two categorical sample groups, when the dependent variable is ordinal or continuous, is not normally distributed.

3.7.1.1 Other tests used

A *Shapiro-Wilk test* is used to verify if a continuous dependent variable is normally distributed. When the variable is not normally distributed (p value < 0.05), then some nonparametric tests may be used to verify the hypothesis. In the survey, *an independent samples test,* the correct test for continuous variables assumes a normal distribution. It is therefore advisable to undertake an *independent sample test with bootstrapping. Bootstrapping* helps to calculate the variances, bias or confidence intervals of an estimate through resampling (Jarman 2015), and is a 'robust' method which does not require dependent variables to be normally distributed (Field 2009).

Levene's test is used to assess if there is equality of variance in, for example, gender responses. Some statistical tests assume equal variances and this test verifies that assumption This test is used to inform the *bootstrapping test* interpretation. Bootstrapping tests will provide the results with and without equality of variances assumed, with differences in their final p values (Field 2009).

3.7.2 Testing and Trimming Outliers

In random samples it is normal to "eliminate the effects of wild shots" (Tukey 1962 p 17) - the responses which do not accurately reflect the respondents who gave them - and it is expected a higher efficiency - after trimming - when the sample comes from a long-tailed distribution (ibid). For example, in some cases, in this survey, due to the nature of the answer boxes allowing 3 units for response, a few respondents gave exaggerated responses, (e.g. 'how long should a car last in years' = 999) (Sections 4.3.2, 4.3.5, 4.3.7). Those responses, although scarce, skewed the normal distribution and were distorting the final *mean*.

To find and eliminate any response outliers, the 25th and 75th percentiles were calculated using a weighted average (Tukey 1977). Weighted average is calculated through the multiplication of each coefficient by the number of cases used in the calculations, adding these multiplications and dividing the sum by the number of cases (e.g. Table 27).

3.8 Computer Assisted Analysis

The large amount of data produced by any research (e.g. interviews or surveys) is often difficult to manage in a timely manner. Mixed methods may generate large sets of data (Robson 2002). Qualitative and quantitative analysis software is widely used and accepted (Bryman 2008), and there is no preference for any specific programme (Bryman 2008, Miles and Huberman 1994). The software chosen for analysing the qualitative data was NVivo and for the quantitative data, Statistical Package for Social Sciences (SPSS). These packages were available from Nottingham Trent University and were used accordingly. NVivo, like similar qualitative data software packages, enables researchers to manage data and ideas, enquire, visualise information and produce reports (Bazeley and Jackson 2013) but does not interpret the data nor codify it (Bryman 2008). SPSS enables data analysis as long as the data has been cleaned and verified. However, these software packages can also distance researchers from their data, dominating code-and-retrieve methods in favour of other analytical approaches leading to misconceptions about the capabilities of analysis software (Bazeley and Jackson 2013).

The use of Nvivo enabled the qualitative data from this research to be codified in manageable portions, enquire the data when necessary for analysis, and to store it and retrieve it securely.

The use of SPSS enabled an effective analysis and statistical testing of the data collected from the survey.

4 RESEARCH FINDINGS

This chapter is divided into three subsections and presents the outcome of the methodology described in Chapter 3. The interviews (Sections 4.1 and 4.2) explored barriers and opportunities to passenger car longevity and intensive use, the systemic barriers towards upscaling car sharing and the survey (Section 4.3) explored behaviour, beliefs, attitudes and habits of passenger car users in the UK.

4.1 Design for Car Longevity (Interview Set 1)

The first set of exploratory in-depth interviews aimed at understanding the role of designers and vehicle engineers in passenger car development and how the concept of a longer life car could be achieved. Each interview was divided into four questions and was conducted to assess the feasibility of longer lifespan cars and shared, use-intensive cars (Appendix E and Appendix L). Designers and engineers were named D1, D2, etc. and engineers E1, E2 and so on (Section 3.3.4) (Table 5).

When interrogating car industry experts on potential longer lifespan cars through design, using guidelines from literature for longer lifespans, some scepticism was found. The reasons varied between design obstacles, manufacturing and market acceptance. Some experts affirmed that passenger cars are already designed to be durable and therefore their lifetime is optimised. This resistance to new ideas and manufacturing methods confirms the conclusions of Orsato and Wells (2007), Wells (2010), and Wells and Nieuwenhuis (2012) and contributes with new knowledge as to why the automotive paradigm is not evolving (Sections 1.2 and 2.2).

4.1.1 Design and Development

Passenger cars already incorporate some of the sustainability strategies described in the literature (e.g. Vezzoli and Manzini 2008, van Nes 2010) for reasons of cost and material savings. For example, in 'design for repair', repair times or maintenance of certain systems, such as engines and brakes, are taken into account during the design stage (respondent E3), in order to save labour and energy costs. Modularity in the automotive industry must be approached somewhat differently from other industries, for example, micro-computers, where structures and modules can be easily assembled and disassembled to upgrade and update the product without significant safety risks. In the case of passenger cars, manufacturing processes have barely changed in ninety years; the main structure, once welded, cannot be modified without important safety compromises, thus hindering upgradability. It is possible to change the basic design of the structural system to incorporate wider modularity but the associated costs are too high for mass-manufacture. Likewise, a reduction in production volume would increase the unit cost, which, under the current paradigm would make cars difficult to sell (E3).

4.1.2 Design for Product Attachment

Product attachment was explored during this set of interviews despite not being explicitly asked in the questionnaire. Some of the designers and engineers suggested that for a longer lifespan car design to be feasible, it would need high levels of personalisation in order to create some form of longer-lasting attachment; *"I think purely the double lifespan one* [20 years] *gives you an idea of how you might create something very personal and bespoke from a hardware point of view"* (respondent D2). *"With one model, you could get something that is much more highly personalised to somebody and potentially upgradable to suit as that personality changes"* (respondent E4). This could enable car users to make the car evolve with themselves, re-creating it to match their evolving needs and perhaps increase their attachment to the product through what Chapman (2010 p 72) call "sophisticated and intense" experience over a longer period of time. However, a re-designed passenger car, able to accommodate evolving needs, would have to be structurally modular and transformable. Nonetheless, it will be difficult to protect a design against obsolescence, despite examples of iconic cars with very long market lifecycles, such as the VW Beetle, Mini, Citroën 2CV and Land-Rover, and anecdotal cases of product attachment from their owners. The average market lifecycle of a passenger car is between six and seven years, with a facelift at the end of the third year (Volpato and Stocchetti 2008). Marketing and design teams create a style that matches the expectations of their target market for that period of time. However, changing this mind-set is possible if designers engage in creating 'timeless designs'; *"it goes back to the point about doing something that is essentially timeless, as opposed to something that's on trend. I think it's a very different mind-set when you're coming into a design"* (respondent D2). This design would have to be, on one hand, technological obsolescence as much as possible, especially in energy efficiency and safety. Conversely, it should enable some form of upgradability by the customer, enough to enhance the user-experience and thus product attachment. A longer lifespan car design approach would have to be supported by a long-term view of the market, protecting the design from major style changes; "*the barriers for the long-life car are clear in terms of being able to imagine what changes might need to be design-protected for. I think that's very, very difficult. And not impossible, but difficult"* (respondent E4).

Achieving a timeless style would involve designers in proposing a neutral style but one open to personalisation, technological and style updatability (respondent D2). Personalisation should reflect the owner's personal taste creating differentiation, in line with Govers and Mugge's (2004) model of user 'personality'. The interior should have tactile quality with superior grade materials and higher attention to detail. This would ensure a longer ageing process where such materials age gracefully, making the interior pleasurable but durable. *I […] actually see it as a challenge to the designer to come up with something that is so elegant and pure and timeless* *for want of a better word, 'cos you're having to live with that, like, canvas, if you like, for a period of time"* (respondent D2).

Another aspect that surfaced from this analysis is the relationship some people have with ageing materials. Arguably, some materials age better than others. For example, faded plastic generally has less visual appeal than cracking leather in a sofa. *"Natural materials do age in a particular characterful way. It's like an old Chesterfield sofa or something like that, so there's something to be celebrated in a car that lives on throughout"* (respondent D2). Some niches in the car market value the 'patina': the dull paint, the superficial rust in the car body or other visual elements that transmit the vehicle's age or the occasional dent (Figure 24). This acceptance of material ageing and non-critical damage may be the key mind-set enabler that could create a different type of product attachment and an acceptance that products wear and get damaged. "*So, I think if you could create a car that was sufficiently attractive that people just fell in love with it and wanted to keep it, then I think that's a different angle on it, because then they would actually accept certain, if you like, deficiencies because they like the car"* (respondent E4). Cars would have to be attractive enough to people wanting to keep them for longer. However, this product's personality needs to match the target market 'personality' (Govers and Mugge 2004). This market, in turn, needs to change attitude and behaviour towards ageing and small damage. Interviewee D2 gave the example of a student project for a car bumper coated with several layers of different colours that would bear those scratches as something to celebrate rather than a problem reducing the car´s subjective value.

Figure 24. Car with stickers over dent. Author's picture (2015).

4.1.3 Design for Variability

Design for variability is “the possibility of the product to offer some kind of variation and benefits to the user” (van Nes 2010 p 123). Variability is possible if there is some degree of modularity (Section 4.1.4), where either the component parts can be switched from their original place, (e.g. furniture in a room), or outdated parts of a product can be replaced by up-to-date components (respondent D2). In current passenger cars variability is limited due to the design and manufacturing process paradigm (Wells and Nieuwenhuis 2012). What automotive marketing jargon calls ‘interior modularity’ is, often, variability. (cf. Section 2.4.2). The limited variability found in every car is the consequence of mass-assembly design and safety regulations. Seats, for example, need to be secured to the structure; in the event of an accident they have to guarantee passenger safety. It is, therefore, difficult to introduce variability in passenger cars without higher levels of modularity.

4.1.4 Upgradability and Modularity

Modularity, when present, is an important design strategy set at the beginning of the car design process, enabling easier access to parts for reparability, replacement and upgradability. The interview analysis shows that important compromises during design, manufacturing and user phases have to be made when designing a vehicle to be totally modular; higher development costs, additional homologation or type approval - a set of regulatory, technical and safety requirements -, additional material usage during manufacturing, comfort and safety issues during the user stage. Such an approach to car design was considered undesirable and challenging by many respondents, despite being technically possible. Modularity in modern cars is currently limited to a few components. Bumpers, for example, are a sacrificial module that has been left out of the main car structure. This component is important to absorb energy from lower speed impacts. Therefore, there is economic value in not integrating bumpers with the rest of the structure, because; it enables consumers to replace them at a relatively low-cost (respondent E3).

The main barrier for vehicle modularity, during user stage, is structural integrity. A mass-produced car main loadbearing structure is designed and built to optimise comfort and safety. Any post-manufacturing changes to this structure will not guarantee its integrity in both safety and comfort (respondent E3). Retrospective structural reinforcement through structural upgradability is not physically possible (respondent E3). Safety requirements are the main reason for this, as car structures are designed and built to behave as single entities during an accident. *"It's not plausible to disassemble those joints and remake them and have any confidence in their durability and integrity"* (respondent E3). There are structural elements, in the case of a high-speed impact, that absorb and dissipate energy from collisions. Interfering with the structure can compromise its capability to absorb and dissipate energy during an impact.

Structural interchangeability leads to design complexity. More joining materials are needed and joining parts need to be reinforced with extra material (respondent E4). Such type of structure would have to rely on different joining techniques, making the overall product more expensive to produce and structurally less rigid (respondent E4). Car mass-manufacture uses mainly spot and fusion welding to join structures (Michalos, et al. 2010). Mechanical joining techniques would be needed to enable interchangeability. Such techniques require regular maintenance to guarantee component integrity and are neither optimised for comfort or light-weighting (respondent D1). Heavy Goods Vehicles (H.G.V.s) and some buses use this type of construction to join the chassis frame to the body. This construction enables customisation during manufacturing, to a certain extent, and enables different chassis' sizes to be assembled for purpose-built bodies (Salvador, Forza and Rungtusanatham 2002). Vehicles using this technique are neither very effective structurally nor do they have a refined ride and handling, because they prioritise component accessibility, modularity and longevity (respondent D1).

A different approach would be to employ the use of removable 'sacrificial' modules, which are currently used and replaceable in the event of a high-speed crash. Only very expensive sports cars have such arrangements, usually at the front and rear of the vehicle. In the event of a collision, the entire front or rear structures of the vehicle can be replaced without writing-off the whole car. Nonetheless, this approach will limit the upgradability of sacrificial structures. These structures, once joined to the central structure, or 'tub', act as a single entity in a collision. Changing the module characteristics by means of an upgrade could compromise the capability of the whole structure to absorb and dissipate energy during a crash. *"[It's] very difficult to design a specific crash structure to work on an already existing body-in-white and to get the two* *to work together in such a way, because… although it's sacrificial, the way that they work is designed to work together"* (respondent E2).

Part of the decision to cease manufacturing the Land Rover Defender (Figure 25) was partly due to changes in safety, emissions standards and economics. Its architecture could no longer meet stringent future safety demands and its manufacturing process was too expensive and time consuming, due in part to the nature of its modularity (Lissaman 2016). This modularity also reflected uncompetitive pricing in the market (Antonio, Yam and Tang 2007), despite the model still being a vehicle with referential off-road capabilities. The car was originally designed for in-life changes to its structure and body at a time when materials were scarce and repairs had to be undertaken with few tools (respondent D1). Furthermore, it was a vehicle that made no concession to fashion, styling or comfort. Despite being available to the general public, this was not its main or intended target market which was mostly agricultural, commercial and military. It was nonetheless, built to be robust and longer-lasting. If changeable configuration was possible, it would be cheaper for a consumer to swap their car for one more suitable to their needs. A modular car would have to be designed to be functional, enabling upgrades and body panel changing (respondent D1) (e.g. Figure 10 and Figure 11). It would also have to make concessions to aesthetics with a straight, "boxy" utilitarian shape (respondent D1 and D3). Components would have to be joined mechanically, by means of fasteners, and easy to access (respondent D1). It may be difficult to propose to consumers a car not aesthetically pleasing enough, not very comfortable nor potentially safe - after being modified - despite being upgradable and modular.

Figure 25. Land Rover Defender 110 Station Wagon (2016). Wikimedia Commons.

Another important barrier to longevity is predicting future developments of safety features and standards. However, Burns' (2010) suggestion to evaluate a design's 'weakest link' could be adopted; examining the evolution of past and current technologies to decide areas for future development. *"You can only design for what you know about at the time and for what you think might be coming… I haven't witnessed any sudden drastic change in the technology"* (respondent E6). Structural safety in cars has been fully developed. The industry is now focusing on developing cars for pedestrian protection. *Now, if you're locked in to a twenty-year structure, it's difficult to imagine how you would be able to do that [safety upgrade]"* (respondent E4). Despite the slow evolving nature of the automotive industry (Wells and Nieuwenhuis 2012) predicting future technology and safety can potentially be achieved. Past examples from SAAB and Volvo manufacturers show that advanced design in safety enabled cars to stay in the market for very long time and still be a reference in safety.

Powertrains, (i.e. engines and gearboxes), were seen by interviewees as another potential area for increased modularity. Powertrains are, to some extent, modular and have a degree of interchangeability. However, car manufacturers tend to have several engines for each model, making interchangeability challenging. Several components in one engine may not fit another, (e.g. timing-belt, inlet manifold). Further powertrain standardisation may reduce the number of different engines for manufacture, thus reducing the stochastic nature of powertrains received by remanufacturers (Kenne, Dejax and Gharbi 2012). There are cost savings for doing so; less tooling, less dissimilar components, for example, different sized pistons, and reduction in manufacturing time by reducing tooling changing times. An anecdotal example, Volvo, is adopting this approach. It offers one single internal combustion engine block with the same cylinder volume; 2000 cm^3, two fuel types plus a hybrid version (English 2014). The difference between engines is the total power output and fuels used (ibid). This strategy has the potential to save time and cost when it comes to future disassembly for reuse or remanufacturing. Component standardisation was noted positively by respondents but the industry needs to innovate further (respondents D1 and E2). Non-visible part standardisation across brands from different multinationals could enhance remanufacturing and component interchangeability; *"the idea is to commonalise* (sic) *on those components that are not specific to that vehicle"* (respondent E6) without impacting on product desirability. Electric powertrain motors and batteries are also potential areas for modularity and standardisation, perhaps because these are hidden components and will not interfere with styling differentiation. The strategy is similar to internal combustion engines. Electrical powertrain standardisation would need architectural innovation across the industry, to standardise floor-pans for storing batteries. Currently, each car manufacturer will have their proprietary solution for battery accommodation and floorplan arrangement. Standardisation could be adopted for batteries with different sizes of batteries for different power outputs, like ignition batteries already in use by the industry. This interchangeability could enable faster energy replenishments and battery replacement. *"The French have looked into this model, the Americans looked at this model, no one's really cracked that yet, 'cos you need the standardised battery"* (respondent D1).

Targeting parts for modularity through experimentation and evolution is another possible approach (respondent E6). Certain vehicle parts are more suited for modularisation and upgradability than others. Parts that are expected to have shorter lifespans than the whole car could be a potential target. However, car structures will have to be future proof. Modular components will have to be designed to fit retrospectively in older cars. This will enable instant component upgrade in an older vehicle without major changes to its layout.

One of the most challenging areas in car design is the electrical system and its architecture. This system coordinates all the functions of other systems across the vehicle. Its complex wiring structure is made of several miles of copper wires insulated with PVC and loomed together running through the structure and integrating all the electric and electronic functions. These functions are connected to different types of interfaces at the end of each set of wires, creating a complex an inflexible system. Once assembled, the system is very difficult to replace or upgrade. An upgradable electric system must be designed to take into account backdated electrical architecture; *I think you could start off with devices in the car that talk to each other or, you know, much in the way that we have hub systems"* (respondent D2). Hub-system devices could work via wireless communication, already used in 'drive-by-wire' steering and braking, enabling an easier reset or upgrade, together with a reduction in material and energy. This electrical architecture, within the confines of a car, should be able to communicate with the different components without electro-magnetic interference while safeguarding the vehicle's integrity.

One of the criticisms of a longer-lifespan car made by interviewees was the structural complexity with increased modularity construction. This would increase vehicle weight and compromise emission targets manufacturers have to meet (respondents D1, E3, E5 and E6). However, if the lifecycle embodied emissions of longer-lasting cars were lower than standard passenger cars, such vehicle could be viable (respondent D4). Potentially, modularity, the reuse of parts, upgradability, remanufacturing and easier disassembly could reduce overall embodied energy, emissions and materials throughout the car's lifespan. Such a longer lasting car would reduce manufacturing demand of new cars and, therefore, the impact of manufacturing on the environment.

Design for modularisation is challenging, but not technically impossible. Notwithstanding, whole structure modularisation may be undesirable due to important constraints in vehicle architecture, complexity and safety, and parts durability contradicting in part Nieuwenhuis' (2008) (Section 2.4.4). It is, nonetheless, possible to adopt a selective approach to this strategy, namely at component level (Christensen 2011) with broader standardisation across the industry. Modular components exist in cars for practical reasons. Extending this modularisation to more components that are expected to fail or wear during the vehicle's lifetime may contribute to an increase in lifespan as long as they do not compromise reliability or safety. The structure of the vehicle will have to be designed in a way that enables modularity. This could be in the form of a non-modular main structure, which, nonetheless, enables modularity in several key points of the car where access is important (e.g. hinges to access hard-to-reach parts). Designing for longer lifespans must enable future proof design in areas such as structural safety and adaptability and assure that overall lifecycle emissions are lower than current vehicles.

4.1.5 Design for Disassembly

Design for Disassembly (DfD) facilitates essential activities in sustainable design and has an important role in reducing material and energy demand. DfD enables maintenance, repair, updating and remanufacturing (Vezzoli and Manzini 2008). Automotive companies already have in place some, although not comprehensively, design strategies for easier disassembly. These are mainly driven by insurance costs, from replacing damaged parts, in response to the European Directive 2000/53/EC (respondent E3). The design process of cars incorporates their assembly. This is the combination of manufacturing, with manual and automated labour or a combination of both, and manufacturing investment. During the design for assembly process, considerations include ergonomics of assembly, tooling and the servicing and repair times during usage (respondent E3). Repair, as seen above, is driven mainly by the impact on the cost of insurance premiums of drivers.

Design for disassembly optimises a car for its End-of-Life and remanufacturing potential of some of its component parts (respondents E3 and E6), concurring with Go, et al. (2011). Improving this optimisation will rely on more standardisation of parts, especially those not specific to a particular model, for example, non-visible parts or parts shared with other models such as engines, suspension and electronic components. Such standardisation is already existent, nevertheless, it needs to go beyond one brand or a group of brands (respondent E6). It needs to be taken to another level where all car manufacturers, working with their suppliers, produce standardised components, for example batteries for electric vehicles (Section 4.1.4), making them cheaper and easier to disassemble and replace.

Another obstacle for the disassembly processes is that many components' assemblies irreversible (Pandremenos, et al. 2009). There are welds, especially in structural profiles, rivets and other irreversible joining techniques that cannot be taken apart without component destruction (respondent D3). Modularity, can eliminate this barrier, however, it leads to added complexity for assembly and potential rebound effects for comfort and reliability; more panels and hinges for access, enabling parts to rub against each other that create unnecessary vibration, noise and potential for early failure. In a dashboard, for example, there are safety and comfort systems that often work together. "*When you happen to design a thing in the interior that can be really upgradable, you would notice that every single function would come separated from the whole"* (respondent D3). This separation may enable easier disassembly throughout the vehicle's lifespan, but, it may increase assembly complexity of, for example, mechanical joining and electric connections for wiring looms, potentially increasing unreliability and material and energy use.

4.1.6 Design for Durability and Robustness

During the design stage, prototype cars, are tested and assessed for durability and reliability (Happian-Smith 2001). The broad spectrum of users and disparate operating environments are difficult to predict (respondent E3) (Kleyner and Sandborn 2008), as opposed to heavy machinery, such as earth movers or public transport. One car model (e.g. Ford Fiesta) can be sold worldwide and operate in disparate environments. Thus, development engineers try to simulate or test in these operating environments, from dry deserts to arctic climate, during the product development stage. Some pre-production prototypes are taken to these environments to test whole vehicle capability and performance under such conditions, whilst others are tested in simulation rigs, where such conditions can also be simulated for component assessment. Manufacturers have to ensure consumers and regulators that under any possible weather and driving condition the vehicle will be operational and reliable (Happian-Smith 2001). This is the main reason cars and their components are subject to intensive laboratory and field testing (Kleyner and Sandborn 2008). Testing benchmarks simulate ten years of use under the worst possible conditions, with prototype cars being driven intensively during their development stage but reflecting differences in manufacturers practice ranging from 100,000 km (respondent D1), 150,000 km (respondent E4) and 320,000 km (respondent E2).

Cars are, allegedly, longer-lasting, durable and designed with an optimised lifespan (respondent D3 and E6), around ten years. It is presently possible to extend their lifespan towards twenty years or more (respondent E2 and E6). Some interviewees affirmed that increasing the lifespan of cars by design would be ineffective from the perspective of material use, energy and emissions, however they also assert that cars are already durable enough or that it would be possible to increase their lifespan through a mix between age, mileage (Cooper 2010) and operating environment. Moreover, there are development costs that may hinder the design of longer lifespan cars. For example, vehicle testing would have to be extended in order to develop a more durable car (respondent E2) and corrosion protection was seen as the main area for increased testing (E1, E2, E4). This would, in turn, increase the time it takes to develop, validate and produce a car from concept to market (E4).

Another impact of designing for longevity, under the current automotive paradigm, would be a potential increase in material use. Creating more durable, thus robust structures and components, would increase material and energy use, irrespective of the adoption of lightweight materials such as aluminium and carbon-fibre instead of steel (E3, E4). This would directly increase vehicle weight, which in turn may create a 'vicious circle' of more powerful engines, brakes, radiators and water pumps, potentially hindering CO_2 emission targets (D1, E3). However, such a longer-lifespan design alternative, could potentially be offset if associated with throughput reduction. In other words, the impact per vehicle produced could be higher, but a substantial a reduction of manufactured vehicles could reduce the overall material and energy usage. Sharing cars during the use-stage could further reduce the number of cars needed, despite being slightly more polluting, reducing negative environmental impact across their lifetime.

Longevity would be another specification to add at the design stage (respondent E3). Designers and engineers would, within project budget, need to choose appropriate materials, manufacturing processes and technology to meet longevity specifications (respondent E3). Nonetheless, when starting a project for a new generation product, manufacturers try to minimise material, due to cost, but also tailpipe emissions, due to regulations. Designers aim to use as little material as possible (respondents D1, D4, E1, E4 and E6), although enough to meet performance and safety requirements, whilst mitigating emissions.

There is a disparity in the number of miles cars are tested during product development stage in different manufacturers. Each company has different standards for testing longevity. Another divergence was the reaction to increasing longevity through design. Some interviewees rejected the idea, arguing that this would increase weight and emissions. Others maintained that cars can be designed to be longer lasting with minimal effort. Increasing overall weight and emissions would potentially be beneficial if production numbers decreased together with overall emissions from production, consumption and EoL management accounted for. Improved corrosion protection could reduce structural failure and increase the potential lifetime enabling an opportunity for the industry to gain experience in this area.

4.1.7 Maintenance and Reparability

One interviewee claimed that increasing maintenance frequency potentially contribute to a car's durability (respondent E2). Increasing maintenance frequency could increase material and energy usage if, for example, service maintenance increases too. Another design requirement during product development is the time it takes to service a passenger car, including labour time, tooling requirements and ergonomics (respondent E3). Servicing a car involves material and energy use that may not be environmental desirable.

Cars, due to safety and relative value, are one of the few household goods with recommended regular maintenance and compulsory safety checks. The car industry has gained extensive experience in both. However, later in the vehicle's life, when costly maintenance is needed on parts that take longer to wear (e.g. clutch and bearings), some design compromises surface (respondent E4). These compromises may be a result of design specifications, safety requirements, regulations, technology applied, repair costs and parts availability. In Japan, for example, cars are often discarded at the end of seven years due to high maintenance costs, stricter safety checks and expensive insurance premiums (Nieuwenhuis 2008).

4.1.8 Design for Intensive Use (Interview set 1)

This section is divided into the main design strategies identified by Vezzoli and Manzini (2008) for user-intensive products, adapted to cars. It was left to interviewees' consideration if this hypothetical intensively used car had implications in car design and product development, that could be explored in mass-manufacturing. For example, Autolib in Paris, with cars purposely developed for intensive shared use. The interviews undertaken in this section explored two design strategies proposed by Vezzoli and Manzini for use-intensive products (ibid) during the design and development stages: design for shared use and integrated functions. The other strategies: intensive used-products, services, components and design for multi-functionality were not considered because, although surfacing throughout this interview set, they did not produce significant data relevant to this section. These strategies were often raised during the first set of interviews, either due to being asked (cf. Section 3.3), or for the reason that interviewers made analogies, intentionally or not, with longer lasting cars. However, where relevant and appropriate, they were analysed separately from the data obtained in section 4.1.

Some interviewees often highlighted the importance of economic incentives to introduce some of the use-intensive strategies, in line with Wells (2010), but also a change in younger generations' perceptions, and needs, of private mobility (Metz 2012), lateness in acquiring driving licenses and cars (Delbosc and Currie 2013) and changes in demography and mobility options within large cities in developed countries (Metz 2013). Such attitudinal difference could potentially be explored to upscale car sharing and use-intensive cars. In line with Vezzoli and Manzini's (2008) assertions, intensification of use enables the spread of negative impacts through several users, reducing, at the same time, the number of vehicles on the road. It has, however, the potential to shorten the lifespan of cars by optimising their utilisation, enabling thus an earlier replacement, potentially towards more efficient vehicles.

The interviewees' reflections presented below, together with the literature reviewed, led this research to further explore the car sharing sector. For example, current socio-economic constraints affecting how people travel, highlighted by David Metz (Metz 2013, Metz 2012), and the socio-technical transport niches slowly emerging in today's society (Wells 2010, Geels, et al. 2012), with the potential to widen the 'cracks' in the car regime, drew this research to further explore the systemic nature of car sharing. At design level these changes, and their implications, are still being explored, even by the established automotive industry (e.g. autonomous vehicles or car-to-infrastructure communications). The following sub-sections offer a glimpse of how the incumbent automotive industry approaches such changes.

4.1.9 Design for Shared Use

Design for shared use implies product sharing between a number of users. This practice raises concerns such as sharing a car with strangers (E3), time-sharing or individual use (E4), societal acceptance (E4) and hygiene (E3). It also changes the purpose of the car from a narrower owner/user perspective (e.g. cocooning in Wells, Xenias (2015)) to wider and greyer definitions (respondents E1, E2 and E3) sustained by service providers; the target market may be broader and cars may have to be less market segmented. Car sharing vehicles could be completely different to modern passenger cars, reflecting upon optimal design solutions. In other cases, they could offer a service where the user pays for the car without owning it and the manufacturer becomes a service provider by designing the model for the maximisation of resource efficiency (informative interview #1). In such cases, manufacturers' revenue stream comes from the cars they have in operation.

Younger generations, the so-called millennials or Y generation – born around 1980 and 2000 (Valentine and Powers 2013), were acknowledged to be either buying cars at later stages in their lives or, if living in large cities and not purchasing cars at all (respondent E4). This generation is more open to the sharing of products (respondent D1), willing to socialise online without the need for travelling so often (respondent E4). Interviews suggested that the mainstream car industry is at a socio-technical crossroads with future implications for car design, where the choice and the definition of what a private car is could change. *"You're filling a gap, you're going somewhere between personal ownership and somewhere between public transport"* (respondent D1), *"the target set would vary when you have multiple users, which is why I say, it's half way between private and public transport"* (respondent E3).

If the definition and use of the car changes, as a societal and cultural element, due to socio-technical transitions, then design targets or priorities must change accordingly. These should be defined at the design stage. The target market will be broader and cars will have to be less segmented to cater for this market (respondent E1). Such vehicles could become completely different from traditional passenger cars (respondent E3). Conceivably, and paradoxically, these should be called mobility solutions rather than cars (respondent D1). The former can be any solution that fulfils personal transport needs. These, possibly shared, mobility solutions will need to satisfy different requirements: be stylistically neutral, containing minimal equipment, enough to meet regulatory standards, and basic levels of comfort (respondent E1). However, customers may not want to perceive the car *"like a piece of public transport"* (respondent D2). It needs to be sufficiently attractive to engage a large number of people into such a product, but, at the same time, be aesthetically neutral (respondents E1, E3, E4, D2). The overall design will need to be sufficiently distinctive from the utilitarian bus, for example, but without any styling flair typical of some passenger cars and giving emphasis to function over form; *"I'd suggest you would be looking at something much less personalized"* (respondent E4), *"if it is less individual then* *probably change the look. It will become more a utility"* (respondent E1). Cars, under such definition, would become pieces of 'shared hardware' with users carrying the software (e.g. an app) necessary to access the hardware. The software could enable the user to personalise different vehicle settings through an interface (e.g. smartphone); *"it prepares itself for your arrival and has all your settings intelligently loaded"* (respondent D2).

The idea of sharing a product that traditionally has been owned or used by one person or household, found, some scepticism. However, some interviewees reflected upon how the design stage should be approached and, in some cases, possible design outcomes in a user-intensive scenario; *"there is an acceptability issue with multiple users. Or an unacceptability about private space being shared with other users, which inevitably would drive different requirements and targets."* (respondent E3). Mobility services, such as 'Autolib' in Paris or 'Smart City' Ha:Mo in Grenoble, France, (Autopartage 2015) offer widely used shared cars as part of the public transportation system. According to Ha:Mo's website, cars are cleaned regularly at the parking spaces (ibid). Some cleanliness arguments can also be rejected with the example of taxis, which are not cleaned after every passenger uses them. Such a task is perhaps undertaken at the end of the working day. However, cars like the 'London Taxi', or Autolib's are designed to be easier to clean than normal cars, incorporating hardwearing materials (respondents D3 and E2).

Overcoming some of the social barriers, however, will require incentives to move people away from car ownership (respondents E3, D1 and D2). The proposition for an intensively used car within any kind of sharing scheme needs to make economic sense to potential users (respondent E4) and appeal to subjective motives that make consumers buy certain cars that portray a desired/aspired image. "*You'll need to actually give them an incentive that works beyond just the economy and, you know, you need to give them something that, you know, they get satisfaction out of" (respondent D2).* The different areas of interviewees' expertise offered guidance on where design interventions should take place. Opportunities were mainly found in the interior layout of fully autonomous vehicles (respondents D2, D3, E1 and E2), gradually eliminating interfaces such as steering wheels and pedals, liberating space for more passengers or reducing vehicle footprint, and thus, material and energy. It was acknowledged that autonomous cars will have seats with multiple configurations.

Ride sharing, as defined in section 2.5.2, was seen as less desirable. Time-shared cars, such as car hire or car club, have been offered to customers for a long time. In PSS, ‘use oriented service provision’, as defined by (Vezzoli and Manzini 2008), for example, is not dissimilar to current car hire services, where a pool of different types of vehicles is available and the user will choose the one most convenient for the intended activity; “*some kind of a compromise between owning a car and or the multiple user, dial-a-car on your phone app wherever you want to, whenever you want and then dial for the car that’s fit for the purpose.”* (respondent E5).

Intensifying car use was seen generally as positive by the interviewees. Two reasons for this may be, first, the industry does not see car sharing as threatening to the current regime paradigm, and second the rate of product generational replacement can be potentially faster. Designing for shared use will be triggered by socio-technical transitions. These, in turn, will have to be, somehow, influenced by social instruments beyond economic reasoning. Such mechanisms must appeal to, and exceed, car user’s expectations by providing greater satisfaction than car ownership. In, turn, design for shared use of cars may blur the clear definition of private and public transport, helping thus to widen the existing cracks in the current regime paradigm.

4.1.10 Integrated Functions

The reduction of car component functions into integrated functions has been rapidly developing since the end of the 20th century, as part of a design optimisation approach. Integrated function is, thus, at the opposite end of modularity. “S*o, modularity where it’s worthwhile but where it’s possible to integrate function to get more than one function from one component”* (respondent E3). An example of a significant evolution of integrated functions are car stereos. These became embedded in the dashboard and protected by pin codes to discourage theft. The advent of touch screens further optimised the integration of several functions into one single control unit. All these functions are controlled via touch screens, eliminating the use of several switches. This enables the integration of personal technology into the vehicle’s systems, enabling users to mirror their smartphone screen on the vehicle touch screen (respondent E2). Conversely, this integration of functions may have rebound effects clashing with sustainable design strategies, such as repair, material separation at EoL (e.g. touch screen units) and with modularity.

Integrated functions can enable, on one hand, simplification and a reduction in the number of parts produced in cars. On the other hand, it also has rebound effects such as the use of rare-earth materials, such as indium, that are harder to disassemble and separate (e.g. touchscreens).

4.1.11 Conclusion (Interview set 1)

The multifaceted constraints of car design feeds the role of car designers with both inspiration and limitations. Designing a car for a longer lifespan or for intensive use will enhance those constraints, especially in the current paradigmatic car regime. Such complex challenges surrounding the automotive industry often surfaced during this set of interviews.

The longer lifespan of cars option has encountered conflicting views; some in the industry are of the opinion that cars already last long enough, whilst others believe that such cars would become heavier and less appealing. Weight and size increase have not been barriers for the car industry in the recent past due to safety and market demands (Danilecki, Mrozik and Smurawski 2017). Both regulatory needs in safety and consumer expectations of standard equipment, or a push from the industry towards it, have made the average car heavier (ibid). In order to offset the emissions during production stage alone, the average car will have to be used for a minimum of 21 years (ibid), far longer than the UK average of 13.5 years. Cars always had the potential to last longer than their intended lifespan but with a cost in the time and money (Nieuwenhuis 2008).

The industry is aware of changes in attitudes towards more sustainable forms of consumption and social responsibility, but also has financial priorities. The sector is clearly at some cross-roads with technology, society and the environment. The uncertainty of future technologies and investments in shared use - with different car manufacturers investing in different approaches, and new innovative entrants in the market - will bring to the fore those that best adapt to the needs of that market. Attracting people to shared mobility, highlighting the advantages beyond economic reasons, in comparison with ownership, but also the idea of a more sustainable form of transportation with emphasis in material and energy reduction, makes this proposition foreseeable. Essentially, it could provide consumers with the right choice for their real needs instead of the default ‘one-size-fits-all’ car the incumbent industry offers.

Consumers need to be wiser in their choices, but for many that mindset seem to be anchored in ownership (Section 4.3.6). The millennial generation is potentially the most prepared - of the living generations - for such choice and adaption. The use of social networks to share information with sway from traditional institutional marketing for purchasing decisions may enable them to make the most appropriate choices (Valentine and Powers 2013). The industry itself will most likely offer in the future a pool of different technologies for different usage of cars. Governments and policy makers will perhaps need to provide a framework for this transition to happen.

4.2 Car Sharing (interview set 2)

This section presents the findings of the second set of interviews (cf. Section 3.3). It is divided into seven sub-sections. The first sub-section concerns consumer, business and policy makers awareness of car sharing. The latter presents views on policy making and the different approaches towards car sharing from two UK metropolitan transport authorities and two examples of different approaches to car sharing in two UK cities. The second conveys the social barriers towards car sharing, such as, the limitations of car sharing and motivations of users to do so. The third focuses upon the barriers to shifting from ownership to shared use. The fourth concerns the role of technology as an enabler of car sharing in the recent decades and its potential to future upscale. The fifth presents the views from different car sharing actors of integration of car sharing schemes into the local public transport offer. The sixth describes how car sharing vehicles are acquired, used and disposed of by car clubs and car hire companies. The seventh section concludes the findings.

4.2.1 Awareness

A general lack of awareness has been pointed out by nine out of ten interviewees as the main barrier to an upscale car sharing. This lack of awareness can be broken down into three types:

- consumer awareness
- business awareness
- policy-making

4.2.1.1 Consumer Awareness

Most interviewees mentioned a lack of conceptual knowledge or a misconception about car sharing and its advantages. People who are aware of car sharing often cannot describe it correctly (respondent CS9) or do not understand the concept; *"when you walk around town you see buses and you see taxis but I don't think you really notice car club vehicles. A lot of them aren't branded"* (respondent CS3).

The car sharing sector recognises an often wrongly assumption that everybody knows and understands the premise of car sharing and its advantages to society (respondent CS7). In London, this unawareness may be further enhanced by the transport authority's and the metropolitan boroughs' disincentive signage to avoid street clutter (respondent CS3). As an example, Transport for London consulted, in an unpublished survey (Transport for London 2014), non-car club members about their openness to car sharing; the data showed that a third of respondents were totally unaware and a third were aware but do not see it as being relevant to them. The last third was divided into two groups: those who have reflected upon it and believe it does not work for them and those who believe it might work for them but not right now (ibid).

The integration of car sharing into public transport (Section 4.2.5) could raise awareness, credibility and endorsement to the car sharing sector (respondent CS9) in London and worldwide, where the strength of TfL's logo is recognised (respondent CS3).

Cultural differences between the UK and other European countries, concerning car sharing, may also have an influence its uptake and upscale; UK car users are still tied to the concept of car ownership (respondent CS2), despite the UK government recognising that the sharing economy is growing (Wosskow 2014, Department for Business, Innovation and Skills 2015).

4.2.1.2 Business Awareness

The automotive industry is acknowledging that the relationship of users with cars is changing (respondent E4). *"There's a few interesting things going on with the young generation at the moment. And there are, typically, not as many learning to drive at seventeen as in the past. A lot of them are delaying it till later, and who knows whether they'll eventually even bother. I think there's a change in how people are interacting, so that having mobility of a car in past* *generations was critical to even being able to almost have a social life. And yet, so much social life now is actually done online and the car and physical presence becomes then less important*."

The automotive mass-manufacturers and car hire multinationals have been setting up, or merging with, car sharing schemes to understand such changes and expand their offer and market share (Shaheen, Cohen and Jaffee 2018). This acknowledgement can be understood under what Chesbrough (2010) describes as business model experimentation; a large business experimenting, at smaller scale, with an innovative business model. Such experimentations are useful for companies to acquire data, try new approaches, and model uncertainties and update financial projections.

Car clubs and car hire organisations are asset intensive businesses demanding large capital investment. Therefore, they need relatively large markets to become profitable. Despite such investment, business awareness of car sharing was also judged as being very low by interviewees (respondents CS4, CS6, CS7, CS8 and CS9). The lack of awareness by the businesses in general can be divided into two forms:

Internal to car sharing sector - Large car hire multinationals who have acquired car club organisations are often felt by the latter that they misunderstand car clubs, seeing them as a disruptive business model, despite acknowledging their importance as alternative mobility providers (respondents CS8). The role these car club organisations see for themselves is to raise awareness within their larger partners and to embed their business model into the multinational's own business model; influencing from inside and educating the larger partner on how the car club business model can work alongside their traditional business model (respondent CS7). There are, however, business risks to the multinationals, such as, a balance between fleet costs, (e.g. purchase, usage, depreciation and sale to second-hand market) and asset usage (Section 4.2.6.2). Investing in car sharing companies, such as car clubs, is a medium to long-term commitment and short-term cash flow concerns may surface (Ceschin and Vezzoli 2010). These conditions, could stimulate a government intervention in the form of policies, creating the background economic conditions for the dissemination of this type of business, providing information and knowledge, implementing an economic framework and enable users to accept such mobility solutions (ibid):

External to car sharing sector: Some interviewees felt that businesses and government bodies, like private car users, are unaware of, or misunderstand car sharing and how the shift towards the latter may reduce grey-fleet costs, i.e. private cars used for business travel, and uncontrolled travel allowances (respondents CS4, CS6 and CS9). The example of local authorities, Tamworth City Council (Example 1) and Salford Council (Example 2) were cases of an attitudinal change by stakeholders towards car sharing and shared mobility given by interviewees.

Example 1: Tamworth Council

Ride-share, an online platform for ride sharing, has partnered with Stagecoach, a bus operator, to provide better transport solutions in large employment sites such as Birch Coppice, an industrial estate in Tamworth. By working in partnership with the companies at the site, the partnership was able to provide transport solutions that were in line with the needs of both the recruited staff and the employers.

(respondent CS8)

Example 2: Salford Council

Salford council adopted a sustainable travel policy wherein other modes, such as walking, cycling and public transport are promoted first, with car club further down the list, eliminating excessive costs with grey-fleets and introducing the option of contracted car sharing amongst staff. By moving to automated mileage capture, through the car club, it is hoped that further business mileage cost savings will be made. Prior to agreement of such policy with the unions, Salford Council had to educate their staff in order to understand car sharing and its advantages. With this in place, the council was able to change its travel policy and to make considerable savings.

(respondent CS6)

Car sharing services are usually based in large, densely populated metropolitan areas. However, lift-sharing, which does not require captive car assets to be operative, is less capital demanding, relying on a network of users who are willing to share their cars. This network is managed through online platforms. Lift-sharing is better adapted to small communities or with users sharing the same interests where a degree of trust or similar interest exist, for example, rural communities or staff members of organisations that have engaged in lift-sharing, freeing up space on commuting roads and reducing car park demands (respondent CS8). This form of car sharing seems better suited than car clubs for daily commuters.

4.2.1.3 Policy Making

To some interviewees policy makers are unaware of car sharing and misinformed about its different modes failing to distinguish them, similarly to consumers and business (respondent CS8). The increase in environmental awareness brings to the fore the importance of car sharing. Central government and local authorities should be promoting car sharing within the context of a shift towards public and alternative modes of transport. Car sharing can be an option when other modes of transport are not available (respondent CS2 and CS7), such as local authorities introducing barriers to private cars in city centres (respondent CS9), similar to London's Congestion Charge, or cars with only one occupant.

The UK also lacks champions in this sector, such as politicians, parties, local authorities supporting car sharing as part of their political manifesto or policy. With such champions in major UK cities, the expansion of car sharing could happen at a faster rate (respondent CS2); *"we lack large scale demonstration projects, we lack political understanding, political support"* (respondent CS8).

TfL, has been a facilitator in the creation of the London Car Club Coalition (London Car Club Coalition 2015), but not a champion of car sharing. TfL is a coordinating body, a strategic road authority and does not deal directly with car sharing (respondent CS3). The fact that car sharing operators negotiate parking tariffs with 33 London metropolitan boroughs individually (respondent CS6, CS7 and CS9) exacerbates the problem. Some boroughs do not offer discounts or free parking to car clubs despite recognising their role in alleviating congestion. Councils have their own traffic and environmental strategies and policies which can change after elections are held (respondent CS3). According to some of the operators interviewed, this approach from different councils is compliant to political priorities or important revenues coming from parking permits; *"London is the bastion of car sharing in the UK, but has the most challenging government structure*" (respondent CS7).

Elsewhere in the country, many city regions and rural areas are relying on public funding to initiate or stimulate local car sharing (respondent CS4). In such cases political engagement is aligned with, and depending upon, public funding to enhance car clubs and lift-share operations. The car sharing market is still incipient, and without public funding support car sharing organisations believe there is not enough scale to run a profitable operation (respondent CS4 and CS9). The Department for Transport (DfT) is not focusing on real sustainable transport alternatives, including car-share (respondent CS2). For example, DfT allocated £100m into CATAPULT (autonomous vehicles) in 2017 and only £1.5m to help fund 23 car sharing schemes (Department for Transport and Andrew Jones MP 2016). Such lack of strong investment in alternative modes of transport, together with underinvestment in public transport, undermines the uptake and upscale of car sharing. "*[The Government] see it as the responsibility of local authorities, local governments, to promote policies that help to achieve with accuracy the targets they need to, rather than it being a national imperative to do so*" (respondent CS2). Furthermore, governmental mixed messages regarding UK major carbon targets (Daly, et al. 2015, Scott, et al. 2016) further undermines car sharing.

Manchester, for example, lags behind London and other major European cities in car sharing solutions. At the time of the interviews, the local transport authority, Transport for Greater Manchester (TfGM), was stimulating car sharing by promoting two different funding bids; electric cars replacing the current small car club stock and a single supplier framework accessible to any borough covered by TfGM. Operators must come forward with their own solutions. TfGM, to overcome similar parking issues car club operators have in London, is taking a different approach: free-floating parking permit solutions. TfGM, in agreement with the local traffic authorities, can geo-fence areas where free-floating parking permits are allowed (respondent CS4). Geofencing approach refers to geographic areas bounded by polygons. Geofencing is based on the observation that users move from one place to another and then stay at that place for a while. These places can be, for example, commercial properties, homes and office centres and so on (Namiot and Sneps-Sneppe 2013).

The differences between London and Manchester car sharing approach reflect two different realities and cultures within the UK. London, due to is population size and density, stands back from creating policies stimulating the use of car sharing, leaving the market to shape itself and grow. Conversely, Manchester is actively tendering for solutions adapted to its metropolitan area's embryonic market, working with operators to create the best possible solution. This may enable car sharing to grow and close the region's gaps in public transport. The free market approach of London, by far the largest UK market for car sharing, does not address some problems such as parking bay availability and disparate parking policies in different boroughs. Elsewhere, transport authorities could enable appropriate alternative mobility policies, reflecting the needs of their areas and social context, (e.g. rural, urban, population density and economic activities). The intended shift from private ownership to a range of mobility solutions could be accelerated by removing some car share business risks, thus, ultimately, reducing the negative impact of cars on the environment.

4.2.2 Social Barriers

Kingham, Dickinson and Copsey (2001) argue that cycling, public transport, car sharing and home working can have potential to take cars off the roads. People are aware of pollution and congestion due to excessive car use and are prepared to improve this provided there is an increase in public transport and cycling (ibid). Car sharing, arguably, may not be appropriate for all *"social categories"* (respondents CS1 and CS9). The interviewees claim that segmentation figures are consistent with the umbrella organisation surveys (ComoUK 2018, formerly Carplus) throughout the years (and the potential market for car sharing in the UK is 3m people, drawing such conclusions from those consistent social groups that have engaged with car sharing (respondent CS1). Lifestyle marketing campaigns could help raise the numbers of car sharing users rather than confronting car owners with the true cost of motoring; *"there's no point in us pretending that financial drive is the main motivation for people changing behaviour. I just think it's a myth*" (respondent CS1).

Nonetheless, some interviewees believe consumers do not fully understand the true cost of motoring, especially the cost of depreciation, and often do not take it into consideration when purchasing a car (respondent CS1, CS2, CS6 and CS9). Therefore, financial benefits may not be the most important driver in changing behaviour towards car ownership and car sharing.

Sharing rides with strangers may contradict some of the automotive expert's assertions (Section 4.2.1. Liftshare online platforms have user ratings for drivers and users (respondent CS10), similar to other online service providers such as eBay, Airbnb or Uber for their sellers, lenders, drivers and customers; *"if you match people up with something in common, then many of those trust fears disappear"* (respondent CS10).

The social barriers found in the first set of interviews (i.e. sharing cars with strangers), are partly unsupported by this second set. Car sharing companies monitor and rate their users' behaviour, and consumers do not see sharing a car with strangers as a main reason for not engaging in car sharing.

4.2.3 Shifting from Traditional Ownership to Shared Service.

There has been signs of changes in society towards the sharing economy. Consumers are becoming comfortable with collaborative consumption and resource sharing (respondent CS7). However, part of the automotive manufacturer's strategy for car sharing is to make users accustomed to their brands so that in later stages in life, when people move away from the city centre and consider the acquisition of a private car, they will prioritise that brand (respondent CS1 and CS9). This attitude from car manufacturers suggests that they are trying business model innovation (Chesbrough 2010) and that car sharing is a transitional mobility option. Nonetheless, it is acknowledged by the sector actors that car sharing is a risky business (respondent CS1, CS7, CS8 and CS9). However, car users are captive to car ownership (respondent CS6). Together with lack of awareness, ownership is one of the key barriers for users towards car sharing. *"It does not come into people's mind that car sharing and car hire are alternatives to private ownership"* (respondent CS6). According to interviewees, consumers underestimate the real cost of motoring and the impact this may have in their household budget; *"I don't think they [the consumers] understand what the total impact of car ownership actually means"* (respondent CS6). The highest cost of all, depreciation, is often underestimated and people are unaware of it because "*they don't see it disappearing from their bank accounts"* (respondent CS1). Contrastingly, a key driver towards car sharing is service cost (respondent CS2). TfL's car club survey (Transport for London 2014) shows that, in order to appeal to those who are not car club members, the service would have to be cheap, convenient - with parking bays - and hubs being based near enough people's homes for higher engagement. Parking allocation is one of the main barriers car clubs face from boroughs (Section 4.2.1.3). This is unlikely to change, unless boroughs are forced to. Also, potential users would need to see the benefits of the service, such as convenience and affordability before they switch to car sharing (respondent CS3).

There is a predetermination from consumers to own a car (respondent CS9). When faced with the dilemma of either owning a car or not, consumers seem to choose the first option; "*thinking* *about one specific use case"* (respondent CS9), for example, the annual holiday or the occasional large item transport. The cost of car depreciation distorts the true cost of motoring, contributing further to the prevalence of ownership, despite a growth in demand for shared use services (respondent CS7), reflecting, in the UK, the low engagement of people with car sharing (respondent CS6).

The average annual miles driven by car per person is 6,648 miles (Department for Transport 2015). The cost/benefit of such lower average mileage travelled may be difficult to justify. However, car sharing may not be suitable for every car driver (respondent CS1 and CS7). Nonetheless, there is a potential untapped market for whom any form of car sharing solution is viable for personal transportation at a lower cost than car ownership. The problem may be the large availability of cars, new and used, for private use (respondent CS6). Nevertheless, as explained later (Section 4.2.6), car hire, and to a less extent car sharing, are partly responsible for flooding the second-hand market with relatively new, low mileage cars, bought from automotive manufacturers, in large quantities.

Many interviewees agree that there is no coincidence about the highest proportion of car sharing users in the UK being in London, as the cost of motoring in the UK's capital is significantly higher than the rest of the country (Metz 2012). Population density, congestion charge, car parking availability and motoring overheads make car ownership expensive. However, despite London's public transport reaching most urban areas and being quite often the best option for travel needs, car sharing may serve the purpose of journeys public transport or taxis cannot fulfil.

Outside of London, car ownership has been increasing (Figure 26). The regular costs of motoring and population density are comparatively lower. In many important cities, public transport fails to reach some districts and communities (respondent CS6). For these suburban and rural communities, private cars are a necessity, as they often provide access to basic services (respondent CS7). In order to be able to make a shift towards car sharing, the offer outside London needs to be more consistent (respondent CS7). This, however, needs to be approached with a realistic alternative to car ownership, where public transport is sufficiently developed and reliable (respondent CS6), reducing the need of a car for social activities (respondent CS1). Such conditions are now happening in new housing developments in London and elsewhere in Europe (respondent CS2), creating the conditions for a car-less environment.

Nonetheless, opportunities to attract car users to car sharing, as part of a multi-modal transport system, may lie with millennials. This generation is relying on online social networks to socialise (Valentine and Powers 2013). As a largely connected generation which was brought up with computers and the internet, they are prolific users of smartphones and online apps. This may be seen as a cultural shift, coming from outside the transport domain (Sheller 2012). For example, Go-carshare and Liftshare have apps linked to social networks, such as Facebook, enabling people to book a car-share service via this platform (respondent CS2).

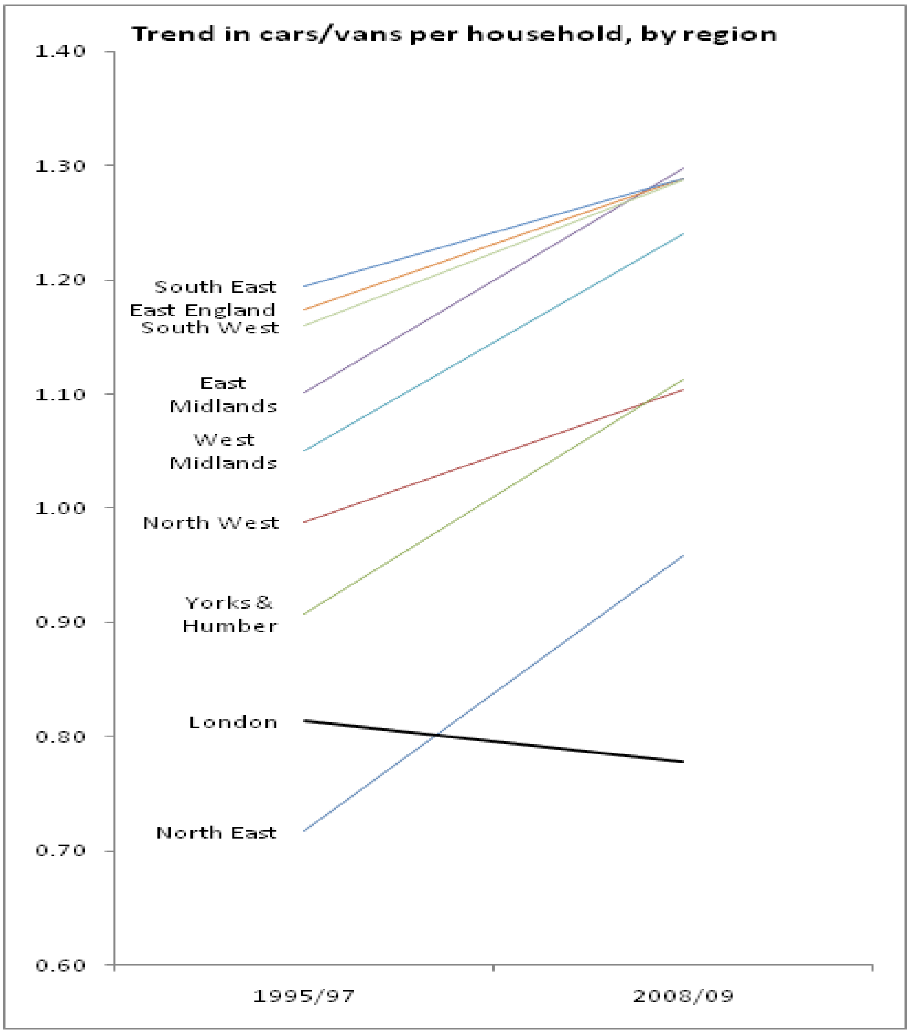


Figure 26. Car/Van per household per UK region, 1995-2009 (DfT 2012).

4.2.4 The Role of Technology

The car sharing sector acknowledges the benefits of new technologies that enable the integration of processes, (e.g. booking, billing and ticketing), or system integrators allowing real-time vehicle-infrastructure and public transport data to deliver benefits to operators and users. Technology has been an enabler of car sharing use. The introduction of telematics and smarter internet-based technologies, such as smartphones and apps, seems to have revived the sector, liberating it from the past bureaucracy and excessive paperwork (respondent CS1). Some vehicle technologies, such as autonomous cars, can raise strong opinions. *"The idea of lots of private pods going either as platoons into a town centre or zapping around to take people from here to there in a sort of the ultimate demand-response form of transport, it's just not what we want"* (respondent CS1). Government funding for this technology, rather than car sharing, may have an influence. Conversely, autonomous vehicles maybe seen as a positive, although unready, solution for A-to-B or free-floating car sharing service solutions (respondent CS9), enabling the car to find the user and reducing the distance between both.

An important opportunity is the availability of Original Equipment Manufacturers (OEM) telematics in mass-manufactured cars, reducing further the cost of installation in shared vehicles. Contrastingly, this may create a barrier: proprietary OEM technology systems leading to a car sharing operator only working with one system in order to avoid having different car sharing related tracking systems in their fleet (respondent CS6 and CS7). Furthermore, if proprietary systems are offered by car manufacturers, an intermediate service will have to be available to translate all the different proprietary code language into the car sharing service provider's information systems (respondent CS9), thus increasing service costs; *"It's a balancing act […] holding the vehicles for a long enough period that you're able to justify a telematic installation cost that may be in the region of £800 to £1,000 s per vehicle"* (respondent CS8).

There are opportunities for free-floating, fully autonomous, pooling cars. The automotive industry is currently working on self-driving technologies (Wright 2017, Morris 2017), telematics and autonomous vehicle logistics management. Such technologies need to be standardised across the industry to maintain low fleet costs for operators. User-friendly open systems, working with different manufacturers, could enable the upscale of car sharing from a technological perspective. Nevertheless, such solutions could be vulnerable to illegal hacking, hindering car sharing organisations' reputations.

4.2.5 Integration with Public Transport

Car sharing service integration, with local or national public transport, may be an incentive for service providers to upscale (Mont 2004, Loose, Mohr and Nobis 2006, Nykvist and Whitmarsh 2008, Firnkorn and Müller 2011). In the UK, car sharing operators maintain that there is a lack of integration of car sharing with local public transport, neither through franchises nor partnerships. As an example, TfL franchised transport operators are paid for the quality of service provided (respondent CS3). There is little data collected on the impact of car clubs on the public transport network, and the lack of car sharing integration with local public transport reflects that (respondent CS3). The car sharing sector perceives integration with local public transport as a strategy to increase awareness and trust from prospective users.

Multiple borough negotiation is an efficiency barrier to upscale car sharing (Section 4.2.1.3) and having operations in only one borough is not profitable. Cars must be able to cross municipal borders to attract customers and provide a seamless service. The dissimilar approaches taken by TfL and TfGM, for example, help explain why it is important to integrate transport solutions that would bring flexibility and simplicity to car sharing organisations and users. Car sharing operators feel that integration is inevitable, if hard to achieve at the moment, because of the fragmented nature of public transport in the UK. Building an integrated public transport network would be the most efficient form of linking up the different shared transport modes. *"I think it needs to happen in an iterative manner where it's more about… collaborations that leads towards an end goal."* (respondent CS7). Organisations such as the London Car Club Coalition are positioned to start collaboration, addressing for example, the problem of parking allocation and parking fees for car sharing organisations (respondent CS7).

Lifestyle choice can also be an approach to incentivise potential user engaging in car share solutions (respondent CS1), integrating, for example, a monthly public transport pass with car sharing (e.g. car club membership). It has the potential to become an added option for those already using multi-modal transport, providing an end-to-end mobility solution. Despite few examples of car sharing integration with public transport (Carplus 2015a), there is potential to stimulate users to shift away from car ownership; a broad collaborative approach between all the stakeholders is, therefore, desirable. The complex UK public transport landscape is unfavourable to integrate car sharing. The number of different operators throughout the country, and the approach taken by local transport authorities and boroughs, is inefficient and a barrier to a more comprehensive uptake and upscale of car sharing.

4.2.6 Car Sharing Cars

Car sharing is important to reduce levels of greenhouse emissions, congestion (Shaheen and Cohen 2012), and perhaps new car demand. The performance of car share vehicles, should be measured by their ability to transport as many passengers as possible from one point to another. This intensive use, as taxis do, could bring annual mileage to 20,000 miles/year or more. A shared car could quickly reach 150,000 miles (240,000 km) within 7.5 years. This would then lead to a replacement of each car with a more efficient unit without raising demand for cars, since each unit could be shared between a large number of people (Vezzoli and Manzini 2008). Furthermore, cars shared by a relatively large number of users, but with an extensive use, with less annual miles, could last, hypothetically, longer. Creating product scarcity hypothetically increases the intensity of use (ibid). However, this is not happening, especially with car hire and car club fleets, potentially undermining the positive environmental impacts of this type of service provision (4.2.6.1).

For lift-sharing, it was not possible to determine the age of cars used, since these are private cars. Lift-sharing companies do not usually establish an age or mileage limit to their member's cars as long as they are road-legal.

4.2.6.1 Car Share Fleet Acquisition and Profits

Car club cars and car hire vehicles are in service for a relatively short time-span (respondent CS5, CS7, CS8 and CS9). Despite being driven between 10,000 to 20,000 miles per year, perhaps more in the case of some hire cars (respondent CS9), these vehicles will be in service between one and two years on average and a maximum of three years for independent car clubs (respondent CS5, CS7, CS8 and CS9). The short service life is related with four main reasons:

- Contracts between car clubs and car manufacturers

- Annual mileage driven
- Annual market value depreciation
- Telematics equipment cost and financial depreciation

Car clubs negotiate directly with car manufacturers the asset service-life and how many miles will be travelled based on assumptions made by the car club (respondent CS7). In other words, the contract with the manufacturer will dictate how long a car club car will operate as such. Before the acquisitions by large car hire multinationals, independent car clubs had less leverage to negotiate prices due to operational size. Currently, the vehicles are held on a contract-hire agreement (respondent CS7). Car sharing organisations calculate the monthly costs of each fleet vehicle and try to exploit this asset to the maximum and minimise the effects of market depreciation during its service-life (respondent CS9).

Car manufacturers want to feed the used car market at different ages, different mileages and price points to try and keep a wide offer in this market (respondent CS9). They offer deals to car sharing organisations according with their forecast of the used car market. Car sharing organisations will try to negotiate with the car manufacturers according to the offer on the table (respondent CS9).

Large multinationals, buying more than 50,000 cars/year, have higher leverage to negotiate purchase prices (respondent CS6). The acquisition and disposal of cars acquired, including car club vehicles, may vary, depending upon the degree of integration with their parent companies and business model. The profits of a car club car vary between £6,000 to £10,000 per vehicle per annum (respondent (respondent CS8). This depends upon:

- Vehicle powertrain
- Vehicle maturity
- Attractiveness of the site

Car clubs and car hire purchasing strategy depends partly on the car sharing company, if independent or subsidiary, strategic objectives and car manufacturers' offers, (e.g. buyback deals). In the case of multinational car hire, and their affiliated car clubs, the parent company is constantly changing what is a buyback deal, what is on risk, how long are the buyback terms, thus influencing its car club organisation’s own purchasing (respondent CS4). With electric vehicles, for example, variable costs are low, especially during the warranty period (respondent CS8). When the breakeven point is reached, returns of around £5,000 per car per annum are considered good and margins beyond that point can reach 80% to 90% (respondent CS8). Electric vehicles asset utilisation is more uncertain. Around £5,000 revenue equates between 15-20% utilisation of the vehicle (respondent CS8).

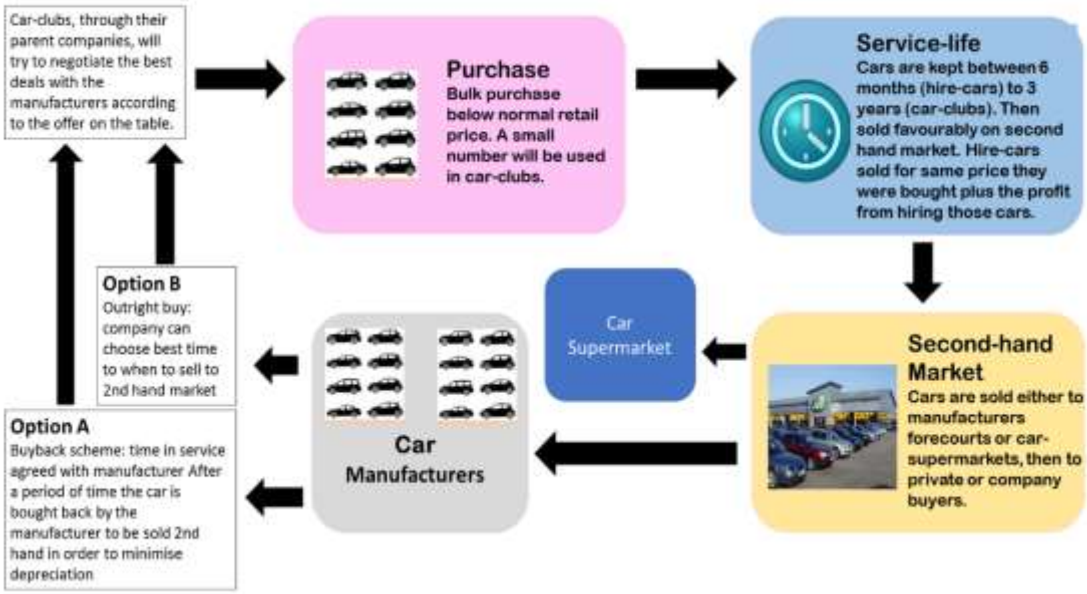


Figure 27. Purchase and service-life of a car sharing car (car club, car hire).

4.2.6.2 Car Clubs and Car Hire Fleet Age and Mileage

Research suggests that car sharing reduces the impact of car manufacturing and usage (Shaheen and Cohen 2012, e.g. Firnkorn and Müller 2011). For every car club car, around 10.5 cars are sold and removed from the street and 22 more are not purchased and the demand for a private car is reduced by a factor of 32.5 (Haywood 2016 personal communication). At a macro level, car clubs can reduce the demand for second hand cars and can, in the longer term, lead to behaviour change with fewer consumers buying and using cars (old or new) wit implications in energy and material demand in the longer-term.

The number of car club cars in the UK is quite low when compared to other European countries (Shaheen and Cohen 2012). Car sharing is not frequently used and its environmental benefits may be quite small during the car's service-life. For community car clubs and lift-sharing there is no reliable data on age and on mileage, nor the method through which these cars are acquired. The average service-life of a multinational subsidiary car club car is between 2 and 3 years (respondent CS5, CS7, CS8, and CS9). For hire-cars the average service-life is lower; between 6 and 12 months (respondent CS7 and CS8). However, these hire cars travel more than car club cars; between 27,200 km and 28,800 km (17,000 miles and 18,000 miles) annually (respondents CS9 and CS7, respectively). For car club cars the average annual mileage was calculated on the basis of information provided by Carplus' annual surveys (Carplus 2015a, Carplus 2015b, Carplus 2015c); car clubs in the UK have 156,112 members, 3,398 cars and each member travels on average 347 miles per year. In total, all members will travel 54,170,864 miles. This makes an average of 24,788 km per car per year (15,492 miles per car per year). In 3 years, the typical warranty period, this will amount to 74,400 km per car (46,500 miles per car). To be utilised to its full potential of around 240,000 km (150,000 miles) (cf. section 4.1.6), the service-life of car clubs cars would amount to around 10 years. However, the service life of car club and car hire cars is shorter than this, in contrast with some of the assumptions of intensive usage found in literature (Vezzoli and Manzini 2008, Mont 2004). Other reasons are that larger car clubs, and car hire organisations, prefer to have modern vehicles in order to attract customers, reduce maintenance costs and, in the case of car clubs and meet the umbrella organisation's accreditation (respondent CS7).

Car sharing vehicles are held generally within the manufacturer's warranty period. Thus, maintenance costs are relatively low and predictable, especially with electric vehicles (respondent CS8). Nonetheless, damage costs tend to be higher for car clubs and lower for car hire. The former, due to the variety of drivers with disparate driving experiences and more aggressive driving styles, and on-road parking, the latter because cars are only insured when on hire (respondent CS8).

Contrary to what is expected of products used intensively and shared (Vezzoli and Manzini 2008, Mont 2004), car clubs and hire cars in the UK, in general, are being used neither intensively nor extensively, especially car club cars, and their annual mileage is similar to a private car. Car sharing cars, once the purchase contract ends, are re-sold in the second-hand market (respondent CS9). By acquiring large quantities of cars, car hire organisations are contributing to high volumes of annual car production and flooding the second-hand car market with usable cars, keeping prices relatively low. Nonetheless, there is some evidence of contribution to environmental sustainability whilst in service and reduction of personal annual mileage. However, the lifecycle impact of car sharing cars may not be as important, because only a small proportion of the population currently engages in car sharing.

The acquisition of UK car clubs by car hire multinationals has led to a reduction of service time of car club cars. It has not yet reached the service-time of car hire cars, but that seems to be the goal. However, asset usage is still lower than car hire, additional equipment is required and the business risks for car hire companies are higher. This reduced service-life may decrease further once full consolidation into the car hire business is undertaken and an offer of different hire services is made to customers under one service package.

4.2.7 Conclusion (interview set 2)

Car sharing awareness is seen as generally poor by the car sharing sector and integration with public transport is key to raising awareness in the UK. Integrating car sharing service as part of a local transport offer is perceived by the car sharing sector to provide public confidence and awareness. The UK, contrary to other European countries, does not have centralised policies towards mobility or a nationalised train or bus operator that could facilitate the upscale of this service. However, the complex public transport landscape enables bespoke local solutions that meet the needs of users, businesses and local authorities.

Indeed, car clubs and ride-sharing are marginal modes of car usage, with little awareness from consumers (Sections 4.2.1.1 and 4.2.1.2) making them risky business models (Sections 4.2.3 and 4.2.6.1). Furthermore, the relatively fast rate of product replacement after a short service life is not met by an intensive use by car hire and car clubs (Section 4.2.6.2).

Car sharing may not be reaching potential users due to the complex nature of travelling patterns, local transport and particularly a lack of willingness of car users to shift, where relevant and useful, from product ownership to shared service. The role of technology as a barrier is not the main issue to this sector, nor is it to consumers who adapt with relatively ease to information technologies if beneficial to them (Venkatesh, Thong and Xu 2012). Car users perceive service cost, perhaps incorrectly, as a barrier for some forms of car sharing.

There is a contradiction between product service system principles and car sharing asset usage. The process of acquisition, service-life and disposal of cars by car sharing companies does not differ from traditional business models; the fleet is acquired at favourable rates, either outright buy, leasing or buy-back agreement. The service-life is no more than 3 years, with cars travelling low annual mileages. Car sharing incentivises the use of other mobility solutions and thus, less use of cars, but car sharing cars, particularly car club cars, are being underutilised due to a small number of users. The role of reducing the overall lifecycle impact of car use is potentially offset due to a short service-life. Depreciation costs, disparate driving patterns, emission standards and the car sharing accreditation process limit the service-life of these vehicles. At end of the service-life, but with further lifespan potential, the car is sold on the second-hand market. Likewise, hire cars, despite reaching higher, annual mileage than car club cars whilst in service, and comprising the vast majority of shared use vehicles, are typically traded-in after six to twelve months. They flood the second-hand market, further contributing to high demand for new and used cars.

4.3 Consumer Survey

This section reports on the findings of a UK wide consumer survey (*n* =1,019) conducted between December 2017 and January 2018. The survey explored user perceptions and expectations of passenger cars in general, but also norms, attitudes and behaviours of car users. It reports on how cars are typically acquired, and for how long consumers expect to keep them. It also explored if, and how consumers undertake car maintenance and repair, the reasons consumers change cars and their expectations towards this process. Another area of this survey is the perception consumers have of passenger car lifespans and the ideal lifespan of cars. The survey explores users' perceptions of alternative passenger car usage, in the form of car sharing discussed earlier (e.g. Sections 2.3, 2.5, 2.5.4, 2.5.6, 4.2.1.1) and longer lasting cars (e.g. Sections 2.3, 2.4.7, 2.5, 4.1.7).

4.3.1 Sample Composition

Respondents were selected through a set of three screening questions eliminating those who work for the automotive industry or car sharing sector and those who do not hold a full valid UK/EU driving licence or not drive frequently, (i.e. less than once per month). The survey sample taken for this survey comprised of 52% male and 48% female. Around 10% of respondents have a higher university degree (MA or PhD), 24% have a university degree (BA or BSc), 15% have A-levels, 23% have GCSEs whilst 16% have technical or vocational training, and 6% other professional qualifications, around 58% live in two people households, followed by about 27% living in single households and around 10% in three people households, with 23% situate their income between £20,000 and £29,000 followed by about 20% between £10,000 to £19,000 and around 16% between £30,000 and £39,000.

For comparison, data from DfT's driving licence database Autumn collection (Department for Transport 2017) was used as this was mostly likely to match the target population defined by this research, except driving regularity (Section 3.4.4). The sample, despite being nationally representative in gender distribution, was skewed towards the older age categories, with overrepresentation of the 55-64 and above age categories, and under-representation of all other age categories (Figure 28). Because the sample was skewed towards older age drivers, it did not reflect the actual age distribution of UK driving licence holders, limiting generalisation. A weighted sample for age, education, income and geography distribution was also considered. However, this could skew other variables such as gender distribution (Wright 1997). A population weight adjustment (Blair and Blair 2015) could have been assigned to each age category, calculated by dividing the proportion in the DfT's data by the survey sample's proportion. However, doing so could have had an 'explosive effect' on sampling error where the disparities between the DfT and the sample were large (Blair and Blair 2015). For example, the 18-24 age category is heavily underrepresented in the sample. The age distribution in this survey was the following (Figure 28):

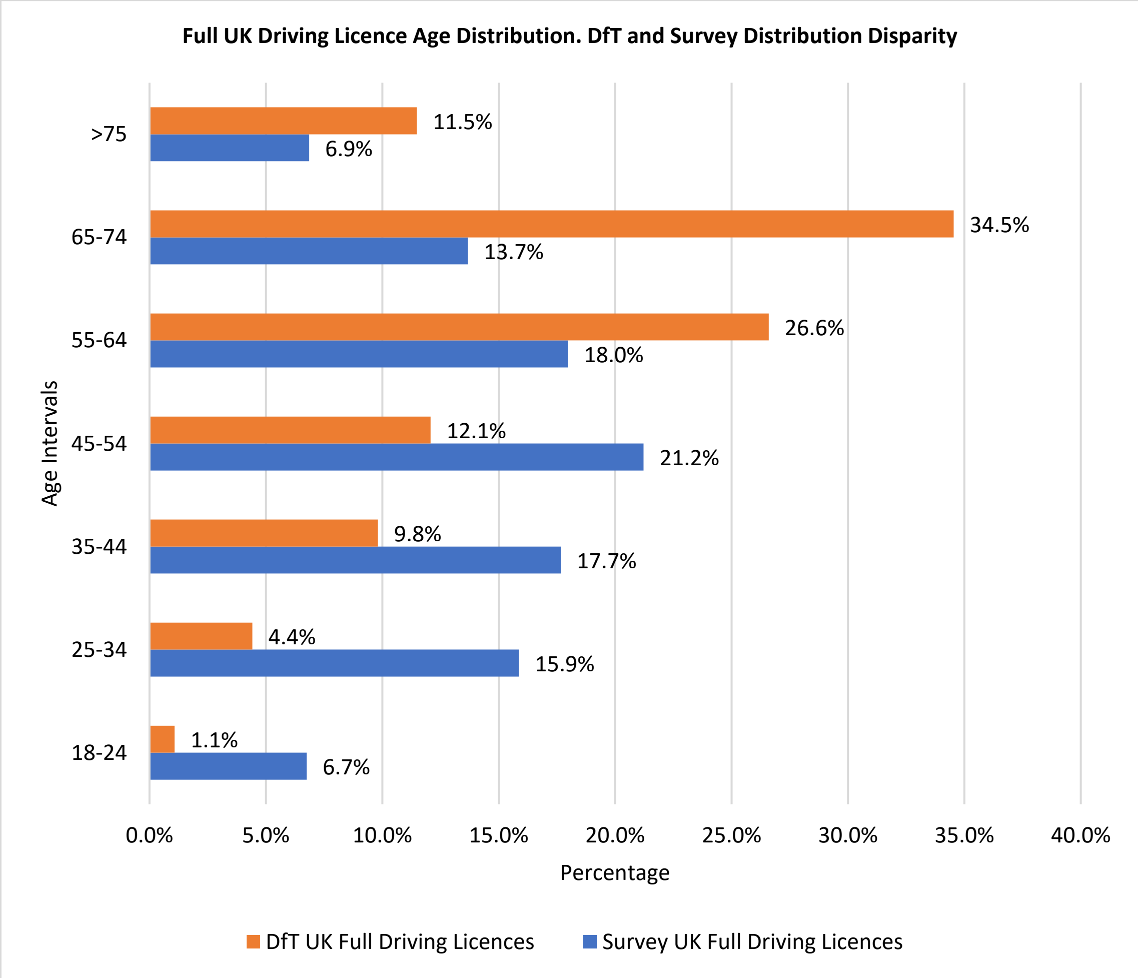


Figure 28. Survey respondents and DfT's driving licence age distribution.

The questionnaire was sent to respondents during a week day starting at 9.00 am. It is reasonable to infer that at this time of the day people in working age were at work, hence the overrepresentation of the semi-retired and retired age groups.

Limitations external to this research prevented the reduction of age skewness, although this was contemplated by extending the survey to an extra 500 respondents to reduce the age distribution imbalance, whilst at the same time, keeping the correct gender distribution (see section 3.4.4). This extension would be targeting the underrepresented age categories and would be sent at different times and days of the week (e.g. Friday 6.00 pm), to capture people in working age. However, the survey organisation used to capture the data went into administration after the sample was taken, and due to time constraints, it was not possible to arrange for another survey with a different organisation. The gender distribution of driving licence holders closely matched data from the Department for Transport (DfT 2018) and this is the category against to which the data is analysed.

4.3.2 Car Ownership

The respondents were divided into two groups, those who drive regularly (i.e.at least once per month), and have cars registered in their names (91.2%), and those who drive regularly, at least once per month, but do not own any cars (8.8%). Respondents owning at least one car (CAR 1) that is driven at least once per month were 82.4%, 7.5% have 2 cars (CAR 1, CAR 2) and only 0.7% have three or more cars (CAR1, CAR2, CAR 3) driven at least once per month. 9.3% have zero cars. The questions asked owners of three or more cars to only consider the three most used cars. The average age of all cars in this survey was 6.7 years, slightly under the reported national average of 7.8 years (Society of Motor Manufacturers and Traders 2015). A *one sample t-test* was used to compare the survey and SMMT's reported mean age reference using SPSS (Table 7). SPSS's *one sample t-test* function enables to compare a reference mean value to the data from the survey. There is a statistically significant difference (p value < 0.05) between the SMMT's reported mean and this survey's mean (Table 7). However, there is no statistical significant difference between the age of cars owned by men and women (p value > 0.05). An *independent sample t-test* would ideally have been used to compare the figures of this research's sample and the SMMT's. However, access to key data beyond their reported mean, such as sample size and variance, was not achieved.

Table 7. Average age of owned cars sampled compared with UK national average.

One-Sample Test						
	Test Value = 7.8					
C1 C2 C3 combined mean age	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
	-5.872	872	0.000	-1.05407	-1.4064	-0.7017

A large proportion of the car owners in this survey driving at least once per month in their most used car estimated low annual mileages (Appendix P). A *Wilcoxon Mann-Whitney test* was undertaken between the male and female differences in annual mileage travelled and revealed a statistically significant difference between gender and annual mileage travelled (p value < 0.05 p = 0.00) (Table 8). In the two first categories of annual mileage, < 3,000 miles per year, women are more represented than men, but from the third category onwards men are more represented (Appendix P).

Table 8. Annual mileage travelled, Wilcoxon Mann-Whitney test.

Test Statistics [a]	
	Annual mileage
Mann-Whitney U	110542.500
Wilcoxon W	227912.500
Z	-4.165
Asymp. Sig. (2-tailed)	0.000

a. Grouping Variable: Gender

The most frequent method of car purchase for 73.8% of respondents who own a car, was paying the purchase cost of the vehicle up front, followed by credit card or bank loan/personal finance at 9.3% (Appendix Q). A *chi-square test* was used to test whether there is a statistically significant difference between gender and the payment method. For some of the methods more than 20% of expected frequencies in a cross tabulation were less than 5 and the *chi-square test* couldn´t be used (cf. Section 3.7.1). A *Fisher's exact test* was, thus, used instead. Where this test was used in other questions below is also indicated. There was no statistically significant difference between payment method and gender, (Table 9) except for 'No purchase' (i.e. gift or inheritance)' (p value < 0.05).

Table 9. Car purchasing method. Chi square tests and Fisher's exact tests.

	Tests	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Paid in full up front / Cash or debit card	Pearson Chi-Square	0.131	1	0.718		
Credit card or bank loan / Personal finance	Pearson Chi-Square	1.192	1	0.275		
Hire Purchase (car is owned at end of contract)	Pearson Chi-Square	0.673	1	0.412		
Personal Contract Purchase (option to own at end of contract)	Pearson Chi-Square	1.764	1	0.184		
Leasing scheme / Personal Contract Hire (no option to own at end of contract)	Pearson Chi-Square	1.329	1	0.249		
No purchase (i.e. gift or inheritance)	Fisher's Exact Test				0.007	0.005
Other	Fisher's Exact Test				1	0.595
Cannot recall	Fisher's Exact Test				0.336	0.249

Respondents believe that the environmental impact of cars is moderately or very important 37.2% and 30.0% respectively, only 11.3% think it is extremely important (Appendix R). Undertaking a *Wilcoxon Mann-Whitney test* to assess if gender has an influence on the importance of environmental impacts, there is a statistical significance between gender response (p value < 0.05 $p = 0.01$) (Table 10), slightly more women than men considered cars' environmental impacts very important. Such belief could provide leverage to engage in more sustainable policies towards lower energy and material consumption. However, this refers back to Johansson-Stenman and Martinsson's (2006) statement about discrepancy between status and to be concerned about the environment, even though, when purchasing cars, people do not show much concern about the environment (Section 4.3.8).

Table 10. Importance of cars' environmental impact Wilcoxon Mann-Whitney U test.

Test Statistics [a]	
	Importance of environmental impacts
Mann-Whitney U	95973.500
Wilcoxon W	222729.500
Z	-2.560
Asymp. Sig. (2-tailed)	0.010

a. Grouping Variable: Gender

The *mean* age of respondents' cars when acquired, all cars combined, was 3.31 years. A *Shapiro-Wilk test* found the distribution was non-normal (p value < 0.05) and a *Levene's* test assumed equal variances between gender responses (Table 11, Table 12). An *independent samples test with bootstrapping* was used to calculate if there was a statistically significant difference between gender responses (Table 13). The most used car in the household being acquired aged 3.25 years on average. There is no statistical significant relationship between the age of cars and gender using an *independent samples test with bootstrap* (p value > 0.05). The same tests were undertaken for mileage and gender with final similar results (p value > 0.05) (Table 14, Table 15, Table 16). The *mean* mileage of all cars combined when acquired is 29,321 miles (46,913 km).

Table 11. Average age of Car 1, Car 2, Car 3 when acquired. Shapiro-Wilk test of normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig.(*p* value)
Average age of Car 1, Car 2, Car 3 when acquired	Male	0.681	488	0.000
	Female	0.589	396	0.000

Table 12. Average age of Car 1, Car 2, Car 3 when acquired. Levene's Test for equality of variance between gender responses.

		Levene's Test for Equality of Variances	
		F	Sig.(*p* value)
Average age of Car 1, Car 2, Car 3 when acquired	Equal variances assumed	1.281	0.258

Table 13. Average age of owners' cars (in years) when acquired. Bootstrap for independent samples test.

Bootstrap [a]						
Average age of Car 1, Car 2, Car 3 when acquired	Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	0.123	-0.015	0.349	0.721	-0.573	0.803

a. Unless otherwise noted, bootstrap results are based on 884 bootstrap samples

Table 14. Average mileage of Car 1, Car 2, Car 3 when acquired. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Average mileage of Car 1, Car 2, Car 3 when acquired	Male	0.367	454	0.000
	Female	0.336	319	0.000

a. Lilliefors Significance Correction

Table 15. Average mileage of Car 1, Car 2, Car 3 when acquired. Levene's Test for equality of variance between gender responses.

		Levene's Test for Equality of Variances	
		F	Sig. (*p* value)
Average mileage all cars when acquired	Equal variances assumed	0.297	0.586

Table 16. Average mileage of Car 1, Car 2, Car 3 when acquired. Bootstrap for independent samples test.

Bootstrap[a]						
Average mileage of Car 1, Car 2, Car 3 when acquired	Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	-0.494	0.106	5.777	0.922	-12.405	10.994

a. Unless otherwise noted, bootstrap results are based on 773 bootstrap samples

Respondents intend to keep their cars for 2.79 years on average and there is no statistical significance between gender and time intended to keep cars, using the *Shapiro-Wilk test* for normality, the *Levene's test for equality of variance* and a *bootstrap for independent samples test* (p value > 0.05) (Table 17, Table 18, Table 19). These results show that such a high turnover of cars per owner, long before their potential lifespan is exhausted. This result also indicates that respondents are not interested in owning a car that can be kept for two decades (Section 4.3.7).

Table 17.Intended years of ownership. Shapiro-Wilk test for normality

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
For how many years do you intend to keep your car(s)	Male	0.566	294	0.000
	Female	0.807	192	0.000

a. Lilliefors Significance Correction

Table 18. Intended years of ownership. Levene's test for equality of variances between gender responses

Levene's Test for Equality of Variances			
		F	Sig. (*p* value)
For how many years do you intend to keep your car(s)	Equal variances assumed	2.313	0.129

Table 19. Intended years of ownership. Bootstrap for independent samples test.

Bootstrap [a]						
For how many years do you intend to keep your car(s)	Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	0.38409	0.01854	0.22901	0.092	-0.01330	0.86725

a. Unless otherwise noted, bootstrap results are based on 486 bootstrap samples

The survey shows that the majority of respondents' previous cars, 56.8%, were traded for a replacement (Appendix S). There is no statistical significance (*p* value > 0.05) between outcome of previous car and gender when undertaking *chi-Square* and *Fisher´s exact tests* for each category (Table 20).

Table 20. Outcome of previous car. Pearson Chi-square and Fisher's exact tests. Gender response.

Chi-Square Tests						
Outcome of previous car		Value	df	Asymptotic Significance (2-sided) (*p* value)	Exact Sig. (2-sided) (*p* value)	Exact Sig. (1-sided)
It did not replace another car	Pearson Chi-Square	0.004	1	0.947		
Traded for a replacement (part exchange)	Pearson Chi-Square	0.839	1	0.360		
Sold directly to a dealer (e.g. webuyanycar.com)	Pearson Chi-Square	0.003	1	0.953		
Sold privately	Pearson Chi-Square	0.873	1	0.350		
SORN (Statutory Off-Road Notification) (stored off road)	Fisher's Exact Test				1	0.495
Taken to or collected by a scrapyard	Pearson Chi-Square	0.217	1	0.642		
Other (e.g. stolen, given away)	Pearson Chi-Square	0.01	1	0.921		
Do not know	Pearson Chi-Square	0.036	1	0.850		

The most common motivation respondents gave for car replacement - all cars combined - was wanting a newer car (47.1%), followed by wanting a different type of car (20.5%) (Appendix T). Reliability was third reason for replacement (16.1%). Insurance costs, fuel costs, tax and depreciation were less common motivations. Women responded proportionally more than men to six categories (Appendix T), however there is no statistical significance (*p* value > 0.05) between gender and any of the categories using *Pearson chi-square and Fisher´s exact tests* (

Table 21), except for 'Change in amount of commuting' (*p* value < 0.05, p = 0.046).

Table 21. Reasons for car replacement. Pearson Chi-square and Fisher's exact tests.

Pearson Chi-Square Tests						
		Value	df	Asymptotic Significance (2-sided) (*p* value)	Exact Sig. (2-sided) (*p* value)	Exact Sig. (1-sided)
Failed its MOT	Pearson Chi-Square	0.915	1	0.339		
Replacement parts unavailable	Fisher's Exact Test				0.737	0.505
Cost of remedying a specific fault	Pearson Chi-Square	0.059	1	0.808		
Cost of fuel	Pearson Chi-Square	0.248	1	0.619		
Cost of insurance	Pearson Chi-Square	0.039	1	0.843		
Cost of road tax (Vehicle Excise Duty)	Pearson Chi-Square	0.014	1	0.904		
End of contract (i.e. Personal Contract Plan, Leasing, etc.)	Pearson Chi-Square	3.032	1	0.082		
Appearance (i.e. dated or worn)	Pearson Chi-Square	0.048	1	0.826		
Mileage	Pearson Chi-Square	3.344	1	0.067		
Reliability (i.e. risk of fault or breakdown)	Pearson Chi-Square	1.728	1	0.189		
Change in size of household	Pearson Chi-Square	0.131	1	0.717		
Change in amount of commuting	Pearson Chi-Square	3.978	1	0.046		
Change in financial circumstances	Pearson Chi-Square	1.136	1	0.286		
Rate of depreciation	Pearson Chi-Square	0.021	1	0.884		
Wanted a newer car	Pearson Chi-Square	2.295	1	0.130		
Wanted a different type of car	Pearson Chi-Square	0.203	1	0.652		
Written off (i.e. damaged beyond repair)	Pearson Chi-Square	0.478	1	0.489		
Other	Pearson Chi-Square	0.379	1	0.538		

4.3.3 Maintenance

Maintenance and repair are important to prolong the life of a product (Section 2.4.7). Regular maintenance or service interval plans are advised by car manufacturers and independent garages. Servicing intervals are undertaken at a set number of miles or periods of time (e.g. 10,000 miles or annually). Respondents were, thus, asked which servicing methods (franchised dealer, independent garage, self-service or other) they use for each car and could chose more than one method. As some respondents have more than one car, the total number of responses, 1,042, is thus higher than the number of respondents who have at least one car (n = 926) (Table 22):

- CAR 1 had 950 multiple responses for all servicing method categories. In other words, there were 24 respondents for CAR 1 that use more than one type of servicing methods; 926 respondents use at least one servicing method (100%). Of those, 22 (4.2%) use two methods. And only 2 (0.4%) use three different servicing methods.

- There were 84 respondents with at least two cars. For CAR 2, there were 85 responses, with only one respondent using two different servicing methods.
- There were 7 respondents with three cars. CAR 3 had exactly 7 responses, therefore no multiple responses. In other words, these seven cars only use one servicing method.

Table 22. Preferred servicing methods. Observed responses.

How is each car that you own and regularly drive usually serviced? All cars combined (1042 responses from 926 respondents).		**Responses**		**Percent of**
		N	**Percent**	**Cases**
Preferred servicing methods	Franchised dealer	462	44.3%	49.9%
	Independent garage	511	49.0%	55.2%
	Service it myself	58	5.6%	6.3%
	Other	11	1.1%	1.2%
	Total	1042	100.0%	112.5%

Most respondents either use independent garages (55.2 %) or prefer franchised dealers (49.9%), all cars combined, with a small proportion servicing their main car (6.3 %) or using other methods (1.2%) (Table 22). Undertaking *Chi-square and Fisher´s exact tests* (Table 23), a statistical significant difference between male and female responses to this question was found for 'franchised dealer' and 'independent garage' (p value < 0.05, $p = 0.023$ and $p = 0.005$ respectively). Proportionally, more women than men prefer 'independent garage', but proportionally more men than women prefer 'franchised dealer' (Appendix U). There was no statistical significant difference between male and female responses for 'service it myself' and 'other' (p value > 0.05).

Table 23. Servicing methods. Pearson Chi-square and Fisher's exact test.

Service method	Tests	Value	df	Asymptotic Significance (2-sided) (*p* value)	Exact Sig. (2-sided) (*p* value)	Exact Sig. (1-sided)
Franchised dealer	Pearson Chi-Square	5.179	1	0.023		
Independent garage	Pearson Chi-Square	8.012	1	0.005		
Service it myself	Pearson Chi-Square	.991	1	0.319		
Other	Fisher's Exact Test				1	0.583

When asked about which type of maintenance tasks they undertake, the most common answer was 'minor tasks' (63.6%). The second most common answer was 'I never undertake such tasks' (30.3%) (Table 24). Respondents were asked what type of maintenance and repair they perform in their cars. The total number of responses (*n* 1,110) is higher than the number of respondents who have at least one car (*n* 926) (Table 24):

- CAR1 had 1,012 multiple responses for all servicing method categories. In other words, there are 27 respondents for CAR1 that undertake at least two different repair and maintenance task levels.
- CAR2 had five 91 multiple responses from 84 respondents who own at least two cars.
- Over a quarter of respondents affirmed that they never undertake any maintenance or repair tasks themselves. Of the 926 respondents, 22 (4.2%) use two methods. And only 2 (0.4%) use three different servicing tasks.
- There are 84 respondents with at least two cars. For CAR2, there were 85 responses with only one respondent using two different servicing tasks.
- There are 7 respondents with three cars. CAR3 had 7 responses, therefore no multiple responses. In other words, these seven cars only use one servicing task.

There is a small number of people who claim to undertake moderate and major tasks. A statistically significant difference (p value < 0.05) (Table 25) was observed between gender responses to 'moderate', 'minor' and 'I never undertake such tasks' using an *independent samples Mann-Whitney U test*. Of all women respondents, 36.7% said they never undertake maintenance tasks as opposed to 15.9% of all men respondents (Appendix V).

Table 24. Repair and maintenance tasks personally undertake by car owners.

Which repair and maintenance tasks do you personally undertake on the car(s) that you own and regularly drive? All cars combined		**Responses**		**Percent of Cases**
		N	**Percent**	
All cars maintenance tasks	Major tasks	73	6.6%	7.9%
	Moderate tasks	167	15.0%	18.0%
	Minor tasks)	589	53.1%	63.6%
	I never undertake such tasks	281	25.3%	30.3%
	Total	1110	100.0%	119.9%

Table 25. Repair and maintenance tasks personally undertake by car owners. Wilcoxon Mann-Whitney U test.

Test Statistics[a]				
	Major tasks	Moderate tasks	Minor tasks	No tasks undertaken
Mann-Whitney U	126708.000	120250.000	103441.500	100099.500
Wilcoxon W	287169.000	221275.000	204466.500	260560.500
Z	-0.173	-2.294	-5.958	-7.510
Asymp. Sig. (2-tailed) (*p* value)	0.863	0.022	0.000	0.000

a. Grouping Variable: Gender

4.3.4 User Attachment to Cars

Respondents who were very or extremely attached to their previous cars represent 40.6 % with 32.2% being moderately attached (Appendix W). A *Wilcoxon Mann-Whitney U test* found there is no statistical significance difference between gender responses (p value > 0.05) (Table 26). These results suggest respondents have only moderate to strong attachment to their previous cars. 93.3% of respondents use an independent garage or a franchised dealer. Such analysis can be compared with Nieuwenhuis (2008), who argues that an ability to maintain one's car builds emotional attachment. However, this survey indicates that there are perhaps other reasons for car attachment, since most people will undertake either minor or no maintenance tasks.

Table 26. Car attachment levels.

Test Statistics[a]	
	Car Attachment levels
Mann-Whitney U	92080.000
Wilcoxon W	206083.000
Z	-0.196
Asymp. Sig. (2-tailed) (*p* value)	0.845

a. Grouping Variable: Gender

4.3.5 Depreciation

During the second interview set, it was affirmed that consumers neglect motoring costs such as parking fees or depreciation (respondent CS1, CS2, CS6 and CS9). Depreciation, the rate at which a car loses market value through time, especially during its first three years, reaches an average of 20% per year (Section 2.4). Three questions about vehicle depreciation were asked to explore if car users understand the real cost of depreciation and residual value.

Respondents were asked to predict the average residual value of an average new car worth £16,000 after 3, 7 and 14 years respectively. The 3rd year interval was chosen as this is the benchmark in the market to calculate depreciation and it is the interval where a car loses the highest proportion of its value. The 14th year interval was chosen because this is the nearest rounded value for an average lifespan of cars in the UK (Skelton and Allwood 2013, Oguchi and Fuse 2014, Dun, Horton and Kollamthodi 2015). The 7th year is therefore half that lifespan. The responses were tested for skewed distribution (i.e. if the distribution is asymmetrical). Some degree of skewedness was found where a few respondents predicted that an average, new £16,000 car, would increase in value over time. This would raise the average value and an inaccurate *means*. For this reason, they were considered outliers as only very few collectible cars will raise their value after 3, 7 or 14 years. Another caveat is that only 240 people provided a value at year 14, raising the margin of error to 6.4%.

The UK car market values were taken from a UK independent credit broker of passenger cars (Wisercarbuyer 2017) for use as comparison between consumer expectations and actual market residual values. This broker was chosen because it was currently the only one offering a depreciation and residual value calculator for the UK car market. An average depreciation indicator from the website as used as an example. The calculator uses current car price estimates and differentiates between manufacturers' list price and actual paid price. However, for this research there was no disparity between the list price and the paid prices so that notional and actual depreciation values coincide. The prices used were taken on the 23rd February 2018.

To find and 'trim' any response outliers, the 25th and 75th percentiles were calculated using a weighted average of the values (Tukey 1977). The 75th percentile (£10,000) was then subtracted from the 25th percentile (£7,000) and a 'g' factor of 2.2 was multiplied by the result, (i.e. £3,000) (Hoaglin, Iglewicz and Tukey 1986, Hoaglin and Iglewicz 1987). The 'g' factor is dependent on *n.* For this sample size, it is recommended 2.2 (Hoaglin and Iglewicz 1987). The result, 6,600, is then added to the 75th and 25th percentiles. The outliers were, thus, calculated by adding the factor 'g' to the 75th percentile (ibid). The lower cut-off value was £400. However, the minimum value entered by respondents was £1,000. The upper value for outlier cut-off was £16,600 (Table 27). This value is above the average price as new. Neverthless, no respondents used this exact value. The next lower value indicated by a few respondents was £16,000 (no depreciation) and the next upper value was £24,000, which was then trimmed. The median value was then calculated without the upper outliers.

A mean of £8,348 was found for the value of a new £16,000 car after 3 years, which is 10.6% above the market values used for reference. A similar approach to outliers by trimming was used for the variables of 7 and 14 years (Table 28, Table 29). For these latter two variables, the cut-off values were not taken into consideration as the value of a functioning car does not drop below zero (Table 28 and Table 29). The values obtained at 7 and 14 years were -2.8% and -21.7% below the reference market value used in this study. In other words, respondents overestimate the value of a new £16,000 car after 3 years but underestimate its value after 7 and 14 years with the caveat of a 6.4% margin of error for the latter (Figure 29). Nonetheless, the upper mark of this error would be below the £2,022 market benchmark, but closer to Storchmann's (2004) estimate.

Table 27. Outliers calculation for predicted average value of a 3-year-old average ar. Adapted from Hoaglin and Iglewicz (1987).

Q1 (25th percentile)	Median	Q3 (75th percentile)	g	Lower outliers cut-off	Upper outliers cut-off
£7000		£10000	2.2	£400	£16600
Q3 - Q1	£3000				
g1	£6600				

Table 28. Outliers calculation for predicted value of a 7-year-old average car.

Q1 (25th percentile)	Median	Q3 (75th percentile)	g	Lower outliers cut-off	Upper outliers cut-off
£2000		£6000	2.2	£-6800	£14800
Q3 - Q1	£4000				
g1	£8800				

Table 29. Outliers calculation for predicted value of a 14-year-old average car.

Q1 (25th percentile)	Median	Q3 (75th percentile)	g	Lower outliers cut-off	Upper outliers cut-off
£1000		£2000	2.2	£ -1200	£4200
Q3 - Q1	£1000				
g1	£2200				

The average residual value calculated (i.e. a percentage of the original price) from responses was 52.2% (52.8% reference market value) after 3 years, 26.3% (27.0% reference market value) after 7 years and 9.9% (12.6% reference market value) after 14 years.

Undertaking *a one sample t-test* for each age variable against the 'Wisercarbuyer' references, there is a statistically significant difference (p value < 0.05, p = 0.000) between the predicted value (£8,349) and the reference value (£7,552) for a 3 year old car; there is no statistically significant difference (p value > 0.05, p = 0.151) between the predicted value of £4,203 and the reference value (£4,326) for a 7 year old average car; and there is a statistically significant difference (p value < 0.05, p = 0.000) between the predicted value of £1,584 and the reference value (£2,022) for a 14 year old average car (Table 30).

Survey respondents are optimistic about the rate of depreciation of vehicles after 3 years, but pessimistic after 14 years, with very small variation at 7 years. Storchmann (2004) suggested that after 10 years a car would be worth around 10% of its original value (Section 2.4), which would put the value at around £1,600 after 14 years, close to the means obtained from the sample and with no statistically significant difference (p value > 0.05). Women estimated higher mean values than men in all three-year categories with a statistically significant difference between gender at 7 and 14 years (p value > 0.05). Women estimated higher mean values than men in all three-year categories with a statistically significant difference between gender at 7 and 14 years (Table 31 and Figure 30), using *independent samples test with bootstrapping* with equal variances assumed. In other words, women seem to be more optimistic than men with regards to residual value. The general overestimation of residual values of nearly new cars by respondents is an indication that the costs of motoring are not completely understood.

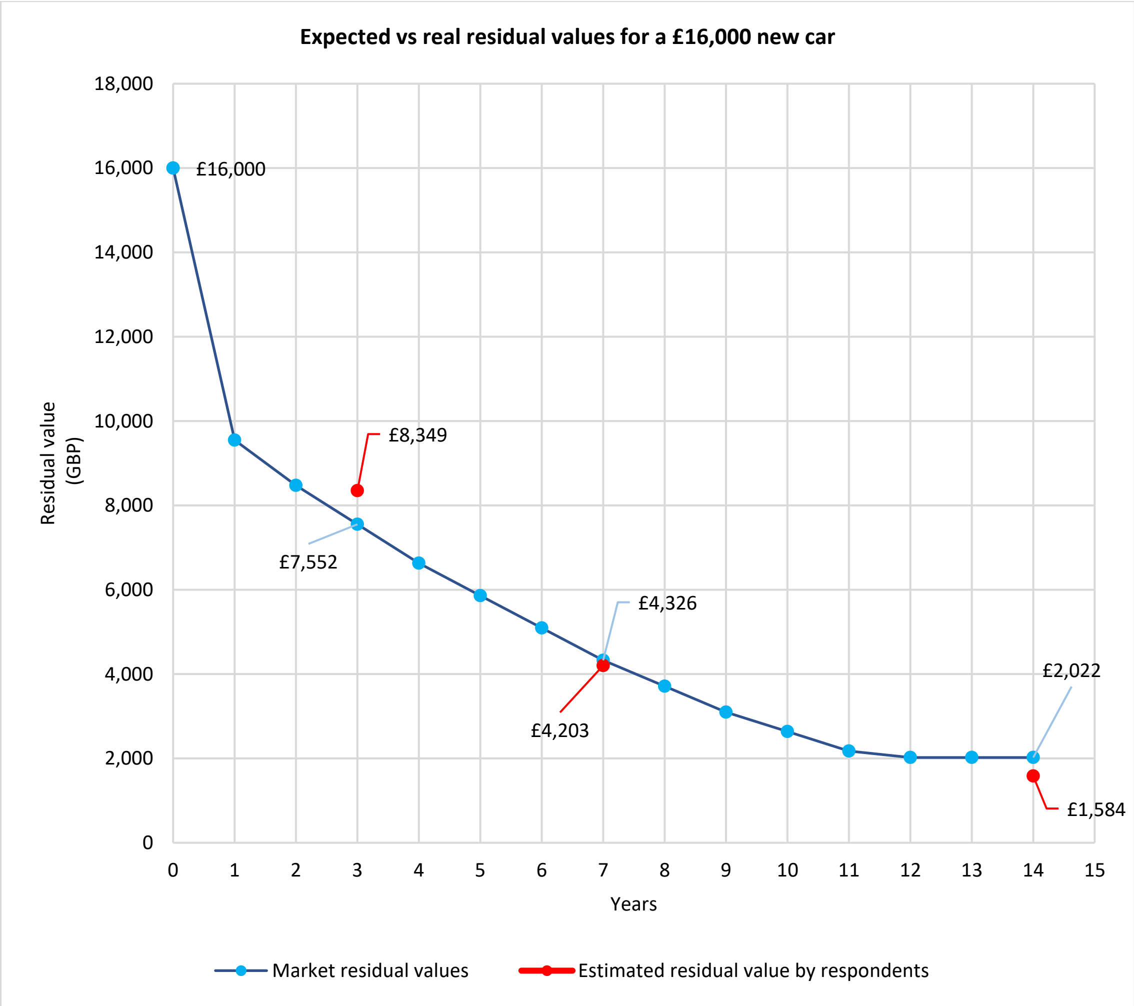


Figure 29. Expected vs. real residual values for an average £16,000 new passenger car.

Table 30. One sample t test for average estimated value versus reference value of a new £16,000 car after 3, 7 and 14 years

	Mean	Reference cost of car	Sig. (2-tailed) (*p* value)
Estimated cost of average UK car after 3 years	8349	7552	0.000
Estimated cost of average UK car after 7 years	4203	4326	0.151
Estimated cost of average UK car after 14 years	1584	2022	0.000

Table 31. Mean average value difference of a £16,000 car between gender mean response (at 3, 7 and 14 years)

Mean average value. Independent samples test with bootstrapping					
3 Years (*n* 725)		**7 Years (*n* 704)**		**14 Years (*n* 221)**	
Male	Female	Male	Female	Male	Female
8248.78	8479.37	3874.06	4628.66	1476.56	1731.18
Sig. (2-tailed) (*p* value)		Sig. (2-tailed) (*p* value)		Sig. (2-tailed) (*p* value)	
0.166		0.000		0.027	

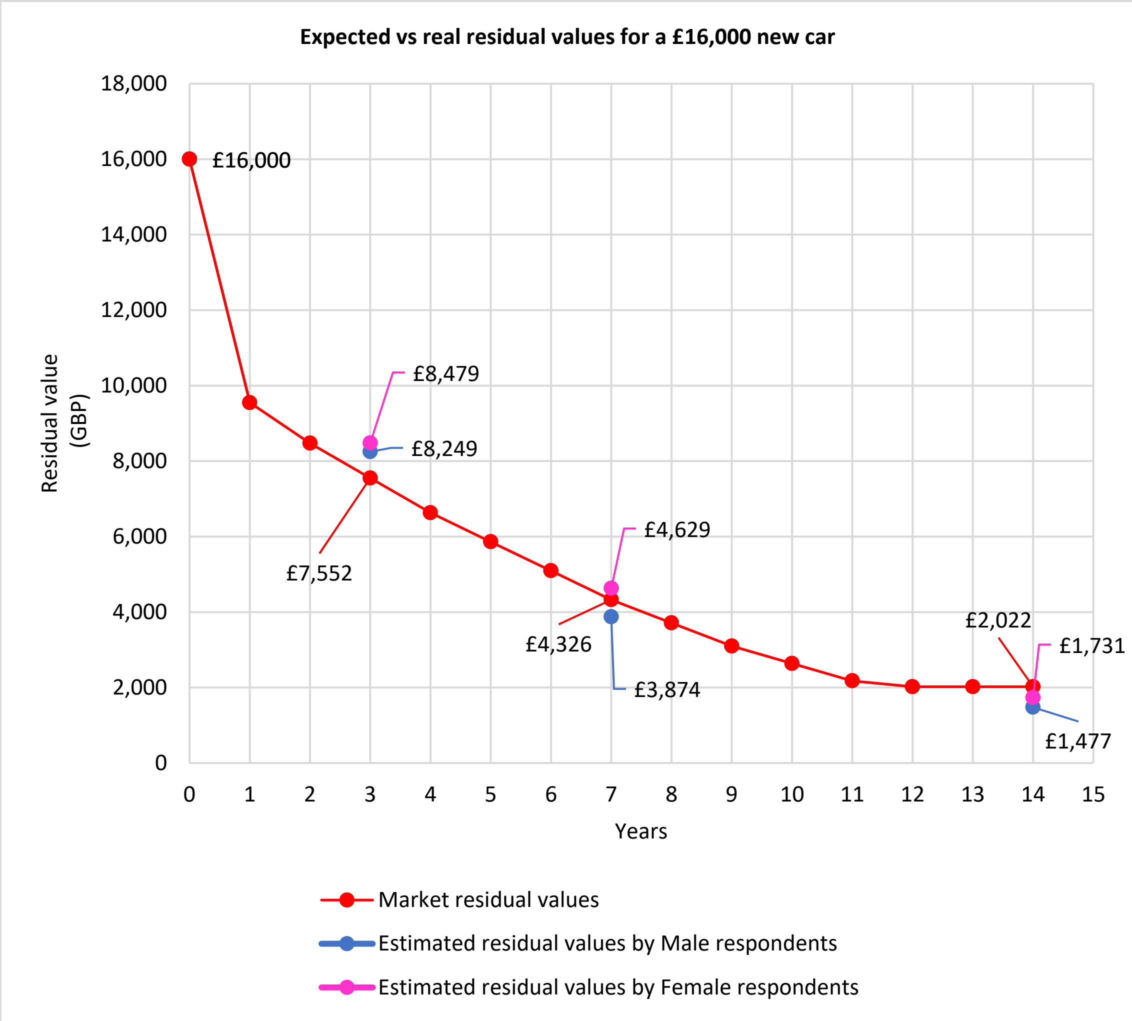


Figure 30. Expected vs residual values for a £16,000 new car by gender

4.3.6 Car Sharing

In this section of the survey respondents were asked about their awareness and usage of three modes of car sharing (Appendix X, Appendix Y): car hire, car clubs and rideshare (Sections 2.5.2 and 2.5.3). They were also asked about any reasons for not using each of the three modes and, for those who used them in the past, the reasons for not doing so anymore. The number of respondents aware of car-sharing was higher than expected but those using car clubs and ride-share were a very small number of the sample, 9 for rideshare and 18 for car clubs. Through a *Pearson chi-square test* analysis, it was found that there is no statistical significant difference (p value > 0.05) between gender responses in awareness except for car club, for which p value < 0.05 (Table 32).

Table 32. Car share awareness and gender. Pearson Chi-square tests.

Pearson Chi-Square Tests				
Car share awareness		Value	df	Asymptotic Significance (2-sided) (p value)
Traditional car hire or car rental	Pearson Chi-Square	0.513	1	0.474
Car Club	Pearson Chi-Square	7.096	1	0.008
Rideshare	Pearson Chi-Square	0.962	1	0.327
None of these	Pearson Chi-Square	0.319	1	0.572

Traditional car hire is the most commonly known and used form of car sharing. It is the oldest and most popular car sharing service available to consumers, and many of its operators are large multinationals operating large fleets worldwide. Car clubs and ride-share are less well known and used despite the recent acquisitions of larger car clubs by car hire multinationals and investment in this sector by the automotive industry. A *Pearson chi-square test* performed showed a statistical significant difference (p value < 0.05) between gender response to 'traditional car hire or car rental' and 'none of these'. The difference in use between car clubs and ride-share is small, although there was lower usage by respondents of ride-share compared to car clubs (Table 33).

Asked about car share usage, 49.7% of respondents had never used any form of car sharing. Car hire is the most commonly used (48.3%) of the three forms of car sharing; Car clubs have been used only by 2.6 % of respondents and ride-share by 1.4% (Appendix Y). This is close to what the sector sees as the market potential (~3%) size in the UK (4.2.1.1). Ride-share is still the least used form of car sharing, despite providing, potentially, an efficient use of cars. A *Pearson chi-square* test shows a statistically significant difference between gender responses (p value < 0.05, p = 0.00), with women using car clubs and ride share, or not using car share at all, more than men. However, the small number may be subject to higher margins of error and a higher proportion of respondents could reduce this.

Table 33. Pearson Chi-square test between car share use and gender.

Chi-Square Tests				
Car share use		Value	df	Asymptotic Significance (2-sided) (p value)
Traditional car hire or car rental	Pearson Chi-Square	12.251	1	0.000
Car Club	Pearson Chi-Square	0.003	1	0.958
Rideshare	Pearson Chi-Square	1.231	1	0.267
None of these	Pearson Chi-Square	10.806	1	0.001

Respondents not using car share were asked about why they are not using each of the three forms of car sharing. The main reason in all three modes of car share was because they own a car and do not need one (Appendix Z). This shows that respondents may not be considering other car use options, apart from ownership. If car ownership is excluded, “car hire usage costs” is the main reason for not using car hire (8.8%), “car clubs cars are too far from home” (5.8%) for car clubs, and “not knowing enough of rideshare” (9.5%.) for rideshare.

Chi-square and Fisher´s exact tests were used to test whether there is a statistically significant difference between gender and the reasons for not using the three car sharing methods Appendix Z). The tests show that there is statistically significant difference in gender response to car hire (p value < 0.05) for ‘usage cost’, ‘my travelling freedom was somewhat limited’ and ‘I do not like the service provider’. For car clubs there is no statistically significant difference between gender and one of the reasons for not using car clubs. For ride share there is a statistically significant difference in gender response (p value < 0.05) for ‘Public transport service is satisfactory’ only.

72.8% of respondents said that nothing would attract them to car share (Appendix AA). 14.8% of respondents said that reducing motoring cost would attract them to car sharing, followed by a reduction of environmental impacts (11.2%). The use of hybrid or electric powered vehicles would attract 7.4% of respondents. There was no statistical significance between gender response, (p value > 0.05) obtained through chi-square tests except for 'Integration with public transport' (p value < 0.05, p = 0.046) (Table 34), with 7.4% of women and 3% of men selecting this response (Table 34).

Table 34. What attracts people to car sharing. Pearson Chi Square Tests.

Chi-Square Tests				
Attractions of car sharing		Value	df	Asymptotic Significance (2-sided) (p value)
Reduction in environmental impacts	Pearson Chi-Square	0.866	1	0.352
Improved lifestyle	Pearson Chi-Square	1.465	1	0.226
Reduction in motoring costs	Pearson Chi-Square	2.164	1	0.141
Access to free parking	Pearson Chi-Square	3.154	1	0.076
Integration with public transport	Pearson Chi-Square	3.965	1	0.046
Access to a hybrid or electric car	Pearson Chi-Square	0.643	1	0.423
Nothing attracts me to car sharing	Pearson Chi-Square	2.518	1	0.113
Other	Pearson Chi-Square	0.471	1	0.493

When asked how likely that improved car sharing services would enable the sale of a car, 22.2% of responses were that it was 'very unlikely' (Appendix BB). There was no statistical significance between gender response, (p value > 0.05, p = 0.571) obtained through a *Mann-Whitney U test* (Table 35). Only 3.4% of respondents selected the 'likely' and 'very likely' responses.

Table 35. Improved car sharing services could lead respondents to sell car. Wilcoxon Mann-Whitney U test.

Test Statistics[a]	
	Improved car sharing could lead to car sale
Mann-Whitney U	18148.500
Wilcoxon W	44944.500
Z	-0.566
Asymp. Sig. (2-tailed) (p value)	0.571

a. Grouping Variable: Gender

4.3.7 Car Lifespan Expectations

Understanding consumers expectations about car lifespans was one of the aims of this research. Respondents were asked if they had ever discarded a car for scrap and, if so, what was its age. 34.3% said they had discarded a car for scrap and the average age of those scrapped cars was 13.7 years, close to the UK average lifetime of 13.5 years in 2008 obtained by (Oguchi and Fuse 2014) and 14.2 years in 2013 by (Dun, Horton and Kollamthodi 2015) and not statistically significant (Table 39). To obtain the reference value for the one sample *T*- test a *median* of the two ages found in the literature (13.5 and 14.2 years) was calculated, 13.8 years. The sample was non-normally distributed (Table 36) and equal variances were assumed (p value > 0.05) (Table 37). The average age of discarded cars for scrap owned by women was higher (14.4 years) than men's (13.2 years), however, there was no statistically significant difference between gender responses (Table 38).

Table 36. Average age of scrapped car. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Age of car	Male	0.971	149	0.003
	Female	0.959	103	0.003

a. Lilliefors Significance Correction

Table 37. Average age of scrapped car. Levene's test for equality of means.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig. (*p* value)	t	df	Sig. (2-tailed) (*p* value)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Age of car	Equal variances assumed	0.001	0.977	-1.596	250	0.112	-1.108	0.694	-2.475	0.259
	Equal variances not assumed			-1.601	221.794	0.111	-1.108	0.692	-2.471	0.256

Table 38. Average age of scrapped cars. Bootstrap for independent samples test.

		Bootstrap[a]					
		Mean Difference	Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
						Lower	Upper
Age of car	Equal variances assumed	-1.108	-0.002	0.690	0.107	-2.475	0.247

a. Unless otherwise noted, bootstrap results are based on 252 bootstrap samples

Table 39. Average age of scrapped cars one sample T-test against reference value.

Test Value = 13.8					
t	df	Sig. (2-tailed) (*p* value)	Mean Difference	95% Confidence Interval of the Difference	
				Lower	Upper
-1.468	246	0.143	-0.456	-1.07	0.16

Respondents who had scrapped their cars were satisfied or very satisfied with the car's age (67.1%) and more women than men were 'very satisfied' with the car's age (Appendix CC). Using a *Wilcoxon Mann-Whitney U* (Table 40) was found that there is a statistical significant difference between gender responses (*p* value < 0.05, *p* = 0.010). Satisfaction with product lifetime is aligned with Gnanapragasam, et al. (2018) who found, for a range of household products including cars, that UK consumers believe car longevity is extremely important.

Table 40. Satisfaction with car age. Wilcoxon Mann-Whitney U test. Gender response.

Test Statistics[a]	
	Satisfaction with car age
Mann-Whitney U	12612.500
Wilcoxon W	33522.500
Z	-2.560
Asymp. Sig. (2-tailed) (*p* value)	0.010

Respondents estimate the lifespan of cars, in the UK, from brand new until being scrapped, to have a mean of 14.4 years. This result was obtained by testing the sample for skewness and outliers. 5% of the sample were outliers which does not affect greatly the hypothesis testing (Tukey and McLaughlin 1963, Ghosh and Vogt 2012). These outliers were trimmed (Appendix DD) and an average age was obtained, 14.21 years, with the same trimming method used in Section 4.3.5. Using a *Shapiro-Wilk test of normality*, it was found that the distribution was non-normal (p value = 0.00) (Table 41). Equal variances were assumed (p value = 0.261) (Table 42) and therefore a *bootstrap* for *independent samples test with* was performed. There was no statistically significant difference between gender responses (Table 43). The perceived average lifespan is above Oguchi and Fuse (2014) (13.5 years) and Dun, Horton and Kollamthodi (2015) (14.2 years). Dun, Horton and Kollamthodi combined light duty cars in their study, which may raise the average lifespan. Nonetheless, the *one sample t-test* showed that there is a statistically significant difference (p value < 0.05, p = 0.001) between the perceived average lifespan and the *median* reference of 13.8 years (Oguchi and Fuse 2014, Dun, Horton and Kollamthodi 2015) (Table 44).

Table 41. Estimated average lifetime years of UK cars. Shapiro-Wilk test of normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (p value)
Estimated average lifetime years of UK cars	Male	0.950	416	0.000
	Female	0.949	316	0.000

Table 42. Estimated average lifetime of UK cars. Levene’s test.

Levene's Test for Equality of Variances		
Estimated average lifetime years of UK cars	F	Sig. (p value)
Equal variances assumed	1.264	0.261

Table 43. Estimated average lifetime years of UK cars. Bootstrap for independent samples test.

Bootstrap[a]						
Estimated average lifetime years of UK cars	Mean Difference	Bias	Std. Error	Sig. (2-tailed) (p value)	95% Confidence Interval	
					Lower	Upper
Equal variances assumed	-0.286	-0.020	0.332	0.402	-0.930	0.344

a. Unless otherwise noted, bootstrap results are based on 732 bootstrap samples

Table 44. Estimated UK passenger car age compared to reference value.

One-Sample Test						
	Test Value = 13.8					
	t	df	Sig. (2-tailed) (*p* value)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Estimated average lifetime years of UK cars	3.392	732	0.001	0.552	0.23	0.87

Respondents estimate the mean lifetime mileage of cars to be 204,366 km (126,987 miles), higher than the actual mean lifetime mileage of around 180,000 km (115,000 miles) used as reference for this study (Dun, Horton and Kollamthodi 2015). Oguchi and Fuse (2014) do not provide lifetime mileage in their study. A *one sample t-test* shows a statistical significant difference (p value < 0.05, p = 0.000) between perceived lifetime average mileage of UK cars and actual lifetime average mileage from the reference (Dun, Horton and Kollamthodi 2015) (Table 48). The distribution was non-normal (Table 45) and equal variances were assumed (Table 46). There was no statistical significant difference between gender responses (p value > 0.05, p = 0.230) using a *bootstrap for independent samples test*, with men estimating a slightly higher mileage (207,374 km ~ 128,856 miles) than women (197,747 km ~ 124,117 miles) (Table 48Table 46).

Table 45. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Estimated average lifetime mileage of UK cars	Male	0.952	390	0.000
	Female	0.952	248	0.000

a. Lilliefors Significance Correction

Table 46. Estimated average lifetime years of UK cars. Levene's test for equality of variances and t-test for equality of means.

		Levene's Test for Equality of Variances	
		F	Sig. (*p* value)
Estimated average lifetime mileage of UK cars	Equal variances assumed	0.445	0.505

Table 47. Estimated average lifetime mileage of UK cars. Bootstrap for independent samples test.

Bootstrap[a]							
		Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
						Lower	Upper
Estimated average lifetime mileage of UK cars	Equal variances assumed	4739.475	129.084	3970.234	0.230	-3362.934	12345.937

a. Unless otherwise noted, bootstrap results are based on 639 bootstrap samples

Table 48. Estimated UK passenger average car mileage compared to reference value.

One-Sample T Test						
	Test Value = 115000					
	t	df	Sig. (2-tailed) (*p* value)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Estimated average lifetime mileage of UK cars	6.262	638	0.000	11987.480	8228.61	15746.35

Respondents were invited to indicate the ideal lifespan of a UK car, which was an average of 16.8 years. To obtain this *mean*, the same trimming process used in section 4.3.5 was used. However, the response box for this question enabled up to three digits. There were a few number of respondents who opted to provide lifespans above 100 years (Appendix FF). This would raise the average ideal lifespan to 18.9 years without trimming. Using a *one sample t-test* with a reference *median* of 13.8 years, there is a statistical significant difference (*p* value < 0.05, $p = 0.000$) between the reference value and the obtained mean of 16.8 years (Table 52). The same normality, variance and one sample tests were undertaken as for above (Table 49

Table 50, Table 51). An *independent samples t-test* shows there is no statistical significant difference between male (16.8) and female (16.9) respondents (*p* value > 0.05, $p = 0.787$) (

Table 50). Nevertheless, the results show that overall respondents believe that the average car lifetime should increase.

Table 49. Ideal average lifetime years of UK cars. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Ideal average lifetime years of UK cars	Male	0.950	392	0.000
	Female	0.944	282	0.000

a. Lilliefors Significance Correction

Table 50. Ideal average lifetime years of UK cars. Levene's test.

Levene's Test for Equality of Variances		
Ideal average lifetime years of UK cars	F	Sig. (*p* value)
Equal variances assumed	0.245	0.621

Table 51. Ideal UK car lifespan years. Bootstrap for independent samples test.

		Bootstrap[a]					
		Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
						Lower	Upper
Ideal UK car age	Equal variances assumed	-0.104	0.021	0.413	0.787	-0.924	0.748

a. Unless otherwise noted, bootstrap results are based on 675 bootstrap samples

Table 52. Ideal average lifetime years of UK cars compared to reference value.

One-Sample Test						
	Test Value = 13.8					
Ideal average lifetime years of UK cars	t	df	Sig. (2-tailed) (*p* value)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
	14.540	674	0.000	3.041	2.63	3.45

Respondents indicated that an ideal mean lifetime mileage would be of 272,354 km (169,233 miles). The procedure to obtain this average mileage value was through a detection and trimming process (Section 4.3.5). The calculation of the upper and lower quartile outliers gave a 420,000 miles upper cut-off point. The lower cut-off point, -120,000 miles, was increased to zero because no response below zero was possible (Appendix GG). 30 outliers were identified, slightly below 5% of the sample. The *mean* value for the ideal lifespan mileage was found to be 259,548 km (162,218 miles). This is much higher than the actual average lifetime mileage of around 180,000 km (115,000 miles) found in 2013 for cars and vans and used as reference for this study (Dun, Horton and Kollamthodi 2015). A *Shapiro-Wilk test* for normality was undertaken and the result was a non-normal distribution (Table 53). The *Levene's test* showed equality of variance between gender responses (Table 54). Performing a *bootstrap independent samples test* no statistical significance between genders was found (Table 55), with men providing a slightly higher mileage (265,203 km ~ 165,752 miles) than women (250,854 km ~ 156,784 miles) (Table 56).

Table 53. Ideal average lifetime mileage of UK cars. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Ideal average lifetime mileage of UK cars	Male	0.955	375	0.000
	Female	0.962	237	0.000

a. Lilliefors Significance Correction

Table 54. Ideal average lifetime mileage of UK cars. Levene's test.

Levene's Test for Equality of Variances			
		F	Sig. (*p* value)
Ideal average lifetime mileage of UK cars	Equal variances assumed	3.263	0.071

Table 55. Ideal average lifetime mileage of UK cars. Bootstrap for independent samples test.

		Bootstrap[a]					
		Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	95% Confidence Interval	
						Lower	Upper
Ideal average lifetime mileage of UK cars	Equal variances assumed	8967.190	-282.080	5720.635	0.117	-3548.758	19099.221

a. Unless otherwise noted, bootstrap results are based on 612 bootstrap samples

Table 56. Ideal average lifetime mileage of UK cars compared to reference value.

One-Sample Test						
	Test Value = 115000					
	t	df	Sig. (2-tailed) (*p* value)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Ideal average lifetime mileage of UK cars	17.142	612	0.000	47218.597	41808.98	52628.22

When informed during the survey that the actual average lifespan of UK passenger cars is 13.8 years, there was a division of opinion (Figure 31). 42% of respondents believed the average lifespan should be higher than 13.8 years and 46.1% believed it is about right. A *Wilcoxon Mann-Whitney U test* was undertaken and it was found that there is no statistical significant difference (*p* value > 0.05, *p* = 0.964) between gender responses (Table 57).

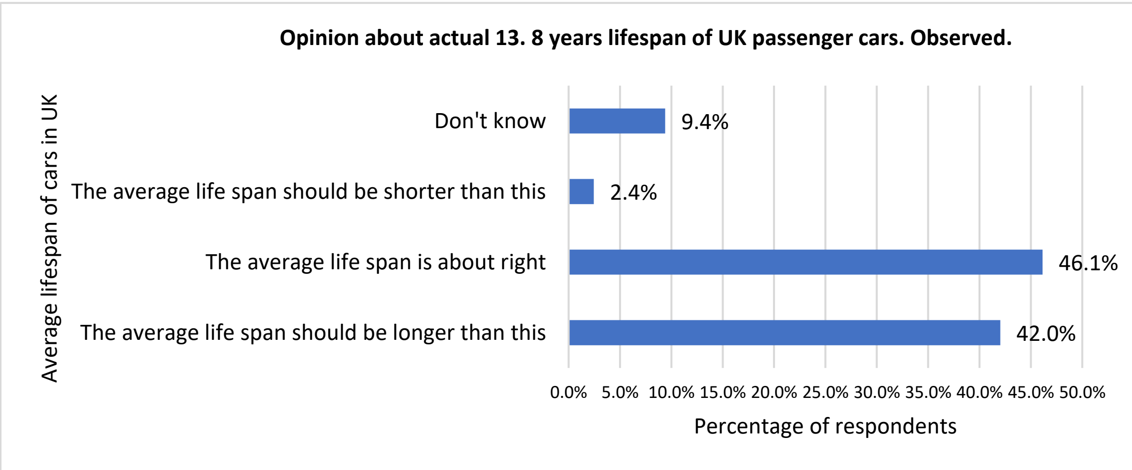


Figure 31. Respondent opinion about 13.8 years UK passenger car lifespan.

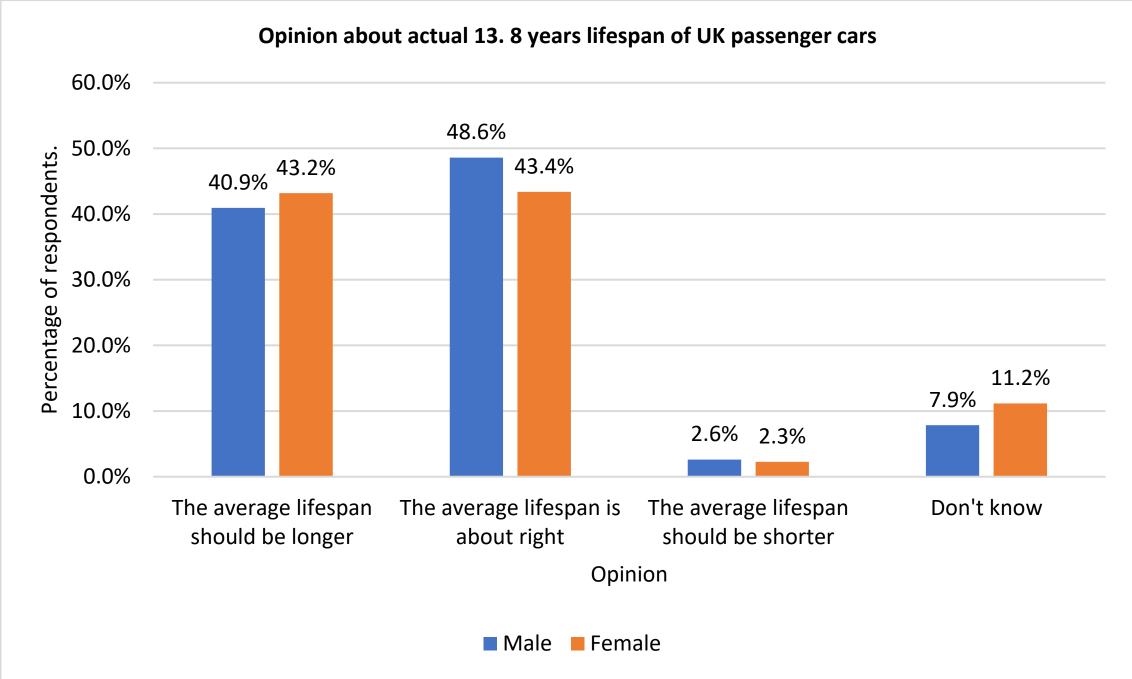


Figure 32. Respondent opinion about 13.8 years UK passenger car lifespan.

Table 57. Respondent's opinion about 13.8 years UK passenger car lifespan. Wilcoxon Mann-Whitney U test.

	Average UK car age adequate
Mann-Whitney U	129277.500
Wilcoxon W	246647.500
Z	-0.045
Asymp. Sig. (2-tailed) (*p* value)	0.964

Respondents were invited to indicate if a car lifespan label would be appealing. 32.5% said a lifespan label would be moderately appealing and 30.7% thought this would be very or extremely appealing (Appendix II). A *Wilcoxon Mann-Whitney U test* was undertaken and it was found that there is no statistically significant difference (p value > 0.05) between gender responses (Table 58). The result suggest that automotive manufacturers should be engaging in lifespan labelling of their products, to better inform consumers and help them make more informed decisions before purchase.

Table 58. Appeal of lifespan label in new cars. Wilcoxon Mann-Whitney U rank correlation test.

	Appeal of lifespan label in new passenger cars
Mann-Whitney U	101521.500
Wilcoxon W	194186.500
Z	-1.263
Asymp. Sig. (2-tailed) (*p* value)	0.206

Respondents were asked how much they would be prepared to pay for a 15-year lifetime warranty if purchasing a £16,000 passenger car. The detection and trimming process found 6% outliers. It is not advisable to cut more than 5% of the sample (Tukey and McLaughlin, 1963, Hoaglin, Iglewicz and Tukey 1986, Hoaglin and Iglewicz 1987). The calculation for the lower and upper quartile outliers gave a result of £7,400 cut-off point (Table 59). In other words, 22 outliers were identified. It was decided to cut at the 18th outlier (5% of the sample) to keep in line with Tukey and associates' recommendation. This raised the cut-off point to £15,000. Nevertheless, the distribution was still skewed to the right, although less pronounced. The mean value obtained after trimming was £1,817 for a 15-year lifetime warranty. Normality, variance and independent samples tests were undertaken (Table 60, Table 61). The distribution was non-normal with equal variances assumed. A *bootstrap for independent samples test* was undertaken and there is no statistical significant difference between gender responses (*p* value > 0.05) (Table 62). However, women indicated a lower sum, for a 15-year lifetime warranty (£1,749), than men (£2,039).

Table 59. Lifespan warranty cost. Trimming outliers

Q1	**Median**	**Q3**	**g**	**outliers cut-off point**	
				Lower threshold	**Upper threshold**
£1000		£3000	2.2	£-3400	£7400
Q3 - Q1	£2000				
g1	£4400				

Table 60. Lifespan warranty cost. Shapiro-Wilk test for normality.

Gender		Shapiro-Wilk		
		Statistic	df	Sig. (*p* value)
Warranty cost	Male	0.813	207	0.000
	Female	0.847	136	0.000

a. Lilliefors Significance Correction

Table 61. Lifespan warranty cost. Levene's test.

Levene's Test for Equality of Variances	F	Sig. (*p* value)
Equal variances assumed	0.293	0.588

Table 62. Lifespan warranty cost. Botstrap for independent samples test.

	Bootstrap[a]					
					95% Confidence Interval	
Warranty cost	Mean Difference	Bias	Std. Error	Sig. (2-tailed) (*p* value)	Lower	Upper
Equal variances assumed	289.811	-4.495	181.810	0.111	-59.522	670.583

a. Unless otherwise noted, bootstrap results are based on 360 bootstrap samples

A passenger car's value, in general, is dependent on both its age and mileage, the main determinants for its longevity (Cooper 2010). Mileage will provide some indication of wear and tear, although this can vary from car to car, and age will be indicative of how long the car has been around since first registration. Respondents estimated that cars last longer than the actual average lifespan and also believed cars should last longer, and that average lifespan mileage should also be higher. The majority of respondents had never scrapped a car 65.7% and usually had trade in their cars before their end-of-life. The reasons for changing cars are mainly because want a newer or a different car (Appendix T) with reliability issues in third.

4.3.8 Purchasing Criteria

Purchasing goods, such as cars, involves several stages such as awareness, knowledge, liking, preference, conviction and purchase (Kotler and Keller 2009). Purchasing involves reflecting upon a number of general marketing and functional criteria such as brand, perceived or actual reliability and quality, price or performance (ibid). Information about these criteria can be found in consumer magazines, brochures, or in showrooms. The survey asked respondents to classify general purchasing criteria by order of importance using a Likert scale, from ‘not important at all’ to ‘extremely important’. ‘Environmental impact’ was seen as ‘moderately important’ by 29.6% of respondents (Appendix JJ). Only in two categories was gender response difference statistically significant (p value < 0.05) (Appendix HH) ’features’ and ‘environmental impact’, after undertaking a *Wilcoxon Mann-Whitney U test*.

When asked to identify three most important purchasing criteria for a new car that would last longer than others (Figure 33) price was classified as the most important criteria (18.4%) for manufacturers reputation (16.5%) and length of warranty (16.3%). A *Pearson chi-square test* performed shows there are statistical significant differences between gender response ($p < 0.05$) in several criteria: ‘manufacturer's reputation’, ‘how it feels during a test drive’, ‘quality of the interior components’, ‘advice from friends, family or colleagues’ and ‘user reviews’ (Table 63).

When asked to identify three most important purchasing criteria for a used car that would last longer than others (Figure 34) price was once more classified as the most important criteria (18.4%) of respondents followed by mileage (13.0%) and length of warranty (12.9%). A Pearson chi-square test performed shows there is a statistical significant difference between gender response ($p < 0.05$) in only one criteria, ‘manufacturer's reputation’ (Table 64).

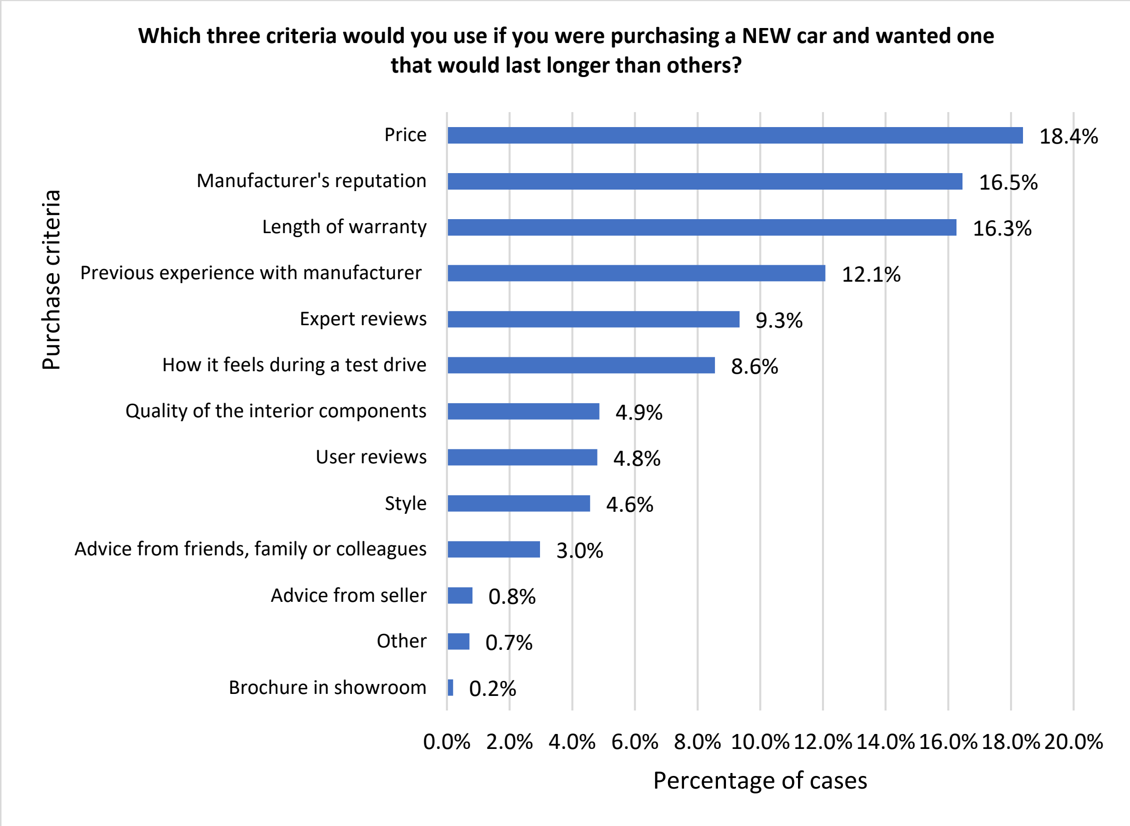


Figure 33. Criteria for purchasing 'New' longer lasting car.

Table 63. New car purchase criteria. Chi square and Fisher's exact tests.

Chi-Square Tests						
		Value	df	Asymptotic Significance (2-sided) (*p* value)	Exact Sig. (2-sided) (*p* value)	Exact Sig. (1-sided)
Manufacturer's reputation	Pearson Chi-Square	6.243	1	0.012		
Price	Pearson Chi-Square	0.904	1	0.341		
Length of warranty	Pearson Chi-Square	0.332	1	0.565		
Style	Pearson Chi-Square	0.296	1	0.586		
How it feels during a test drive	Pearson Chi-Square	4.366	1	0.037		
Quality of the interior components	Pearson Chi-Square	22.592	1	0.000		
Advice from friends, family or colleagues	Pearson Chi-Square	4.626	1	0.031		
Advice from seller	Pearson Chi-Square	0.208	1	0.648		
Previous experience with manufacturer	Pearson Chi-Square	1.3	1	0.254		
Expert reviews	Pearson Chi-Square	2.011	1	0.156		
User reviews	Pearson Chi-Square	5.536	1	0.019		
Brochure in showroom	Fisher's Exact Test				0.108	0.087
Other	Pearson Chi-Square	0.391	1	0.532		

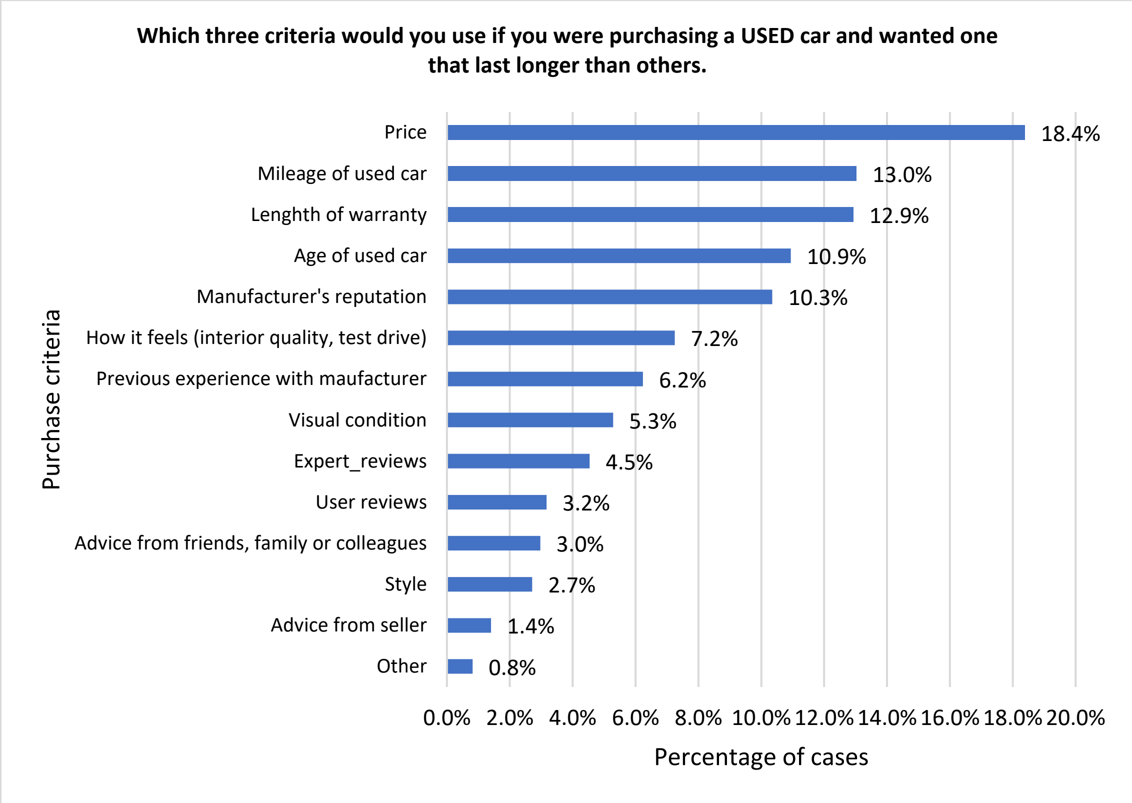


Figure 34. Criteria for purchasing 'Used' longer lasting car.

Table 64. Criteria for purchase used longer lasting car. Gender proportion Pearson chi square tests.

Chi-Square Tests

		Value	df	Asymptotic Significance (2-sided) (*p* value)
Manufacturer's reputation	Pearson Chi-Square	7.426	1	0.006
Price	Pearson Chi-Square	0.005	1	0.946
Length of warranty	Pearson Chi-Square	1.957	1	0.162
Style	Pearson Chi-Square	0.873	1	0.350
How it feels (interior quality, test drive)	Pearson Chi-Square	0.007	1	0.933
Advice from friends, family or colleagues	Pearson Chi-Square	2.927	1	0.087
Advice from seller	Pearson Chi-Square	1.906	1	0.167
Previous experience with manufacturer	Pearson Chi-Square	1.019	1	0.313
Expert reviews	Pearson Chi-Square	0	1	0.997
User reviews	Pearson Chi-Square	0.17	1	0.680
Age of used car	Pearson Chi-Square	0.022	1	0.881
Mileage of used car	Pearson Chi-Square	0.502	1	0.478
Visual condition	Pearson Chi-Square	0.026	1	0.871
Other	Pearson Chi-Square	0.003	1	0.959

4.3.9 Survey Conclusions

The descriptive statistical analysis used for this survey revealed a number of social barriers but also opportunities for longer lasting cars and car sharing. It also brought to light norms, attitudes and behaviours of car users, their degree of awareness of car sharing and motoring costs.

4.3.9.1 Social barriers and opportunities for longer lasting cars

The survey enquired mileage travelled to understand how intensively or extensively car users drive. Despite driving relatively low annual mileages on average, buying cars regularly, intending to keep them for relatively short periods of time and moving on to a newer one, can be seen as a habit that 'took over' consumers (Section 4.3.2). Cars are sold or exchanged for another car, continuously stimulating a consumerist demand and feeding the linear economy cycle and maintaining the car regime. The environmental impact of cars is declared - on the surface - important to users, especially women. Nevertheless, environmental concern comes lower as a criterion when purchasing a car, despite fuel efficiency be seen as extremely important, possibly due to its cost. Contrastingly, important features to car longevity, such as reliability and durability, were classified as 'extremely important', and warranty 'very important' (Section 4.3.8). Reliability was also pointed as the third reason for changing car, after the more hedonistic 'wanted a different car' and 'wanted a newer car'.

It was found that nearly half the respondents - women more than men - use independent or franchised garages to maintain their cars (Section 4.3.3). Such behaviour would predict a low attachment to their cars, but on the other hand may stimulate smaller local businesses. Car users seldom perform major or moderate repair tasks themselves. A higher proportion of those, not performing any task at all, are women (Section 4.3.3). Despite keeping a car for a relatively short time on average, cars are known to be bought for several reasons beyond their transport utility. There is some form or another of car attachment with a gender proportion balance (Section 4.3.4) contradicting some anecdotes about men being more attached to cars than women.

Respondents were generally optimistic about the actual average lifespan and mileage of UK passenger cars, but not by much (Section 4.3.7). Women, more than men, estimated the average car lifespan to be longer than the reference, but men, more than women, estimated the average lifespan mileage to be higher (Section 4.3.7) than the reference, although, gender wise, none of those two estimates were statistically significant. Respondents would like cars to last longer and run higher mileages, despite exchanging them frequently. The ideal average lifespan, age and mileage, of a UK car was significantly longer (16.84 years) and higher (169,233 miles) than the actual average (Section 4.3.7). Male respondents provided higher ideal lifespan average mileage than women. There is, thus potential support to increase the lifespan of cars, reducing their energy and demand.

4.3.9.2 Car Sharing awareness and social barriers

Contrary to what the car sharing sector described, more than three quarters of respondents were aware of car-sharing (Sections 4.2.1.1 and 4.3.6) and more than half have used it (Section 4.4.6). However, the vast majority of those used car hire, with both car clubs and ride share use being marginal (Section 4.4.6), confirming the assertions made by the car sharing sector (4.2.1.1). Those using car hire may have done it, hypothetically, as a temporary measure rather than a lifestyle choice. One of the aims of this survey was to understand how car sharing was known and used by different age ranges. However, the skewedness of age distribution did not enable this research to understand if younger drivers are more or less aware of car share than older drivers. Ownership seems to obfuscate the other reasons for not engaging in car share. Nonetheless, these partially support the affirmation that financial drive is not the main motivation for not using car share (Section 4.2.2). If we exclude the default car ownership, user cost was rated the highest reason for not using car hire, but it was not for car clubs. Distance of car club cars from home and knowledge about the service were rated higher. Knowledge about the service and travel limitations were rated higher for ride share (Section 4.3.6). With the variable 'Why are you not using ride sharing?', the category 'I do not wish to share a car with someone else (or with strangers)' was included and only 4.8% of respondents opted for this response. This contrasts with the affirmation in (Section 4.2.1) where it was affirmed that people do not wish to share their cars with strangers.

Finally, respondents do not consider exchanging their cars for car sharing, and nothing would attract them to this type of service (Section 4.3.6), despite advances in car sharing and vehicle technology. One of the variables included in this question was 'Integration with public transport (links with bus/ train/ tram services)' as this was strongly seen by the car sharing sector (4.3.5) as a scheme that could raise awareness, was ranked seventh out of eight variables.

4.3.9.3 Consumer awareness of true costs of motoring

One of the highest costs of motoring is depreciation, especial for cars under 10 years. The *mean* age of respondents' cars circulating was 6.7 years, nearly coinciding with the average 'half-life' of cars in the UK (7 years). Notably, when asking about the value of depreciation at 7 years, respondents were closer to the market benchmark than at 3 and 14 years (Section 4.3.5). Another interesting finding is the average age of car acquired being just over 3 years - and 29,321 miles - when the rate of depreciation starts to slow down, despite respondents overestimating by over 10% the value at this year point. This confirms in part the assertions made in section 4.3.2 that consumers may not understand the total cost of motoring and the implications this may have in their budgets. Furthermore, this bring back full circle the initial social barriers for longer lasting cars. The positive feedback loop of buying-using-dispose-buying may have consequences in impoverishing people in lower income brackets of society, who in turn, may not have other options, such as public transport, or bike infrastructures. In other cases, acquired habits through positive emotions may 'dominate' decisions to keep buying cars. In some cases, this consumerist approach may provide a false sense of status and safety, as demands to maintain the expenses of a car constantly being exchanged, supporting the cost of depreciation, insurance, fuel, road tax, maintenance and parking may play an important role in impoverishing and strapping people in a constant loop. To meet this aim three objectives were devised.

5 DISCUSSION AND CONCLUSION

This chapter revisits the aims and objectives (Section 5.1) and how they were met: first by drawing conclusions with a discussion on design for car longevity and car users' expectations. Second, a reflection upon how an intensification of car share use could be attained. Third, a consideration upon consumer behaviour through the lens of Theory of Interpersonal Behaviour (TIB). Fourth, ideate upon cultural change, triggered by nudge, leading to a car regime transition and change. And finally, proposing policy options for optimised lifespans of passenger cars. The chapter ends by identifying limitations to the research, the main contributions to knowledge and recommendations for further research.

5.1 Revisiting the Aims and Objectives

The aim of this research was to develop behavioural change policy options devised to achieve car users' sustainable behaviours towards the purchase, use and disposal of cars, thus reducing energy demand at the user stage, and at the same time influence car manufacturers to address changes in design, manufacturing and their overall business models, envisaging the reduction of energy and materials used to produce cars. This in turn would enable a faster transition to a more sustainable, and less dominant, car regime.

The first step to satisfy the objectives was to enquire in the automotive industry about two concepts, longer lasting cars and use-intensive cars (Section 4.1 and 4.1.8). The thematic analysis described the barriers and opportunities for designing a longer lasting car using design for longevity approaches, and the opportunities for use-intensive cars. It put to designers' consideration which of the two concepts would be more feasible and the barriers and opportunities for both. The longer lasting option was seen more sceptically than the use-intensive one. The latter has more systemic implications than the former.

The second step focused upon the social and technological systemic barriers and opportunities for car sharing (Section 4.2). An exploratory interview set was devised using concepts and ideas from literature on car sharing and product service-systems together with some of the findings from the first set. The thematic analysis approach revealed a series of findings that were used for the third step.

The third step, a consumer survey, was built upon the findings from both studies and the literature on sustainable behaviour. Through statistical analysis it was possible to understand respondents' approaches to car purchase, use and disposal, their awareness and use of car sharing, and their beliefs about car longevity (Section 4.3).

The results from the three studies are discussed in the sections below (Sections 5.2.1 to 5.2.5). They include car longevity design and consumer expectations, promotion and intensification of car share, the role of lifecycle assessments and finally how cultural theory and theory of interpersonal behaviour help explain and devise nudge policy options that may ultimately lead to a change in behaviour influencing the necessary regime transition towards more sustainable forms of production and consumption of passenger cars. This section ends with a discussion of the limitations to the study (Section 5.3), contributions to knowledge (Section 5.3) and recommendations for future research (Section 5.5).

5.2 Discussion

5.2.1 Design Barriers and Expectations towards Passenger Car Longevity

Designing a car for an increased lifespan poses several, often conflicting, challenges both technical and social. The current socio-technical car regime, and its continuity, underpinned by mass-production and the *Budd* system (Section 2.2) presents many barriers intended for sustainability and has been contributing to the slow evolution of passenger cars. Deep-rooted ‘car consumerism’ may also contribute to limit acceptance of changes towards car longevity. And finally, physical and process constraints may be in conflict with one another. However, some strategies the automotive industry adopts for cost and competitive advantage reasons, such as design for repair, could be recognised as sustainable strategies.

Design for repair, in the automotive industry, is driven by labour, insurance and material cost reduction. These factors lead to reduced energy and material use. In some cases, this may lead to a competitive advantage over rival manufacturers. This strategy is already included in the design specifications but depends upon the priorities of the manufacturer (Section 4.1.7). It is later in a vehicle’s life, when depreciation has eroded the car value, that compromises in reparability emerge and may dictate the exchange of the car or its complete disposal. Labour, material and energy are included in the design specification for maintenance and repair, however, the environmental costs of car replacement versus repairing are not. These costs need to be understood. The environmental cost of repairing versus buying a new(er) car could be added to the design specification, either through manufacturer’s voluntary decision or government policy together with lifespan labelling. By having this information available, consumers could then make a more informed choice regarding car purchase and disposal.

Design for product attachment may be challenging to achieve in terms of styling, but not impossible, if there is enough commitment from manufacturers, car designers and marketeers (Section 4.1.2). Car designers suggested that one of the strategies could be the use of a blander but timeless style that, nonetheless, would enable a deeper personalisation, matching the owner's personality (Govers and Mugge 2004) and updatability. Consumers could then, as has been proposed by Chapman (2010), create a more sophisticated and intense relationship with their cars. Survey consumers say they have some form of attachment to their cars (Section 4.3.4), nevertheless, their attitude towards keeping cars for relatively short periods of time (Section 4.3.2), and exchange them for indulgent reasons (ibid), provides yet another argument to regime stagnation. The relationship with ageing materials has, equally, potential to be explored but may be of interest only to a niche of the market. However, for car engineers, such timeless and personalised style would face technological and legal barriers regarding obsolescence. With the limitations of upgradability and modularity, it would be challenging to design a car that could accommodate changes in technology and safety during a, for example, twenty-year lifespan. The other greater challenge would be to persuade consumers to keep such cars for very long periods of time. A longer warranty seems to be appealing to only a third of owners who, in turn, are prepared to pay around £1,800 for a 15-year warranty (Section 4.3.7). Likewise, around one third find a lifespan label very or extremely appealing and another third only moderately appealing (ibid) perhaps reflecting the uninterest of people for longer lasting cars, despite acknowledging that the lifespan of cars should be longer than at present. These results are similar to those of researchers at Brook Lyndhurst (2011) who found that consumers do not rate durability as important when buying household products but are interested in how long a product lasts.

Car maintenance is mostly performed by franchised dealers or independent garages, with women preferring the latter. Very few people do maintain their cars themselves, and those who do only perform minor tasks confirming the trend in low repair (Nieuwenhuis 2008). It is, thus, challenging to affirm that nowadays car attachment is related to repair and maintenance. There is a conflict between what owners say is their car attachment and the short vehicle ownership periods. The survey results imply that people may get quickly uninterested in their cars and ownership turnover may be very high. However, this research did not explore any direct causality between maintenance and attachment or attachment and ownership. Such disinterest for cars after a short period of time could be explored by service system operators of car sharing who can, and are accredited to, offer newer vehicles frequently.

Design for disassembly (DfD) strategies are being used by car manufacturers and are driven mainly by insurance costs related to repair of damaged components. Assembly times are also important as shorter times reduce the energy and labour hours to produce a vehicle. ‘Decontenting’ of cars, the simplification of the product - by stripping the car of superfluous complexities, has been in use since the beginning of this century {{1230 Freyssenet, Michel 2000}}, despite weight increase since the 1970s for each new model generation {{826 Danilecki,Krzysztof 2017}}, which seems to be reversing lately. However, the industry uses these strategies to increase the volume of units produced. The industry acknowledges that DfD optimises a car for its EoL and therefore its components remanufacturing (Section 4.1.5) but in reality, many component assemblies are irreversible due to material or energy cost reduction as suggested by Pandremenos, et al. (2009). Despite this being an industry with many standardised components, mainly ‘endogenous’, an effort would be necessary to standardise more ‘exogenous’ components that could be re-used in vehicles of different multinational brands. Modularity could facilitate such standards, but would create complexity during assembly stage, potential reliability and comfort issues, added material for joining parts reinforcement and potential rebound effects for longevity.

Design for longevity, without throughput reduction, as a strategy for passenger cars, may be paradoxical with sustainable design. Increasing durability and robustness beyond necessity may also have negative effects during the user stage (Section 4.1.6), which is responsible for 80% of primary energy consumption (Section 1.3.2). The adverse effects of material increase could lead to higher energy costs such as fuel and an overall increase in engine power to enable a minimum performance, larger cooling systems, dimensionally superior brakes to stop larger masses and CO_2 emissions.

However, there was no unanimous opinion among the car industry interviewees about durability. Some experts maintain that increasing structural reinforcements may also increase overall fuel derived emissions and resource consumption, whilst others believe that current car structures are durable enough (Section 4.1.6). Nonetheless, longevity, if applied, would have to be another feature in the design specification similar to Allwood and Cullen’s (2012) proposed changes in design to reduce material usage whilst maintaining the same performance or moving away from steel as a production material to reduce weight and de-power vehicles ({{1231 Cousins,S.H. 2007}}. Another example, better corrosion treatments could increase durability further (Section 4.1.6), but, speculatively, at an environmental cost, for example, the increased use of volatile organic compounds currently used in structural corrosion protection.

The application of modularity as proposed by van Nes (2010) or Vezzoli and Manzini (2008) is very challenging to apply in passenger cars. Structural modularisation, and consequently variability, where cars could change shape and function throughout their lifespan, was perceived by the car industry interviewees as another main barrier, both costly and technically (Section 4.1.1 and 4.1.6). Despite modularity being an important design approach towards longevity (Section 2.4.4), passenger car structure integrity, due to physical forces cars are subject to whilst in use (e.g. torsion, tension or friction), may decrease with modularity leading to early material fatigue, reduced structural integrity and therefore longevity (Section 4.1.4). Not all products are able to be designed to be modular and cars, under the current automotive paradigm, could be placed in such category. Material demand could also increase due to different construction methods required to accommodate interchangeability or upgradability and the reinforcement of contact points (Section 4.1.4). Mechanical joining is labour and maintenance intensive and not optimised for comfort, as opposed to, for example, spot welding, which is optimised for comfort and light-weighting and does not require maintenance.

Despite testing cars for integrity, safety and durability (Section 2.4.6), sometimes due to consumer pressure (Nader 2011 [1965]) and by legislation (e.g. Whole Vehicle Type Approval), each manufacturer will have disparate longevity targets before their models are launched in the market (Section 4.1.6) just like there are different safety targets for cars (e.g. EuroNcap results). A standard for mileage longevity testing has not yet been devised by the automotive industry, consumer groups and policy makers. It is not clear to consumers how much and how intensive car testing is and how much impact it has on overall car longevity. With the high rates of car exchange and the attitudes of consumers to short term car ownership (Section 4.3.2), but high expectations for car longevity (Section 4.3.7), those test results could be made public to inform, for example, second-hand car buyers of expected longevity for a potential purchase.

More than half of respondent car owners drive less than 6,000 miles per year (Section 4.3.2). Such low annual mileage may not justify a short ownership span, especially for newer cars. It can be argued that such mileage should stimulate car owners to extend, if not the lifespan, the ownership of their cars. This, if in tandem with lifespan extension, could, in principle, reduce the demand for newer cars, thus energy and material use. Another area explored was the understanding of depreciation by consumers (Section 4.3.5). Although, there were no major discrepancies in residual value perception, consumers tend to overestimate the value of three-year-old cars. But, perhaps more interestingly, they undervalue 14-year-old cars. This perception may be crucial when deciding to prolong, or not, the lifespan of their cars for another year with implications in emissions as Kagawa, et al. (2013) found. The argument that older cars pollute more has already been refuted in Japan when taking into account manufacturing emissions and other energy demanding activities around manufacturing and sales of cars (Kagawa et, al. 2006, Kagawa et, al. 2011, Kagawa et. al 2013). Production volume reduction could, in principle, contribute to a greater reduction of manufacturing emissions, which, according to Danilecki, Mrozik and Smurawski (2017), are difficult to reduce even when using less energy intensive materials in car manufacturing.

Car longevity has been slowly increasing since the 1960s (Packard 1960, Fuhrmann 1979, Nieuwenhuis 1994, Oguchi and Fuse 2014), due to technological developments, such as manufacturing process efficiency and component testing (Sections 2.4.6 and 4.1.6), corrosion protection (Section 4.1.6) and structural safety (Section 4.1.4), thus increasing their potential lifespan. Nonetheless, and despite unexplored causes for national differences in car longevity (Oguchi, Fuse 2014), test transparency from car manufacturers could enable consumers to acknowledge passenger car potential longevity. The different strategies that enhance longevity in other household products may not be applicable to cars due to their different nature and usage (Section 2.4.1 to 2.4.7). Cars are indeed a 'special' category of household product. Their design and usage demand materials and testing processes that have to be more durable and rigorous respectively (Section 4.1.6). They are far more complex than a washing machine or a fridge and with higher impacts. And yet they may be as ubiquitous as those latter two products but more demanding in the extraction of raw materials and use of energy (Section 1.3).

The automotive industry envisages the reduction of material and energy mainly because of financial rather than environmental costs (Sections 4.1.5 and 4.1.7). Yet every gain in efficiency is arguably channelled to increase production throughput (Section 2.1). The 'incumbent regime' is solidly stabilised through gains in efficiency, despite apparent cracks that are emerging such as fringe automotive manufacturers with innovative designs or service systems that attempt to change the ownership and usage of cars (e.g. Wells 2010, Geels, et al. 2012). Although there are physical limitations to more sustainable approaches to design using, for example, modularity, this can be partially used in some components to facilitate disassembly and remanufacturing (Section 4.1.4). Design for disassembly is desirable, however, facilitating such strategy, through the increase of component modularity, could lead to adverse impacts in component longevity, assembly times or reliability (Section 4.1.4). Longevity by design may be difficult to attain but knowing the potential lifespan of a car is possible and, arguably, desirable. Consumers do not wish to own their cars for long periods of time but expect them to last longer than they do (Sections 4.3.2, 4.3.7). The regime is based upon the sale of a mass manufactured products relying upon very tight processes that are expensive to disrupt (e.g. Wells 2010), yet it is essential to reverse such unsustainable form of production. It seems that for every design or business solution proposed, a rebound effect of equal proportions negates that same innovation (Section 4.1). These opposed and neutralising 'forces' help to reinforce the regime, nonetheless during its design and manufacturing stages, but also by its consumers who cannot see beyond the default ownership proposition (Section 4.3.6), perhaps because it is convenient (Section 2.5.6) or because there are no realistic alternatives of transportation available (Section 4.2.3).

Despite the need to effectively reduce energy and materials from the production and usage of passenger cars, society seems to be entrenched in traditional car ownership. The sampled majority in the survey buy their cars outright and keeps them for a relatively short period of time (Section 4.3.2). Respondents are divided between those who believe an average lifespan of 13.8 years is reasonable for a car to last, but there was also 42% of the sample who believed cars should last longer (Section 4.3.7).

Car longevity perceptions and expectations, for survey respondents, are above the current UK lifespan average (Section 4.3.7), suggesting that there is openness for longer lasting cars. Increasing passenger car lifespan can have positive environmental impacts (Kagawa, et al. 2011, Kagawa, et al. 2013), such as a reduction of CO_{2eq} emissions from manufacturing and use. The acceptance of longer lifespans and changes in consumer attitudes and behaviour towards the car as a status symbol (Section 2.5) could reduce material and energy usage.

Survey respondents are divided into those who believe the current average passenger car lifespan in the UK is adequate and those who think it should be longer (Section 4.3.7), despite the higher expectations towards average lifespans. Nonetheless, a majority would be ‘moderately’ or ‘extremely interested’ in lifespan labelling in new cars (Section 4.3.7). This interest in lifespan labelling could potentially be interpreted as an openness to claim transparent and public environmental lifecycle impact analysis (Section 4.3.7) to support policies for passenger car longevity instead of, or in tandem with, tailpipe emissions. For example, given that price is the most important factor when buying a new or used car, such policies could either increase the price through lifecycle impact taxation stimulating consumers to reflect upon the impact they produce when using a car or road tax penalties for the use of a car. The UK, and other EU countries, example of taxing cars based upon their tailpipe emissions had a positive effect in reducing the number of cars sold with higher CO_2 emissions ((Ryan, Ferreira and Convery 2009) and this could be extended to lifecycle impact expressed in CO_{2eq}. The environmental and financial costs of replacing a car, earlier than its optimal lifespan should be made more transparent. The environmental benefits of repairing versus replacing a car earlier than its optimal lifespan should be clearly presented to consumers (Sections 4.1.1. and 4.1.7), taking the example of historical consumer demand for safer cars (Nader 2011 [1965]). Pressing the automotive industry to label the optimal lifespan of a car could bring benefits in reducing emissions from vehicles and from manufacturing, in the short to medium term, and increasing transparency to consumers.

Policies toward lifecycle impacts could potentially change business and consumer behaviour in respect to consumption and ownership. These policies could also have an effect in delaying cars from scrappage, encouraging repair later in the car’s life and creating a consciousness among consumers of the impact their car has throughout its lifecycle. There are clear benefits in prolonging the use of cars (Danilecki, Mrozik and Smurawski 2017, Kagawa, et al. 2011, Kagawa, et al. 2013). Passenger car LCAs are calculated through the annual mileage travelled and the average age of cars (Danilecki, Mrozik and Smurawski 2017). For example, car sharing can be beneficial in optimising passenger car’s service-life, but this needs an intensification of car use or a longer service-life.

5.2.2 Intensifying Use through Car Sharing

Currently, the rules for ‘full accreditation’ by car sharing umbrella organisations support the use of car club vehicles under four years of age since first registration “to protect the image of car clubs as an alternative to private ownership” (Carplus 2017 p 6). However, ‘basic accreditation’, used by small community car sharing schemes, enables cars up to 8 years old. Car sharing companies need to have appropriate incentives to change behaviour towards an optimised asset service-life if they wish to make a positive impact, such as tax rebates from government, and different car-sharing accreditation rules, with mileage included, from the sector's umbrella organisations to support optimal lifespans.

One of the reasons the automotive industry is not yet seriously investing in car sharing may be related to the risks involved in this business (Sections 4.2.1.2, 4.2.1.3, 4.2.3). The concept of time-shared cars (i.e. car club and car hire) was favoured by the automotive industry experts who feel sceptical of ride-share due to the element of sharing with a stranger (Section 4.1.9). However, of all the reasons highlighted by survey respondents for not using ride-share, only a few said they did not wish to share a car with someone (Section 4.3.6).

The automotive industry is nowadays at critical crossroads (section 4.1.9). Technically, the development of electric and fuel-cell powertrains together with autonomous vehicle technologies may change some of the established principles of car design, especially concerning interior layouts and 'packaging' (Section 4.1.9), providing more design freedom. Socially, if the sharing economy gains significant momentum, the definition of a car as a personal transportation product may change if car sharing services become more widespread. However, that momentum may take some time.

There is an imbalance between car share awareness and use, especially car clubs and ride share (Section 4.3.6). The sharing of cars is still far from being accomplished and it does not seem to be developing at the same pace as, for example, powertrain technology. This imbalance may hinder the prospect of socio-technical transitions in mobility (Geels, et al. 2012) and new car technology will continue to assist the individual consumer-owner. Most car users believe and behave themselves as owners and the vast majority cannot foresee car use beyond that premise. As such, they do not feel attracted, and nothing would attract them, to car share (Section 4.3.6). The prospect of reducing motoring costs was seen as attractive towards car share but it was far less favoured (Section 4.3.6). Technology may not be the most important factor for any transition towards car sharing, neither lifestyle improvement as claimed in section 4.2.2, nor integration with public transport significant as claimed by interviewees in section 4.2.5. None of these hypothetical improvements in car sharing could lead to disposing of cars in favour of using car sharing services (Section 4.3.6 and Appendix AA).

The automotive industry has recognised that autonomous technologies may have an effect on car design: vehicle guidance, vehicle interfaces, vehicle interior layout and logistics complexity (Section 4.1.9). Contrastingly, the car sharing sector seems to be divided. On one hand, government investment has preferred autonomous technology instead of public transport and shared use mobility (Section 4.2.1.3), and the concept of private 'autonomous pods' transporting people in a demand-response transportation market was not highly regarded by some in the car sharing sector (Section 4.2.4). On the other hand, free-floating car-sharing companies perceive this technology as beneficial enabling the car to find the user (Section 4.2.4). Nevertheless, autonomous vehicle technology, in isolation, may not be well received by consumers, perhaps because the dominant car cultures (Miller 2001, Sheller 2012, Wells and Xenias 2015) perceive the car as an object of ownership and status built to be driven by humans. It is, therefore, easier for the automotive industry to target this technological potential to the private consumer, who is not engaging in car share anyway, as a form of market differentiation. Risking applying such innovations in the car sharing sector, which the industry does not yet totally understand and where there is a low uptake by consumers, may not bring the desired return on investment.

Designing purposely built car-share vehicles is not a barrier in itself, (e.g. Autolib in Paris) (Section 4.1.9). Nevertheless, the potential of new technologies enabling a higher degree of design freedom, such as electric powertrains and autonomous vehicles, together with the systemic barriers found in car sharing, may prove more difficult to surpass. More intensive use could bring benefits that consumers are not yet aware of, such as motoring costs for low annual mileage drivers, the majority of survey respondents (Section 4.3.2). The current low annual mileage of shared cars may not be positively impactful enough to reduce car sharing vehicles overall lifecycle impact, contrasting with the overoptimistic assumptions made by Skelton and Allwood (2013) about car sharing vehicles' annual mileage. However, the behavioural shift from private ownership towards car sharing and public transport use needs to be nurtured, to break away from today's dominant car culture (e.g. Sheller 2012, Xenias and Wells 2015). This behavioural shift needs to be met by a general increase in public transport, bicycle infrastructure, together with car sharing provision and further restrictions to private car use.

Such a transition should be ever changing and adapting to consumers' needs. When public transport does not reach rural areas, perhaps community car sharing could better satisfy the needs of those communities (Lucas, Pangbourne 2012), instead of relying on a car that is seldom used and has a significant cost that may not be recouped. Integrating car sharing with public transport could change the definition of public and private car (Sections 4.1.9 and 4.2.5), but also allegedly raise awareness of car sharing amongst potential users (Section 4.2.5) despite their disinterest (Section 4.3.6).

The dominance of private car ownership found in this research confirms Wells and Xenias (2015) argument that there is both a functional dependency and cultural factors of car users and that any form of transition to more sustainable forms of auto mobility will have to concern both. This goes beyond Schot and Geels (2008) and Geels, et al. (2012) assertion that technological and social interrelated change is needed. However, it is aligned with Bergman's (2017) argument that we are as yet far from the intended 'visions' of sustainable mobility and car sharing, suggesting that a more distinctive understanding of behaviour is needed to strengthen the value of those visions.

5.2.3 Car User Behaviour and Theory of Interpersonal Behaviour

This research suggests that car user behaviour is unlikely to change from the current pattern of purchasing, a relatively short period of usage and then buying a newer passenger car (Section 4.3.2). This pattern responds to stimulus to exchanging cars "just because I want something newer or different" and, in the case of car sharing, to be within demands of accreditation and low consumer demand (Section 4.2.6.2), and to the 'flooding' of cars in the market, relatively low prices and attractive financial contracts, both new and second-hand ((e.g. Wells 2008). Government policies, compelling manufacturers to release to the public domain the lifecycle impact and longevity of each car model, together with nudge messages could contribute to limit this pattern.

Despite survey respondents suggesting the environmental impacts of cars they own is relatively important (Section 4.3.2), when asked about general purchasing criteria for a car, such impacts become secondary (Section 4.3.8). For Triandis (1977), one way to reduce the difference between beliefs and attitudes, or cognitive dissonance, is to make the former consistent with the latter. Dissonance, nonetheless, causes discomfort (Triandis 1977) and it can be seen as another crack in the incumbent car regime that could be exploited through disclosure and optimal lifespan policies. Car users may not be totally aware of the social and environmental impacts of their consumption behaviour (e.g. Murphy and Cohen 2001) or believe the alternatives are not good enough, (e.g. lack of good public transport) despite apparent concerns with cars' poor environmental credentials. Vested interests in infrastructure, sunk investments in manufacturing plants and in people, social embeddedness of the car, beliefs and socio-cultural values, attitudes and behaviours are still strong towards car ownership and usage (Sections 4.2.3, 4.3.2, 4.3.4 and 4.3.8), thus reinforcing the regime prevalence, may hinder a quicker transition (Geels 2012). A stronger message regarding the true impact of cars throughout their lifespan needs to be passed to society, as was for smokers in the past to act strongly upon behaviour.

The symbolic role of the car, and of those who defend it (Section 4.1), as a cultural and status reference in a developed society, is slowly starting to change (Sections 4.2.1.1 and 4.2.1.2). However, in the UK, this change has been timid and mainly limited to large metropolitan areas where the negative effects of population density - and consequently the number of cars - and pollution, force policymakers to restrict car usage (e.g. London Congestion Charge or parking restrictions) (Metz 2013). However, people also tend to change behaviour if they admire or respect the character of those with who they interact with, the role-model (Triandis 1977). For example, the role between father and son, or between a respected celebrity and its audience. If, the information about the true costs or the environmental impacts of motoring (Sections 4.3.5 and 4.3.2) were conveyed through a respected role-model, raising awareness of alternatives to car ownership which consumers may not envisage (Sections 4.2.3 and 4.3.6), it is more likely that people - or at least role-model followers - would start changing their attitudes and intentions (Amos, Holmes and Strutton 2008). The role of the car as a status-symbol could diminish once its whole lifecycle impacts were known and alternatives are supported by role-models.

Regimes are often governed by standards and norms (e.g. Geels 2010). However, existing 'cracks' in the regime, such as urban density and its consequences, car restraining measures, such as tolls, restrictions to parking, car mobility decline, awareness of environmental limits and a more critical attitude to cars from policy makers (Geels 2012) could be exploited to accelerate a transition towards normative change. Disclosing information on lifecycle impact and costs could be explored, for example through car longevity narratives by role-models, which may have consumer support (Section 4.3.7). This could trigger a change in consumers towards optimised passenger car lifespans or moving away from ownership. Any future measure increasing the real cost of motoring could potentially be more accepted and invert the notion that financial drive is not a motivation towards behavioural change (Section 4.2.2).

The self-concept is the perception someone has of themselves (Section 2.7). However, this research found cognitive dissonance between some drivers thinking they care about the environment (Section 4.3.2) and purchasing behaviour that is harmful to that same environment (Sections 4.3.2 and 4.3.8). Changing the self-concept towards cars may change the construct an individual makes about their behaviour (Triandis 1977). Nevertheless, if people are subject to outside pressure, because a certain behaviour is not acceptable anymore, (e.g. commuting by car), then they may change their self-concept accordingly (ibid). The source of information, the medium through where information is conveyed and the audience are important to change the perception of self-concept (ibid). If a new message about car impacts is conveyed by peers or role-models, then acceptance may take place by a change of the person's references. It is this notion of changing the self-concept that is required and may, perhaps, trigger a behavioural change towards passenger cars.

It is important for individuals to know and interpret what people who are important to them think of a specific behaviour creating thus a subjective or personal norm (Section 2.7). This is a slightly departure from Triandis's (1977) definition of norms (Section 2.7). Peer pressure and car reference groups (e.g. trend setters and car celebrities) may have a role in behavioural intentions acting upon emotions. Conforming to the new established norms, where car ownership or car usage is not the default option (Sections 4.2.3 and 4.3.2) and is associated with support from peers it will have a positive value for emotions. Information disclosure and change of cultural norms towards cars influenced by reference groups or role-models, may generate negative environmental behaviour avoidance.

Social factors leading to intentions, such as norms, roles and self-concept determine a change in the image of car users. For example, if excessive car use is linked to a negative image. Such change in image could be provided through nudging narratives (Thaler and Sunstein 2009)and could start with those who have high or very high potential to change their car use and perhaps car ownership (Sections 4.3.2 and 4.2.3). Intensive interactions between stakeholders, such as industry, policy makers and users, may start a social change (Vergragt and Brown 2007), nevertheless, their narrative of visions may not find echo with themselves and a more subtle – and granular - understanding behaviour of car users is needed in order to bring about necessary changes (Bergman 2017). One of the reasons is because the current car regime is a compromise that shapes and has been shaped to serve the majority of car consumers, but has important inadequacies, technological, environmental and social (Wells 2010).

One important norm that also needs to be demystified is the idea of the car as conducive to personal freedom (e.g. Miller 2001, Dennis and Urry 2009). For example, people who think that having access to a car provides more freedom, even when they are stranded for hours in a traffic jam, may assume that users of public transport are less free and poorer. This cognitive dissonance and individualistic view of attributions towards the car, which may come from a habit of using vehicles for different purposes, its convenience together with the status provided, are determinant towards certain attitudes and behaviours. For example, not pondering about other transport options or alternatives to ownership (Section 4.3.6), even when there is acknowledgement about the negative attributes and impacts of cars (Section 4.2.3). Nevertheless, modern industrial societies are more tolerant of deviations from the norm and an increase in alternatives to the norm, the car, are also tolerated (Triandis 1977). However, certain conditions need to be met for these alternatives to become the norm.

Frequent car replacement (Section 4.3.2) may support the fact that car users seem to be at the tail end of the automotive regime lock-in behaviour, reinforcing the development loop of this industry (Wells, Nieuwenhuis and Orsato 2011, Wells and Nieuwenhuis 2012). The idea that radical changes in the current car regime are needed, perhaps through policy interventions, in order to transition from one culture of ownership to multiple with shared use (Section 2.5.6), where relevant, and extended lifespan.

Car share awareness and usage remains low, especially car clubs and ride-share. It is debatable if the potential positive impacts of car sharing are being reaped due to low intensive use. First, the low mileage driven and relatively short service-life of shared cars (Section 4.2.6.2) and second, the limited uptake of car sharing by car drivers (Section 4.3.6). Low annual mileage shared cars (car hire and car clubs) (Section 4.2.6.2) could be kept for longer in service, thus potentially reducing their negative environmental impact. Alternatively, an increase in car sharing use could increase the intensity of use of each shared car. In such a case, the intensively used car would reach an efficient lifespan quicker, due to higher mileage, and could be replaced by a more efficient unit (Sections 1.3.4 and 2.5.1). Consumers should also be made aware of the material and energy used and their impacts, for example, type of resources used, social and environmental damage inflicted to communities and nature to make their cars, by tracking materials and processes throughout the extensive manufacturing supply chain.

The acceptance by consumers of longer lifespans of passenger cars (Section 4.3.7), or their optimisation, would benefit energy, material and emissions reduction (Kagawa, Tasaki and Moriguchi 2006, Kagawa, et al. 2011, Kagawa, et al. 2013) despite a divide between those who believe a 13.8 years passenger car lifespan is reasonable and those who believe it should be longer. Nudge policies, such as information disclosure (Thaler and Sunstein 2009) of social and environmental impacts of car manufacturing could stimulate this lifespan increase. Should the attitudes of consumers and businesses change, in relation to extending the average lifespan of passenger cars, then the resultant decrease in car demand could also decrease depreciation rates by depleting the car market of new units. This demand reduction could, as a result, increase manufacturing costs and sales prices (Section 4.1.1). Lower depreciation could enable cars to be kept for longer, thus increasing their potential to fulfil their optimised lifespan. Second-hand car buyers would have to acquire older cars to have access to mobility for the same cost or pay more to access a newer car. This could stimulate consumers to use alternative forms of transport, such as public transport and car sharing. The price increase, due to lower throughput, could reduce car consumption, as price is regarded the most important factor when buying any car, new or used (Section 4.3.8) and reduction in motoring costs was the second most important factor to switch to car share (Section 4.3.6). For businesses, including car sharing organisations, capital investment would increase to be able to purchase cars. That investment, which would have to be paid back through a more intensive or extensive use of the car, (Sections 4.2.6.1 and 4.2.6.2) which ideally should coincide with the car's optimal lifespan. Consumer and business policies for demand reduction and more efficient use of cars, either intensive or longer lifespan, would reduce demand for cars, which, in turn, would reduce throughput influencing manufacturing policies. These, in turn, would have to adapt to reduce material and energy demands.

Manufacturing costs would increase for car manufacturers and return on investment would be slower. The resulting price increase of cars would, in turn make the use of cars more efficient and service-life would be, in principle, longer because the reduced offer of newer vehicles would slower the rate of depreciation. (Figure 35).

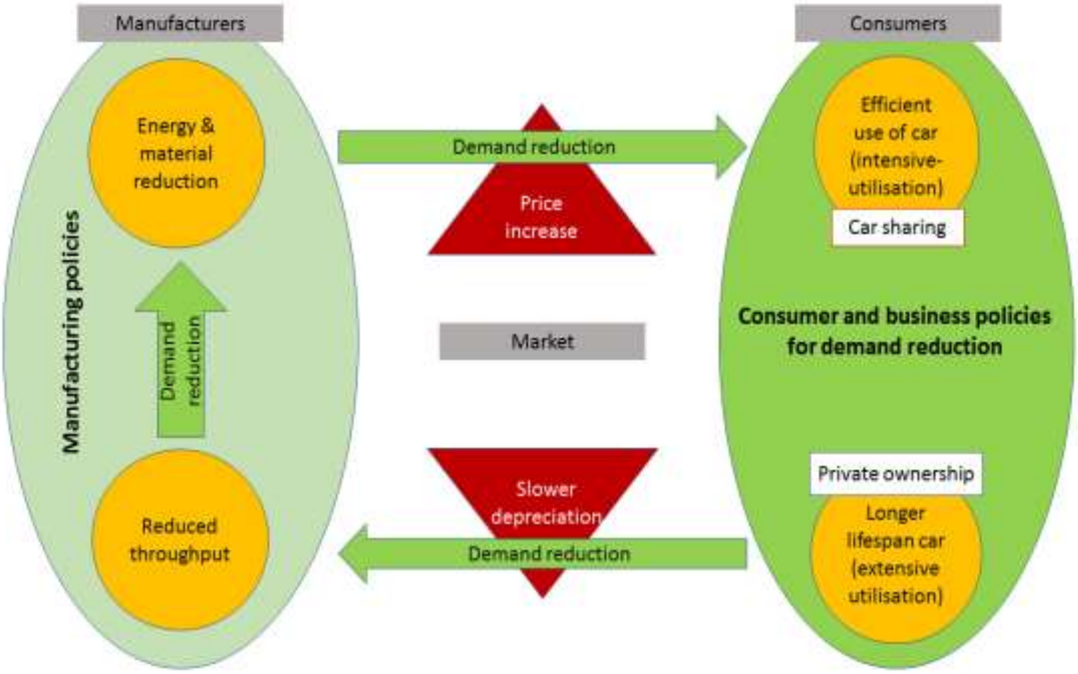


Figure 35. Passenger lifespan optimisation

Under the circumstances described above, government policy would not, initially, need necessarily to tax vehicles with higher lifecycle CO_{2eq} emissions. Policies could be more persuasive to enhance consumer choice and induce a change in accepted norms, adding pressure rather to policymakers to then create policy mechanisms adjusted to demand reduction. This informational social influence through disclosure would be quicker to uptake and subsequent normative social influence and change, leading to behaviour and policy change (Figure 36), would, however, be slower (Section 2.7). This could, in turn, potentially increase the use of less impactful materials and manufacturing methods, reducing the lifecycle impact and optimise the lifespan, although at a slower pace.

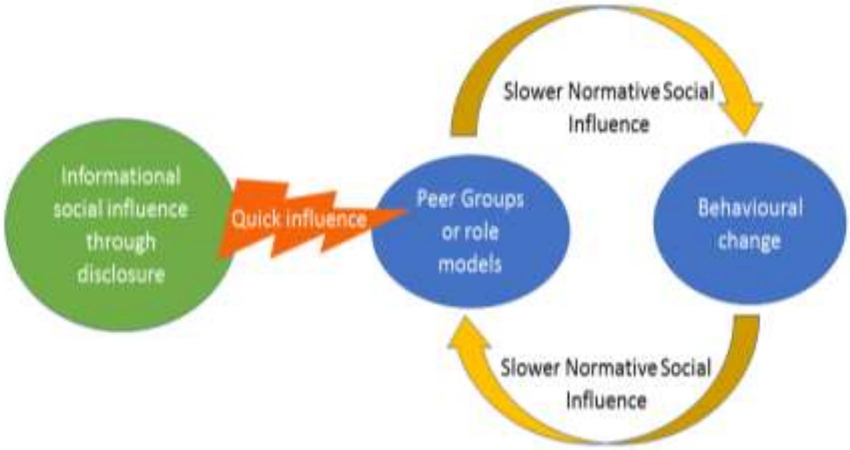


Figure 36. Nudge policies inducing behavioural change through peer groups.

The use of nudge policies (Section 2.8) to reduce lifecycle impacts of passenger cars would not prevent manufacturers from building their cars under the current regime paradigm. It would, nonetheless, disclose passenger car lifecycle impacts (Section 1.3.1). This could lead to a demand from pressure groups, or role-models, to demand changes to other punitive policies, such as car taxation, or demanding car manufacturers to reduce the lifecycle impact of their cars. Recent scandals involving car manufacturers' emissions disclosure has put pressure on policy makers to change the nature of emissions testing (Neslen 2015). This could mandate car companies to reduce lifecycle impacts; more impactful cars could bring negative publicity, forcing the industry to act upon car design and manufacturing. It could stimulate a better-informed society to be more demanding of less impactful cars or to keep their cars for longer (Section 4.3.7), at least until the point where manufacturing and use emissions are met (Danilecki, Mrozik and Smurawski 2017). The consequence would be a reduced manufacturing throughput and an increase in the value of each car, stimulating fleets, for example, to keep their cars for longer (Sections 4.2.6.1 and 4.2.6.2). Adding lifecycle impacts, on top of other procedures the automotive industry is facing – the 'cracks in the regime' - could, perhaps in the medium to longer term, contribute to a change of paradigm.

Conformism accepts actions initiated by others, whereas compliance is acting upon what is demanded, without necessarily accepting the new norm (Triandis 1977). Internalising new information, ideas and concepts involves acceptance of a new norm because it is aligned with one’s own views (Section 2.7). This in turn, could help break some social barriers, such as status or social categories, in car longevity and car sharing respectively (Sections 4.2.2 and 2.5). Reference groups are important for conformists because they ‘dictate’ what norms are to follow (Section 2.7). Nudge, and in particular ‘type 1 nudge’ (Section 2.8) can have a role in changing attitudes, beliefs and behaviours, not by direct punishment but through choice architecture (Section 2.8).

Policies towards optimised car longevity should be persuasive, aiming at a reflective behaviour rather than by stealth (Hansen and Jespersen 2013). Persuasion relies on norm internalisation, whereas stealth relies on norm compliance and not necessarily acceptance (Triandis 1977, Mols, et al. 2015). To achieve lasting behaviour and cultural change, acceptance and internalisation must be acknowledged by people as symbols of persuasion through power and influence (Mols, et al. 2015). The key is to influence groups of common interest such as car users and car pundits. Behavioural change comes from the skill to find common identity grounds and redefine those grounds in such a way that the new norms are accepted by peers in the same group, as part of a shared self-understanding (ibid). These reference groups, such as car owners who seldom drive (Section 4.3.2), need to be better informed to slowly wean themselves out of car ownership or from replacing cars on an impulse (Section 4.3.2).

Thaler and Sunstein (2009) suggest labelling information has enormous potential because it induces comparison and demystification. Both information disclosure and subsequent labelling have been important to challenge and change attitudes towards CO_2 emissions and diesel emission pollutants. However, persuading consumers away from cars needs reliable alternatives and government investment in public transport (Section 4.2.1.3), in tandem with the new norm acceptance. A concerted effort should be made by those who wish to depart from car use or ownership to demand better provision of comprehensive public transport, in which car sharing could have a role (Figure 37).

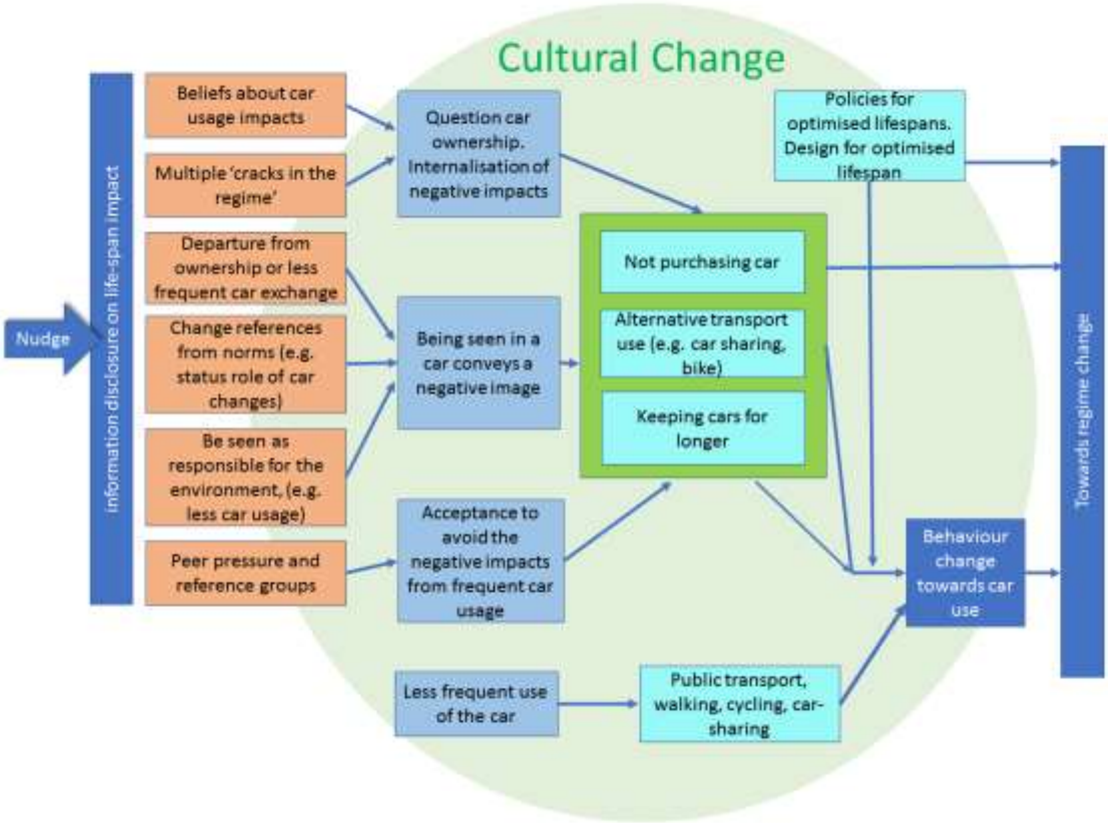


Figure 37. Nudge as a trigger to interpersonal behaviour change of car users.

5.2.4 Cultural Theory and Transition Towards Regime Change

The UK as a country, shows, together with wealth increase and consumerism, a high degree of individualism (Hofstede 2018). This may explain the reason why car owners 'indulge' in exchanging cars so frequently (Section 4.3.2). This does not mean that such behaviour, influenced by cultural dimensions, is immutable (Schwartz 2014). However, to overcome a culture of individualistic ownership and consumerism, a new, powerful narrative or vision needs to be in place, so that the necessary bottom-up behavioural and cultural change can empower top-down policy-making. Dominant cultural groups and values can characterize a society (ibid), let alone powerful lobbies, thus limiting its openness towards behavioural change. This research found that car usage in car sharing is far from realising its social and environmental potential (Sections 4.2.2 and 4.3.6) and policies in place in London would have, perhaps, to be different from those applied in other towns and cities (Section 4.2.1.3). Potential solutions for one part of the country, region or social group, may not be beneficial to another (Schwanen, Banister and

Anable 2012, Lucas and Pangbourne 2012). Nonetheless, a negative outcome can change culture; serving as an enabler of change. A negative environmental outcome, such as climate change, may trigger positive behavioural changes by creating new narratives (e.g. disclosure of information), creating, in turn, alternative new meanings, such as understanding the consequences of one's own consumerism (Adger, et al. 2013).

Car niches (Section 2.5.6) could be regional, urban, rural, neighbourhoods, communities, etc. For example, Micro-Factory Retail, MFR, (Wells 2010) is an example of a niche that can be adapted to local circumstances. 'Micro-Factory Retailing' adopts opposing features of mass-manufacturing: low capital cost manufacturing, non-steel materials used in car construction, extensive consumption of raw materials, local markets, manufacturing and repair in the same site. Riversimple's business model (Wells 2010) is a practical application of this, but it is struggling against the incumbent regime. In some areas, passenger cars could be sold, in others, they could be part of a service provision, using autonomous technologies or not, depending upon local circumstances such as access to public transport, available technology, power generation, road infrastructure, social fabric, pollution, etc. Importantly, people should be able to have access to mobility. Where they live and their social and local circumstances need to be taken into account by policy makers (Lucas and Pangbourne 2012).

Continuous cultural changes can also affect the different niches (Sections 2.6.1 and 2.7), affecting, in turn, socio-technical dimensions (Wells and Xenias 2015). These different niches could also be linked by common interests such as business model innovations or technologies (e.g. Micro-Factory Retail or electric powertrains) (Wells 2010). Wells suggests that such niche business models, if based on circular value systems, have the potential to reduce energy demand. Such diversity could limit the scope for bigger players to arise, or indeed to replace them in a 'creative destruction' scenario where social economic and environmental aspects are embraced (ibid). However, this could come at the cost of the scale efficiencies that mass-manufacturing enables or, alternatively, reduce mobility demands (ibid). This could have implications for how vehicles are manufactured, acquired, used and disposed. Also, how people access, behave towards, share and maintain them.

The automotive industry must be challenged in two ways. First, by increasing the lifespan of cars (Sections 1.3.1 and 4.3.7) if there are no changes in design to reduce overall lifecycle impacts

(Section 1.3.1). Second, by reducing the lifecycle impact of cars through design (Sections 1.3.1 and 4.1.6) in order to sustain throughput. However, given its historical continuity (Section 2.2), the industry may not be capable of reducing the lifecycle impact of cars much further (Section 4.1.4). Optimising passenger cars' lifespans (Section 4.1.4 and 4.1.6) could enable the incumbent automotive industry to change if policy makers and consumers act at different pressure points. The former, from a top-down approach, the latter, from bottom-up, increasing new and widening known 'cracks' in the automotive regime (Section 4.1.8). A change in attitudes from the bottom-up may be more difficult due to lack of transparency, and a predictable challenge from the automotive industry (Sections 1.3.1) and due to cognitive dissonance (Section 5.2.3) or habit (Section 4.3.9.3) from consumers. However, an initial top-down nudge approach could trigger a change (Section 2.8). If a break in the continuity cycle happens, car manufacturers could become, ideally, full product-service providers of mobility (Section 4.1.9) responsible for the whole lifecycle of their cars. In such case alternative forms of business and manufacturing, such as 'Micro Factory Retailing' could break through replacing and becoming the current regime. Novel and disruptive types of business models could create the necessary changes for regime transition. If a reduced throughput increases manufacturers costs and final retail prices, then there is scope for service providers further stimulating an optimised lifespan.

5.2.5 Nudge Policies for Optimised Lifespans

The combination of Nudge, TIB, cultural theory and MLP - the latter as an element of transitions theory - would be the foundations for a desired paradigmatic change in car consumption. Nudge policies could act at two stages. First, group interaction and peer pressure groups (Section 2.7), such as consumer groups, and public policymakers demanding information disclosure. Environmental impacts of cars are not important to consumers when they buy a car (Section 4.3.8). Awareness of the impact of cars, through information disclosure, before purchase, could have a dissuasive effect on consumers, who otherwise remain oblivious of their impact and alternatives to ownership (Sections 4.3.2 and 4.3.6). Informed consumer groups and policymakers would be the cornerstone of cultural change. This social facet of the socio technical transition could be incorporated into the MLP framework.

Consumer groups could start by demanding more transparent information from car manufacturers about the lifespan impacts of car manufacturing and use through the disclosure of lifecycle analyses and potential lifespan whilst at the same time promoting other forms of car use (Section 4.2.1.3). Information should be a mix of annual mileage (Section 4.1.6), the time it takes user stage CO_{2eq} emissions to meet manufacturing emissions (Section 1.3.1) and the environmental and social impacts (Sections 4.3.2 and 4.3.6) and how individual impacts compare with, for example, car sharing. This could put more pressure on automotive companies about the negative social and environmental effects of car manufacturing and usage. When such information is available, there will be scope for public opinion to demand changes in car policy.

At manufacturing level, the lifespan impact of cars could be penalised through taxation on environmental impacts and an average lifespan (e.g. the time user-stage emissions take to meet manufacturing emissions) for each manufacturer's product portfolio could be demanded as it is for CO_2 emissions by the European Union. At consumer level, a similar or replacement level of taxation as on CO_2 could be implemented. This more comprehensive taxation should include emissions and environmental impacts. Such taxation could disincentivise car owners from exchanging cars so regularly. Ideally, the revenue from such taxes should be used to invest in public transport, bicycle road infrastructure and car-less city planning (Section 4.2.1.3).

At the same time, car sharing companies should be incentivised to intensify the use of each car. The service-life of car sharing vehicles and their taxation should reflect the intensity of use per car, either in mileage or rates of occupancy (Section 4.2.6.2), depending upon the type of service provided. Such pressure could act as a nudge for automotive manufacturers to increase research and development towards less energy and material demanding cars and manufacturing plants and could stimulate their entrance into product-service system business models faster (Section 2.5.1). This extra pressure, adding to existing cracks in the regime, should enable, or at least trigger, the necessary paradigmatic change in this sector (Figure 38).

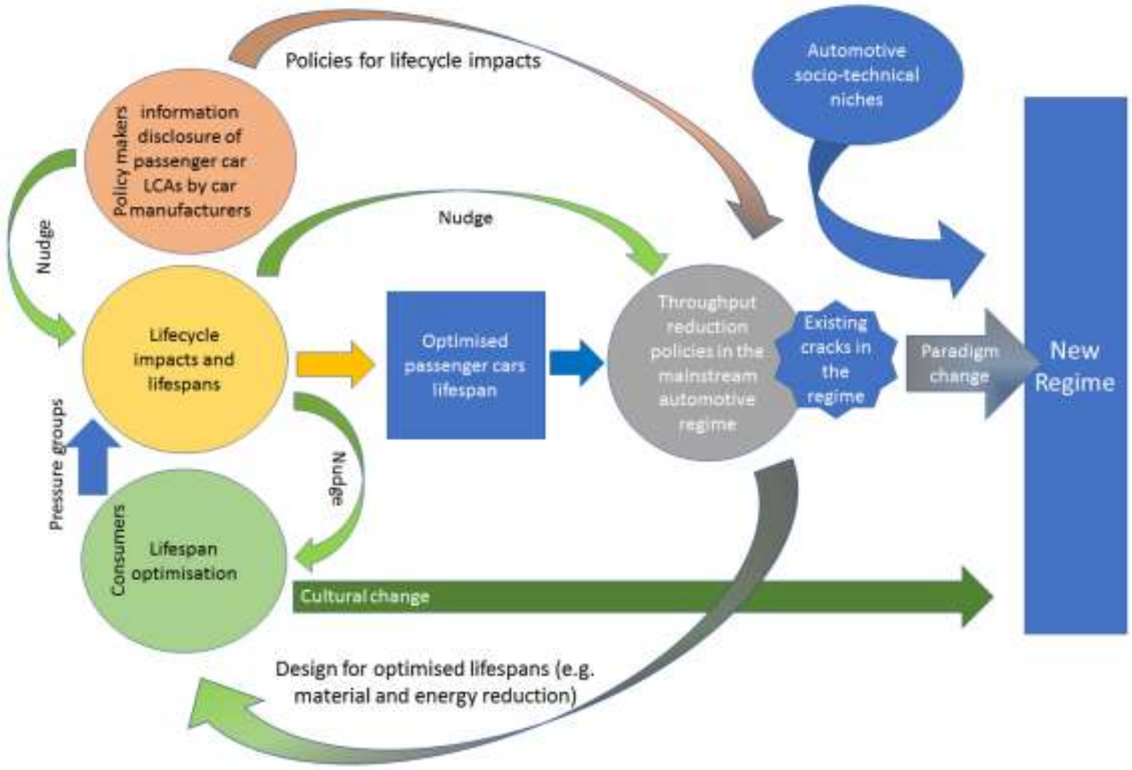


Figure 38. Nudge policies for optimised lifespans

5.3 Contributions to Knowledge

5.3.1 Barriers to Longer Lasting Cars and to Car Sharing

Previous studies in passenger car longevity focused on age as a reference for lifespan (Skelton and Allwood 2013, e.g., Nieuwenhuis 1994, Oguchi and Fuse 2014, Cooper, et al. 2014). In product longevity studies, design has been held responsible for low product durability. This is because of design's importance in defining materials, energy and manufacturing outcomes, relegating the consumer to a second order of importance when it comes to product longevity. Car sharing, studies have been focusing on the potential positive impacts and benefits of this service (e.g., Meijkamp 1998, Shaheen and Rodier 2005, Martin, Shaheen and Lidicker 2010, Barth and Shaheen 2002). In tandem, other studies have looked into intensively used products

– mostly household appliances - usually through a service-system business model involving product share (e.g. Mont 2004, Bocken et al. 2016).

There was a knowledge gap in understanding how the passenger car fits into these different categories: product longevity and product service system through sharing. These seem to be polarised approaches to the same objective; energy and material demand reduction through more efficient use of a product. In car longevity, the element of mileage, and its extension in a vehicle lifespan, was lacking and it is as important, if not more so, than age. This doctoral research showed that mileage, more than age, can define powertrain and user-machine interface wear and tear (Section 4.1.6), and it should be taken into account when defining feasible car lifespans. Mileage becomes more important than age when a passenger car is used intensively (Section 4.2.6.2). The extreme example of this is the taxi which can sustain very high mileages in just a few years of utilisation.

The interviews revealed that car industry designers and engineers are ambiguous about longer lasting cars (Sections 4.1, 4.1.6). Some believe they last long enough, whereas others believe that incrementing the lifespan of a car would penalise weight and emissions unless, in the longer-term, this could be beneficial in terms of emissions. These assertions stem from the fact that these experts work within the incumbent automotive paradigm and embracing new designs and manufacturing processes is seen to be risky. The design and manufacturing processes rigidity and the belief that this industry is developing and manufacturing products within energy and material constraints may be behind such assertions. The consequences of such beliefs may also contribute to explain the continuity in the automotive industry and its failure to transition to a more sustainable regime.

The findings from this research revealed that designing a car for longevity within the current car industry paradigm may not be attainable (Section 4.1.11), but elements of it can be further integrated in car design (Section 4.1.4). It also suggests that design, and the car industry itself, may not be solely responsible for short car longevity (Section 4.1.11). Other non-design related studies opened the door for this assertion (e.g., Oguchi and Fuse 2014) by observing disparate lifespans in different countries worldwide. The survey found that car users favour slightly longer lifespan cars. They were somewhat optimistic about the lifespan and mileage of cars. However, they exchange them frequently. This suggests that there is room to incentivise longer lifespans of cars, but a careful strategy needs to be devised to contradict the quick turnover of cars by consumers. This doctoral research shows that, in the UK, society has a very important role in car longevity by demonstrating and exposing consumer attitudes and behaviour towards car ownership and use (Sections 4.3.2, 4.3.3, 4.3.4 and 4.3.8). It is important thus, to redefine car longevity but also change consumer attitudes and behaviour towards ownership and use. The lifespan of a car should be an optimisation of its lifetime through lifecycle impact assessment, which, in turn, can be disparate for each different car and its usage. Extensive use of a car – generally through less mileage and over a very long period of time – can contribute to its longevity beyond what was intended by design and contribute to reduce energy and material demand. But, an intensively used car - through shared use and high mileage - may wear out rapidly and longevity may cease to make sense, and, likewise, may reduce the need for more cars. In both situations the car has fulfilled its role with a lower negative impact.

This research suggests that the car sharing sector is self-limiting in relation to its target market (Section 4.2.2) and car sharing vehicles are being underutilised, especially car clubs (Section 4.2.6). The positive impacts of car sharing, although acknowledged, are questioned by this research in the sense that they may not be as broad as claimed (Section 4.2.7). Vehicles have a relatively short service-life and product replacement is relatively fast. The assets are not intensively used until breakdown due to depreciation, warranty, maintenance costs and accreditation conditions. Therefore, the definition of product service system may not fully fit car sharing. This research also confirms that awareness of car clubs and rideshare is low and their use is very marginal (Section 4.3.6). However, this PhD confirms assertions made by the sector that consumers perceive service cost, especially car clubs and car hire as barriers towards its use (Appendix Z).

5.3.2 Strategic Options Towards the Optimisation of Lifespan of Passenger Cars

It is possible, through lifecycle assessment, to identify an optimised lifespan (e.g., Kim, et al. 2003, Danilecki, Mrozik and Smurawski 2017). Their analysis of the lifecycle impact takes annual mileage into account and environmental impacts from manufacturing, use and EoL to calculate the ideal lifespan of a vehicle. A more focused approach to the intended use of a car, whether extensive or intensive, should define its lifecycle impacts. For example, car insurance is already based on intended annual mileage. Consumers expect cars to last longer (Section 4.3.7), despite the ambiguous t response to car longevity from the industry (Section 4.1).

This PhD presented two complementary policy options to decision makers towards the optimisation of passenger car lifespans (Section 5.2.5). Both intend to reduce the use of energy and materials by acting upon consumer attitudes and beliefs towards the purchase, ownership, use and disposal of passenger cars.

The first, through policies that may enable the disclosure of environmental and social impacts of vehicles together with their optimal lifespan. The second, by nudging consumers, based upon disclosed information from lifecycle impacts and assessments of cars through policies for transparent information, about their consumerist behaviour towards passenger cars and its negative impacts.

This two-pronged approach of nudging as a trigger for behavioural change could disrupt the incumbent car culture. In turn, it may influence passenger car design towards lifespan optimisation and changes in the automotive industry business model, contributing, thus to a regime change. It would, ultimately, lead automotive manufacturers to begin a transition into different business models that could redefine and accelerate the car regime towards sustainability.

5.4 Limitations

Despite the general acceptance of small samples found in the literature in regard to semi-structured interviews (Kvale 1996, Crouch and McKenzie 2006, Robinson 2014), a larger sample of interviewees could have been more beneficial to this research in part because interviewees provided examples from their own specific work. For example, ideally, automotive industry interviewees would have been more numerous and separated by skills (e.g. several powertrain engineers, several structural engineers and so on).

This research avoided, as much as possible, bias from the interviewees. However, a degree of bias was found within interviewees, especially in the first set of interviews. Nevertheless, through triangulation (Sections 3.5, 3.5.1) it was possible to eradicate bias. This first group, working for the mainstream automotive sector, was not heterogeneous, because they all came from the mainstream industry (Section 3.3.3). An informative interview, however, was arranged with a senior member of a start-up automotive company, with a different approach from the mainstream industry, based upon the principles of Micro-Factory Retail (Wells 2010) and selling mobility but retaining ownership of cars. He was highly critical of the mainstream automotive industry, providing, to a very limited extent, some balance of views (Section 4.1.9). These limitations were expected (Robson 2002, Hammersley 2003). People liable to be critical of industry practices do not have the automotive design knowledge this research required. It was necessary to comprehend ideas and concepts, mainly coming from automotive designers, and physical limitations, from automotive engineers.

The second set of interviewees were more heterogeneous because of the systemic nature of car sharing. However, some of the structured questions were not responded to by all interviewees, despite being asked. For example, questions relating to car sharing fleet service life and annual mileage were only responded by four of the ten interviewees. Interviewees who did respond to fleet purchase and service-life questions were senior managers from car sharing companies with access to purchasing, service life and mileage data, suggesting that this was information not available to all respondents.

The survey sample gender distribution reflected that of driving licence holders in the UK. The age distribution is skewed towards older drivers and does not reflect the DfT's driving licence database age distribution. The sample, was not, thus, representative of demographics of the UK population and so does not allow a generalisation of results.

This research did not break down the annual mileage by activity, or type of activity. Further research could focus on breaking down travelled mileage by type of activity to compare the costs of car ownership per year and the costs of car sharing per year to understand where the threshold lies between being financially justifiable to own a car.

Due to time constraints, the large dataset was not subject to further cross tabulation or (e.g. analysis by income or education). This largely descriptive analysis does not scrutinise the results in more depth. However, it does provide a glimpse of attitudes, norms and behaviours towards car ownership and alternative forms of car usage.

Finally, car club and ride-share survey respondent numbers were lower than expected and whilst in some instances they were relevant and statistically possible, in others they had to be combined with car hire to become meaningful. In those cases, the responses were insufficient for significant tests, could not be analysed separately and had to be ignored. Ideally two separate surveys, one for car clubs and other for rideshare, could permit the capture of much more detailed data from these two subgroups with dedicated questions. However, this would entail target samples and two surveys, thus requiring greater time and budget.

5.5 Further Research (Recommendations)

Despite the findings this PhD produced, further and more detailed research is needed. Some examples are:

- Test the policy options presented by this research, with all the relevant stakeholders. Understand the far-reaching social, economic and environmental consequences of reducing the throughput of cars through nudge policies
- Explore the contextual differences of car lifespans around the world. The disparate numbers do not provide an indication as to why this happens. Legal and cultural aspects could be better understood to provide a clearer picture for such disparate lifespans.
- Car lifespan optimisation, through more detailed lifecycle assessments and the implications this could have in reducing material and energy demand.
- Car design experiments with prototypes using sustainable approaches to prolong the lifespan of cars.
- Understand, at granular level, through qualitative research methods, the norms, attitudes and beliefs of car users towards car consumption. This knowledge could bring more insights towards cultural changes needed in order to overcome the prevalent car regime.
- Understand the different aspects leading to disparate car longevity in different countries (e.g. taxation policies, car cultures and native car manufacturing). Research into these areas could shed light on how changes in policy, behaviour and culture could reduce the throughput of passenger cars by optimising their lifespan for each country.
- Understand the effects of extending cars' lifespans in reducing CO_2 throughout the UK's manufacturing supply chain, replicating studies made in other countries.

- Explore any direct causality between maintenance and attachment or attachment and ownership. Short-term ownership mindsets could be explored by service system operators of car sharing who can, and are accredited to, offer newer vehicles frequently.
- Explore the social, economic and environmental impacts of a decrease in number of cars scenario. Its potential effects on car depreciation, market dynamics and social and cultural values.
- The environmental and social impacts of increased service-life of car sharing vehicles. Compare the impacts of current service-life of shared cars with those with an increased service-life and how much more intensive should the use of a shared car be to justify a shorter service-life.
- The small number of respondents for car sharing usage in this research did not provide enough knowledge about this subgroup of consumers. Research into this subgroup would enable further knowledge about attitudes, beliefs and behaviours of such consumers. It is important to understand separately ride sharers, car club members and car hire users, especially those who migrated from car ownership.

Reflecting upon this research and its potential implications to society, the environmental lifecycle impact of cars needs to be brought to the fore as much as CO_2 emissions have been in the recent past. These impacts reach far and beyond greenhouse gas emissions and are related to social and environmental effects of resource extraction in faraway communities. They should be made more transparent. If social and environmental impacts, such as labour conditions in developing countries, have been under scrutiny by public opinion, so should the far-reaching hand of the long automotive supply chain in its role of resource extraction and transformation and its impacts in society.

REFERENCES

ACEA, 2015. *Supporting Document - ACEA - Legacy Spare Parts. Public consultation on streamlining and simplification of the REACH authorisation application procedure for applications concerning uses of substances in low volumes and on a one-time extension of transitional arrangements for uses of substances in legacy spare parts.* Brussels: European Automobile Manufacturers Association (ACEA).

Adger, W.N., Barnett, J., Brown, K. Marshal, N., O'Brien, K. 2013. Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change,* 3 (2), 112-117.

Ahmadjian, C.L. and Lincoln, J.R. 2001. Keiretsu, governance, and learning: Case studies in change from the Japanese automotive industry. *Organization Science,* 12 (6), 683-701.

Allwood, J. and Cullen, J. 2012. *Sustainable Materials. With Both Eyes Open.* Cambridge: UIT.

Allwood, J.M., 2014. Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies. *In:* E. Worrell and M. Reuter, eds., *Handbook of recycling.* Elsevier, Amsterdam, 2014, pp. 445-477.

Allwood, J., Ashby, M., Gutowski, T. and Worrell, E., 2011. Material efficiency: A white paper. Resources, Conservation and Recycling, 55 (3), 362-381

Amos, C., Holmes, G. and Strutton, D., 2008. Exploring the relationship between celebrity endorser effects and advertising effectiveness: A quantitative synthesis of effect size. *International Journal of Advertising,* 27 (2), 209-234.

Andrews, D., Nieuwenhuis, P. and Ewing, P.D. 2006. Black and beyond—colour and the mass-produced motor car. *Optics & Laser Technology,* 38 (4), 377-391.

Antonio, K.L., Yam, R.C. and Tang, E. 2007. The impacts of product modularity on competitive capabilities and performance: An empirical study. *International Journal of Production Economics,* 105 (1), 1-20.

Arena, M., Azzone, G. and Conte, A., 2013. A streamlined LCA framework to support early decision making in vehicle development. *Journal of Cleaner Production,* 41 (0), 105-113.

Automobile Association, 2017. *DIY car maintenance vs mechanic: What can I fix and what should I leave to a professional?* [online]. Automobile Association Developments Ltd. Available at: https://www.theaa.com/breakdown-cover/advice/diy-car-maintenance-vs-mechanic [Accessed 30/06 2016].

Autopartage, 2015. *Cité Lib by Ha:mo* [online]. Autopartage. Available at: http://citelib.com/citelib-by-hamo-page/ [Accessed 14/09/2015].

Ayres, R.U., 1995. Life cycle analysis: A critique. *Resources, Conservation and Recycling,* 14 (3-4), 199-223.

Baines, T.S., et al., 2007. State-of-the-art in product-service systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 221 (10), 1543-1552.

Bakker, C., den Hollander, M., Van Hinte, E. and Zljlstra, Y. 2014. *Products that Last. Product Design for Circular Business Models*. Delft: TU Delft.

Bakker, C., Wang, F. Huisman, J. and den Hollander, M., 2014. Products that go round: exploring product life extension through design. *Journal of Cleaner Production,* 69, 10-16.

Baptista, P., Melo, S. and Rolim, C. 2014. Energy, Environmental and Mobility Impacts of Car-sharing Systems. Empirical Results from Lisbon, Portugal. *Procedia - Social and Behavioral Sciences,* 111, 28-37.

Barbiroli, G., 2008. Profile of products enduring quality over long periods as strategic factor to increase their utilisation rate. *International Journal of Product Development,* 6 (3-4), 450-467.

Barrett, J., Cooper, T., Hammond, G. P., Pidgeon, N. 2018. Industrial energy, materials and products: UK decarbonisation challenges and opportunities. *Applied Thermal Engineering,* 136, 643-656.

Barth, M. and Shaheen, S., 2002. Shared-use vehicle systems: Framework for classifying carsharing, station cars, and combined approaches. *Transportation Research Record: Journal of the Transportation Research Board,* (1791), 105-112.

Baxter, J. and Eyles, J., 1997. Evaluating Qualitative Research in Social Geography: Establishing Rigour in Interview Analysis. *Transactions of the Institute of British Geographers,* 22 (4), 505-525.

Bazeley, P. and Jackson, K., 2013. *Qualitative data analysis with NVivo.* London: Sage Publications Limited.

Becker, H., Ciari, F. and Axhausen, K.W. 2017. Comparing car-sharing schemes in Switzerland: User groups and usage patterns. *Transportation Research Part A: Policy and Practice,* 97, 17-29.

Behrendt, S., et al., 2003. *Eco-service development-reinventing supply and demand in the European Union.* Emerald Group Publishing Limited: Bingley.

Bellu, S. 2002. *500 Voitures Extraordinaires.* Paris: Solar.

Bergman, N., 2017. Stories of the future: Personal mobility innovation in the United Kingdom. *Energy Research & Social Science,* 31, 184-193.

Bhamra, T. and Lofthouse, V., 2007. *Design for sustainability: a practical approach.* Farnham: Gower Publishing, Ltd.

Blair, E. and Blair, J., 2015. *Applied Survey Sampling.* London: Sage Publications.

Blume, T. and Walther, M. 2013. The end-of-life vehicle ordinance in the German automotive industry–corporate sense making illustrated. *Journal of Cleaner Production,* 56, 29-38.

Bogue, R. 2007. Design for disassembly: a critical twenty-first century discipline. *Assembly Automation,* 27 (4), 285-289.

Boyce, C. and Neale, P., 2006. *Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input.* Watertown, MA: Pathfinder International.

Braun, V. and Clarke, V., 2012. Thematic Analysis. *In:* H. Cooper, ed., *APA handbook of research methods in psychology Volume 2.* Washington, DC: APA, 2012, pp. 57-71.

Brezet, J., Bizma, A., Ehrenfeld, J. Silvester, S. 2001. *The design of eco-efficient services; method, tools and review of the case study based 'Designing eco-efficient services' project.* Delft University of Technology.

Brook Lyndhurst, 2011. *Public understanding of product lifetimes and durability.* London: Department for Environment, Food, and Rural Affairs.

Bryman, A., 2016. *Social Research Methods.* 5th ed. Oxford: Oxford University Press.

Bryman, A., 2008. *Social Research Methods.* 3rd ed. Oxford: Oxford University Press.

Bryman, A., 1988. *Quantity and quality in social research [electronic resource].* 4th ed. London: Routledge.

Buckley, M. and Rees, C., 2006. *Cars. An encyclopaedia of the world's most fabulous cars.* 2nd ed. London: Hermes House.

Burns, B., 2010. Re-evaluating Obsolescence and Planning for It. *In:* T. Cooper, ed., *Longer Lasting Products. Alternatives to The Throwaway Society.* Farnham: Gower Publishing, Ltd., 2010, pp. 39-60.

Carbon Trust, 2011. *International Carbon Flows - Automotive.* London: Carbon Trust.

Carplus, 2017. *Car Club Accreditation Criteria. Full, Provisional and Basic Standard Accreditation.* Leeds: Carplus.

Carplus, 2015a. *Carplus Annual Survey of Car Clubs 2014/15 England and Wales.* Leeds: Steer Davies Gleave.

Carplus, 2015b. *Carplus Annual Survey of Car Clubs 2014/15 London.* Leeds: Steer Davies Gleave.

Carplus, 2015c. *Carplus Annual Survey of Car Clubs 2014/15 Scotland.* Leeds: Steer Davies Gleave.

Cash, D., 2017. The Warning Light of Automobile Securitization: Credit Rating Agencies and Their Role in a Post-2016 World. *Business Law Review*, *38*(5), pp.187-189. *Business Law Review,* 38 (5), 187-189.

Chapman, G., 2013. *The Land Rover Story.* Stroud, Gloucestershire: History Press.

Chapman, J., 2015. *Emotionally Durable Design electronic resource]: Objects, Experiences and Empathy.* 2nd ed. Florence: Taylor and Francis.

Chapman, J., 2010. Subject/Object Relationships and Emotionally Durable Designs. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the Throwaway Society.* Farnham: Gower Publishing, Ltd., 2010, pp. 61-76.

Chapman, J., 2009. Design for (emotional) durability. *Design Issues,* 25 (4), 29-35.

Charter, M. and Tischner, U., 2001. *Sustainable Solutions: Developing products and services for the future.* Oxford: Routledge.

Chesbrough, H., 2010. Business model innovation: opportunities and barriers. *Long Range Planning,* 43 (2), 354-363.

Ceschin, F. and Vezzoli, C., 2010. The role of public policy in stimulating radical environmental impact reduction in the automotive sector: the need to focus on product-service system innovation. *International Journal of Automotive Technology and Management,* 10 (2-3), 321-341.

Christensen, T.B., 2011. Modularised eco-innovation in the auto industry. *Journal of Cleaner Production,* 19 (2–3), 212-220.

ComoUK, 2018. *Annual Car Club Survey [Search].* [online]. ComoUK. Available at: https://como.org.uk/?s=annual+car+club+survey [Accessed 07/22/2018].

Cooke, P., 2013. *The Used Car Market Report 2013. A report for BCA.* [online]. Centre for Automotive Management, The University of Buckingham Business School. Available at: https://www.bcamarketplaceplc.com/~/media/Files/B/BCA/documents/bca-2013-used-car-market-report.pdf [Accessed 06/05/2015].

Cooper, D., et al., 2014. Component level strategies for exploiting the lifespan of steel in products. *Resources, Conservation and Recycling,* 84, 24-34.

Cooper, T., 2004. Inadequate life? Evidence of consumer attitudes to product obsolescence. *Journal of Consumer Policy,* 27 (4), 421-449.

Cooper, T., 2002. Durable consumption: reflections on product life cycles and the throwaway society. *In: Proc. of Lifecycle Approaches to Sustainable Consumption Workshop,* pp. 11-27.

Cooper, T., 1994. *Beyond Recycling: the longer life option.* London: New Economics Foundation.

Cooper, T., 2010. The significance of Product Longevity. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the Throwaway Society.* Farnham: Gower, 2010, pp. 3-36.

Cooper, T., 2005. Slower consumption: reflections on product life spans and the "throwaway society". *Journal of Industrial Ecology,* 9 (1-2), 51-67.

Cooper, T. and Mayers, K., 2000. *Prospects for Household Appliances.* Electronics Industry - Social Considerations of Product End-of-life project. Halifax: Urban Mines.

Cox, J., et al., 2013. Consumer understanding of product lifetimes. *Resources, Conservation and Recycling,* 79, 21-29.

Creswell, J.W., 2012. *Educational research: Planning, conducting, and evaluating quantitative and qualitative research.* 4th ed. Boston: Pearson Education.

Crouch, M. and McKenzie, H., 2006. The logic of small samples in interview-based qualitative research. *Social Science Information,* 45 (4), 483-499.

Dake, K. and Thompson, M., 1999. Making ends meet, in the household and on the planet. *GeoJournal,* 47 (3), 417-424.

Dalmijn, W. and De Jong, T., 2007. The development of vehicle recycling in Europe: sorting, shredding, and separation. *The Journal of the Minerals, Metals & Materials Society,* 59 (11), 52-56.

Daly, H.E., et al., 2015. Indirect CO2 emission implications of energy system pathways: linking IO and TIMES models for the UK. *Environmental Science & Technology,* 49 (17), 10701-10709.

Danilecki, K., Mrozik, M. and Smurawski, P., 2017. Changes in the environmental profile of a popular passenger car over the last 30 years – Results of a simplified LCA study. *Journal of Cleaner Production,* 141, 208-218.

Dargay, J.M., 2001. The effect of income on car ownership: evidence of asymmetry. *Transportation Research Part A: Policy and Practice,* 35 (9), 807-821.

Delbosc, A. and Currie, G., 2013. Causes of youth licensing decline: a synthesis of evidence. *Transport Reviews,* 33 (3), 271-290.

den Hollander, M.C., Bakker, C.A. and Hultink, E.J., 2017. Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology,* 21 (3), 517-525.

Dennis, K. and Urry, J., 2009. *After the Car.* Polity: Cambridge

Denscombe, M., 2014. *The good research guide [electronic resource]: for small-scale social research projects* [online]. Open University Press. Available at: https://books.google.co.uk/books?hl=en&lr=&id=C5BFBgAAQBAJ&oi=fnd&pg=PR3&dq=Denscombe+The+good+research+guide+for+smal+scale&ots=guOi7t-x9E&sig=L5tkWbxmtCsQvI6HCqBXA64xC1k#v=onepage&q=Denscombe%20The%20good%20research%20guide%20for%20smal%20scale&f=false [Accessed 26/06/2017].

Denscombe, M., 2008. Communities of Practice: A Research Paradigm for the Mixed Methods Approach. *Journal of Mixed Methods Research,* 2 (3), 270-283.

Department for Business, Innovation and Skills, 2015. *Independent review of the sharing economy. Government response.* London: Department for Business, Innovation and Skills.

Department for Transport, 2017. *GB Driving Licence Data* [online]. Department for Transport. Available at: https://data.gov.uk/dataset/d0be1ed2-9907-4ec4-b552-c048f6aec16a/gb-driving-licence-data [Accessed 07/21 2018].

Department for Transport, 2015. *Annual Travel Survey: England 2015.* London: Department for Transport.

Department for Transport and Andrew Jones MP, 2016. *A smarter vision for transport* [online]. Department for Transport. Available at: https://www.gov.uk/government/speeches/a-smarter-vision-for-transport [Accessed 05/18/2016].

Desai, A. and Mital, A., 2003. Evaluation of disassemblability to enable design for disassembly in mass production. *International Journal of Industrial Ergonomics,* 32 (4), 265-281.

Dillman, D.A., Smyth, J.D. and Christian, L.M., 2014. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method.* New York: John Wiley & Sons.

Dobbs, R., Oppenheim, J., Thompson, F., Brinkman, M. and Zornes, M., 2011. *Resource Revolution: Meeting the World's Energy, Materials, Food and Water Needs* [online]. McKinsey.

Available at:
https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability%20and%20Resource%20Productivity/Our%20Insights/Resource%20revolution/MGI_Resource_revolution_full_report.ashx [Accessed 25/11/2015].

Dower, G., 2006. Modularity for greening the automobile. *In:* P. Nieuwenhuis, P. Vergrart and P. Wells, eds., *The Business of Sustainable Mobility.* Sheffield: Greenleaf, 2006, pp. 92-102.

Dun, C., Horton, G. and Kollamthodi, S., 2015. *Improvements to the definition of lifetime mileage of light duty vehicles.* Didcot: Ricardo-AEA.

Dworkin, S.L., 2012. Sample size policy for qualitative studies using in-depth interviews. *Archives of Sexual Behavior,* 41 (6), 1319-1320.

Eatherley, D. and Morley, N., 2008. *Material Security: Ensuring Resource Availability for the UK, Economy.* Chester: C-Tech Innovation Ltd.

Ehrenfeld, J., 2001. Designing sustainable product/service systems. *In: Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium on,* IEEE, pp. 12-23.

Ellen MacArthur Foundation, 2018. *GLOBAL PARTNERS OF THE ELLEN MACARTHUR FOUNDATION* [online]. Available at: https://www.ellenmacarthurfoundation.org/ [Accessed 04/24/2018].

Ellen MacArthur Foundation, 2014. *Towards the Circular Economy Vol. 3: Accelerating the scale-up across global supply chains.* Cowes, Isle of Wight: Ellen MacArthur Foundation.

Ellen MacArthur Foundation, 2013. *The Circular Economy Applied to the Automotive Industry.* [online]. Ellen MacArthur Foundation. Available at:
https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/the-circular-economy-applied-to-the-automotive-industry [Accessed 07/18/2018].

Engers, M., Hartmann, M. and Stern, S., 2009. Annual miles drive used car prices. *Journal of Applied Econometrics,* 24 (1), 1-33.

Engineering Employers' Federation, 2014. *Materials for Manufacturing. Safeguarding Supply.* London: EEF.

English, A., 2014. *Volvo's new engines reviewed* [online]. The Telegraph. Available at: https://www.telegraph.co.uk/motoring/car-manufacturers/volvo/10364069/Volvos-new-engines-reviewed.html [Accessed 07/22 2018].

Enterprise Holdings, 2016. *Enterprise CarShare* [online]. 2016 Enterprise Holdings Inc. Available at: https://www.enterpriseholdings.com/en/total-transportation-solution/neighborhood-network/enterprise-carshare.html [Accessed 05/08/2017].

Ervine, C., 2010. Durability and the Law. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the Throwaway Society.* Farnham: Gower, 2010, pp. 181-194.

European Commission, 2011. *Roadmap to a Resource Efficient Europe*. *COM (2011),* 571.

European Commission, 2005. *Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council.* Brussels: European Commission.

European Commission, 2000. *Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on End-of-life Vehicles.* Regulation ed. Brussels: European Union.

Eurostat, 2016. *International Standard Classification of Education (ISCED)* [online]. European Union. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/International_Standard_Classification_of_Education_(ISCED) [Accessed 03/01 2017].

Evans, J., 2016. *Rusty cars: why they're not a thing of the past* [online]. Available at: http://www.autocar.co.uk/car-news/industry/rusty-cars-why-theyre-not-thing-past [Accessed 03/03/2017].

Evans, S. and Cooper, T., 2010. Consumer influences on product lifespans. *Longer Lasting Products: Alternatives to the Throwaway Society*, 319.

Farmer, T., et al., 2006. Developing and implementing a triangulation protocol for qualitative health research. *Qualitative Health Research,* 16 (3), 377-394.

Fellows, N.T. and Pitfield, D.E., 2000. An economic and operational evaluation of urban car-sharing. *Transportation Research Part D: Transport and Environment,* 5 (1), 1-10.

Field, A.P., 2009. *Discovering statistics using SPSS*. 3rd ed. London: Sage.

Firnkorn, J. and Müller, M., 2011. What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm. *Ecological Economics,* 70 (8), 1519-1528.

Fischer, R., et al., 2010. Are individual-level and country-level value structures different? Testing Hofstede's legacy with the Schwartz Value Survey. *Journal of Cross-Cultural Psychology,* 41 (2), 135-151.

Fishbein, M. and Ajzen, I., 1975. *Belief, attitude, intention and behavior: An introduction to theory and research.* Reading: Addison-Wesley.

Freund, P. and Martin, G.T., 1993. *The Ecology of the Automobile.* Black Rose Books Montreal.

Fuhrmann, E., 1979. The long-life car. *Futures,* 11 (3), 216-223.

Gallagher, D., 2018. *Survey Queries.* [Email].

Gärling, T., et al., 2002. A conceptual analysis of the impact of travel demand management on private car use. *Transport Policy,* 9 (1), 59-70.

Gartman, D., 1994. Harley Earl and the Art and Color Section: the birth of styling at General Motors. *Design Issues,* 10 (2), 3-26.

Gartman, D., 2004. Three Ages of the Automobile: The Cultural Logics of The Car. *Theory, Culture & Society,* 21 (4-5), 169-195.

Geels, F., 2012. A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography,* 24, 471-482.

Geels, F., 2011. *The multi-level perspective on sustainability transitions: Responses to seven criticisms.*

Geels, F., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy,* 39 (4), 495-510.

Geels, F. and Kemp, E., 2012. *The multi-level perspective as a new perspective for studying socio-technical transitions.* N.A.

Geels, F., Kemp, R., Dudley, G. and Lyons, G., 2012. *Automobility in transition? A socio-technical analysis of sustainable transport.* Oxford: Routledge.

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy,* 33 (6-7), 897-920.

Geels, F.W. and Schot, J., 2007. Typology of sociotechnical transition pathways. *Research Policy,* 36 (3), 399-417.

Ghosh, D. and Vogt, A., 2012. Outliers: an evaluation of methodologies. *In: Joint statistical meetings,* San Diego, CA: American Statistical Association, pp. 3455-3460.

Gilg, A., Barr, S. and Ford, N., 2005. Green consumption or sustainable lifestyles? Identifying the sustainable consumer. *Futures,* 37 (6), 481-504.

Gilmore, E.A. and Lave, L.B., 2013. Comparing resale prices and total cost of ownership for gasoline, hybrid and diesel passenger cars and trucks. *Transport Policy,* 27, 200-208.

Giudice, F. and Kassem, M., 2009. End-of-life impact reduction through analysis and redistribution of disassembly depth: A case study in electronic device redesign. *Computers & Industrial Engineering,* 57 (3), 677-690.

Gnanapragasam, A., et al., 2018. Consumer perspectives on longevity and reliability: a national study of purchasing factors across eighteen product categories. *Procedia CIRP,* 69, 910-915.

Go, T.F., et al., 2011. Disassemblability of end-of-life vehicle: a critical review of evaluation methods. *Journal of Cleaner Production,* 19 (13), 1536-1546.

Good, P.I. and Hardin, J.W., 2012. *Common errors in statistics (and how to avoid them).* Fourth edition ed. Hoboken: Wiley.

Goodwin, T., 2012. Why we should reject ‘nudge’. *Politics,* 32 (2), 85-92.

Govers, P. and Mugge, R., 2004. "'I Love My Jeep, Because Its Tough Like Me': The Effect of Product-Personality Congruence on Product Attachment,". *In: Proceedings of the Fourth International Conference on Design and Emotion, Aren Kurtgözü, 2004.* Ankara, Turkey.

Graham, S. and Thrift, N., 2007. Out of order: understanding repair and maintenance. *Theory, Culture & Society,* 24 (3), 1-25.

Grant, T. and Macdonald, F., 2009. Life cycle assessment as decision support: a systemic critique. *In:* R. Horne, T. Grant and K. Verghese, eds., *Life Cycle Assessment: Principles, Practice and Prospects.* Melbourne: CSIRO Publishing: 2009, pp. 33-41.

Groupe Renault, 2016. *Renault and the family cars: 50 years of history since the Renault 16* [online]. Groupe Renault. Available at: https://group.renault.com/en/news/blog-renault/renault-and-the-familiy-cars-50-years-of-history-since-the-renault-16/https://group.renault.com/en/news/blog-renault/renault-and-the-familiy-cars-50-years-of-history-since-the-renault-16/ [Accessed 05/20/2016].

Gwilt A., Leaver J., Fisher M., Young G, 2015. Understanding the caring practices of users. *In: Product Lifetimes and The Environment - Conference Proceedings, Nottingham, UK, 17 - 19 June 2015.* Nottingham: Nottingham Trent University, pp. 125.

Hammersley, M., 2003. Recent radical criticism of interview studies: any implications for the sociology of education? *British Journal of Sociology of Education,* 24 (1), 119-126.

Hansen, P.G. and Jespersen, A.M., 2013. Nudge and the manipulation of choice: A framework for the responsible use of the nudge approach to behaviour change in public policy. *European Journal of Risk Regulation,* 4 (1), 3-28.

Happian-Smith, J., 2001. *An introduction to modern vehicle design.* Elsevier.

Hawken, P., Lovins, A.B. and Lovins, L.H., 1999. *Natural capitalism: The next industrial revolution.* Boston, MA: Little, Brown and Company.

Haywood, J., 2016. *Response to: Draft Report to the Car Sharing Sector - Alex Rodrigues, Nottingham Trent University. [email].*

Henn, M., Weinstein, M. and Foard, N., 2006. *A short introduction to social research.* London: London: SAGE.

Hertzog, M.A., 2008. Considerations in determining sample size for pilot studies. *Research in Nursing & Health,* 31 (2), 180-191.

Hildebrand, D., Laing, J. and Rosenthal, H., 1993. Analysis of Ordinal Data. *In:* M. Lewis-Beck, ed., *International Handbook of Quantitative Applications in the Social Sciences. Volume 1. Basic Statistics.* London: Sage, 1993, pp. 235-308.

Hoaglin, D.C. and Iglewicz, B., 1987. Fine-tuning some resistant rules for outlier labelling. *Journal of the American Statistical Association,* 82 (400), 1147-1149.

Hoaglin, D.C., Iglewicz, B. and Tukey, J.W., 1986. Performance of some resistant rules for outlier labelling. *Journal of the American Statistical Association,* 81 (396), 991-999.

Hofstede, G., 2018. *What about the UK?* [online]. Hofstede Insights. Available at: https://www.hofstede-insights.com/country-comparison/the-uk/ [Accessed 06/28/2016].

Hofstede, G., 2011. *Dimensionalizing cultures: The Hofstede model in context* [online]. International Association for Cross-Cultural Psychology. Available at: https://scholarworks.gvsu.edu/cgi/viewcontent.cgi?article=1014&context=orpc [Accessed 19/10/2017].

Hofstede, G., 1983. National cultures in four dimensions: A research-based theory of cultural differences among nations. *International Studies of Management & Organization,* 13 (1-2), 46-74.

Holder, J., 2016. *Depreciation - what is it, and how do I avoid it?* [online]. Haymarket Media Group. Available at: https://www.whatcar.com/advice/buying/depreciation-what-is-it-and-how-do-i-avoid-it/ [Accessed 07/03/2017].

Holweg, M., 2007. The genealogy of lean production. *Journal of Operations Management,* 25 (2), 420-437.

Hsu, A., 2016. Track climate pledges of cities and companies: data transparency is key to accounting for how local governments and the private sector are contributing to global emissions reduction, say Angel Hsu and colleagues. *Nature,* 532 (7599), 303-307.

Inglehart, R. and Baker, W.E., 2000. Modernization, cultural change, and the persistence of traditional values. *American Sociological Review,* 65 (1), 19-51.

Jackson, T., 2005. *Motivating sustainable consumption.* Guildford: Centre for Environmental Strategy.

Jarman, K.H., 2015. *Beyond Basic Statistics: Tips, Tricks, and Techniques Every Data Analyst Should Know*. Chichester: John Wiley & Sons.

Jick, T.D., 1979. Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly,* 24 (4), 602-611.

Johanson, G.A. and Brooks, G.P., 2009. Initial scale development: sample size for pilot studies. *Educational and Psychological Measurement,* 70 (3), 394-400.

Johansson-Stenman, O. and Martinsson, P., 2006. Honestly, why are you driving a BMW? *Journal of Economic Behavior & Organization,* 60 (2), 129-146.

Johnson, R.B., Onwuegbuzie, A.J. and Turner, L.A., 2007. Toward a definition of mixed methods research. *Journal of Mixed Methods Research,* 1 (2), 112-133.

Jones, R., Pykett, J. and Whitehead, M., 2010. Governing temptation: Changing behaviour in an age of libertarian paternalism. *Progress in Human Geography,* 35 (4), 483-501.

Kagawa, S., et al., 2013. Better cars or older cars? Assessing CO 2 emission reduction potential of passenger vehicle replacement programs. *Global Environmental Change,* 23 (6), 1807-1818.

Kagawa, S., et al., 2011. Role of motor vehicle lifetime extension in climate change policy. *Environmental Science & Technology,* 45 (4), 1184-1191.

Kagawa, S., Tasaki, T. and Moriguchi, Y., 2006. The environmental and economic consequences of product lifetime extension: Empirical analysis for automobile use. *Ecological Economics,* 58 (1), 108-118.

Katzev, R., 2003. Car sharing: A new approach to urban transportation problems. *Analyses of Social Issues and Public Policy,* 3 (1), 65-86.

Kenne, J., Dejax, P. and Gharbi, A., 2012. Production planning of a hybrid manufacturing–remanufacturing system under uncertainty within a closed-loop supply chain. *International Journal of Production Economics,* 135 (1), 81-93.

Khalil, O.E.M., 2011. e-Government readiness: Does national culture matter? *Government Information Quarterly,* 28 (3), 388-399.

Kim, H.C., et al., 2003. Life cycle optimization of automobile replacement: model and application. *Environmental Science & Technology,* 37 (23), 5407-5413.

Kingham, S., Dickinson, J. and Copsey, S., 2001. Travelling to work: will people move out of their cars? *Transport Policy,* 8 (2), 151-160.

Kleyner, A. and Sandborn, P., 2008. Minimizing life cycle cost by managing product reliability via validation plan and warranty return cost. *International Journal of Production Economics,* 112 (2), 796-807.

Kolarevic, B., 2003. *Architecture in the Digital Age: Design and Manufacturing.* London: Taylor & Francis.

Kollmann, K., 1992. Hidden costs of consumption. *Journal of Consumer Studies & Home Economics,* 16 (3), 273-281.

Kotler, P. and Keller, K.L., 2009. *Marketing Management.* 13th ed. London: Pearson Education.

Kvale, S., 1996. *InterViews: an introduction to qualitative research interviewing.* London: Sage.

Lancaster, G.A., Dodd, S. and Williamson, P.R., 2004. Design and analysis of pilot studies: recommendations for good practice. *Journal of Evaluation in Clinical Practice,* 10 (2), 307-312.

Legard, R., Keegan, J. and Ward, K., 2003. In-depth interviews. *In:* J. Ritchie and J. Lewis, eds., *Qualitative Research Practice. A Guide for Social Science Students and Researchers.* London: Sage, 2003, pp. 138-169.

Leggett, W., 2014. The politics of behaviour change: Nudge, neoliberalism and the state. *Policy & Politics,* 42 (1), 3-19.

Lewis-Beck, M.S., 1993. *International handbooks of quantitative applications in the social sciences. Volume 1. Basic statistics.* London: Sage.

Liddle, J., McElwee, G. and Disney, J., 2012. Rural transport and social inclusion: The DalesBus Initiative. *Local Economy,* 27 (1), 3-18.

Liebetrau, A., 1993. Measures of Association. *In:* M. Lewis-Beck, ed., *International Handbook of Quantitative Applications in the Social Sciences. Volume 1. Basic Statistics.* London: Sage, 1993, pp. 309-397.

Liker, J.K., 2006. *The Toyota Way.* Audio Book ed. New York: McGraw-Hill Education.

Lilley, D., 2009. Design for sustainable behaviour: strategies and perceptions. *Design Studies,* 30 (6), 704-720.

Lissaman, C., 2016. *The Last Defender: Is Land Rover's off-road heyday over?* [online]. BBC News Online. Available at: http://www.bbc.co.uk/news/uk-england-35285258 [Accessed 01/27/2017].

London Car Club Coalition, 2015. *A Car Club Strategy for London. Growing car clubs to support London's transport future.* London: London Car Club Coalition.

Longmuss, J. and Poppe, E., 2017. Planned obsolescence: Who are those planners? *In: PLATE: Product Lifetimes and The Environment: Conference Proceedings of PLATE 2017, Delft, 8-10 November 2017.* Delft, the Netherlands: IOS Press, pp. 218-221.

Loose, W., Mohr, M. and Nobis, C., 2006. Assessment of the future development of car sharing in Germany and related opportunities. *Transport Reviews,* 26 (3), 365-382.

Lucas, K. and Pangbourne, K., 2012. Transport and Climate Change Policy in the United Kingdom: A Social Justice Perspective. *In:* T. Riley and L. Chapman, eds., *Transport and Climate Change.* Bingley: Emerald Group Publishing Limited, 2012, pp. 287-312.

Lucas, K., 2006. Providing transport for social inclusion within a framework for environmental justice in the UK. *Transportation Research Part A: Policy and Practice,* 40 (10), 801-809.

Lund, R.T. and Hauser, W.M., 2010. Remanufacturing-an American perspective. *In: ICRM2010-Green Manufacturing, Ningbo, N.D.* China: IET, pp. 1-6.

MacDougall, C. and Fudge, E., 2001. Planning and recruiting the sample for focus groups and in-depth interviews. *Qualitative Health Research,* 11 (1), 117-126.

Mackenzie, D., 1997. *Green design: design for the environment.* 2nd ed. London: Lawrence King.

Mackenzie, D., Cooper, T. and Garnett, K., 2010. Can durability provide a strong marketing platform? *In:* Cooper, T. ed., *Longer Lasting Products: Alternatives to the Throwaway Society,* Farnham: Gower, pp. 297-315.

Manzini, E. and Vezzoli, C., 2003. A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize. *Journal of Cleaner Production,* 11 (8), 851-857.

Martin, E., Shaheen, S. and Lidicker, J., 2010. Impact of carsharing on household vehicle holdings: Results from North American shared-use vehicle survey. *Transportation Research Record: Journal of the Transportation Research Board,* (2143), 150-158.

Mathews, J.A. and Tan, H., 2011. Progress toward a circular economy in China. *Journal of Industrial Ecology,* 15 (3), 435-457.

Mayyas, A., Qattawi, A., Omar, M. and Shan, D., 2012. Design for sustainability in automotive industry: A comprehensive review. *Renewable and Sustainable Energy Reviews,* 16 (4), 1845-1862.

McAuley, J.W., 2003. Global sustainability and key needs in future automotive design. *Environmental Science & Technology,* 37 (23), 5414-5416.

McDonough, W. and Braungart, M., 2002. *Cradle to cradle: remaking the way we make things.* New York: North Point Press.

McDuffie, J.P., 2013. Modularity-as-property, modularization-as-process, and ‘modularity'-as-frame: Lessons from product architecture initiatives in the global automotive industry. *Global Strategy Journal,* 3 (1), 8-40.

McSweeney, B., 2002. Hofstede’s Model of National Cultural Differences and their Consequences: A Triumph of Faith - a Failure of Analysis. *Human Relations,* 55 (1), 89-118.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens, W.W., 1972. The limits to growth. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind.*

New York: Universe Books.

Meijkamp, R., 1998. Changing consumer behaviour through eco-efficient services: an empirical study of car sharing in the Netherlands. *Business Strategy and the Environment,* 7 (4), 234-244.

Metz, D., 2013. Peak car and beyond: the fourth era of travel. *Transport Reviews,* 33 (3), 255-270.

Metz, D., 2012. Demographic determinants of daily travel demand. *Transport Policy,* 21, 20-25.

Michalos, G., Makris, S., Papakostas, N., Mourtzis, D. and Chryssolouris, G., 2010. Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. *CIRP Journal of Manufacturing Science and Technology,* 2 (2), 81-91.

Mildenberger, U. and Khare, A., 2000. Planning for an environment-friendly car. *Technovation,* 20 (4), 205-214.

Miles, M. and Huberman, A., 1994. *Qualitative Data Analysis. An Expanded Sourcebook.* 2nd ed. London: Sage.

Miller, D., 2001. *Car cultures.* Oxford: Berg Publishers.

Minkov, M. and Hofstede, G., 2010. Hofstede's fifth dimension: New evidence from the World Values Survey. *Journal of Cross-Cultural Psychology,* 43 (1), 3-14.

Mols, F., et al., 2015. Why a nudge is not enough: A social identity critique of governance by stealth. *European Journal of Political Research,* 54 (1), 81-98.

Mont, O., 2004. Institutionalisation of sustainable consumption patterns based on shared use. *Ecological Economics,* 50 (1), 135-153.

Mont, O., 2002. Clarifying the concept of product–service system. *Journal of Cleaner Production,* 10 (3), 237-245.

Mont, O. and Power, K., 2010. The role of formal and informal forces in shaping consumption and implications for a sustainable society. Part 1. *Sustainability,* 2 (7), 2232-2252.

Moreno, M., et al., 2016. A conceptual framework for circular design. *Sustainability,* 8 (9), 937.

Morris, D., 2017. *Driverless Cars Will Be Part of a $7 Trillion Market by 2050* [online]. Fortune/Time. Available at: http://fortune.com/2017/06/03/autonomous-vehicles-market/ [Accessed 06/07/2017].

Moura, F. and Viegas, J., 2009. Car organ transplant-Anticipating energy and environmental benefits of cleaner technologies. *In: eceee 2009 Summer Study Act! Innovate! Deliver! Reducing energy demand sustainably, La Colle sur Loup, France, 1-6 June 2009.* Stockholm, Sweden: ECEEE, pp. 1303-Volume 1, pp 1–510; Volume 2, pp 511–1034; Volume 3, pp 1035–1464; Volume 4, pp 1465–1918.

Murphy, J. and Cohen, M.J., 2001. Chapter 13 - Sustainable Consumption: Environmental Policy and the Social Sciences. *In:* M.J. Cohen and J. Murphy, eds., *Exploring Sustainable Consumption.* Oxford: Pergamon, 2001, pp. 225-240.

Nader, R., 2011. Unsafe at Any Speed: The Designed-In Dangers of the American Automobile. Unsafe at Any Speed. Excerpted from: Ralph Nader, Unsafe at Any Speed: The Designed-In Dangers of the American Automobile (New York, NY: Grossman Publishers,1965). *American Journal of Public Health,* 101 (2), 254-256.

Namiot, D. and Sneps-Sneppe, M., 2013. Geofence and network proximity. *In:* Geofence and network proximity. *Internet of Things, Smart Spaces, and Next Generation Networking.* Springer, 2013, pp. 117-127.

Nemry, F., et al., 2008. *Environmental Improvement of Passenger Cars (IMPRO-car).* Luxembourg: European Commission Joint Research Centre. Institute for Prospective Technological Studies.

Neslen, A., 2015. *Car makers face 'real world' emissions tests in EU pollution clampdown* [online]. Guardian News and Media Limited. Available at: https://www.theguardian.com/environment/2015/feb/03/car-makers-face-real-world-emissions-tests-in-eu-pollution-clampdown [Accessed 01/19/2018].

Nieuwenhuis, P., 2008. From banger to classic–a model for sustainable car consumption? *International Journal of Consumer Studies,* 32 (6), 648-655.

Nieuwenhuis, P., 1994. The Long-life Car. Investigating a Motor Industry Heresy. *In:* Nieuwenhuis P. and Wells P., eds., *Motor Vehicles in The Environment. Principles and Practice.* Chichester: John Wiley & Sons, 1994, pp. 153-172.

Nieuwenhuis, P. and Wells, P., 2007. The all-steel body as a cornerstone to the foundations of the mass production car industry. *Industrial and Corporate Change,* 16 (2), 183-211.

Nykvist, B. and Whitmarsh, L., 2008. A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change,* 75 (9), 1373-1387.

Oakdene-Hollins, 2008. *A Review of Policy Options for Promoting Remanufacturing in the UK.* Oakden-Hollins.

OECD, 2002. *Indicators to measure decoupling of environmental pressure from economic growth.* Paris: OECD.

OECD, 1982. *Product durability and product-life extension.* Paris: OECD (Organisation for Economic Co-operation and Development).

Office of National Statistics, 2017. *United Kingdom population mid-year estimate 2016* [online]. Office of National Statistics. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates [Accessed 03/15/2018].

Office of National Statistics, 2011. *Percentage of the population with different levels of qualification: United Kingdom (Percentages).* Archived: The National Archives ed. Office for National Statistics.

Oguchi, M., Tasaki, T., Daigo, I., Cooper, T., Cole, C. and Gnanapragasam, A., 2016. Consumers' expectations for product lifetimes of consumer durables. *In: Electronics Goes Green 2016 (EGG), 2016, Berlin, 7-9 September.* Berlin: Fraunhofer IZM, pp. 1-6.

Oguchi, M. and Fuse, M., 2014. Regional and Longitudinal Estimation of Product Lifespan Distribution: A Case Study for Automobiles and a Simplified Estimation Method. *Environmental Science & Technology,* 49 (3), 1738-1743.

Olafsson, A.S., Nielsen, T.S. and Carstensen, T.A., 2016. *Cycling in multimodal transport behaviours: Exploring modality styles in the Danish population.*

Organisation Internationale des Constructeurs d'Automobiles, 2018. *Production Statistics* [online]. Organisation Internationale des Constructeurs d'Automobiles. Available at: http://www.oica.net/category/production-statistics/ [Accessed 27/02/2018].

Orsato, R.J. and Wells, P., 2007. U-turn: the rise and demise of the automobile industry. *Journal of Cleaner Production,* 15 (11–12), 994-1006.

Packard, V., 1960. *The Waste Makers.* Harmondsworth, Middlesex: Penguin Books.

Pandremenos, J., et al., 2011. Machining with robots: a critical review. *In: 7th International Conference on Digital Enterprise Technology, Athens, 28-30 September.* Athens: DET, pp. 1-9.

Pandremenos, J., et al., 2009. Modularity concepts for the automotive industry: a critical review. *CIRP Journal of Manufacturing Science and Technology,* 1 (3), 148-152.

Paralikas, J., et al., 2011. Product modularity and assembly systems: An automotive case study. *CIRP Annals-Manufacturing Technology,* 60 (1), 165-168.

Park, M., 2010. Defying Obsolescence Miles Park. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the Throwaway Society.* Farnham: Gower Publishing, Ltd., 2010, pp. 103-132.

Parkers, 2008. *Why does motoring cost so much?* [online]. Bauer Consumer Media Limited. Available at: http://www.parkers.co.uk/car-buying/2008/Why-motoring-costs/ [Accessed 06/28/2016].

Piscicelli, L., Cooper, T. and Fisher, T., 2015. The role of values in collaborative consumption: insights from a product-service system for lending and borrowing in the UK. *Journal of Cleaner Production,* 97, 21-29.

Power, K. and Mont, O., 2010. The role of formal and informal forces in shaping consumption and implications for sustainable society: Part 2. *Sustainability,* 2 (8), 2573-2592.

Pressnell, J., 1999. *Citroen DS. The Complete Story.* Hungerford: Crowood.

Prettenthaler, F. and Steininger, K., 1999. From ownership to service use lifestyle: the potential of car sharing. *Ecological Economics,* 28 (3), 443-453.

Prolific, 2016. *How Prolific Works* [online]. Prolific Academic. Available at: https://www.prolific.ac/about/prolific [Accessed 04/07 2017].

RAC, 2011. *Cost of Motoring Index 2011.* London: RAC Foundation.

Ramcharan, R., Van den Heuvel, S. and Verani, S., 2016. From Wall Street to main street: the impact of the financial crisis on consumer credit supply. *The Journal of Finance,* 71 (3), 1323-1356.

Rapley, T.J., 2001. The art (fulness) of open-ended interviewing: some considerations on analysing interviews. *Qualitative Research,* 1 (3), 303-323.

Razavi, B., Densmore, O.M. and Martin, G.W., 2002. *Upgradable Vehicle Component Architecture.* Washington D.C. US 6,370,449 B1. Patent Application 09/332,349. 2002.

Rebitzer, G., et al., 2004. *Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications.*

Reynolds, J., 2005. *Citroen 2CV.* 3rd ed. Sparkford, Somerset: Haynes.

Ritchie, J. and Lewis, J., 2003. *Qualitative research practice: A guide for social science students and researchers.* London: Sage.

Rivera, J.L. and Lallmahomed, A., 2016. Environmental implications of planned obsolescence and product lifetime: a literature review. *International Journal of Sustainable Engineering,* 9 (2), 119-129.

Robinson, O.C., 2014. Sampling in interview-based qualitative research: A theoretical and practical guide. *Qualitative Research in Psychology,* 11 (1), 25-41.

Robson, C., 2002. *Real world research: a resource for social scientists and practitioner-researchers.* Oxford, Massachusetts: Blackwell.

Rogers, J.G., Cooper, S.J., Cooper, S., Tingley, D.D., Braithwaite, N., Moreno, M., Rodrigues, A. and Salvia, G., 2015. Product longevity and shared ownership: Sustainable routes to satisfying the world's growing demand for goods. *AIMS Energy,* 3 (4), 547-561.

Rogers, J.G. and Rodrigues, A., 2015. Product leasing: a strategy to allow manufacturers and customers to benefit from elongation of product life. *In: PLATE 2015 Product Lifetimes and The Environment, Nottingham, 17-19 June.* Nottingham: Nottingham Trent University: CADBE, pp. 318-323.

Rouder, J.N., et al., 2009. Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review,* 16 (2), 225-237.

Rumsey, D., 2011. *Statistics for Dummies.* 2nd ed. Hoboke: Wiley Publishing.

Ryan, B., 2008. *Finance and accounting for business.* London: Cengage Learning.

Ryan, L., Ferreira, S. and Convery, F., 2009. The impact of fiscal and other measures on new passenger car sales and CO2 emissions intensity: Evidence from Europe. *Energy Economics,* 31, 365-374.

Rydén, C. and Morin, E., 2005. *Mobility Services for Urban Sustainability. Environmental Assessment.* Stockholm: Trivector Traffic AB.

Sachs, W., 1992. *For love of the automobile: Looking back into the history of our desires.* Berkley: University of California Press.

Salvador, F., Forza, C. and Rungtusanatham, M., 2002. Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions. *Journal of Operations Management,* 20 (5), 549-575.

Sanne, C., 2002. Willing consumers—or locked-in? Policies for a sustainable consumption. *Ecological Economics,* 42 (1-2), 273-287.

Saris, W. and Gallhofer, I., 2014. Concepts-By-Postulation and Concepts-By-Intuition. *In:* W. Saris and I. Gallhofer, eds., *Design, Evaluation, and Analysis of Questionnaires for Survey Research.* 2nd ed. New York: John Wiley & Sons, 2014, pp. 15-29.

Schifferstein, H.N. and Zwartkruis-Pelgrim, E.P., 2008. Consumer-product attachment: Measurement and design implications. *International Journal of Design,* 2 (3), 34-40.

Schot, J. and Geels, F., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management,* 20 (5), 537-554.

Schwanen, T. and Lucas, K., 2011. Understanding auto motives. *In:* R. Weinberger, E. Blumenberg and K. Lucas, eds., *Auto motives: Understanding car use behaviours.* Bingley: Emerald Group Publishing, 2011, pp. 3-38.

Schwanen, T., Banister, D. and Anable, J., 2012. Rethinking habits and their role in behaviour change: the case of low-carbon mobility. *Journal of Transport Geography,* 24 (Supplement C), 522-532.

Schwartz, S.H., 2003. *A proposal for measuring value orientations across nations.* Jerusalem: The Hebrew University of Jerusalem.

Schwartz, S.H., 1994. *Beyond individualism/collectivism: New cultural dimensions of values.* London: Sage Publications, Inc.

Schwartz, S.H., 2014. National Culture as Value Orientations: Consequences of Value Differences and Cultural Distance. *In:* V. Ginsburg and D. Throsby, eds., *Handbook of the Economics of Art and Culture. Volume 2.* Amsterdam: Elsevier, 2014, pp. 547-586.

Schwartz, S.H., 1992. Universals in the Content and Structure of Values: Theoretical Advances and Empirical Tests in 20 Countries. *Advances in Experimental Social Psychology,* 25, 1-65.

Schweimer, G.W. and Levin, M., 2002. *Life cycle inventory for the Golf A4.* Wolfsburg: Volkswagen AG.

Scott, K., Daly, H., Barrett, J. and Strachan, N., 2016. National climate policy implications of mitigating embodied energy system emissions. *Climatic Change,* 136 (2), 325-338.

Seitz, M.A., 2007. A critical assessment of motives for product recovery: the case of engine remanufacturing. *Journal of Cleaner Production,* 15 (11–12), 1147-1157.

Selinger, E. and Whyte, K., 2011. Is There a Right Way to Nudge? The Practice and Ethics of Choice Architecture. *Sociology Compass,* 5 (10), 923-935.

Shaheen, S., 2004. *Dynamics in behavioral adaptation to a transportation innovation: A case study of Carlink–a smart carsharing system.* Berkeley: Institute of Transportation Studies.

Shaheen, S. and Cohen, A., 2012. Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. *International Journal of Sustainable Transportation,* 7 (1), 5-34.

Shaheen, S., Cohen, A. and Jaffee, M., 2018. *Innovative Mobility: Carsharing Outlook.* Berkeley: Transportation Sustainability Research Center, University of California, Berkeley.

Shaheen, S. and Rodier, C., 2005. Travel effects of a suburban commuter carsharing service: CarLink case study. *Transportation Research Record: Journal of the Transportation Research Board,* (1927), 182-188.

Sheller, M., 2012. The Emergence of New Cultures of Mobility: Stability, Openings and Prospects. *In:* F. Geels, R. Kemp, G. Dudley and G. Lyons, eds., *Automobility in Transition?* Oxford: Routledge, 2012, pp. 180-202.

Shove, E. and Walker, G., 2010. Governing transitions in the sustainability of everyday life. *Research Policy,* 39 (4), 471-476.

Skelton, A.C. and Allwood, J.M., 2013. Product life trade-offs: what if products fail early? *Environmental Science & Technology,* 47 (3), 1719-1728.

Slack, N., 2007. *Operations management.* 5th ed.: Harlow, England: Prentice Hall/Financial Times.

Slade, G., 2006. *Made to break: technology and obsolescence in America.* Cambridge, Massachusetts: Harvard University Press.

Sloan, A.P., 1990 [1964]. *My Years with General Motors.* 2nd ed. New York: Currency Doubleday.

Society of Motor Manufacturers and Traders, 2018. *2018 UK Automotive Sustainability Report - 19th Edition - 2017 DATA.* London: Society of Motor Manufacturers and Traders.

Society of Motor Manufacturers and Traders, 2017. *SMMT Motor Industry Facts 2017.* London: Society of Motor Manufacturers and Traders.

Society of Motor Manufacturers and Traders, 2015a. *2015 Automotive Sustainability Report - 16th edition - 2014 data.* London: Society of Motor Manufacturers and Traders.

Society of Motor Manufacturers and Traders, 2015b. *UK new car registrations reach 10-year high in 2014* [online]. Society of Motor Manufacturers and Traders. Available at: http://www.smmt.co.uk/2015/01/uk-new-car-registrations-december-2014/ [Accessed 06/12/2015].

Society of Motor Manufacturers and Traders, 2014. *2014 Automotive Sustainability Report - 15th Edition - 2013 data.* London: Society of Motor Manufacturers and Traders.

Spurling, N.J., McMeekin, A., Southerton, D., Shove, E.A. and Welch, D., 2013. Interventions in practice: Reframing policy approaches to consumer behaviour.

Stahel, W., 2010a. Durability, Function and Performance. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the Throwaway Society.* Farnham: Gower, 2010a, pp. 183-204.

Stahel, W., 2010b. *The Performance Economy.* 2nd ed. Basingstoke: Palgrave McMillan.

Stahel, W.R., 1982. The product life factor. *In:* S. Orr, ed., *An Inquiry into the Nature of Sustainable Societies: The Role of the Private Sector.* Houston: HARC, 1982, pp. 72-96.

Steg, L., 2005. Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice,* 39 (2-3), 147-162.

Steg, L., Vlek, C. and Slotegraaf, G., 2001. Instrumental-reasoned and symbolic-affective motives for using a motor car. *Transportation Research Part F: Traffic Psychology and Behaviour,* 4 (3), 151-169.

Steininger, K. and Bachner, G., 2014. Extending car-sharing to serve commuters: An implementation in Austria. *Ecological Economics,* 101 (0), 64-66.

Steininger, K., Vogl, C. and Zettl, R., 1996. Car-sharing organizations: The size of the market segment and revealed change in mobility behavior. *Transport Policy,* 3 (4), 177-185.

Stern, P.C., 2000. New environmental theories: toward a coherent theory of environmentally significant behavior. *Journal of Social Issues,* 56 (3), 407-424.

Storchmann, K., 2004. On the depreciation of automobiles: An international comparison. *Transportation,* 31 (4), 371-408.

Sturgeon, T.J., et al., 2009. Globalisation of the automotive industry: main features and trends. *International Journal of Technological Learning, Innovation and Development,* 2 (1-2), 7-24.

Sunstein, C.R., 2014. *Why Nudge? The Politics of Libertarian Paternalism.* New Haven: Yale University Press.

Sushandoyo, D. and Magnusson, T., 2014. *Strategic niche management from a business perspective: taking cleaner vehicle technologies from prototype to series production.*

Tanner, C. and Kast, S., 2003. Promoting sustainable consumption: Determinants of green purchases by Swiss consumers. *Psychology & Marketing,* 20 (10), 883-902.

Thaler, R.H. and Sunstein, C.R., 2003. Libertarian paternalism. *American Economic Review,* 93 (2), 175-179.

Thaler, R.H. and Sunstein, C.R., 2009. *Nudge: improving decisions about health, wealth and happiness.* London: Penguin.

Transport for London, 2014. *Car Club Research. Draft Survey v4.0.* Unpublished ed. London: Transport for London.

Triandis, H.C., 1979. Values, attitudes, and interpersonal behavior. *Nebraska Symposium on Motivation,* 27, 195-259.

Triandis, H.C., 2004. The many dimensions of culture. *Academy of Management Executive,* 18 (1), 88-93.

Triandis, H.C., 1977. *Interpersonal Behaviour.* Monterey, CA.: Brooks/Cole Publishing Company.

Tukey, J.W., 1977. *Exploratory data analysis.* Reading, Massachusetts: Addison-Wesley.

Tukey, J.W., 1962. The future of data analysis. *The Annals of Mathematical Statistics,* 33 (1), 1-67.

Tukey, J.W. and McLaughlin, D.H., 1963. Less vulnerable confidence and significance procedures for location based on a single sample: Trimming/Winsorization 1. *Sankhyā: The Indian Journal of Statistics, Series A,* 25 (3), 331-352.

Tukker, A. and Tischner, U., 2006. Product-services as a research field: past, present and future. Reflections from a decade of research. *Journal of Cleaner Production,* 14 (17), 1552-1556.

Umeda, Y., et al., 2008. Product modularity for life cycle design. *CIRP Annals-Manufacturing Technology,* 57 (1), 13-16.

Umemori, Y., et al., 2001. Design for upgradable products considering future uncertainty. *In: Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium, Tokyo,* Tokyo: The Institute of Electrical and Electronics Engineers, pp. 87-92.

UNEP, 2011. *Decoupling natural resource use and environmental impacts from economic growth.* Nairobi: United Nations Environment Programme.

Upton, G.J., 1992. Fisher's exact test. *Journal of the Royal Statistical Society. Series A (Statistics in Society)*, 395-402.

Valentine, D. and Powers, T., 2013. Generation Y values and lifestyle segments. *Journal of Consumer Marketing,* 30 (7), 597-606.

van den Bosch, S.J.M., Brezet, J.C. and Vergragt, P.J., 2005. How to kick off system innovation: a Rotterdam case study of the transition to a fuel cell transport system. *Journal of Cleaner Production,* 13 (10–11), 1027-1035.

van Nes, N., 2010. Understanding replacement behaviour and exploring design solutions. *In:* T. Cooper, ed., *Longer Lasting Products: Alternatives to the throwaway society.* Farnham: Gower, 2010, pp. 107-132.

van Nes, N. and Cramer, J., 2006. Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. *Journal of Cleaner Production,* 14 (15–16), 1307-1318.

van Teijlingen, E. and Hundley, V., 2002. The importance of pilot studies. *Nursing Standard,* 16 (40), 33-36.

Venkatesh, V., Thong, J.Y. and Xu, X., 2012. Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS Quarterly,* 36 (1), 157-178.

Vergragt, P.J. and Brown, H.S., 2007. Sustainable mobility: from technological innovation to societal learning. *Journal of Cleaner Production,* 15 (11-12), 1104-1115.

Verplanken, B., Aarts, H., Knippenberg, A. and Moonen, A., 1998. Habit versus planned behaviour: A field experiment. *British Journal of Social Psychology,* 37 (1), 111-128.

Verplanken, B., Aarts, H. and Van Knippenberg, A., 1997. Habit, information acquisition, and the process of making travel mode choices. *European Journal of Social Psychology,* 27 (5), 539-560.

Vezzoli, C. and Manzini, E., 2008. *Design for Environmental Sustainability.* London: Springer.

Vezzoli, C., Ceschin, F., Diehl, J.C. and Kohtala, C., 2012. Why have 'Sustainable Product-Service Systems' not been widely implemented? Meeting new design challenges to achieve societal sustainability. *Journal of Cleaner Production,* 35, 288-290.

Volpato, G. and Stocchetti, A., 2008. Managing product life cycle in the auto industry: evaluating carmakers effectiveness. *International Journal of Automotive Technology and Management,* 8 (1), 22-41.

Wappelhorst, S., et al., 2014. *Potential of Electric Carsharing in Urban and Rural Areas.*

Ware, C., 1982. *Durable Car Ownership. A New Approach to Low Cost Motoring.* Bath: Morris Minor Centre.

Wells, P., 2010. *The automotive industry in an era of eco-austerity: creating an industry as if the planet mattered.* Cheltenham: Edward Elgar.

Wells, P. and Nieuwenhuis, P., 2012. Transition failure: Understanding continuity in the automotive industry. *Technological Forecasting and Social Change,* 79 (9), 1681-1692.

Wells, P., Nieuwenhuis, P. and Orsato, R., 2011. The nature and causes of inertia in the automotive industry: Regime stability and non-change. *In:* F. Geels, R. Kemp, G. Dudley and G. Lyons, eds., *Automobility in transition? A Socio-technical Analysis of Sustainable Transportation.* Oxford: Routledge, 2011, pp. 123-139.

Wells, P., 2008. Alternative business models for a sustainable automotive industry. *In:* A. Tukker, M. Charter, C. Vezzoli, E. Stø and M. Andersen, eds., *System Innovation for Sustainability.* Sheffield: Greenleaf Publishing, 2008, pp. 19-37.

Wells, P., 2004. Creating Sustainable Business Models: The Case of the Automotive Industry. *IIMB Management Review (Indian Institute of Management Bangalore),* 16 (4), 15-24.

Wells, P. and Xenias, D., 2015. From 'freedom of the open road' to 'cocooning': Understanding resistance to change in personal private automobility. *Environmental Innovation and Societal Transitions,* 16, 106-119.

Westkämper, E., et al., 1999. Integrated development of assembly and disassembly. *CIRP Annals-Manufacturing Technology,* 48 (2), 557-565.

Wheelan, C., 2013. *Naked statistics: Stripping the dread from the data.* New York: W.W. Norton & Company.

Whiteley, N., 1987. Toward a Throw-Away Culture. Consumerism, 'Style Obsolescence' and Cultural Theory in the 1950s and 1960s. *Oxford Art Journal,* 10 (2), 3-27.

Wiedmann, K., Hennigs, N., Pankalla, L., Kassubek, M. and Seegebarth, B., 2011. Adoption barriers and resistance to sustainable solutions in the automotive sector. *Journal of Business Research,* 64 (11), 1201-1206.

Wiedmann, T., Lenzen, M., Turner, K. and Barrett, J., 2007. *Examining the global environmental impact of regional consumption activities — Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. Ecological Economics,* 61 (1) 15-26.

Williams, A., 2007. Product service systems in the automobile industry: contribution to system innovation? *Journal of Cleaner Production,* 15 (11–12), 1093-1103.

Wise, C., 1996. *Lotus Elise. The Inside Story.* Unknown: New Media Television.

Wisercarbuyer, 2017. *Depreciation and residual value calculator* [online]. Wisecarbuyer. Available at: http://www.wisercarbuyer.com/depreciation-calculator.html [Accessed 10/27/2017].

Wosskow, D., 2014. *Unlocking the sharing economy: An independent review.* London: Department for Business, Innovation and Skills.

Wright, R., 2017. *Driverless vehicles learn to get along with city transport* [online]. Financial Times. Available at: https://www.ft.com/content/8fbba39a-34db-11e7-99bd-13beb0903fa3 [Accessed 06/07 2017].

Wright, D., 1997. *Understanding statistics: an introduction for the social sciences.* London: London: SAGE.

Wynn-Williams, M.S., 2009. *Surfing the global tide: automotive giants and how to survive them.* Basingstoke: Palgrave Macmillan.

Yuan, C.Y., et al., 2009. Embedded temporal difference in life cycle assessment: case study on VW Golf A4 car. *In: Sustainable Systems and Technology, 2009. ISSST'09. IEEE International Symposium on,* IEEE, pp. 1-6.

Zaring, O., et al., 2001. *Creating eco-efficient producer services.* Gothenburg: Gothenburg Research Institute.

APPENDICES

Appendix A. Research Questions branching from aims and objectives.

<table>
<tr><th>Aims</th><th>Objectives</th><th>Research Questions</th></tr>
<tr><td rowspan="4">The aim of this research study is to help reduce energy and materials required to manufacture and use passenger cars by developing successful policy options leading to changes in attitudes and behaviours towards more sustainable and less impactful car consumption and production.</td><td>To interrogate the automotive industry about the feasibility of designing and producing longer lasting passenger cars and shared, intensive use cars</td><td>To what extent are longer lasting cars feasible in design and manufacturing?
To what extent are shared, intensive use cars feasible in design and manufacturing?
Which barriers and opportunities exist for both concepts?
Do product longevity approaches apply to passenger cars?</td></tr>
<tr><td>To interrogate the car sharing sector, through its main stakeholders, about the systemic barriers found to upscale car sharing, but also the usage of its main asset, the shared car.</td><td>What are the most important systemic barriers towards upscaling car sharing?
Are there actors to attract car consumers into car sharing?
What is the role of policy makers in shaping car sharing?
How are car sharing cars acquired?
Relevance of technological advances to upscale car sharing?
How long is the service life of car sharing cars?
What are the systemic barriers for upscaling car sharing?</td></tr>
<tr><td>To survey and investigate passenger car users' attitudes and behaviour towards purchase and usage in regard to car sharing and car longevity.</td><td>How do car users use their cars and how open they are to car sharing and car longevity?</td></tr>
<tr><td>To develop policy options using interpersonal behaviour and cultural theories, envisaging a transition towards more sustainable consumption of passenger cars, to optimise passenger car lifespan and reduce its negative lifecycle impacts.</td><td>Which policy options could be created to incentivise passenger car users to adopt alternative forms of car usage and ownership?
How would a socio-technical regime evolve to the needs of communities through policy?
How could a flexible system be designed and implemented through national or regional policy to encourage the adoption of locally relevant models of car sharing for the needs of the local communities?</td></tr>
</table>

Appendix B. Research Consent Information Sheet.

NOTTINGHAM TRENT UNIVERSITY

Proforma: Research Consent Information Sheet

Protocol name	Semi-structured interview.
Principal Investigator:	Alexandre Rodrigues
Project Group	Centre for Industrial Energy, Materials and Products CIE-MAP
Supported By	Nottingham Trent University and Centre for Industrial Energy, Materials and Products

What is the purpose of this study?

This research aims to explore and assess policy and design interventions for scaling-up of car sharing and optimise the lifespan of cars.

What are we asking you?

You are asked to participate in a one-to-one recorded interview.

How we would like to use the information provided

The data will be used in my PhD research and some relevant publications.

Compliance with the Research Data Management Policy

Nottingham Trent University is committed to respecting the ethical code of conducts of the United Kingdom Research Councils. Thus, in accordance with procedures for transparency and scientific verification, the University will conserve all information and data collected during your interview in line with the University Policy and RCUK Common Principles on Data Policy (http://www.rcuk.ac.uk/research/datapolicy/) and the relevant legislative frameworks. The final data will be retained in accordance with the Retention Policy. All data will be anonymised and made available to be re-used in this form where appropriate and under appropriate safeguards.

What are the possible risks or discomforts?

Your participation does NOT involve any risks other than what you would encounter in daily life. If you are uncomfortable with any of the questions and topics, you are free not to answer.

What are my rights as a research participant?

You have the right to withdraw your consent and participation at any moment: before, during, or after the interview. If you do wish to withdraw your consent please contact me using my contact details as below.

You have the right to remain anonymous in any write-up (published or not) of the information generated during this interview.

You have the right to refuse to answer to any or all of the questions you will be asked.

You also have the right to specify the terms and limits of use (i.e. full or partial) of the information generated during the interview.

You have the opportunity to ask questions about this research and these should be answered to your satisfaction.

If you want to speak with someone who is not directly involved in this research, or if you have questions about your rights as a research subject, contact Professor Michael White, Chair for the Joint Inter-College Ethics Committee (JICEC) in Art & Design and Built Environment/Arts and Science at Nottingham Trent University. You can call him at 0115 848 2069 or send an e-mail to michael.white@ntu.ac.uk.

What about my Confidentiality and Privacy Rights?

Participation in this research study may result in a loss of privacy, since persons other than the investigator(s) might view your study records. Unless required by law, only the study investigator, members of NTU staff and the sponsoring organisations (Centre for Industrial Energy, Materials and Products, and Design Research Society) have the authority to review your records. They are required to maintain confidentiality regarding your identity.

Results of this study may be used for teaching, research, publications and presentations at professional meetings. If your individual results are discussed, then a code number or a pseudonym will be used to protect your identity.

Audio/visual recordings

Permission to use audio recordings of your participation is requested below, as this may be necessary to understand and communicate the results.

Any recorded data will be kept confidential and in a secure place in line with the Research Data Management Policy and destroyed in line with the current RCUK/University Guidelines.

Who should I call if I have questions or concerns about this research study?

07756511980

Appendix C. Informed Consent Form.

INFORMED CONSENT FORM

My name is Alexandre Rodrigues and I am doing research for a project entitled 'Driving in the Wrong Lane: Towards an Optimum Lifespan of Cars.

Cars have been identified in the literature as subject to planned obsolescence thus reducing their lifespan considerably. Also issues with reparability and cost versus market value, due to steep product depreciation have been identified as contributors to shorten the potential life of such product. On car usage by consumers, low occupancy rates of for example 1.6 persons per car in the UK and the fact that cars spend 96% of their time parked do contribute to the need of having cars being used more intensively to reduce their environmental impact, especially during user-stage. The initial research deductively explored these questions with designers and development engineers. The aim was to understand which of the two strategies, Longer Lifespan Cars (LLC) and User-intensive Cars (UIC), is the most effective and efficient in order to reduce the environmental burden associated with passenger cars.

The current stage is to assess from UIC experts (e.g. car-sharing, car hire, etc.) about the different barriers for the upscale of car-sharing and what are the current opportunities that need to be explored in order to facilitate such upscale.

The project is sponsored by Nottingham Trent University and also by the CIE-MAP Research Centre.

Professor Tim Cooper is the director of studies (supervisor) and can be contacted at:

Nottingham Trent University

Burton Street

Nottingham

NG1 4BU

Phone: +44 (0)115 115 848 4329

Email: t.h.cooper@ntu.ac.uk

should you have questions. Dr Matthew Watkins, Nottingham Trent University, is the 2nd supervisor. Dr Paul Nieuwenhuis, Cardiff University, has also been engaged in this project by acting as an external adviser.

Thank you for agreeing to take part in the project. Before we start I would like to emphasize that:

Your participation is entirely voluntary;

You are free to refuse to answer any question;

You are free to withdraw at any time.

The interview will be kept strictly confidential and will be available only to members of the research team. Excerpts from the interview / individual results may be made part of the final research report, but under no circumstances will your name or any identifying characteristics be included in the report.

Please sign this form to show that I have read the contents to you.

____(signed)

____(print)

___/____/________ date

Please send a report of the results of the project

YES NO (circle one)

to the following address (if YES).

____

____

____

____

____

____

Appendix D. Informative Business Interview Questions. Automotive Industry.

Informative Business Interview Questions. Automotive Industry.

Introduction:

I will introduce the problem of End-of-Life Vehicles (ELV), the potential for lifespan extension and give an overview of the problem of material scarcity and over consumption.

Questionnaire:

1. What is your perspective of ELVs from a business and environmental point of view?

2. Which, do you think, are the strengths and weaknesses generating opportunities and threats for the current ELV policies?

3. I am familiar with your business model. Can you explain it in more detail? Especially the current relationship with suppliers and clients?

4. Considering your business model what are the factors that will make your product appealing to clients? And how would you describe these potential clients?

5. If you extend the life of your vehicles, say for more than 20 years how will that affect your relationship with your supplier network and clients?

6. In the auto industry several strategies have been identified to prolong the lifespan of cars, (e.g. take-back, repair, re-use, remanufacture) and therefore divert and reduce ELVs. Are you aware of any other strategies (technical or not) that may contribute towards longer lifespans of cars?

7. Which of the above strategies do you think is most viable for industry to develop, and why?

8. From a business perspective how would processes such as upgradeability, and structural modularity contribute towards optimised lifespans of cars and reduce ELV volumes?

9. What are the technological, economic, regulatory and policy limitations that may hinder optimised lifespans of cars?

Appendix E. Interview Set 1. Research Questions – Automotive Design LLC and UIC.

Interview Set #1

Research Questions. Automotive Design

Forecasts for steel, cement, plastic, paper and aluminium until 2050 foresee a sharp rise in demand due to a growth in middle class numbers and population rise. Some researchers propose that in order to save material and energy demand, we should use less materials and in a smarter way and also, among other strategies optimise the lifespan of products. Despite nowadays cars last in average 12-14 years, prolonging their lifespan for more than 20 poses an interesting, but somewhat difficult challenges to the current automotive industry and also to our society. In order to lower demand for materials, there are streams of thought who defend a completely new type of industry, with a different design for their vehicles, different production methods and also different business models, sustainable from their genesis, and in line with policy, not fighting it, but aligned with consumers interests.

Research Questionnaire

1. Imagine you were given two concepts; one that would devise a twenty-year lifespan and allow upgradability but would halve production numbers or a user intensive one used by five people during the week with little idling time between users therefore producing four cars less per person but with a normal lifetime and no upgradability which one would you choose and why?

    1.1 How would these two concepts drastically change the design and/or development process?
    1.2 What design barriers and opportunities can you see for both concepts?
    1.3 What other barriers can you identify that could hinder the whole process? (e.g. process, regulation, social.)

2. If the vehicle design was to be changed in order to accommodate easier disassembly, repair upgrading and re-use of remanufactured components which technical specifications do you think should be incorporated?

2.1 If vehicles were comprehensively modular, i.e. systems, subsystems and also the structure, would the whole vehicle optimisation be compromised?

3. As a car designer/developer, if you were to extend the average lifespan of cars, say for more than 20 years, how would that affect your approach to vehicle design and engineering?

4. How would you design an optimal lifespan car with less material?

Appendix F. Interview Set 1. Thematic Analysis Coding Structure.

	Interview Set 1		
	Optimal Lifespans		
Sub-codes	**Codes**		**Sub-codes**
	Longevity (LLC)	Use Intensive (UIC)	
	Design for Product Attachment (DPA)	Business (BUS)	
Design for Remanufacturing (DFRM)	Design for Disassembly (DFD)	Design and Development (DAD)	Design for Multifunctionality (DFM)
Design for Repair Service and Maintenance (DSM)			
Design for Reuse (DFR)			Design for Shared Use (DSU)
Design for Upgradability and Modularity (DUM)			Integrated Functions (IF)
	Design for Durability, Robustness and Reliability (DDRR)	Regulations (UICREG)	
	Design for Variability (DFV)	Service on Availability (SOA)	
	Regu	Service on Demand (SOD)	
		Market (MRK)	Age groups (AGE)

Appendix G. Coded Interview Transcript Sample.

Coded Interview Sample			**Date**
Interview Set 1 **Interviewee E4**			03/02/15
Name	**Time**	**Interview transcript**	**Code**
AR	**00:00:15**	#####, thank you very much for your time. I know you're always busy and I really appreciate the time you're taking to answer the questions. So, let's start with the first one. Imagine you were given two concepts by your managing company, one that would devise a twenty-year lifespan and allow upgradability of its components but would halve production numbers or a user intensive one used by five people during the week with little idling time between users therefore producing four cars less per person but with a normal lifetime and no upgradability. Which one would you choose and why?	
E4	**00:01:00**	Well, I think what you need to look at is the overall economics. And one of the areas that might be interesting to look at is the comparison with LED lighting, where a similar situation's arising; you have a new technology coming in which is to last longer. And initially, the initial costs are much higher. So, from a business… are we looking at this from a business point of view or from a user's point of view?	LLC
AR	**00:01:35**	From someone who has been designing and involved in design of cars for quite a lot of time. But you can use business if you think is relevant. It's absolutely fine.	
E4	**00:01:49**	I think there's lot of different angles on this. From a simple design point of view trying to conceive of a product in this space that would still be relevant in twenty years' time, even allowing some level of upgradability it's difficult to imagine. If you imagine a car twenty years ago comparing with a car now, it would simply be not competitive in any fashion. So, I think more realistic would be to have a car that is, if you like, on a conventional replacement cycle, or redesign cycle but used by more people to achieve the same result. But of course, from a manufacturer's point of view that's exactly the opposite of you want to achieve. Because you want to maximize your return on development costs which means selling many vehicles as you possibly can. And so, I think those are the tensions that cars at the moment… well the other side is that cars are identified as very much as an	LLC DUM

		extension of an individual's personality and not simply a means of getting from A to B. That's a bus.	
AR	**00:03:06**	Or a taxi.	
E4	**00:03:07**	Yeah. So, the difficulty with both models, with one model you could get something that is much more highly personalized to somebody and potentially upgradable to suit as that personality changes. But it's difficult to imagine how the technology would remain competitive. On the other hand, you have a situation where you are trying to design a product that appeals sufficiently to a group of people so I'd suggest there you would be looking at something much less… something much less personalized and the only way of doing that would be you'd have to have something significantly better economic proposition for the buyer. So, the cost overweighed all the other things and people will go and say ah, it just makes sense.	LLC UIC DAD DUM DSU
AR	**00:04:01**	Going back to the LED lighting that you were mentioning and didn't finish what you were saying. I was quite interested in that	
E4	**00:04:11**	Well, I was just wondering if there are parallels that could be seen in the lighting industry. Really come to terms with LED technology in that clearly there's a market demand for it. It is so much more efficient and… but at the same time there's a knowledge that it's killing the replacement bulb business. So, you got two things going on there. You've got new building that will almost inevitably have to have the LED lights and therefore it's extra revenue generation because LED lights are more expensive than the light incandescence. But then your replacement market is just… it's gonna be, if anything, increased in the short term but there will be a half-life on that and will eventually dwindle to almost zero. You know. LED lights last for twenty years or so, potentially. I don't know the answers but it will be interesting to see how that industry was responding. And also waning paths that kind of thinking as how of products themselves. Because one thing that is happening is that people now designing the lights where you can't change the bulb. You change the all light fitting.	LLC
AR	**00:05:33**	Usually a cluster, isn't' it? The LED lights?	

E4	**00:05:36**	It can be, yeah, usually at the moment. So it would be interesting to think through a little bit further on what unexpected impacts these kind of changes in technology might have in terms of, for example, if you only buy a car every twenty years what does that do to the dealer network? How you got that selling point covered? All that sort of stuff.	LLC
AR	**00:06:02**	Well, some people think of… they've been proposing new business models instead of just selling the vehicle, selling the service of the vehicle, whereas the company, either the manufacturer or the company providing that service for them has that leasing for a very long time. So there's a stream of revenue still coming to the company, not from a one sale of, but from that extended leasing, if you like. Do you have any opinion on that? Any views?	UIC BUS
E4	**00:06:45**	They… it's interesting because that's in a way, that model it's something that the military has come down in the past where really what they are doing nowadays is buying a capability rather than hardware. And so, in some respects, that model is saying the same thing. You don't go to the dealer and pay your car, you go to a dealer and buy the service, the capability of the car. The other question… the other thing that comes to mind is thinking about the twenty-year model and upgradability, probably a lot with that as well depends on what your perception of the maturity of the car is. So, for example, you go back to something very simple like an electric plug. The design of that is extremely mature, and a plug that worked fifty years ago will work perfectly well today. And the user does get no real feel for any deterioration in performance. Now if you could imagine that cars have got to that point, or close to, then you can imagine them having a longer life. If we've still developing and… well it depends on and how we are still developing. And it's probably an interesting question because if you look at where the major developments are happening today, not all but a lot of them are in the electronics. So, if you consider the hardware to be a mature design maybe upgradability and retention of competitive performance is an option. I suspect we're not quite there yet, maybe it's within sight.	UIC SOA
AR	**00:08:36**	So, software could be… because software is already upgradable, as you know, as a good example. But you'll have to be sure that the hardware will cope with that software. Because we know with our mobile phones and computers, you know, the upgrades keep coming everyday but	

		sometimes the hardware doesn't cope with those… and sort of make them obsolete earlier than they should.	
E4	**00:09:03**	As I mean, crash protections are a perfect example of that. Where you could argue that people pretty much got the design now sorted to look after occupant protection, but we now starting to have to develop vehicles for pedestrian protection as well. We are developing vehicles for pedestrian protection. And that's changed the technology. It's changed the design of the (incomprehensible) the front end of a vehicle. Now, if you're locked in to a twenty-year structure, it's difficult to imagine how you would be able to do that.	LLC DUM
AR	**00:09:39**	You mentioned changes in design. Do you think there would be, for these two concepts, so the longer life and the user-intensive one, do you think the design and development processes would change drastically, from what we have nowadays?	LLC UIC
E4	**00:09:59**	I don't think the processes would necessarily change, but I think the constraints and considerations would have to change. Because what you've have to do is to build in a whole lot more modularity into the design to allow complete modules to be updated and that almost necessarily would lead to less integration within the vehicle and ultimately, potentially less optimization to today's requirements.	LLC DUM
AR	**00:10:35**	Would that increase, do you think that would increase complexity and weight? Or is it something that could be circumvented with clever design?	
E4	**00:10:49**	I think inevitably it would increase complexity and the weight compared to not necessarily what you would have as an optimum today, but I still think, you know, an optimum package with everything properly distributed would be more efficient than a modular design. But on the other hand, if you then think five or ten years or fifteen years down the line, once you've started swopping those modules out, then you're limited by the architecture, fundamental architecture, and new vehicles that have been designed will have pushed those in different directions. And you could imagine some examples, so, you could imagine at the moment a lot of electronics on cars in is CAN, it's twisted pair. You could imagine in twenty years' time the CAN fitted in a car that may no longer be applicable. You may want to have optical fibre, you may for example, then in the future if you want optical fibre, the optical fibre embedded in some	LLC DUM

		sort of carbon fibre structure. But you wouldn't dream of doing that today on a production viable vehicle.	
AR	**00:12:11**	So do you think disruptive technologies can sort of, can be an obstacle or because we don't know in five years' time if there's gonna be a new disruptive technology that might not be compatible with what we have nowadays.	DUM
E4	**00:12:26**	I think that's the biggest danger with long term design definitely. And if you consider right now, we know we need to achieve CO2 reductions so we need light-weighting but do we know carbon fibre is gonna be a cost-effective solution? Probably not.	DDRR
AR	**00:12:47**	Probably not because it's energy intensive to produce and exactly the opposite of what we are trying to do.	
E4	**00:12:55**	You know people always underestimate conventional technology. So for example even steels, exotic alloys, new ways of forming, new strengths, new alloys are coming along, meaning that you can create lighter stiffer structures.	DDRR
AR	**00:13:12**	Do you think design has a role in that? In changing the way, we, say, build a door panel or a complete door structure?	
E4	**00:13:23**	I think the two can work together. I think the materials technology and design have to work together in that the materials technology opens up new potential and imposes new constrains on the processes by which can manufacture something. So that allows different freedoms and constraints for the designer. And therefore, I think the designer has a heavy roll in terms of what… in terms of making the best use of material properties.	LLC
AR	**00:14:03**	Do you see any design… well you mentioned some barriers already; design barriers and opportunities for both concepts. We've talked a bit about modularity and we're gonna go to that further down the line. For the user-intensive model can you see any particular barriers? In terms of design. Or do you think it would be the same sort of vehicle nowadays. Because if you think of, you know, the car sharing companies or hire cars, they are very normal cars with no changes, with no structural changes, no… it's a fairly standard model.	DUM UIC DSU
E4	**00:14:50**	I think… it's interesting. In principle you would say there wouldn't be any differences because, you know, cars are designed on which they do appeal to a sector of people and you'd expect those people to naturally come together in a car sharing call, if you like. But, I think what you need to look at is what would drive those people to want to share a	UIC DSU MRK

		vehicle. It has to give them some advantage over owning one today. So, the alternatives would be; it's significantly cheaper. Well, you could argue that actually it would be significantly cheaper today if people did that, you know four people can get together and buy a car, sharing between them but how often does it happen? So, why doesn't it happen? You'd have to address those cause.	
AR	**00:15:55**	Do you think within say a product service system scheme where you buy the service and the service will provide you with a car that you'll probably share with other people, so let's say, you've got, you know when you've give the example of the five people using that car; let's say you need the car for you to commute to your work at that slot of time, you may share it with someone with the same slot that lives nearby or you just use the car for that slot and someone else picks up. I know this is, logistically very complicated but…	
E4	**00:16:30**	Well what's interesting, logistically is complicated unless you talk about driverless car. The second you talk about driverless car it makes perfect sense.	IF DAD DFM DSU
AR	**00:16:42**	And it takes away some other, I think issues, some people mentioned in previous interviews, which is; you've got different people with different driving styles and that puts a strain into the… well into the longevity of the vehicle itself, although some cars nowadays are adaptive. They adapt to your driving style. With a driverless vehicle that would completely vanish, that problem. So, you'd have always the same sort of driving style. You don't have angry drivers or very slow drivers so, it's… Do you think there's a potential there, if this concept would go forward, you already mentioned that there's an opportunity there?	
E4	**00:17:29**	Yeah, I think so. And I think all this is part of the answer to what you get out of this service that's different from what you could do if you shared a car today. And why do people not share a car today. Probably part of it is the sheer logistics of it. And also, there's the fact that cars are not actually very expensive. Yes, a new car, but for a thousand Pounds you could be driving around quite happily, quite reliably, so why would you not have your own car? And I think that's the, that's probably the thing to get over. And as I say, the way I look at it is you have to give people feature that is… what you gotta do is two things; you gotta overcome whatever fears they have about changing the model, so one field as you say would be, what if one of the guys is an idiot and trash the car? I don't want that. So that's one of the things you have to overcome and driverless cars,	DSU MRK BUS SOA SOD

		for example, would be a way to do that. The other is they need to be able to have a car when they want to. So, you'd have to have some sort of a system that actually allow all five people to be able to drive a car at the same time. So that again suggests having a larger pool that's drawn from… So, if your pool is big enough and the number of people picking up this, you work up the ratios and say well, actually I've got five thousand people and I only need two thousand cars, for example. And so, I think then you look at it and you go beyond that say; well ok you've addressed the fears, what are the attracters. And, you know, one of the potential attracters, you know, one of the potential big atracters would be you don't actually have to drive. So, you can use the time in the car productively. Or you can go to sleep… Another one would potentially be that the car is in some ways superior to what you otherwise have. So, for example, if by sharing a car you could drive around in the equivalent BMW X5, whereas if you were doing it on your own, you might have a Ford Focus. Then maybe that becomes attractive to a certain part of the market. It's that… it's understanding who's gonna buy into the concept and why, then tailoring the product suit.	
AR	**00:20:06**	Do you believe the younger generations would be more open to sharing a car then people from our generation?	AGE
E4	**00:20:16**	I think probably so. There's a few interesting things going on with the young generation at the moment. And they are typically not as many learning to drive at seventeen as in the past. A lot of them are delaying it till later and who knows whether they'll eventually even bother. I think there's a change in how people are interacting so that having mobility of a car in past generations were critical to even being able to almost have a social life. And yet so much social life now is actually done online and the car and physical presence becomes then less important. And also of course, the cost are just… the costs of driving a car now relatively to twenty years ago for young drivers are high because of the insurance costs.	AGE
AR	**00:21:17**	And you've got nowadays half of the world population living in large towns where you've got a public transport system in most of them is fairly good.	
E4	**00:21:30**	Yeah, and you also get the case that the car is seen as a liability. You have to find somewhere to park it, it could get vandalised, get stolen, broken into and again, a lot of people don't want that responsibility. So, having the ability to call	AGE SOD

		on a car when they want it but not have it all the time is attractive then you can have that within the current hire car market. And the question then will be why doesn't that work with more people. And again I would give us an example of my son for example, who doesn't have a license. He lives in a big city and probably would like to use a car maybe thirty times a year. But it wouldn't occur to him to spend fifty, sixty pounds a day to hire a car. So there's some strange dynamics going on. Even though doing that would be far cheaper than buying or running even a cheap car.	
AR	**00:22:40**	Cos if you're an occasional user that might be cheaper than owning a car.	
E4	**00:22:46**	It absolutely is. There is some work done by the people that make the London taxi. Probably about going back to twenty years ago and they were looking at the number of people in a vehicle, average journeys, journey times and all the rest of it. Looking really at the taxi fleet. But one of the pieces of research they commissioned was the cost of using public transport and taxis compared to owning a car. And for something like ninety five per cent of the population it would be cheaper to using public transport and taxis rather that owning a car. And yet ninety five per cent plus of the populations are owning a car and use it almost exclusively. So there's some deep psychology going on there.	MRK BUS
AR	**00:23:46**	Actually you have to delve into it to understand why do people have this sort of attachment to cars or owning a car.	DPA
E4	**00:23:56**	Well, let's hope they keep having that attachment. We'll all be in trouble.	DPA
AR	**00:24:03**	Can you identify other barriers in the process? You can use both concepts or just one.	
E4	**00:24:15**	Well, I think the barriers…the barriers if we're talking about design process, the barriers for the long life car are clear in terms of being able to imagine what changes might need to be design protected for. I think that's very, very difficult. And not impossible, but difficult. I think also probably one of the bigger barriers is imagining how you could create styling as it was acceptable and attractive for length of time. If you look at the history of cars, there are very, very few kind of iconic designs that have had a twenty year life. Most of them when they get to four or five years old they're looking pretty odious. So I think that's probably the greatest barrier there.	DUM
AR	**00:25:15**	Do you think regulation is a barrier? In the sense of… specially in safety because nowadays every what, three, five	LLCREG

		years new regulation coming out with new requirements. Do you think that would be hard to predict? Or is it possible to predict?	
E4	**00:25:35**	I think that is more likely to be predictable at least in terms of direction. So you may not know what your absolute requirement is, you can I think, project the direction. The danger is the detail means your concept is not fit for purpose after a certain period of time. So, to an extent, I think you would have to create a situation where the legislation, or the legislators were on board with the concept and to take that into account. So, I mean it's like in the moment you can perfectly legally drive around a twenty year old car, a fifty year old car. Doesn't matter. But its performance isn't such that most driver would not want to do that every day. And the reason the performance isn't as good in a lot of respects it's because the drive of legislation. So legislation stripped off all safety features, most of them, its driven the emissions, which has also driven engine performance and now we're getting into CO_2 reduction as well. So we're actually at a less predictable point than any time we had in the last fifty years. From the point of view that we've got no certainties as to what the right driveline solution is gonna be going for. So for example, if you were to design a car today, you would probably design it with a combustion engine and some form of hybrid driveline or energy recovery. As times go by battery technology will change which means the engine will become massively bigger than it needs to be, in all probability. And the trend it will be towards more battery power, less combustion engine power, for example. At the same time we've got fuel cell technology coming on board and a lot of investment in hydrogen infrastructure. So you can imagine a situation where you might need to plan for removing the combustion engine and replacing it with a fuel cell. Replacing the gasoline or diesel fuel system with hydrogen fuel system. But then you starting to look at it in so well you gotta design each system for the worst case scenario going forward. So for example, fuel cell vehicles need a lot more cooling capacity than a conventional engine. So you'd have to design a car that would have adequate cooling capability for fuel cell for a gasoline or a diesel engine in. That would impact on your aerodynamic efficiency. So you have all these different constrains when you get into the detail of it. You'd say hmm, how does that will actually work.	LLCREG DUM

AR	**00:28:56**	Do you think hypothetically the upgradability would solve that? That sort of uncertainty about the future in terms of design and regulation?	DUM
E4	**00:29:11**	I think it could, but what I think I am getting at is that in design protecting for all the possibilities you got the danger of designing a camel, if you like, you know. If you conceive of a way that maybe actually the only thing that needs to stay constant is a central safety cell. And everything else you could change then potentially yes, you could do that, the upgradability.	DUM
AR	**00:29:45**	But even that hard point which is the safety cell, or the hard points inside the safety cell might change in time through legislation, through technology and…	DUM
E4	**00:29:58**	And then could go both ways, actually. So for an example; at the moment cars are designed to meet an insurance requirement that if you have a crash below a certain speed, I can't remember what it is, it's between five and ten miles per hour, then that shouldn't be any damage to the vehicle whatsoever. I've doing some work with one car manufacturer where they've got collision avoidance systems in that actually prevent low speed impacts. Cos it apply the brakes and stop you doing it. So they're looking then and say, well actually we don't need to design all this low speed protection stuff cos the car cannot, will not crash at those speeds and you could imagine that for example going forward. If you think about the amount of structure needed in a car today to protect you in the case of a frontal impact, if you could conceive a system that eliminated the potential risk of the frontal impact, you could make that structure so much lighter.	LLCREG UICREG
AR	**00:31:06**	Yes. Absolutely. Do you think driverless vehicles have an opportunity there? Because some people, some people say that yes, because the car won't crash. But other people say well, you cannot be one hundred percent sure the car won't crash there might be a failure, an electronic failure or some sort of, I don't know, hacking into the system and the car just crashes. What's your view on that?	
E4	**00:31:35**	I think, it's a really difficult area. And one of the reasons why driverless cars will take a lot longer to take to market than people expect. The reality I think it is if you put a driverless car on the market, it must be to all intents and purposes impossible for it to crash. Because can you imagine the situation where you have vehicles that do crash, all right they might be very rare occurrences. The other vehicle that	

		does crash, then what kind of litigation and cost back to the manufacturer will come from that lawsuit associated with that vehicle crashing and potentially killing people? I don't think you could put a product into the marketplace that is known, has the potential to cause death and injury. So I think from a functional safety point of view those cars have to deal with those cases. Now, of course, will always get the kind of totally unpredictable and unmanageable situation like a tree falling on in front of the car or, you know, someone driving in front of you. So, there always have to be some level of… a bit inherent safety. But I think what you would be able to do potentially is having different systems, different solutions associated with the electronics.	
AR	**00:33:14**	To mitigate that.	
E4	**00:33:16**	Yeah.	
AR	**00:33:18**	If vehicle design was to be changed in order to accommodate easier disassembly, repair, upgrading and reuse of manufactured components, this is to do with the end-of-life vehicles. It's another sort of stream of reducing energy and material usage is by reusing and remanufacture. Parts and systems. Which technical specifications do you think should be incorporated in the vehicle that we don't have nowadays? I know there's quite a lot of legislation, companies are doing an effort for disassembly at the end-of-life mainly through the EC directive from 2000. Do you think something better could be achieved in that sense, in terms of design a vehicle for that.	DFD DFRM DSM DUM DFR
E4	**00:34:29**	Yeah, I think it's an interesting one. If you look at modern vehicles I would argue they're designed… that there's very little consideration within their design for reparability. The emphasis is much more on designing all the systems so they will last for the lifetime of the vehicle. And… and probably that, that plays into part of why people buy new cars. People buy cars for totally irrational reasons. But one of the things that seems to be common is a fear either annoyance at continuing spending money; so for example, they'll spend twice as much in buying a new car that's more fuel efficient than they would ever spend on fuel for their old car. And also, when a car starts to have any failures, people will often sell it because of the fear of high cost of repair.	DSM
AR	**00:35:38**	But because the cost of repair in older cars is higher than the value of the vehicle. So people sometimes think; is it worthwhile for me to spend two or three thousand Pounds in a car that's just worth a thousand.	

E4	**00:35:53**	Absolutely.	
AR	**00:35:55**	Because depreciation is a big, big… well it's probably the biggest cost when you buy a car.	
E4	**00:36:00**	It absolutely is. And I think that's the challenge, the kind of challenge with the reconfigurable car. Because, again, it's like… it's like if you drive a ten or twenty year old car. You could, for example, take the engine out and replace it with a new engine and you would expect to have overhaul in terms of driveline at least, reliability similar to a new car. But people just don't do it. And it's for the reason you said, I think. That put three or four thousand Pounds for a new engine into a vehicle that's maybe worth that, people looking at would say: well, I am putting all this money in and I am getting nothing back. But again, even that is nonsensical. When you really analyse it because if you put five thousand into a car then a year later you lost money. It's not worth that anymore.	DFR
AR	**00:37:00**	It's still depreciating. Do you think… again coming back to the twenty year old car with the upgradability sort of concept embedded in. Do you think that would change the depreciation curve that we have nowadays. So instead of being that sort of, you know, deep curve after three years, if it was a smoother curve. Do you think that would happen or would still have the same sort of pattern in depreciation?	LLC
E4	**00:37:32**	I think a lot of that probably goes along, I think with warranty. I am trying to think why you get a massive depreciation after three years. I mean, one reason will be the impact of company cars, because suddenly you won't see so many cars on the market that are one year or two year old. Because most of company cars are on a three year lease, then the market gets flooded with three year old cars. So it's probably an impact to the market time, I mean that is driving that rather than anything inherent. But then there's also the other fact that after three years vehicles tend to come to the end of the manufacturer's warranty. So again, people fearing the cost of repairs will buy a new car with a one hundred percent… with a normal warranty on it. So how would that change?	DDRR
AR	**00:38:32**	Because if you think of the car as a company asset, let's say the service company or the service provider, again going back to that sort of business model. Because that's an asset of the company, you want that thing to last as long as possible, or at least to perform for the whole lifecycle to perform as much as possible. Because it's your own asset	UIC

		and you want to make money out of it, like a machine in a mill or something.	
E4	**00:39:00**	Well, it is except that the tax laws mean that the employee doesn't want to be driving in an old company car. There's no value to an employee to do that, because you get taxed on the… it's all based on the price of the car when it's new. So, if you drive a five year old car you get taxed on the price it was when it was new. So, therefore from an operator's driver point of view why would they wanna do that? It cost them more to do that then to run throughout the car. So again, there would have to be a shift in legislation to make that model work. I think if you then looked it from a business point of view, then what business is gonna look at it is the total cost of ownership. And defray that over the years in which that vehicle is performing. So if you could come up with a model that said, actually keep this vehicle ten years, twenty years is… you reduce your overall operating cost significantly then a business would be interested in that. Clearly. And I think equally that would be a similar argument to use with people.	UICREG
AR	**00:40:29**	Because people don't look at the overall cost of owning a vehicle. They only look at probably the price. You know, the fuel efficiency or emissions.	
E4	**00:40:40**	Price, fuel efficiency, tax. But if you could come up with, for example, if you could come up with a model that said this is a car… and maybe the way you'd have to actually have to model it, it's to say; ok this a car that you loan for twenty years. It will get upgraded every three years to your specification, and the difficulty would be overcoming that fear of driving around a twenty year old car. And the social stigma that attaches to that, and the implication being, well if you got a twenty year old car, you obviously not doing very well. You can't afford to buy a new one. You know, it's real.	LLC DPA DDRR
AR	**00:41:36**	Now, one of the most controversial questions I have got here is about modularity and you sort of touched it. If vehicles were comprehensively modular, their systems, sub-systems, structural modularity, do you think vehicle optimisation would be compromised?	DUM
E4	**00:41:58**	I think, I think it would be… I'm hesitating because I'm thinking to some extent this is what really happens in the aerospace world. And aircrafts do get substantially updated at points through their life.	DUM

AR	**00:42:21**	00:42:21 But probably because of the value of that aircraft is higher than a vehicle, isn't it? It makes sense to do it.	
E4	**00:42:29**	Well, to some extent but also the operating costs are extremely high. So, I don't know what the balance is between, if you like, asset value and operating cost, if that is substantially different from a car or not. Might not be as far away as you'd imagine and so, in principle I'd say yes, but the reason I'm hesitating is that if I'll look at some older cars, that are still very competent in everyday use, and I look at it and think, well ok, if we took a twenty year old car and what features and systems would you upgrade and you'd say, well we'd upgrade the engine, the exhaust, you probably, possibly upgrade the brakes, but that might not be on the mechanical side, but a bit more on the ABS side. You could upgrade the electronics and entertainment for sure. So you start to look at it and say, well actually if you put modern systems into a twenty year old car, would it be… would it still be competitive? And probably the only area that wouldn't be competitive really would be on crash protection, I think. Which is a significant issue for sure.	DUM
AR	**00:44:05**	But having that structure model to be upgraded, do you think that would be technically possible? Taking off costs or taking away costs from the….	
E4	**00:44:19**	Technically you could. Yes, I think you could do it technically. But there would be a lot of… well, you'd either had to have a lot of compromise in your initial design or you'd have to accept a massive level of rebuild, potentially at some point down the line.	DUM
AR	**00:44:40**	Do you think that would take away the optimisation?.. or not?	
E4	**00:44:45**	If it was done… if it was done extremely cleverly then it would… I think, I think you'd still suffer in terms of optimisation if in no other way than in production process. And your production time for the vehicle. I think would inevitably higher because you'd be using, for example you'd be using fasteners that allowed you to disassemble the vehicle easily. So just doing things like that would result in a sub-optimal solution.	DFD DUM
AR	**00:45:27**	Well, we've mentioned question three already; as a car designer if you were to extend the average age the lifespan of the car how would that affect your approach to vehicle design and engineering. You sort of answered to that. Would you like to add anything to that?	

E4	**00:45:40**	Yeah, there's one thing that I would change on that and would add to that. And that is if you can create a vehicle that is so appealing people just don't want to... and I think we've all add a car that we really liked and got rid off, because it felt to pieces, for example. So I think if you could create a car that was sufficiently attractive that people just fell in love with it and wanted to keep it then I think that's a different angle on it, because then they would actually accept certain, if you like, deficiencies because they like the car.	DPA
AR	**00:46:32**	So a certain sort of product attachment?	DPA
E4	**00:46:36**	Yeah.	DPA
AR	**00:46:37**	More deeper… deeper than the one we have nowadays with cars.	
E4	**00:46:42**	Typically, yeah.	DPA
AR	**00:46:48**	Going back to… another question I want to ask you because you've got quite a lot of experience in testing. And some people already mentioned it, if you create a car for twenty years, the duty cycle will have to be heavier or more comprehensive, more… robust. And the testing would have to be longer.	LLC
E4	**00:47:15**	To some extent. But it depends on your approach. If you go back to aerospace industry they have an approach where systems are designed with a certain life and they are validate to have that life. And after that life they get replaced. That goes right even to engines. So, if you adopted that principle to the car and you say ok this part of the car is designed to last forever. And from a fatigue point of view, what that means is you have to be operating in either an infinite fatigue region which you can do with steels, for example. Or you're operating so far below the ascend curve that you effectively got infinite life or certainly you got twenty year life in a vehicle. And actually when you look at cars even current cars, they're already there. You know, it's almost unheard of that you'd have a fatigue failure in the body of a car for example, any other than major suspension components and so on. So it's kind of already there from that point of view.	DDRR
AR	**00:48:28**	But they're tested for ten years aren't they? In average.	

E4	**00:48:32**	They're typically tested… well and this is an example; cars are typically tested for a hundred thousand miles, maybe a hundred and fifty thousand kilometres or something of that nature. But often especially at premium cars they're tested for significantly longer than that. Because it's not just about the length, it's about the roughness of the roads it goes as well. So the two things play together. And… but then if you look at a truck, a truck can be tested for a million kilometres. And yet it's a much lower volume product. So, that's built into it. And what happens with other significant number of chassis components in trucks is that they're not necessarily tested for a million kilometres. They're tested to a point where they're beyond the 'knee' of the ascend curve. So they're into the infinite fatigue region figure. So you test them to that point, so it's not gonna break. Same happens with exhaust systems, for example, on cars. So, there would be implications but I think you could… if you did it intelligently you could have certain parts of the system which were just designed to be… have effective infinite life. And then you can have other systems on the vehicle that you expect to upgrade anyway.	DDRR
AR	**00:50:01**	Because components age in different ways in cars anyway, don't they?	
E4	**00:50:06**	Of course they do, yeah. And those you then give a normal life or even a reduced life to current… yeah? For example, you ,might be able to reduce the demands of the interior trim components 'cause you know every three or every five years you can replace them all. So…	DUM
AR	**00:50:27**	In terms of structures, do you think it would be a heavier structure for a twenty year old car or not necessarily?	LLC
E4	**00:50:35**	I don't think it will be any different. Because, as I say, you can see cars now that are driven excessive mileage, you can see cars now that have lasted now for fifty years without major failures. So, I think… I think from that point of view it's not, it's not an issue. I think probably one of the biggest areas that might be a problem from a testing point of view will be corrosion protection and validating that over extended life scales. Because… 'cos that's where we don't really have experience, you know. We… again if you go back twenty years, if you looked at a car that was twenty years old, twenty years ago and it would be rusty, and you would need to weld it. And keep welding it to repair it. If you look at a twenty year old car now, doesn't necessarily have any rust problems, because the rust protection has improved so much. But does that mean that it… that that's solved? Or is	DDRR

		that there's something there that are lurking that would need to expose vehicles to extended durations in corrosion environments in order to validate?	
AR	**00:51:53**	Or changing the material? To aluminium which is more… less prone to corrosion.	
E4	**00:51:58**	Yeah.	
AR	**00:52:01**	Right, for the final question now: how would you design an optimal lifespan car with less material.	
E4	**00:52:07**	(laughter)	
AR	**00:52:10**	You can answer anything.	
E4	**00:52:20**	Well, I think I would start from a different point of view. I think I would start from the point of view I wanted to design a car with the lowest energy input. 'Cos I think it may be a different answer. So, I think where… I don't know, it's difficult because I think the guys that are already designing cars are doing a fabulous job at this right now. In that, in what they're doing in designing a car it often they're designing it to achieve its objectives of absolutely minimum manufacturing costs. And to a large extent manufacturing cost is associated with energy. Because a lot of automotive manufacturing's now automated with labour costs relatively low and when you really boil it all the way through and you're using any materials that are so exotic the material itself as a commodity is expensive, not so much. It's the cost of processing the raw materials to create the material. So I'm struggling a little bit because actually that's what people are doing against the current levels of constraints. And wherever everybody seems to have got to, pretty much everybody got has to is this product lifecycle that says a design will basically be competitive for six years. It'll have a refresh after three and then after six years it'll be a significant redesign. And that has to be a response and a reaction to the market dynamics; a mixture of market dynamics and the costs and complexities of the design process. So, in other words, well, just diverting for a second, if you consider where computers have gone, it took I can't remember how many hours it was. It's something like a million man-years to develop the first 386 PC and then that would be in the market for two to three years before the 486 came along. Now, it's taking ten times much the effort to develop the next generation of product because it's just that much more complex and yet that product is only in the market for six months before it's been surpassed by the next. So in the automotive world nobody at the moment has	

		really pushed that to the point where this three year-six year kind of time-scale is significantly different and might be a fundamental of the processes in the industry. But if somebody did and push that then you start to impact the whole design. So going back to the question a little early and how would I do it with less energy input overall… less material. Well, probably the other way to look at it, it's just to look at it purely from a size point of view. The vehicle's small uses less material. What's interesting is that you get vehicles as sort of A class vehicles that have package space better than C class vehicles. And yet they use massively less materials, they're smaller. So I think that would be…that would almost be the direction. Maybe the direction could push that even further and shrink the package again. 'Cos again of you look… you could almost look at it from the perspective of the original mini. It was kind of doing that. It was saying we got four people, we're gonna transport four people, what's the absolute minimum we could put around this? And I guess you've similarly still got that happening at that end of the market. So is there any magic bullet to how you'd do that? I honestly… I don't think there is. I think people are already doing it. And maybe not saying they're doing it but by definition of trying to minimise cost they are. But at the same time the market is at… maybe this is part of the problem actually; the market is looking at it and saying: you know what? I could actually afford to buy something bigger, better. And better in automotive terms is quite effectively bigger and faster. You have seen that in the drive to MPVs, the kind of… more luxury segment vehicles. So whilst is all common sense, which say: have a small vehicle, fuel efficient, it doesn't cost much, people don't aspire to do that. And I suspect if you did the analysis most people who drive those vehicles actually say they like the car but it's not their dream car. And that, I think it's the fundamental problem. That all of this is really wrestling with is that whilst as a designer you can look at it and say: we should be designing vehicles that are more environmentally friendly, use less materials, aren't obsolete after a few years, all these good sensible design things, the market is actually saying: I want something big and powerful and completely different.	
AR	**00:58:34**	And I want to change every two years or every three years or…	
E4	**00:58:37**	Yeah. And I don't want to keep my car for twenty years. I want to buy a new one every year.	MRK

AR	**00:58:41**	Yeah, you're absolutely right. The wrestle is between the market, or what the market thinks and the industry is offering as well. It's something we are trying also research, other people in the group. But it.. yeah it's a very complex sort of question.	
E4	**00:59:03**	And I think, I think the one area that there is potential for is to massively detune the performance of vehicles. If you actually think of driving on the roads, the opportunities you have to use a vehicle's performance are extremely limited. Especially if you live in an urban environment. They're zero. So why would you want this car that'll do a hundred miles an hour plus, nought to sixty in five seconds. Utterly and completely irrelevant and pointless.	MRK
AR	**00:59:45**	And irrational.	
E4	**00:59:46**	And totally irrational. So there may be opportunities there to switch people's mentalities around and if you then said: ok if we designed a vehicle that would have a maximum speed of…even if we said a maximum speed of eighty miles an hour, have the very latest in crash protection in it and had a lot of features around, interconnectivity and really provided a different proposition into the market, there might be a niche for that.	MRK
AR	**01:00:21**	OK, thank you very much. That's all for now.	
E4	**01:00:25**	You're very welcome.	
AR	**02:00:27**	Thank you ####.	

Appendix H. Code sample. Example from Awareness Code and its sub-codes.

Interview Set 2 - Car Sharing		
Code Awareness (AWA) identified in the different interviews		
Awareness Code (AWA) and sub-codes Business (BUS) and People (PPL)		
Car Sharing		
Participant	Answers	Code
CS8	I know certainly speaking from my own experience with E-car we've gone from looking at five, 10 car projects to now that we're majority owned by the ####### group looking at the projects on the scale of several hundred vehicles. So I think this is going to bring a lot more private capital to bear in the sector and some extent reduce the reliance on public subsidy and local authority underwriting for car sharing projects. That's not to say there isn't a policy element to discuss here and I'm sure we'll come on to that, but I do thing that now that the major players, the multibillion ###### rental firms are properly taking notice. We are going to see the scale increase as will public awareness.	PPL
CS8	And in more rural communities or even smaller towns with a less developed public transport network, the need to owning a car is arguably stronger and as a result ownership levels are going to be higher. And you really need your service to become a part of the local transport eco-system before people are going to make that decision. So the lead time to build up use and awareness in those sorts of communities can be much longer.	PPL
CS8	I mean I still think the largest barrier is quite a soft one and it's awareness and I think we as insiders in the sector can be a little be arrogant I think in this area and assume that obviously every relatively uneducated young person now knows about the car sharing solutions and what it means to them. I still actually think that outside certain demographics in central London the awareness of these models and the fact there are alternatives to private ownership is still very low. So I think a lot of the structural barriers have now been overcome and I think really it's time and sector wide marketing which is going to make the difference to awareness levels.	PPL

CS8	And as a result I think there's...there's arguably even more of a responsibility now for the trade associations, the organisations like Car Plus and BBRLA, as well as government bodies to take the initiative and then to help drive forward awareness in this area because I don't...I don't think the Automotive OEM and the car rental firms that ultimately now owned operators in this sector, actually know quite what it is that they're promoting.	PPL
CS8	And I don't think it's...I don't think there's an issue with the attractiveness of car sharing as a model. I think if you run through the economic, the environmentally...the environment, the flexibility, the convenience benefits with prospective consumers, there are very few people that don't get it. It's simply for me a matter of awareness and consistency of offering particularly outside of London that people are going to require before they are prepared to make those behavioural changes.	PPL
CS8	Again, you only had to go back to three or four years and insurance was a real challenge in car sharing because most of the main insurers didn't really know how to see and quantify the risk for this type of model. They typically would view it as car rental when it has some additional risks, but also a much higher level of member awareness and support for the scheme. But there have certainly been periods of time when there have been a very small number of insurers who are actually prepared.	AWA BUS
CS8	Certainly, absolutely. Ultimately our entire business models rely upon it, so it's far more significantly in our interests that anybody else's to make sure that the model is being promoted. And I don't think it's...I don't think there's an issue with the attractiveness of car sharing as a model. I think if you run through the economic, the environmentally...the environment, the flexibility, the convenience benefits with prospective consumers, there are very few people that don't get it. It's simply for me a matter of awareness and consistency of offering particularly outside of London that people are going to require before they are prepared to make those behavioural changes.	BUS
CS1	Now, looked at that from another way in it could be argued that the barrier to accelerate that diffusion would be public awareness, no, would be awareness.	AWA

CS1	Then I think the third set of barriers or limits to growth are the really boring bits and that's to do with these models still rely on on-street parking bays, they still rely on understanding of the bodies that set policies and then implement policy and again that's a different set of issues related to awareness. So rather than awareness of the end-user this is awareness of the policy of decision makers in the sectors that then influence how operations might take place	AWA POL
CS1	Even in areas whether there is high car club activity and fairly significant investment primarily by the operators in marketing to their target markets just the visibility of a car club and by visibility I mean awareness of it means and awareness that it actually exists there let alone whether that person might want to use it is still you know, by no means universal and certainly significantly less than that and I think that shaken up people quite a lot.	PPL
CS1	So therefore, it's about very slowly, slowly raising awareness of the concepts so that people then recognise the marketing and how it relates to them.	
CS1	Of course, it's to get more people to join ##### but they have recognised that it's important to fund marketing to raise awareness of the very concept before people are even then going to notice the marketing relating to ###### so they have been very clear that they know they have to invest in all of that.	PPL BUS
CS1	##### operation would argue that there they have been absolutely committed to and committed significant money to raising awareness and marketing as well.	BUS
CS1	without getting too philosophical we only see messages about things that we understand and if we don't understand car clubs we don't see the marketing in the messages. It's, you know, something else or someone else that effectively doesn't exist. So therefore, it's about very slowly, slowly raising awareness of the concepts so that people then recognise the marketing and how it relates to them.	AWA PPL
CS4	Lack of general awareness. Lack of concept awareness (people who have heard of it cannot describe it accurately). Lack of understanding. Not sure why, despite spending money on marketing, mainstream market is not aware of car-sharing options.	PPL

CS10	Awareness and critical mass. If you only have 5% of people, there you only get 5% people using it. You need to make sure you´re target audience are very aware and then you need to make sure that they know exactly what is there for them. And the hardest thing is to get them try it once.	PPL
CS10	Going back to the individual barriers you've got awareness what's in it for me, we then need the right platform to match people together or for them to know enough people to share with through work or whatever, People need an incentive, sometimes the environment or saving money is enough.	PPL
CS3	The survey was made two and half years ago and in the intervening period quite a lot of apps and websites have popped up so people might have high awareness of the principle of car-sharing. The traditional car club operators a third of people haven't heard of them about a third of people have heard of them but don't think it applies to them, don't see as being relevant to them. The third left some have looked into it and gone oh it doesn't work for me and the others have well it might work for me but not right now.	PPL
CS3	It's not in anybody's radar and none of the marketing that has been done seems to be on there. The general visibility of them in general life, when you walk around town you see buses and you see taxis but I don't think really you notice car club vehicles. But a lot of them aren't branded.	BUS
CS2	Certainly, in terms of car-clubs some of the barriers at the moment are awareness, I mean I talk I guess quite a bit about the London contexts cos I did quite a lot of work for Transport for London. I don't know how much Alistair spoke to you about the different things that we're doing at the moment but yeah certainly awareness is a key one. We, there's quite a lot of evidence even where people living in an area where there are on-street car park bays people don't know what they are, they don't know how the system works, so yeah, that's clearly a key constraint sort of upscaling.	PPL
CS2	I think there are be, there's certain things could be done to improve that, better visibility, so through signage, there are quite a lot of boroughs that, you know, got on-street signage per car-club bays, but not all of them by any	BUS

	means, so, that could change, more visible branding on car-club vehicles, that would certainly help.	
CS2	I guess that the whole awareness is one issue. Political will, you know, political support for actually, you know really upscaling. There are quite a few European cities where there's a really strong, you now, environmental imperative to actually improve air quality. To provide alternatives to private car ownership.	PPL POL
CS7	Two years ago, I would have said yes, absolutely I think that these private organisations, the likes of The Times, Zipcar, City Car Club, et cetera, were well positioned to be taking that lead working with the local authorities and other government bodies as well. But ultimately, I think the driving force was always going to come from the sector itself. Now, a couple of years later as we've seen this period of very intense consolidation here in the UK car sharing market come to an end, where really, you're no longer talking about the likes of Zipcar, City Car Club or even us at E-Car, we're passing AVIS, Enterprise and Europcar respectively.	BUS

Appendix I. Key Findings. Design Barriers and Opportunities. Longer Life Cycle.

Interview Set #1 (Automotive Designers & Engineers)

Barriers:

- **Duty Cycle:** Greater duty cycle implying delays in leading times due to extra time and cost of testing. Passenger vehicle duty cycles are less predictable than other machines (e.g. earth movers) Current Duty Cycle: 10 years, 150000-200000 miles. Tests simulate this. Doubling this would double testing time, therefore leading times to production and ultimately, cost. Operating in an infinite fatigue region, as it is possible to do with steels, then it is possible to prolong the life of certain parts such as structure.
- **Weight:** More weight being carried around creating a vicious cycle of more power to move more mass and larger systems (using more material).
- **Material usage:** More material usage to reinforce structures and components for longer duty cycles. Lithium for EVs is not plentiful. Currently the industry is aiming at reducing materials for weight and cost issues.
- **Design & Development:** Some non-visible components would have to become visible for easy access. More interfaces. Manufacturers don't have experience in designing for longer lifecycles although taxi data is available. Cost of adding new processes (e.g. more robust corrosion prevention). Technology would become outdated at some point. Design would become too complex. Feasibility of some design ideas. Ever changing safety regulations can only be applied in new architectures.
- **Lightweight materials.** Most lightweight materials are more energy demanding than steel. Would have to use more of those to reinforce structure.
- **Ownership/Usage:** Regulation would have to force people out of ownership. Not suitable for everyone. Consumers will not use the vehicle for its entire lifetime.
- **Upgradability:** IC engines are harder to upgrade. Cost of upgrading batteries and electric motors. Hard to predict which components to upgrade in the future and also predict compatibility of future disruptive technologies. Components evolve at different rates.
- **Modularity:** No market for replaceable panels in developed economies (e.g. Smart panels flop). Redundancy needs to be designed for disassembly. Aesthetics; cars are designed with an aesthetic and components are needed to fit that. Cars have a fixed structure that is difficult if not impossible to change without serious compromise. Current drivetrains limit space. Tiny modular structure units would compromise the whole vehicle. Systems that are not visible would have to become to the fore (e.g. dashboards). More cost per unit. Difficult to work/high cost to exchange crash structures

- **Service/Maintenance.** Effort done in later life is greater. Failure towards the end has an exponential curve. Service and maintenance are unpredictable. Instead of having an end-of-life recovery of materials if the concept was to upgrade with modular systems manufacturers would have to set the target for the cost of doing that. Increase in preventive maintenance to make cars last longer.
- **Production**: *Disassemblability* of certain components would add complexity to assembly. Access to these parts would have to be built-in adding more complexity. Hard for industry to change current production system due to cost and risk associated, although some cases exist (e.g. BMW I and VW One Ltr). Cycle times due to regulatory changes also enable the design and production of more up-to-date models. Modularity would increase manufacturing footprint
- **Market.** Moving away from a fashion trend of want now rather than later. People struggle with the notion of old. Would the aesthetics compromise be accepted by the markets? Consumers will change cars regularly anyway. Reduced desirability towards the end of the product lifecycle, leads to lower margins diminishing returns. Consumer representative bodies (EuroNcap, etc.) change benchmarks quicker than regulators. Residual values.
- **Regulatory:** Regulation is the main obstacle for vehicle differentiation, hence the industry pattern of producing mass vehicles in the same way with the same basic design. Would take vehicle manufacturers away from current regulatory targets (safety and emissions). Escalating and competitive safety standards.
- **Business.** No business case for industry to change to this type of vehicle.

<u>Opportunities</u>

- **Duty-Cycle:** Low-cost very robust and small vehicle (2 seats). Taxi data available could help. Operating in an infinite fatigue region, as it is possible to do with steels, then it is possible to prolong the life of certain parts such as structure. Trucks operate in this way. Reduction of the mean operating stress (Operating stress times the number of cycles the vehicle is exposed to that stress, it gives it a proportionate life).
- **Weight:** Lightweight materials such as aluminium (recycled?)
- **Material Usage:** reduce the mean operating stress to extend the life (operating stress times the number of cycles the vehicle is exposed to that stress it gives it a proportionate life).
- **Design & Design Development:** Different design solutions. Timeless aesthetics to overcome fashion, simple basic structures (e.g. doors, instrument panels). More user interface features Designers would constantly be working on the same project evolving it. Smarter design and different processes (more robust corrosion systems) Easy to disassemble. Electrical architecture (loom) would remain but accessible. Upgradable ECUs. "Not-visible" components would be more visible and perhaps unfashionable. Designed and produced by non-automotive traditional companies. Designed around a full lifecycle with known points of change. Space

frame with bolt-in and out parts. Powertrain adaptability. Fixed wheelbase and track width. Hang-on easily replaceable panels. 3d printing potential for componentry number reduction and accelerated response to consumer demand. Technology exists to make possible a body to last 20 years. Move to something more corrosion resistant than steel, perhaps aluminium. Coatings and hard-wearing materials for interiors, more UV resistant materials, suspension bushes, springs, dampers. But delving into military territory for longevity.

- **Lightweight Materials:** Recycled aluminium?
- **Ownership/Usage:** If EV propulsion, then battery leasing could be a solution. A closer rapport between manufacturer and user potentially could enhance brand loyalty. Product value will come from use. Electric or Fuel-cells if cost was taken out of the equation.
- **Upgradability:** Only with Electric Vehicles or fuel Cells if cost is taken out of the equation. Introduce a basic neutral design (blank canvas) where replaceable elements can be added, personalised and upgraded.
- **Modularity:** Fixed structure. Replaceable panels. Suits electric vehicles. Low cost vehicles with basic systems. Total functional design. Little or no concession to aesthetics. Designed to be easily accessible. Design for in-life service. Designed around a full lifecycle with known points of change. Wireless communication between systems would potentially eliminate wiring looms. Easily accessible known points of change (e.g. seats) are easily changeable.
- **Service/Maintenance:** Replaceable panels. Easily accessible. Known points of change for replacement/upgrade. Quick repair with little tools. Fixings would be visible (e.g. screws). No major skills needed for disassembly of main components. Rethink the image of wear. Trying to reduce servicing costs making it easier to maintain (e.g. oil pump that drains oil from engines without taking the sump plug.). Reduce maintenance costs (e.g. quicker services) .
- **Production:** Local production. Implemented locally with local people. Simple and adaptable manufacturing system. Renewable energies to power production of higher energy intensive materials. Extending the lifecycle of a vehicle is desirable from an investment point of view as companies wouldn’t need to invest so many times. Renewable energies to power production of higher energy intensive lightweight materials. 3D printing for non-structural replacement parts. Develop new processes (e.g corrosion systems). Local production and brands engaging more often with customers. Rethink the image of wear. Extending the lifecycle is potentially desirable from an investment point of view (less changes in tooling). However, this would have to offset other investment and risk costs.
- **Market:** Developing countries where transport is at a premium and longevity is already somewhat practised and/or isolated farming regions with little infrastructure available. Move away from cost-effectiveness towards product attachment by valuing the built up “patina”. Perhaps desirable in less developed countries where cost of transportation is higher and vehicles tend to last for longer. Offering replacement parts for longer and easier disassembly could be

potentially successful. Little or no concession to aesthetics and/or timeless design. Designers would be always on the same project making it evolve. New digital technologies can provide opportunities.

Appendix J. Key Findings. Design Barriers and Opportunities. User-Intensive Car.

Interview Set #1 (Automotive Designers & Engineers) Design Barriers and Opportunities. User-Intensive Car

Barriers:

- **Duty Cycle:** Low-cost robust vehicle with simple systems. Little or no electronics
- **Weight:** Use intensity would perhaps require an increase in mass.
- **Material usage:**
- **Design & Development:** Not a fashionable item; utilitarian. Easily accessible to service and upgrade.
- **Lightweight materials**
- **Ownership/Usage:** Semi-public form of transport; would have to be publicly funded; cost of infrastructure integration; not a business case unless subsidised. Sharing a car can be a personal issue. Support every one's needs and expectations. Damage liability. Cleanliness. Car manufacturers do not want to own taxi like vehicles. It's not their business model.
- **Upgradability:**
- **Modularity**
- **Service/Maintenance**
- **Production:** Reducing production numbers in a time of high demand would be very hard to justify.
- **Market**. Frequent users will be better off by owning a car.
- **Regulatory:** Regulation is currently a barrier to come up with new design solutions. Too many constraints.
- **Business**

Opportunities:

- **Duty Cycle:** Potential environmental gains in terms of usability. More predictable duty cycle with driverless vehicles.
- **Weight:** Quicker mass reduction with higher rates of replacing.
- **Material usage:** Durable materials. Intelligent surfaces and displays that can be personalised for each user. Use of non-traditional materials.
- **Design & Development:** Not conventional type of design; a tuk-tuk type of vehicle. Designed around a full lifecycle with known points of change. Potentially enables more software personalisation. Discreet technologies or wearable technologies (e.g. Google glasses). Driverless vehicles can provide new interior architectures. Advantages in quicker mass and material optimisation with the recycling or the upgrading of the vehicle. Designed for new propulsion systems.
- **Lightweight materials.** Opportunities for light weighting are more frequent

- **Ownership/Usage:** Through social network platforms. Car as hardware. User carry the software or make it work and personalise it every time it is used. Users will need an incentive beyond economy to buy into this concept. Driverless cars can enable other activities than driving. Driverless vehicles create new crash avoidance opportunities.
- **Upgradability:** only with EVs or Fuel-cell powertrains. Separation of new technologies from the vehicle interior because car manufacturers cannot follow the technological evolution (e.g. removable touch-screens). Faster upgrading with each new model.
- **Modularity**
- **Service/Maintenance:** Design for in life service. Maintenance points easily accessible. No concession to aesthetics.
- **Production:** Local production adapted to the needs of each city. Potential environmental gains in terms of manufacturing.
- **Market.** Developed economies, large cities. Positive sustainability image. Maybe welcome by younger and more altruistic generations. Infrequent users would benefit the most. Semi-public form of transport that would need to attract different people.
- **Regulatory:** Less restricted by regulation than the longer life concept.
- **Business**

Appendix K. Informative Business Interview Questions. Car Sharing Sector.

Informative Business Interview Questions. Car Sharing Sector

Introduction:

User-intensive products are seen as environmentally advantageous because they can potentially reduce the number of products manufactured, answer the demand of their performance and reducing their environmental impact despite a shorter. Car-sharing and car-pooling is included in this category, However, most cars used in car sharing don't seem to be designed for such an intensive use, especially if demand of these schemes grows,

Questionnaire

1. Where do you think the target market for user-intensive cars is?
    - 1.1 Do you believe the so-called millennial generation is the target –market for user-intensive cars?

2. Are there any social and environmental and economic benefits in having cars used more intensively?

3. Where do you see the evolution of user-intensive cars going in terms of vehicle technology?

4. What lifespan or total mileage do you believe should be expected from user-intensive cars in a car share scheme?

5. Do you believe user-intensive cars should be designed and built for purpose or is the current product good enough, i.e. cars offered by current manufacturers?

    - 5.1 If it should be designed and built for purpose which specifications do you believe it should it have?

6. Do you believe user-intensive car can potentially enable higher levels of car re-manufacturing?
    - 6.1 Riversimple, for example, is using a carbon-fibre reinforced plastic structure. Given the current constraints in CFRP in terms of recycling and re-manufacturing, do you see this as a feasible environmental option?

7. What do you believe is the best scheme for users? car clubs, rentals or ride sharing?
    7.1 Can you explain the advantages and disadvantages of the different schemes?

Appendix L. Interview Set 2. Research Questions - Car Share.

Interview Set #2 (Car Sharing Sector). Systemic Barriers for Upscaling Car Share.

UIC Business interviews

- Car clubs, car-pools, rental cars, taxis and hire cars are different forms of car sharing. From a business perspective alone, what are the main barriers to upscaling these and other forms of car-sharing? You can draw from your own experience.

- From a social perspective alone, what are the main barriers to upscaling the different forms of car-sharing?

    - To what extent are consumers prepared or willing to shift from private ownership towards shared-use?
      One-off – 53% of UK drivers do less than 9000 miles/year. Why aren't car-sharing organisations deliberately targeting these people?

    - Who needs to act to make car-sharing more attractive to consumers? Consumers, government, car-sharing sector, car manufacturers, campaigners, etc.
      One-off What reasons make are younger male drivers and male more attracted to car-sharing than other gender-age groups?

- To what extent car-sharing would be more attractive if better integrated into the local transport infrastructure as it has been done in other countries?

- To what extent technological advances are relevant to make car-sharing more attractive?

- (For Car sharing companies only) What is the turnover of cars in your car-sharing schemes?

    - How long will they be in service, on average?
    - Why are they kept for this period of time?
    - To what extent car-sharing result in different maintenance requirements due to a higher annual mileage or because people drive differently?

Appendix M. Interview Set 2. Thematic Analysis Coding Structure.

Interview set 2

Car Sharing

Codes	**Sub-Codes**	
Users (USRS)	Awareness (AWA)	Business (BUS)
		People (PPL)
	Behaviour (BEHV)	
Car Sharing Sector (CSS)		
Policies (POL)		
Integration with Public Transport (IWPT)		
Technology (TECH)		
Car Sharing Cars (CSC)	Purchase (PUR)	
	Service-Life (SERL)	

Appendix N. Key Findings. Car Share Systemic Barriers and Opportunities.

Key Findings from Car Sharing Interview Analysis.

Potential users

- Lack of awareness seems to be the key barrier, divided into three types
    - public awareness,
    - business awareness
    - policy-maker awareness

- In all three there seems to be a general lack of awareness of the concept of a profound misunderstanding of it.
- Y generation highly educated seems to be the target market for car-sharing
- There is a fair amount of education to be done by all stakeholders.
- In rural and less densely populated areas a significant behavioural change may be needed in order to overcome private car ownership

Steps towards upscale for users

- The mainstream market needs to become more aware of this mobility option.
- Understand how it does work and how relevant is for them
- Public transport options need to be available and reliable and joined up with car-sharing.
- Remove preconceptions about the need to own a private car for those people driving less than 10,000 miles per year.

Policy

- Lack of serious government investment in car sharing and public transport to complement each other (cf. barriers for business).
- Local authorities seem to have different approaches towards car sharing. I have two examples of those approaches, one from London TfL and the other from Manchester's TfGM.
- The car-sharing offer, especially car clubs is now dominated by multinationals, usually car rental, who brought higher leverage for the acquisition of vehicles but also less flexibility
- These multinationals do not yet understand the car club business in its entirety
- Shifting from private to shared ownership will have to appeal to those who do it as a lifestyle choice, therefore, still limited.

- Educational approaches also need to be made in order to attract the general population. This will have to be achieved in conjunction with, and in some instances as a complement of, public transport

Barriers for Business

- Disjointed approach by local transport authorities, especially London, despite being the larger market
- Car-sharing companies have to negotiate with each individual borough the parking fees and release of parking bays.
- Incoherent attitude of some boroughs who, despite supporting car-sharing, rely on parking permit revenues, do not offer discounts for parking bays leading to excessive costs that could be channelled elsewhere, (e.g. awareness campaigns).
- The lack of serious investment by the government in public transport and mobility solutions. DfT is disproportionately funding autonomous vehicles (cf. policy)
- Car-sharing companies seem to be slightly suspicious of car-rental companies. However, there were diverging opinions. On one hand they welcome the capital investment and purchase leverage. On the other hand, they feel they are seen as disruptive businesses, not completely understood by their new masters who sometimes seem to limit their ability to grow…
- Investment for growth therefore, comes from a mix of private and public funding.

Technology

- Tracking technology has not changed much in the last years.
- The advent of the internet and smartphones with apps contributed for the growth of car sharing due to paper barriers been eliminated
- However, there are still some bureaucratic barriers to overcome
- Car manufacturers are now starting to provide tracking and car-sharing systems. For the car sharing companies is a mixed blessing. On one hand reduces costs of after-market assembly but there is the danger of OEMS offering proprietary systems locking-in car clubs to buy a single brand of car.
- Despite car-sharing companies wishing to be part of public transport offer, using their payment cards, the latter believe that with the advent of contactless cards that need will be reduced.

Integration with Public transport

- It is a divisive subject: Some think it will not make any difference for upscaling because it's a lifestyle choice, others want to be officially part of the local transport offer.
- Depends on the approach of local transport authorities. For example, Manchester wishes to integrate car clubs as part of their transport offer. London doesn´t.
- This attitude infuriates car-sharing companies as they see TfL and the 'roundel' logo as something the public sees as credible.
- Car sharing operators feel that integration with public transport will be inevitable.

Car Turnover

- Turnover between £6,000 and £10,000/vehicle/year
- Variable costs are exceptionally low
- After breakeven point, profit margins can go up to 80 to 90%
- Around £5,000 revenue equates in the region of 15-20% utilisation of the vehicles (for electric vehicles)
- Mileage and age:
    - E car club (Europcar): down from 3 years to 2.2. Objective is 2 years. Average mileage 8-12,000 miles/year
    - Zipcar (Avis) 12 to 18 18 months. Average mileage 17,000 miles year
- Car rental fleets:
    - Europcar 6 months old in average. Max 9-12 months. 18,000miles/annum.

Appendix O. Online Survey Questionnaire.

Online Survey Questionnaire.

Thank you for logging on to this survey, which looks at automobile usage and is being carried out by a leading UK university.
Your participation is entirely voluntary, you are free to refuse to answer any question and withdraw at any time.

It should take approximately 15 minutes to complete.

Thank you in advance for your help!

For additional instructions on how to navigate the survey, please click here.
This survey is being hosted by JRA Research - to read their privacy policy, please click here, otherwise press next to continue.

Screener

Q1 Do you currently work for a car club or car hire company (such as City Car Club, E-Car, Zipcar, Hertz, Avis or Enterprise), or for a car manufacturer or dealer?

❍ 1 Yes
❍ 2 No

Q2 Which of the following best describes you at the moment?
Please note that by 'drive regularly' you have driven at least once per month, on average, during the past twelve months

❍ I do not have a UK/EU driving licence
❍ I have a provisional UK/EU driving licence but have not passed my test as yet
❍ I have a valid full UK/EU driving licence but do not drive regularly (as described above)
❍ I have a valid full UK/EU driving licence and drive regularly, but do not have a car registered in my name
❍ I have a valid full UK/EU driving licence, have a car registered in my name, and drive regularly

Section A

Q3 How many cars, if any, do you regularly drive (i.e. at least once a month) that are registered in your name?
Please exclude:
Cars that you do NOT drive regularly
Cars that are not taxed, not insured, or have a Statutory Off Road Notice (SORN)
Company cars

(must be between 0 and 99)

Q4 How many cars, if any, do you regularly drive (i.e. at least once a month) that are NOT registered in

your name (e.g. cars owned by other family members, hire cars and car club cars)?
Please exclude:
<u>Cars that you do NOT drive regularly</u>
<u>Cars that are not taxed, not insured, or have a Statutory Off Road Notice (SORN)</u>
<u>Company cars</u>

(must be between 0 and 99)

Q5 How many company cars, if any, do you regularly drive?
Please exclude:
<u>Cars that you do NOT drive regularly</u>
<u>Cars that are not taxed, not insured, or have a Statutory Off Road Notice (SORN)</u>
<u>Cars that are not registered in your name</u>

(must be between 0 and 99)

Section B

B1 Please enter a short description for the car you drive most often. We'll use this to identify this car throughout the survey.

B2 Please enter a short description for the car you drive second most often. We'll use this to identify this car throughout the survey.

B3 Please enter a short description for the car you drive third most often. We'll use this to identify this car throughout the survey.

Q6 Please identify the manufacturer(s) of your CD1:

- ❍ 1 Audi
- ❍ 2 BMW
- ❍ 3 Citroën
- ❍ 4 Ford
- ❍ 5 Honda
- ❍ 6 Hyundai
- ❍ 7 Kia
- ❍ 8 Land Rover
- ❍ 9 Mercedes-Benz
- ❍ 10 MINI
- ❍ 11 Nissan
- ❍ 12 Peugeot
- ❍ 13 Renault
- ❍ 14 SEAT
- ❍ 15 Skoda
- ❍ 16 Toyota
- ❍ 17 Vauxhall
- ❍ 18 Volkswagen
- ❍ 19 Volvo
- ❍ 20 Fiat
- ❍ 21 Other. Please specify:

Please identify the manufacturer(s) of your CD2:

- ❍ 1 Audi

- ❍ 2 BMW
- ❍ 3 Citroën
- ❍ 4 Ford
- ❍ 5 Honda
- ❍ 6 Hyundai
- ❍ 7 Kia
- ❍ 8 Land Rover
- ❍ 9 Mercedes-Benz
- ❍ 10 MINI
- ❍ 11 Nissan
- ❍ 12 Peugeot
- ❍ 13 Renault
- ❍ 14 SEAT
- ❍ 15 Skoda
- ❍ 16 Toyota
- ❍ 17 Vauxhall
- ❍ 18 Volkswagen
- ❍ 19 Volvo
- ❍ 20 Other. Please specify:

Please identify the manufacturer(s) of your CD3:

- ❍ 1 Audi
- ❍ 2 BMW
- ❍ 3 Citroën
- ❍ 4 Ford
- ❍ 5 Honda
- ❍ 6 Hyundai
- ❍ 7 Kia
- ❍ 8 Land Rover
- ❍ 9 Mercedes-Benz
- ❍ 10 MINI
- ❍ 11 Nissan
- ❍ 12 Peugeot
- ❍ 13 Renault
- ❍ 14 SEAT
- ❍ 15 Skoda
- ❍ 16 Toyota
- ❍ 17 Vauxhall
- ❍ 18 Volkswagen
- ❍ 19 Volvo
- ❍ 20 Other. Please specify:

Q7 What is the age (in years) of your car?
The age is the period since the car was manufactured or registered by the first owner. If you are unsure please enter your best estimate.

CD1
CD2
CD3

Q8 Which method did you use to buy CD1,

☐Paid up front / Cash or debit card
☐Credit card or bank loan / Personal finance

☐Hire Purchase (car is owned at end of contract)
☐Personal Contract Purchase (option to own at end of contract)
☐Leasing scheme / Personal Contract Hire (no option to own at end of contract)
☐No purchase (i.e. gift or inheritance)
☐Other
☐Cannot recall

Which other methods did you use to buy CD1?

Which method did you use to buy CD2

☐Paid up front / Cash or debit card
☐Credit card or bank loan / Personal finance
☐Hire Purchase (car is owned at end of contract)
☐Personal Contract Purchase (option to own at end of contract)
☐Leasing scheme / Personal Contract Hire (no option to own at end of contract)
☐No purchase (i.e. gift or inheritance)
☐Other
☐Cannot recall

Which other methods did you use to buy CD2?

Which method did you use to buy CD3?

☐Paid up front / Cash or debit card
☐Credit card or bank loan / Personal finance
☐Hire Purchase (car is owned at end of contract)
☐Personal Contract Purchase (option to own at end of contract)
☐Leasing scheme / Personal Contract Hire (no option to own at end of contract)
☐No purchase (i.e. gift or inheritance)
☐Other
☐Cannot recall

Which other methods did you use to buy CD3?

Q9 & Q10

	Q9 In what year did you purchase your car?	Q10 And how much did you pay (in £) for your car when you bought it?
CD1		
CD2		
CD3		

Q11 What type of fuel is used by each car that you own and regularly drive?

	Petrol	Diesel	LPG (Liquid Petroleum Gas)	Hybrid(Petro-Electric, Diesel-Electric, Plug-in Hybrid)	Electric	Hydrogen Fuel Cell	Other (e.g. Biofuel/ Bioethanol mix)
CD1	❑	❑	❑	❑	❑	❑	❑
CD2	❑	❑	❑	❑	❑	❑	❑
CD3	❑	❑	❑	❑	❑	❑	❑

Q11 Other: What other fuel do you use in your CD1?
What other fuel do you use in your CD2?
What other fuel do you use in your CD3?

Q12 a & b

	a) What was the age (in years) of your car when you acquired it?	b) And what was the mileage (to the nearest thousand miles) of your car again, when you acquired it?
CD1		
CD2		
CD3		

Q13 For how many more years do you intend to keep your car?

CD1
CD2
CD3

Q14 When you discard this CD1, which of the following is most likely to be true:

☐It will only have scrap value
☐It will be sold to another user
☐Don't know/ Impossible to say

When you discard this CD2, which of the following is most likely to be true:

☐It will only have scrap value
☐It will be sold to another user
☐Don't know/ Impossible to say

When you discard this CD3, which of the following is most likely to be true:

☐It will only have scrap value
☐It will be sold to another user
☐Don't know/ Impossible to say

Q15 For each car that you own and regularly drive please indicate what happened to the previous CD1?

☐Traded for a replacement (part exchange)
☐Sold directly to a dealer (e.g. webuyanycar.com)
☐Sold privately
☐SORN (Statutory Off Road Notification) (stored off road)
☐Taken to or collected by a scrapyard
☐Other (e.g. stolen, given away). What else happened to the car you replaced with your CD1?
☐Do not know

For each car that you own and regularly drive please indicate what happened to the previous CD2?

☐Traded for a replacement (part exchange)
☐Sold directly to a dealer (e.g. webuyanycar.com)

☐Sold privately
☐SORN (Statutory Off Road Notification) (stored off road)
☐Taken to or collected by a scrapyard
☐Other (e.g. stolen, given away). What else happened to the car you replaced with your CD2?
☐Do not know

For each car that you own and regularly drive please indicate what happened to the previous CD3?

☐Traded for a replacement (part exchange)
☐Sold directly to a dealer (e.g. webuyanycar.com)
☐Sold privately
☐SORN (Statutory Off Road Notification) (stored off road)
☐Taken to or collected by a scrapyard
☐Other (e.g. stolen, given away). What else happened to the car you replaced with your CD3?
☐Do not know

Q16 Please enter a short description for the car which was replaced by CD1. We'll use this to identify this previous car throughout the survey.

Please enter a short description for the car which was replaced by CD2. We'll use this to identify this previous car throughout the survey.

Please enter a short description for the car which was replaced by CD3. We'll use this to identify this previous car throughout the survey.

Q17 Why did you replace your previous [P] car(s)?
Please select up to three reasons per car.
(3 maximum responses)

	P1	P2	P3
Failed its MOT			
Replacement parts unavailable			
Cost of remedying a specific fault			
Cost of fuel			
Cost of insurance			
Cost of road tax (Vehicle Excise Duty)			
End of contract (i.e. Personal Contract Plan, Leasing, etc.)			
Appearance (i.e. dated or worn)			
Mileage			
Reliability (i.e. risk of fault or breakdown)			
Change in size of household			
Change in amount of commuting			
Change in financial circumstances			
Rate of depreciation			
Wanted a newer car			
Wanted a different type of car			
Written off (i.e. damaged beyond repair)			
Other:			

What other reason prompted you to replace your P1 with your CD1?
What other reason prompted you to replace your P2 with your CD2?

What other reason prompted you to replace your P3 with your CD3?

Q18 To what extent did you feel attached to your previous [P] car(s)?
Please indicate one answer per car.

	P1	P2	P3
Extremely attached			
Very attached			
Moderately attached			
Slightly attached			
Not at all attached			

Q19 How important to you are the environmental impacts of cars that you own and regularly drive (e.g. air pollution, carbon emissions, fuel consumption, waste, recyclability)?

❍Extremely important
❍Very important
❍Moderately important
❍Slightly important
❍Not at all important

Q20 How important to you is the fuel consumption of cars that you own and regularly drive?

❍Extremely important
❍Very important
❍Moderately important
❍Slightly important
❍Not at all important

Q21 How is each car that you own and regularly drive usually serviced?
Tick all that apply

	Franchised dealer	Independent garage	Service it myself	Other
CD1				
CD2				
CD3				

Other: How else is your CD1 serviced?
Other: How else is your CD2 serviced?
Other: How else is your CD3 serviced?

Q22 Which repair and maintenance tasks do you personally undertake on the car(s) that you own and regularly drive?
Please indicate all that apply. Exclude company cars.

	Major tasks (e.g. replace brake pads or brake discs, change brake fluid, replace clutch, repair bodywork, suspension or engine)	Moderate tasks (e.g. replace air filter, oil change, repair small paint scratches, replace light bulbs)	Minor tasks (e.g. change windscreen washer fluid, top-up oil)	I never undertake such tasks

CD1				
CD2				
CD3				

Section C

Q20 How many miles do you drive annually in the car you use most often [CarMO]?

Please choose 'zero' if you have not driven in the past year.

❍0
❍1 to 999
❍1,000 to 2,999
❍3,000 to 5,999
❍6,000 to 8,999
❍9,000 to 11,999
❍12,000 to 14,999
❍15,000 to 17,999
❍18,000 to 20,999
❍21,000 or over

Q21 Please rank the reasons why you drive CarMO most often in order from 1 (most trips) to 8 (fewest trips) i.e. in terms of numbers of trips rather than distance travelled.

Please leave blank any reasons that do not apply. If you need to deselect an option, click it a second time.

Reason	**Rank**
Commuting	
Business/ Employment	
Shopping	
Visiting relatives	
Holidays/ Day trips	
Leisure activities	
Take children to school or other activities	
Other	

Other, please specify:

Q22 On average, a new car costs £16,000 to purchase in the UK. We would like you to predict how fast it declines in value as it gets older.

1) Please estimate its value after 3 (three) years:

2)Please estimate its value after 7 (seven) years:

3)Please estimate its value after 14 (fourteen) years:

Section D

The following questions ask about your use of cars that you do not own, which is described below as 'car sharing' because the car is used by different people at different times. It may be for days or weeks (i.e. traditional CAR HIRE OR CAR RENTAL) hours (i.e. membership of a CAR CLUB) specific journeys (i.e. using a RIDE-SHARE scheme, whether as driver or passenger). This section is not concerned with car sharing between family members and friends.

Q23 Which of these types of car sharing are you aware of?
(4 maximum responses)
❑Traditional car hire or car rental (i.e. hiring a car for days or weeks).
❑Car Club (i.e. hiring a communal car for as little as one hour, picking it up from a local Car Club parking point).
❑Ride-share (i.e. journeys using formal schemes such as liftshare.com, blablacar.co.uk, and employer schemes that offer benefits such as free parking).
❍4 None of these

Q24 And which have you ever used?
(4 maximum responses)
❑1 Traditional car hire or car rental (i.e. hiring a car for days or weeks).
❑2 Car Club (i.e. hiring a communal car for as little as one hour, picking it up from a local Car Club parking point).
❑3 Ride-share (i.e. journeys using formal schemes such as liftshare.com, blablacar.co.uk, and employer schemes that offer benefits such as free parking).
❍None of these

Q25 For each type of car sharing, please estimate your approximate mileage, to the nearest hundred miles, over the past twelve months:

Type of car sharing	Mileage
Traditional car hire or car rental	
Car Club	
Ride-share	

Q26 How often, if ever, do you use a CAR HIRE/ RENTAL vehicle?

❍Daily (or nearly every day)
❍Once or twice a week
❍Occasionally (once or twice a month)
❍Rarely (a few times each year)
❍I have been a car hire/ rental user but am not any more

Q27 What were your concerns, if any, before you first used CAR HIRE/ RENTAL?
Please indicate all that apply.
(12 maximum responses)
❑Age of cars
❑Mileage of cars
❑Cleanliness of cars
❑Comfort of cars
❑Safety condition of cars
❑Model of cars
❑Cars not easy to drive
❑Cars not located near to me
❑Cars not always available
❑Cost
❑Other
❍I did not have any concerns

Other, please specify:

Q28 Why are you not currently using CAR HIRE/ RENTAL?
Please indicate all that apply.
(21 maximum responses)

❑Usage cost (i.e. charge per day/ week)
❑Moved my job or home to an area where car hire/rental is not available
❑Cars are too far from my home to collect
❑Having to return the vehicle to the same place
❑Public transport service is satisfactory
❑My travelling freedom was somewhat limited
❑Administrative problems (e.g. booking system)
❑Cars were not available for booking
❑Poor customer support
❑I do not like the service provider
❑Not integrated with public transport (e.g. no links with bus/ train/ tram)
❑Technical problems with cars (e.g. damaged cars, entry cards)
❑ Model of cars
❑Cars not easy to drive
❑Cleanliness of cars
❑Comfort of cars
❑Cars are not instantly available
❑It does not fit my self-image
❑I don't know enough about car hire / rental
❑ I have no need as I can always use my own car
❑Other

Other, please specify:

Q29 How often, if ever, do you use a CAR CLUB vehicle?

❍Daily (or nearly every day)
❍Once or twice a week
❍Occasionally (e.g. once or twice a month)
❍Rarely (e.g. a few times each year)
❍I have been a Car Club member but am not any more

Q30 Did you have any concerns before you used a CAR CLUB scheme?
(12 maximum responses)

❑Age of cars
❑Cleanliness of cars
❑Mileage of cars
❑Comfort of cars
❑Safety condition of cars
❑Model of cars
❑Cars not easy to drive
❑Cars not located near to me
❑Cars not always available
❑Cost
❑Other
❍I did not have any concerns

Other, please specify:

Q31 Why are you not currently using a CAR CLUB scheme?

(20 maximum responses)

❑Cost of membership
❑Usage cost (i.e. charge per hour/ mile/ day)
❑Moved my job or home to an area where car club is not available
❑Cars are too far from my home to collect
❑Car club does not allow me to travel to where I need to go
❑Having to return the vehicle to the same place
❑Not knowing where I could return the vehicle_
❑Public transport service is satisfactory
❑My travelling freedom was somewhat limited
❑I was not using the car club scheme enough
❑Administrative problems (e.g. booking system)
❑Cars were not available for booking
❑Poor customer support
❑I do not like the service provider
❑Not integrated with public transport (e.g. no links with bus/ train/ tram)
❑Technical problems with cars (e.g. damaged cars, entry cards)
❑Model of cars
❑Cars not easy to drive
❑Cleanliness of cars
❑Comfort of cars
❑I don't know enough about car clubs
❑I have no need as I can always use my own car
❑Other

Other, please specify:

Q32 How often do you use a RIDE-SHARE vehicle, either as driver or passenger?
(Please refer only to formal ride-share schemes (e.g. liftshare.com or blablacar.co.uk). Do not take account of casual lifts from family members, friends or work colleagues.)

❍Daily (or nearly every day)
❍Once or twice a week
❍Occasionally (once or twice a month)
❍Rarely (a few times each year)
❍I have been a ride-share user but am not any more

Q33 What were your concerns, if any, before you started using a RIDE-SHARE scheme?
(14 maximum responses)
❑Age of cars
❑Mileage of cars
❑Car cleanliness
❑Comfort of cars
❑Safety condition of cars
❑Model of cars
❑Driver's behaviour
❑Driver's ability
❑Other passengers' behaviour
❑Easy access to cars
❑Availability of cars
❑Cost
❑Other
❍I did not have any concerns

Other, please specify:

Q34 Why are you not currently using a RIDE-SHARE scheme?
(18 maximum responses)

❑Cost as driver
❑Cost (as passenger)
❑ Moved my job or home to an area where ride-share is not available
❑Ride-share does not allow me to travel to where I need to go
❑Public transport service is satisfactory
❑My travelling freedom was somewhat limited
❑I was not using the ride-share scheme enough
❑ I did not wish to share a car with someone else (or with strangers)
❑Administrative problems (e.g. booking system)
❑Poor customer support
❑I do not like the ride-share scheme service provider
❑Not integrated with public transport (e.g. no links with bus/ train/ tram)
❑Model of cars
❑Cleanliness of cars
❑Comfort of cars
❑I don't know enough about Ride-share schemes
❑I have no need as I can always use my own car
❑Other

Other, please specify:

Q35 What has been the effect of using car hire/rental, a car club vehicle, or ride-sharing on your TOTAL CAR MILEAGE over the past year?

Please take account of all journeys that you undertake by car, whether or not you own the vehicle.
❍Large increase in total mileage
❍Small increase in total mileage
❍No significant change
❍Small decrease in total mileage
❍Large decrease in total mileage
❍Do not know

Q36 What, if anything, attracts you to car sharing (i.e. car hire/ rental, using a car club or ride-sharing)?
(8 maximum responses)

❑Reduction in environmental impacts
❑Improved lifestyle
❑Reduction in motoring costs (e.g. purchase, insurance, etc.)
❑Access to free parking
❑Integration with public transport (links with bus/ train/ tram services)
❑Access to a hybrid or electric car
❑Nothing attracts me to car sharing
❍Other

Other, please specify:

Q37 How likely is it that improved car sharing services would enable you to sell a car that you own?
❍Very likely
❍Likely

❍Neither likely nor unlikely
❍Unlikely
❍Very unlikely
❍Do not know

Q38 To what extent, if any, is it important for you to be seen in a car that is clearly identified as one that is used for car sharing?

	Extremely important	Very important	Moderately important	Slightly important	Not at all important	I do not wish to be seen in a car identified in this way	Do not know
Car hire							
Car club							
Ride-share							

Section E

Q39 Have you ever discarded a car for scrap?
Please exclude company cars.
❍Yes
❍No

Q40 How old in years, approximately, was the car that you most recently discarded for scrap?
(must be superior to 0)

Q41 How satisfied were you with the age that this car had reached when discarded for scrap?

❍Very satisfied
❍Satisfied
❍Neither satisfied nor unsatisfied
❍Unsatisfied
❍Very unsatisfied

Q42 The next few questions are about how long cars last. Please offer your best estimate.
How long do you think a car lasts, on average in the UK, from first use (i.e. brand new) to when it is discarded for scrap?

Please enter the number of years
(must be inferior to 999)

Q43 What do you think is the total mileage of a car, on average in the UK, when it is discarded for scrap?

Please enter the number of miles
(must be inferior to 999)

Q44 How long do you think an average car in the UK should last, ideally, from first use to when it is discarded for scrap?

Please enter the number of years
(must be inferior to 999)

Q45 What total mileage do you think an average car in the UK should ideally be able to travel, from first use (brand new) to when it is discarded for scrap?

Please enter the number of miles
(must be inferior to 999)

Q46 On average, in the UK a car lasts between 13 and 14 years from first use to when it is discarded for scrap. What is your opinion of this?

❍ No opinion
❍The average life span should be longer than this
❍The average life span is about right
❍ The average life span should be shorter than this
❍Don't know

Q47 If you were purchasing a new car, how appealing would be a label with its expected lifespan (similar to an energy label)?
❍Extremely appealing
❍Very appealing
❍Moderately appealing
❍Slightly appealing
❍Not appealing
❍Don't know

Q48a) If you were purchasing a new car that you wanted to keep for 15 years, would you consider buying a parts and labour warranty that covered all faults throughout its lifespan? Please note that it would not cover consumables (e.g. oil, tyres) or damage caused by accidents.
❍Yes
❍Perhaps
❍No

Q48b) Imagine that the new car that you planned to keep for 15 years cost £16,000. How much would you be prepared to pay in total for a parts and labour warranty that covered all faults throughout its lifespan?

Q49 How important to you would the following be if you were purchasing a car?

	Extremely important	Very important	Moderately important	Slightly important	Not at all important	Don't know
Brand	❑	❑	❑	❑	❑	❑
Reliability	❑	❑	❑	❑	❑	❑
Durability	❑	❑	❑	❑	❑	❑
Size	❑	❑	❑	❑	❑	❑
Length of warranty	❑	❑	❑	❑	❑	❑
Features/ High specification	❑	❑	❑	❑	❑	❑
Appearance/ styling	❑	❑	❑	❑	❑	❑
Price	❑	❑	❑	❑	❑	❑
Engine performance	❑	❑	❑	❑	❑	❑
Fuel efficiency	❑	❑	❑	❑	❑	❑
Comfort	❑	❑	❑	❑	❑	❑
Environmental impact	❑	❑	❑	❑	❑	❑

(Randomized order responses)

Q50 Which criteria would you use if you were purchasing a NEW car and wanted one that would last longer than others?

Please identify the three most important criteria below.

☐Manufacturer’s reputation
☐Price
☐Length of warranty
☐Style
☐How it feels during a test drive
☐Quality of the interior components
☐Advice from friends, family or colleagues
☐Advice from seller
☐Previous experience of manufacturer
☐Expert reviews (e.g. online, magazines)
☐User reviews (e.g. online, magazines)
☐Brochure in showroom
☐Other

Other, please specify:

Q51 Which criteria would you use if you were purchasing a USED car and wanted one that would last longer than others?
Please identify the three most important criteria below.
If you need to deselect an option, click it a second time.

☐Manufacturer’s reputation
☐Price
☐Length of warranty
☐Style
☐How it feels (e.g. quality of interior, test drive)
☐Advice from friends, family or colleagues
☐Advice from seller
☐Previous experience of manufacturer
☐Expert reviews (e.g. online, magazines)
☐User reviews (e.g. online, magazines)
☐Age of car
☐Mileage of car
☐Visual condition (e.g. signs of damage)
☐Other

Other, please specify:

Section F

Demographics

C1 What is the postcode of your main residence? (only the first part is required)

C2 Which of the following best describes the area where you live?
❍Urban
❍Suburban
❍Rural

C3 How many people aged 18 and over usually live in your household, including yourself?
❍1
❍2
❍3
❍4
❍5 or more
❍The number varies

C4 How many children under the age of 18 usually live in your household?
❍0
❍1
❍2
❍3
❍4
❍5 or more
❍The number varies

C5 Which of the following best describes the highest educational qualification you have achieved?

❍No formal educational qualifications
❍GCSE/ O levels/ CSEs (usually taken at the age of 16)
❍A Levels, BTEC/ technical/ vocational training (usually taken up to the age of 18)
❍Technical/ vocational training (usually taken over the age of 18)
❍First university degree (e.g., BA, BSc)
❍Higher degree (e.g., MA, MSc, PGCE, PhD)
❍Other professional qualification (e.g., teaching, nursing, accounting)
❍Prefer not to say / Do not know

C6 Which of the following best describes your normal employment status?

❍Semi or unskilled manual work (e.g. manual workers, all apprentices to skilled trades, caretaker, park keeper, non-HGV driver, shop assistant)
❍Skilled manual worker (e.g. skilled bricklayer, carpenter, plumber, painter, bus/ ambulance driver, HGV driver, AA patrolman, pub/ bar worker etc.)
❍Supervisory or clerical/ junior managerial/ professional/ administrative (e.g. office worker, student Dr, foreman with 25+ employees, salesperson, etc.)
❍Intermediate managerial/ professional/ administrative (e.g. newly qualified Dr, solicitor, board director in small organisation, middle manager in large organisation, principal officer in civil service/ local government)
❍Higher managerial/ professional/ administrative (e.g. established Dr, solicitor, board director in large organisation (200+ employees), top level civil servant/ public service employee
❍Student
❍Casual Worker (not in permanent employment)
❍Housewife/ Homemaker
❍Retired and living on state pension
❍Unemployed/ Not working due to long-term sickness

❍Full-time carer of another household member
❍Other
❍Prefer not to say
❍Other
Other, please specify:

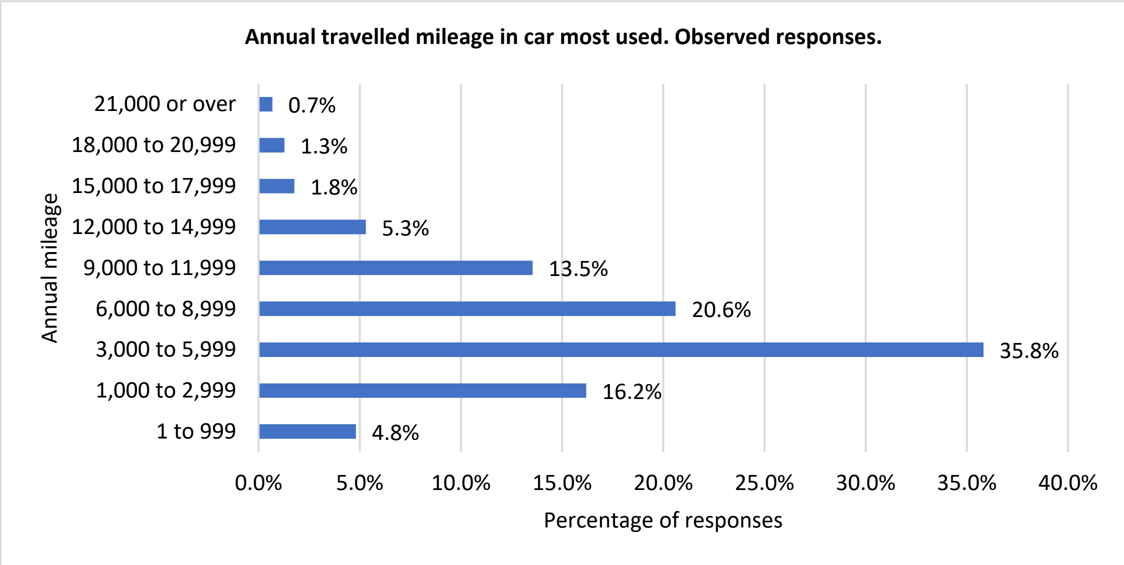
C7 What is your TOTAL household income?
❍Up to £9,999
❍£10,000 to £19,999
❍£20,000 to £29,999
❍£30,000 to £39,999
❍£40,000 to £49,999
❍£50,000 to £59,999
❍£60,000 to £69,999
❍£70,000 or above
❍Prefer not to say
❍Don't know

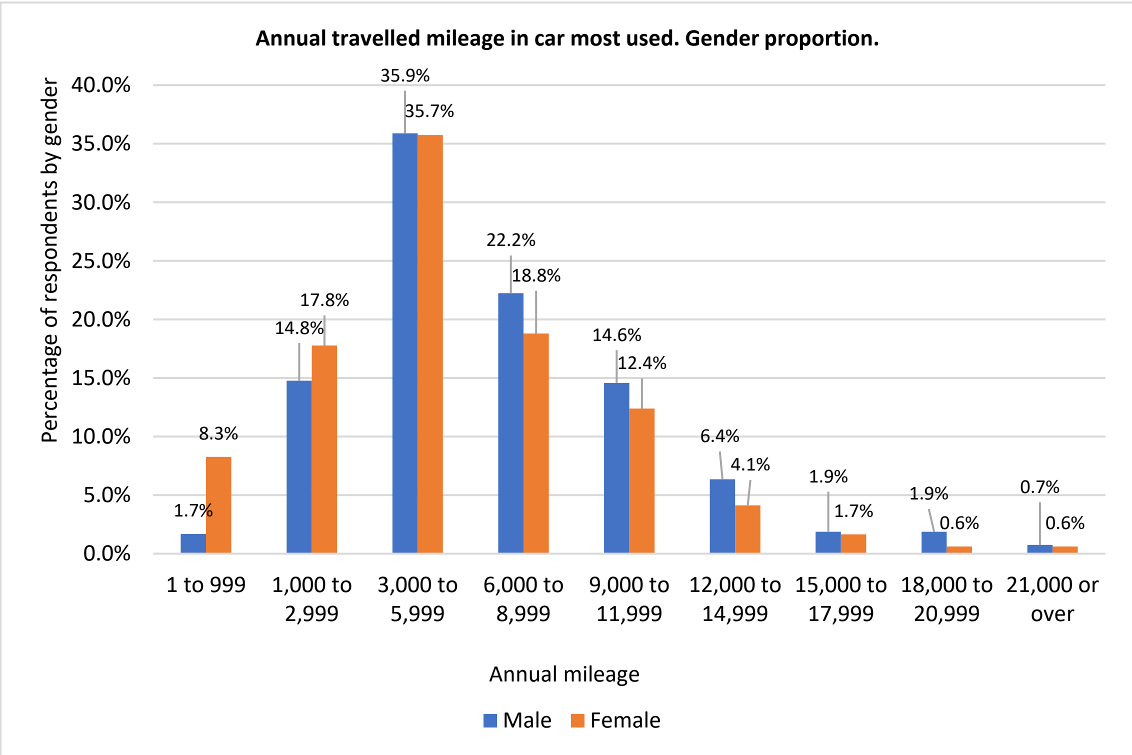
C8 What is your age group?
❍18 to 24
❍25 to 34
❍35 to 44
❍45 to 54
❍55 to 64
❍65 to 74
❍75 years or over
❍Prefer not to say

C9 What is your gender?
❍Male
❍Female
❍Other
❍Prefer not to say

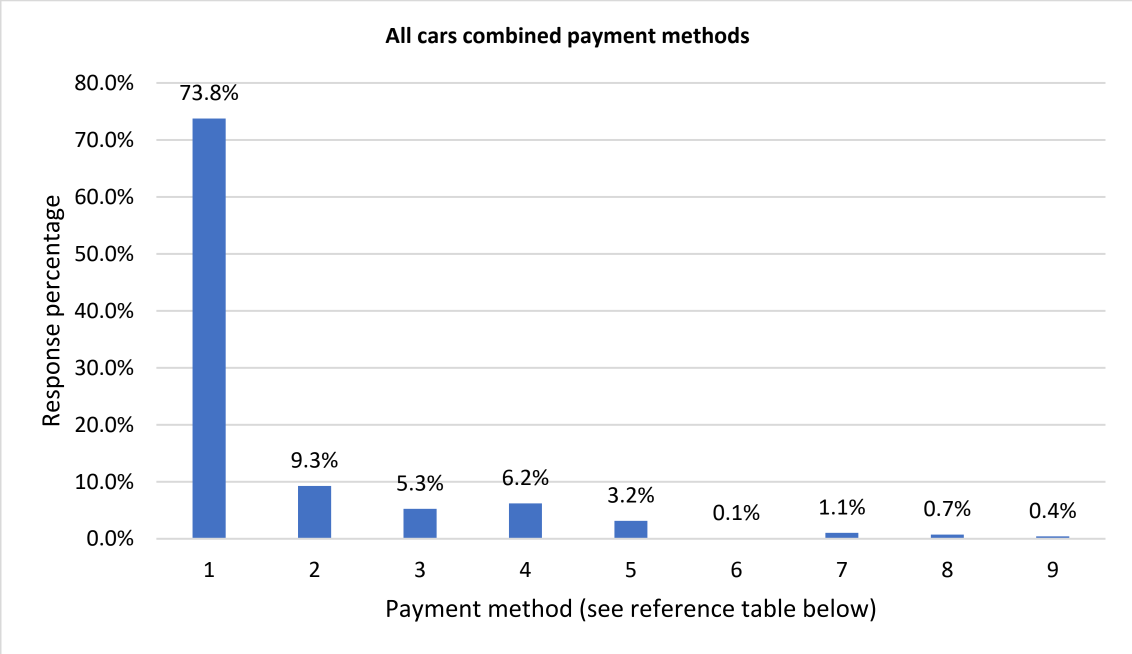
Other Please specify:

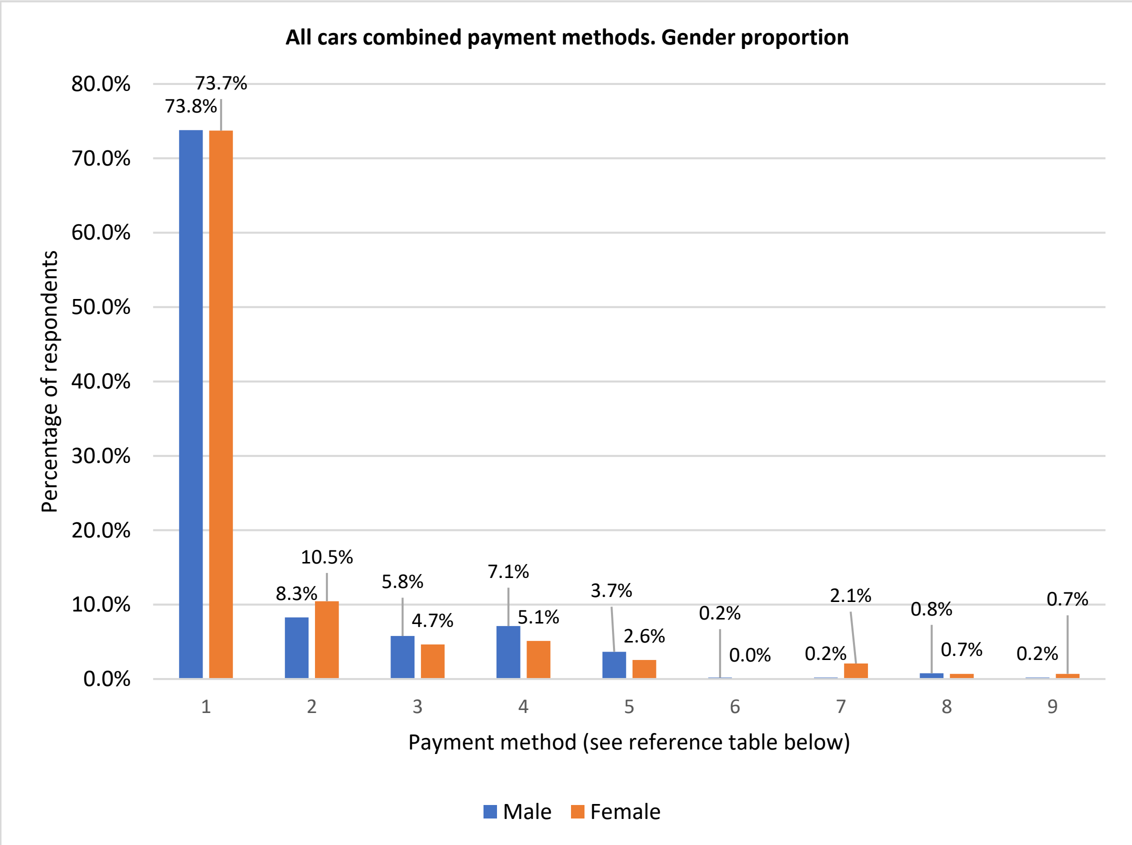
Appendix P. Annual Travelled Mileage in. Observed Responses. Gender Proportion.





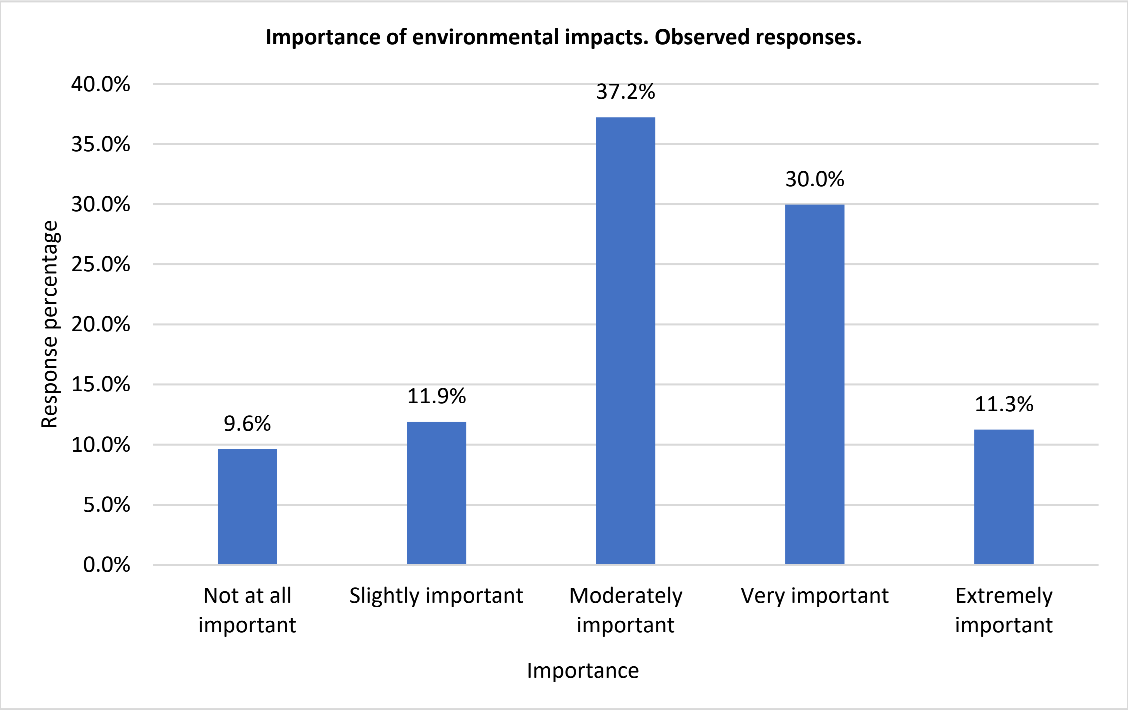
Appendix Q. Payment Methods. Observed Responses. Gender Distribution.

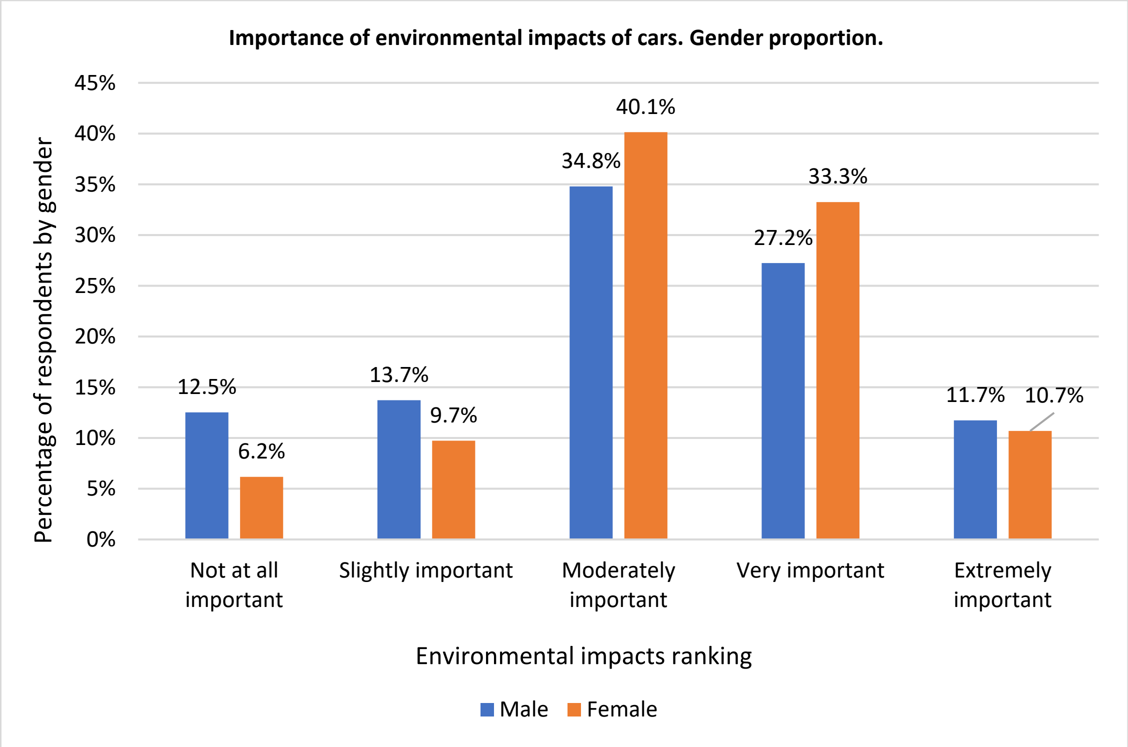




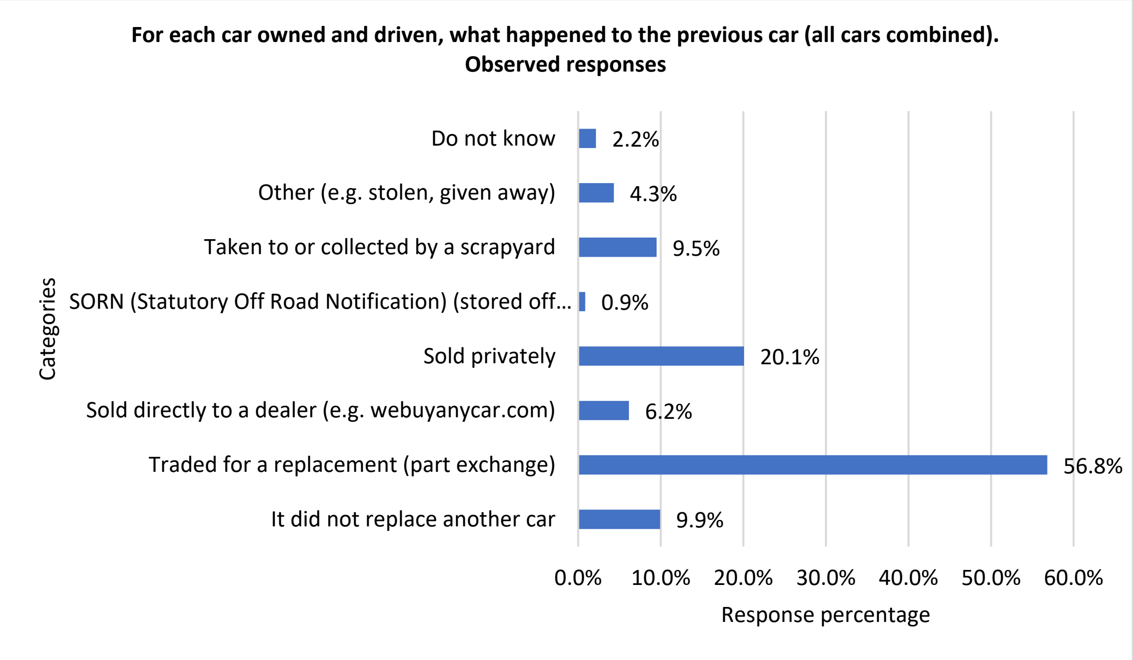
Reference	Payment methods
1	Paid in full up front / Cash or debit card
2	Credit card or bank loan / Personal finance
3	Hire Purchase (car is owned at end of contract)
4	Personal Contract Purchase (option to own at end of contract)
5	Leasing scheme / Personal Contract Hire (no option to own at end of contract)
6	No purchase (i.e. gift or inheritance)
7	Other
8	Cannot recall

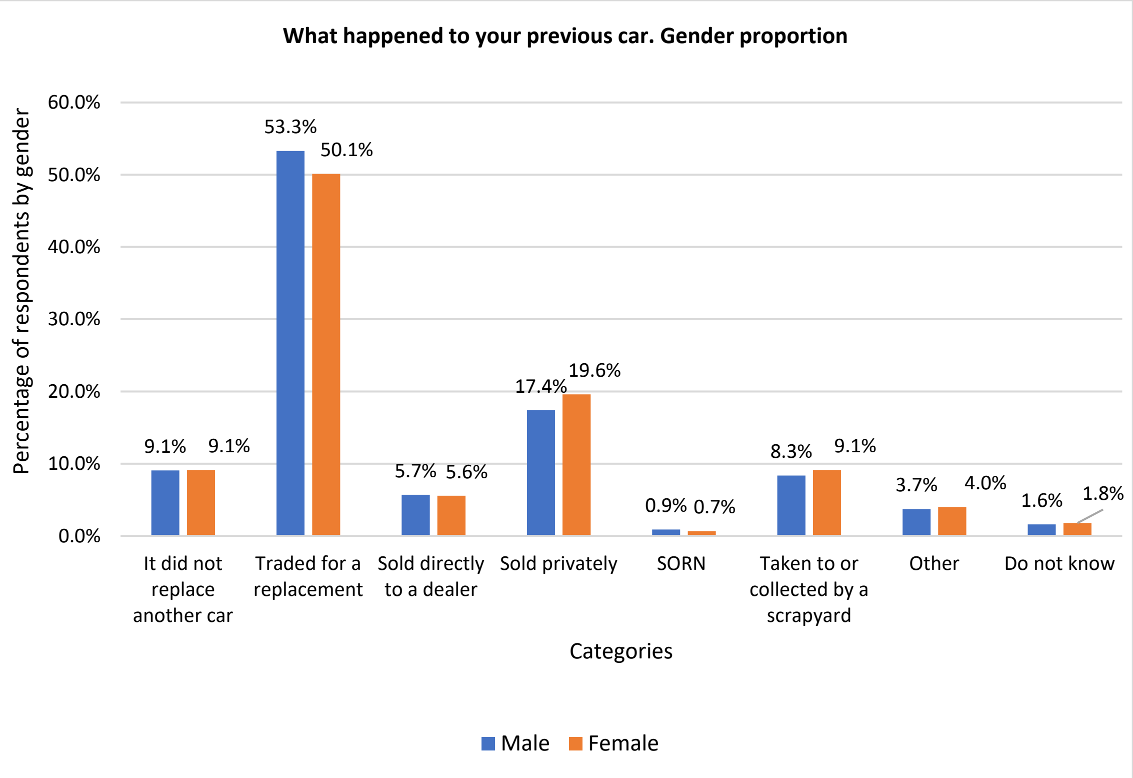
Appendix R. Environmental Impacts. Observed Responses. Gender Distribution.



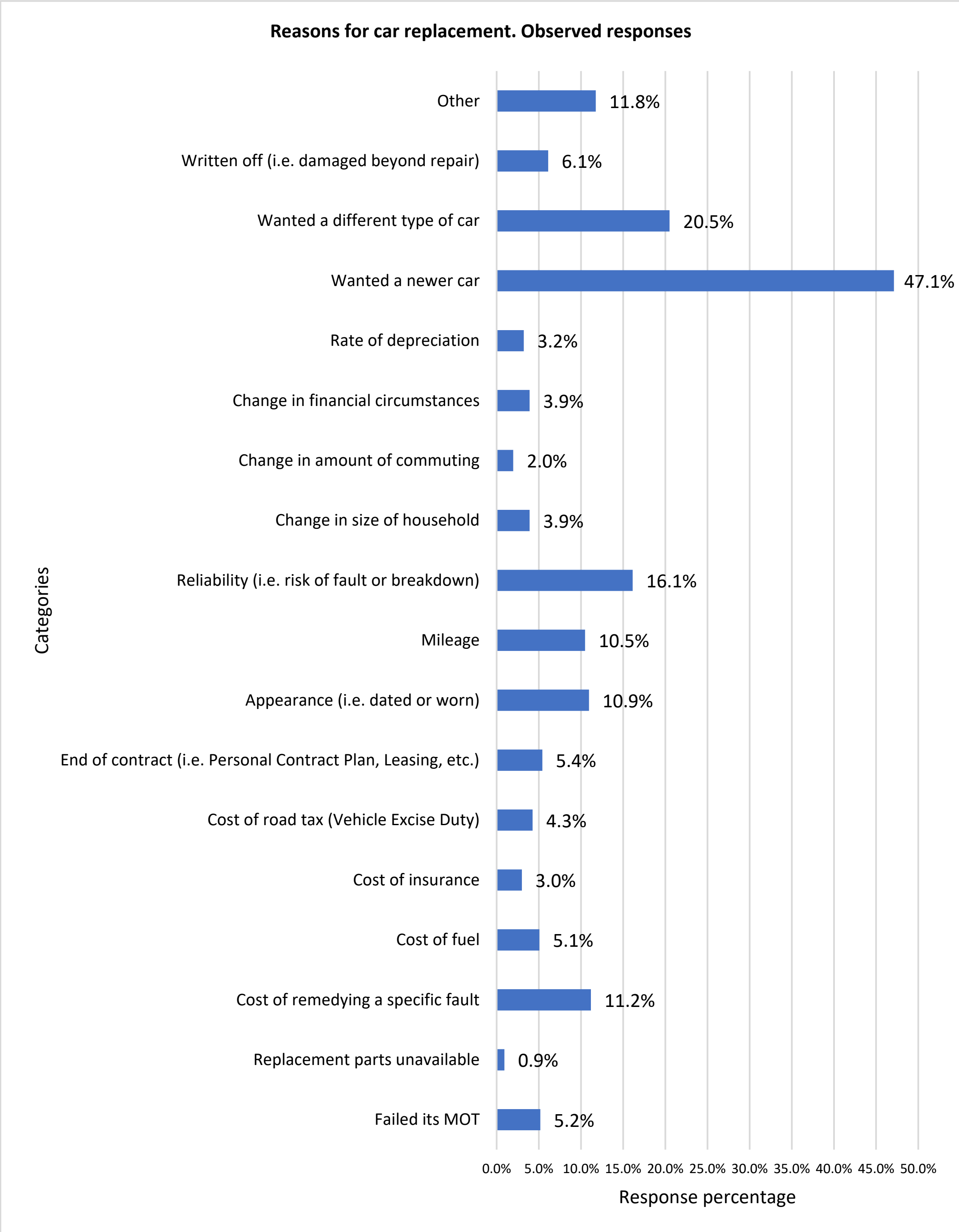


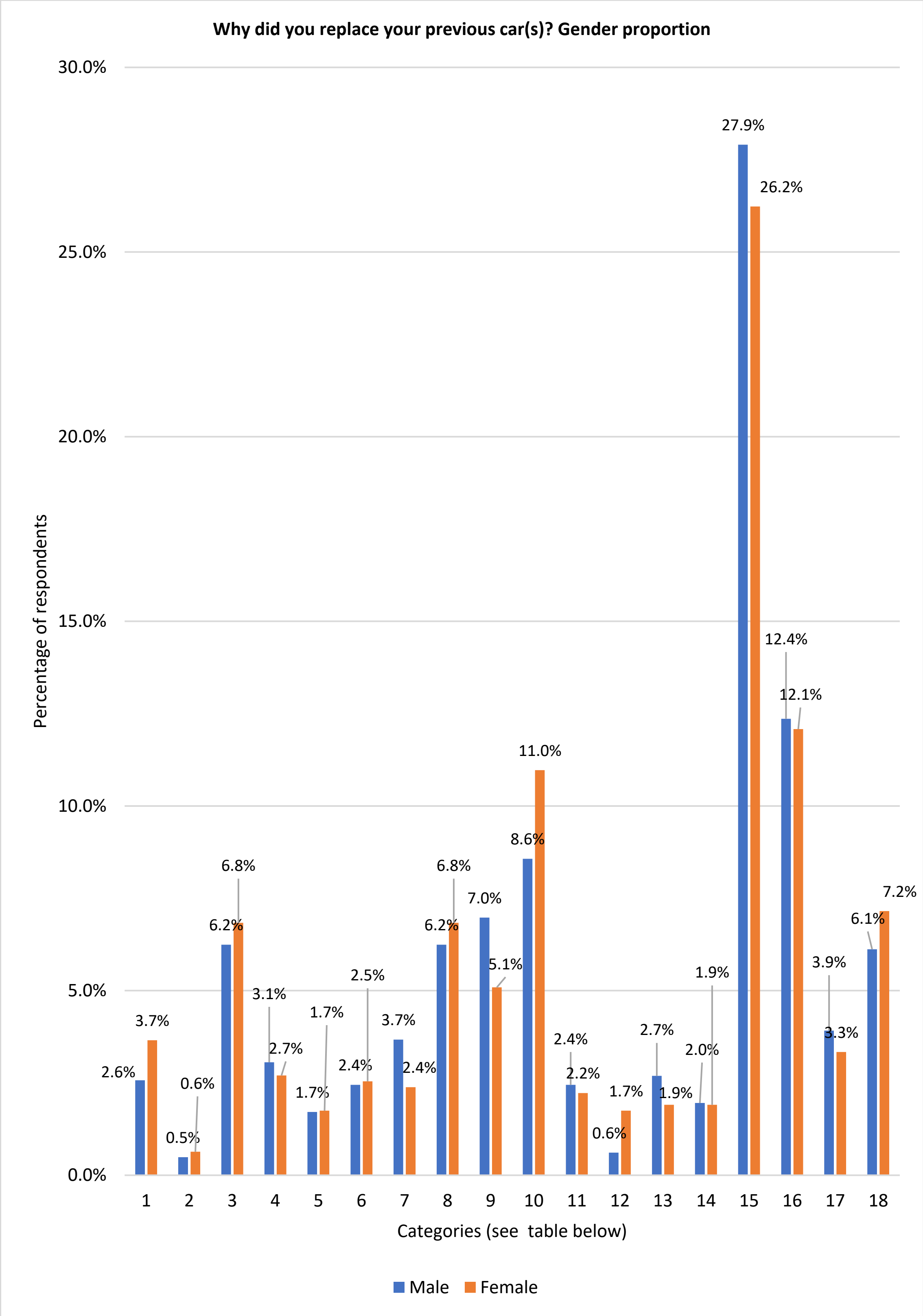
Appendix S. Outcome of Previous Car. Observed Responses. Gender Distribution.





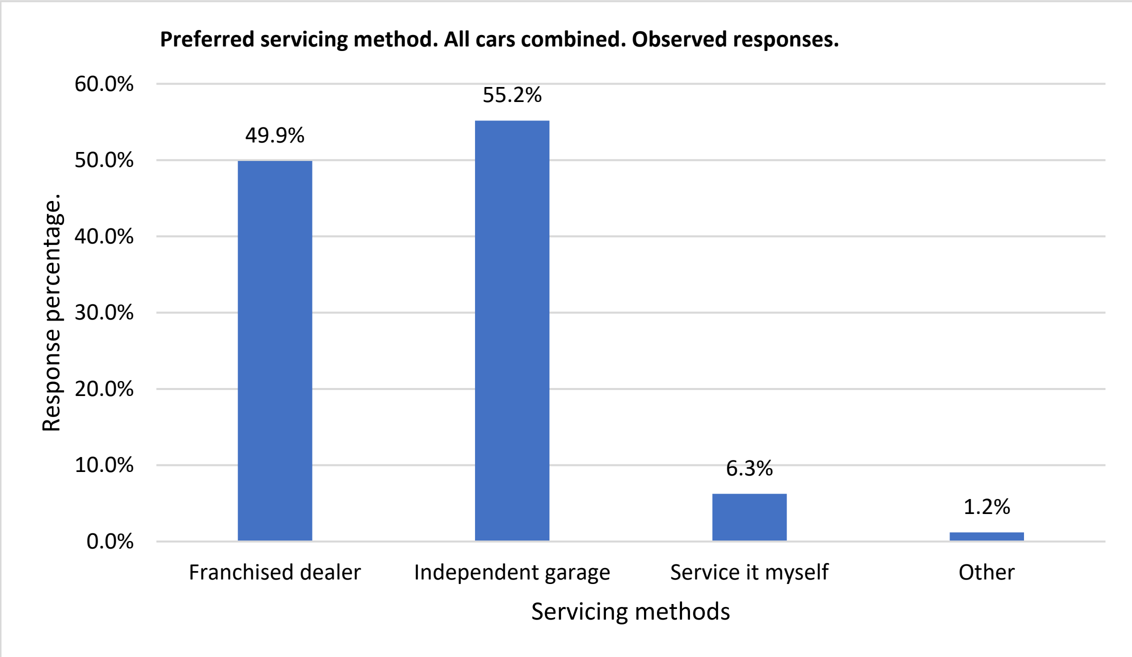
Appendix T. Reasons for Car Replacement. Observed Responses. Gender Distribution. Reference Table.

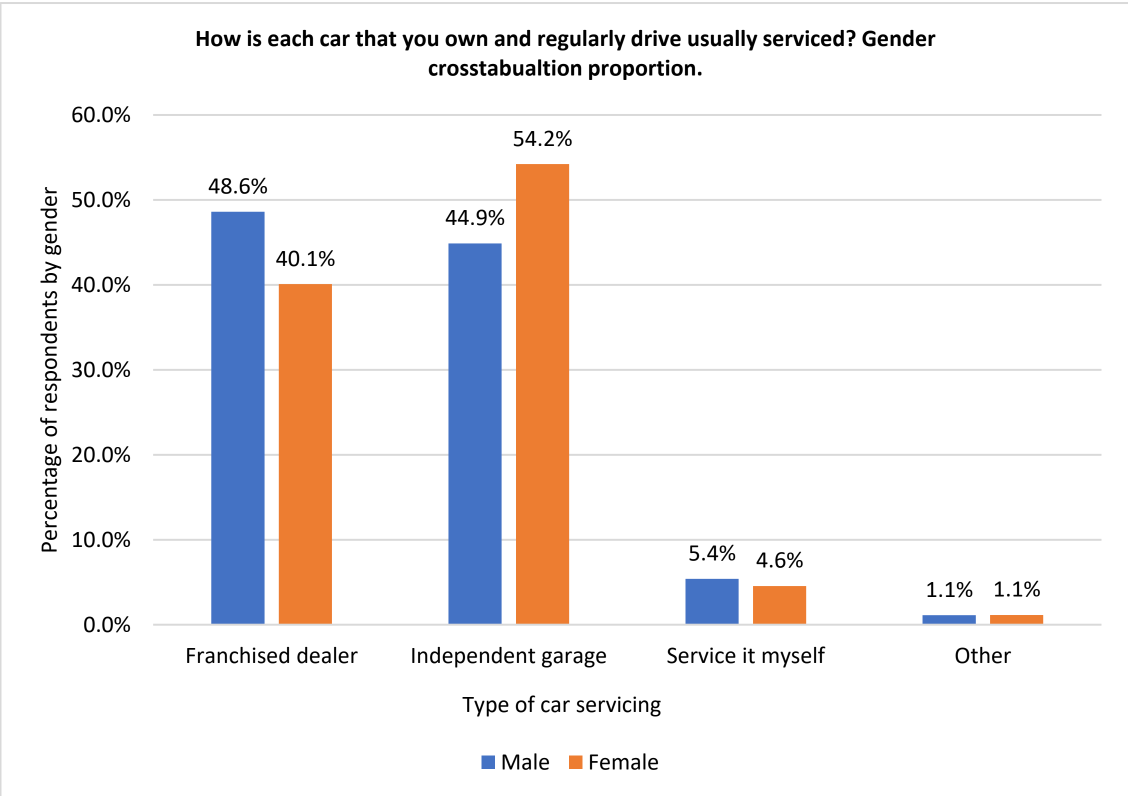



Why did you replace your previous car(s)? Gender proportion
Percentage of respondents
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Categories (see table below)
Male
Female
2.6% 3.7%
0.5% 0.6%
6.2% 6.8%
3.1% 2.7%
1.7% 1.7%
2.4% 2.5%
3.7% 2.4%
6.2% 6.8%
7.0% 5.1%
8.6% 11.0%
2.4% 2.2%
0.6% 1.7%
2.7% 1.9%
2.0% 1.9%
27.9% 26.2%
12.4% 12.1%
3.9% 3.3%
6.1% 7.2%

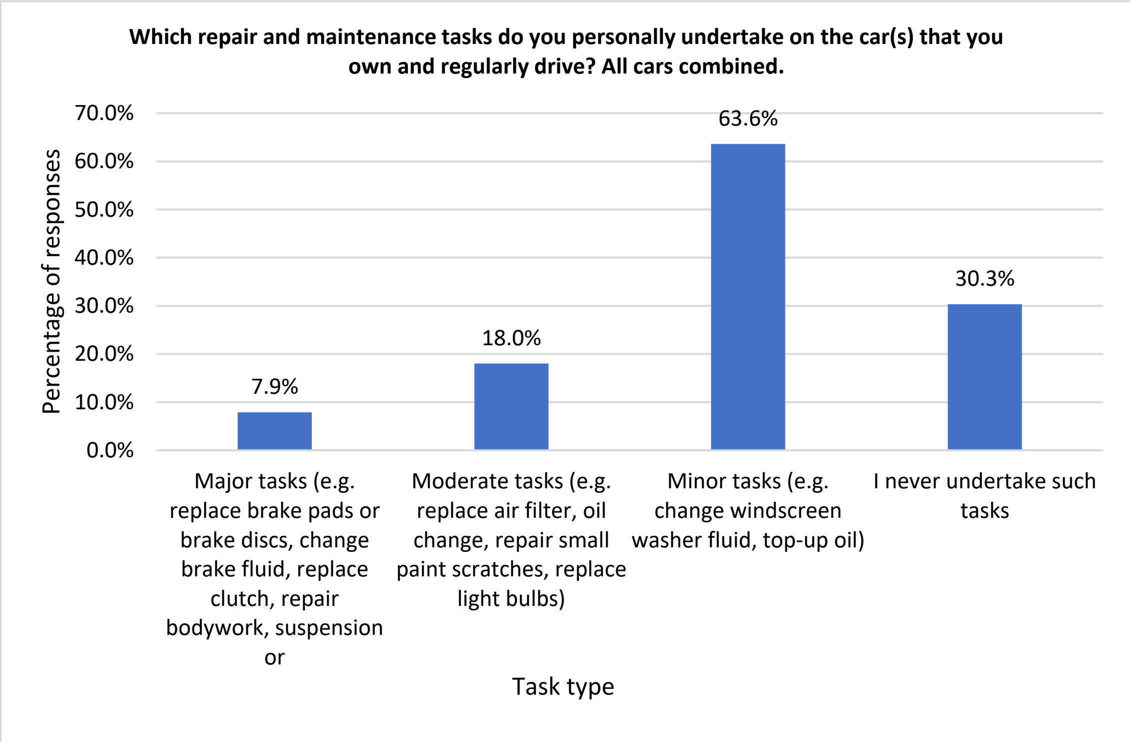
Reference number	Categories
1	Failed its MOT
2	Replacement parts unavailable
3	Cost of remedying a specific fault
4	Cost of fuel
5	Cost of insurance
6	Cost of road tax (Vehicle Excise Duty)
7	End of contract (i.e. Personal Contract Plan, Leasing, etc.)
8	Appearance (i.e. dated or worn)
9	Mileage
10	Reliability (i.e. risk of fault or breakdown)
11	Change in size of household
12	Change in amount of commuting
13	Change in financial circumstances
14	Rate of depreciation
15	Wanted a newer car
16	Wanted a different type of car
17	Written off (i.e. damaged beyond repair)
18	Other

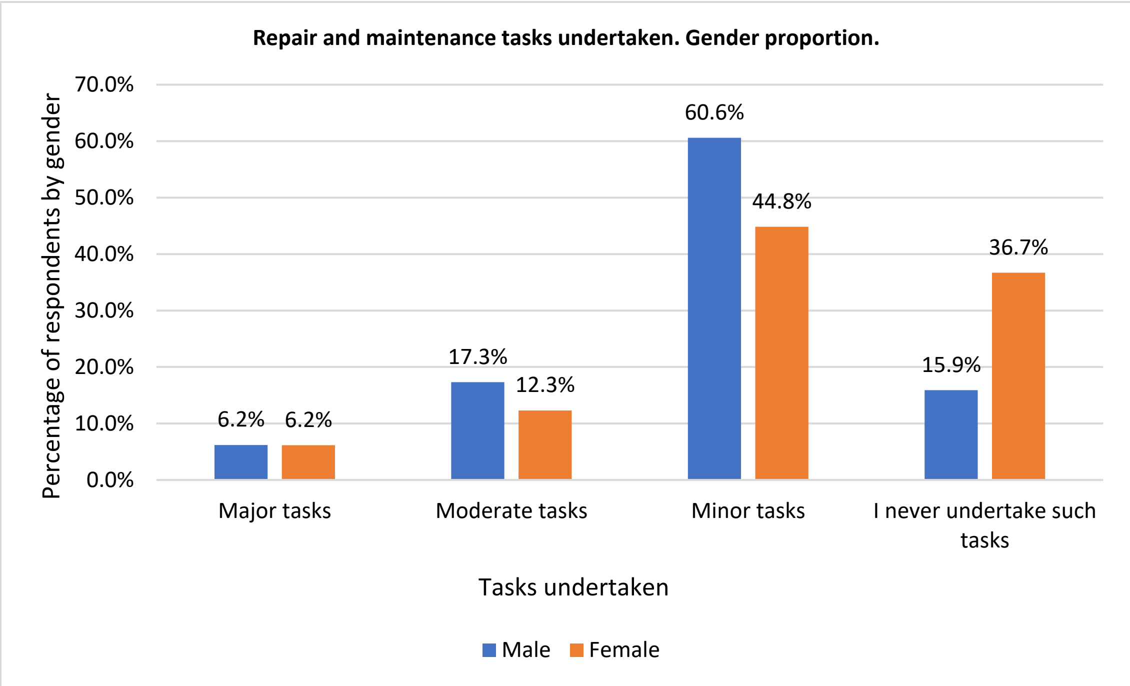
Appendix U. Preferred Servicing Method. Observed Responses. Gender Distribution.



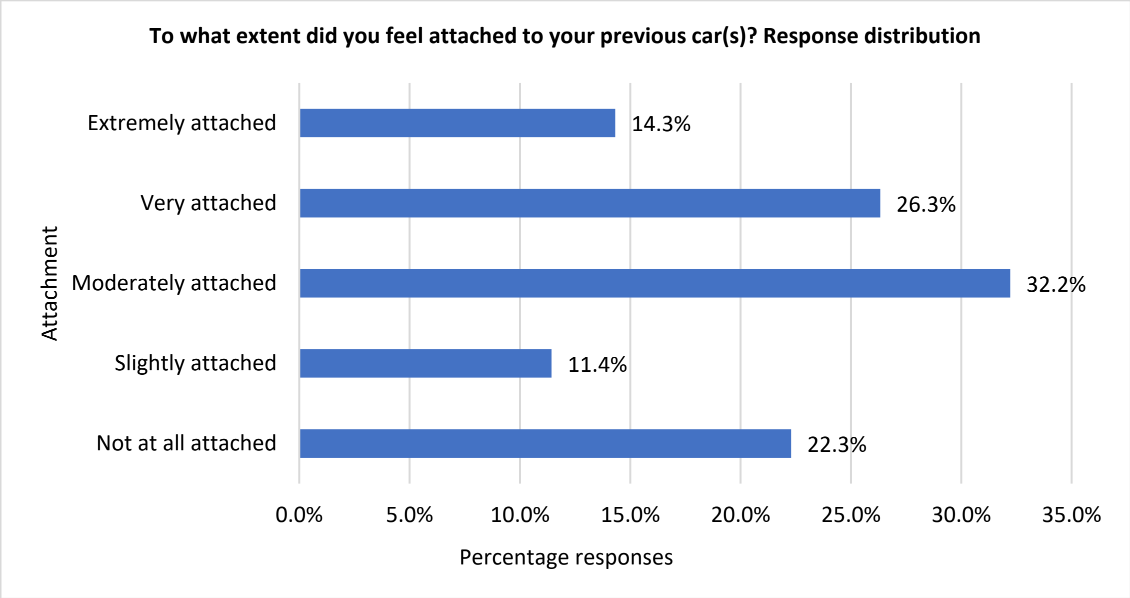


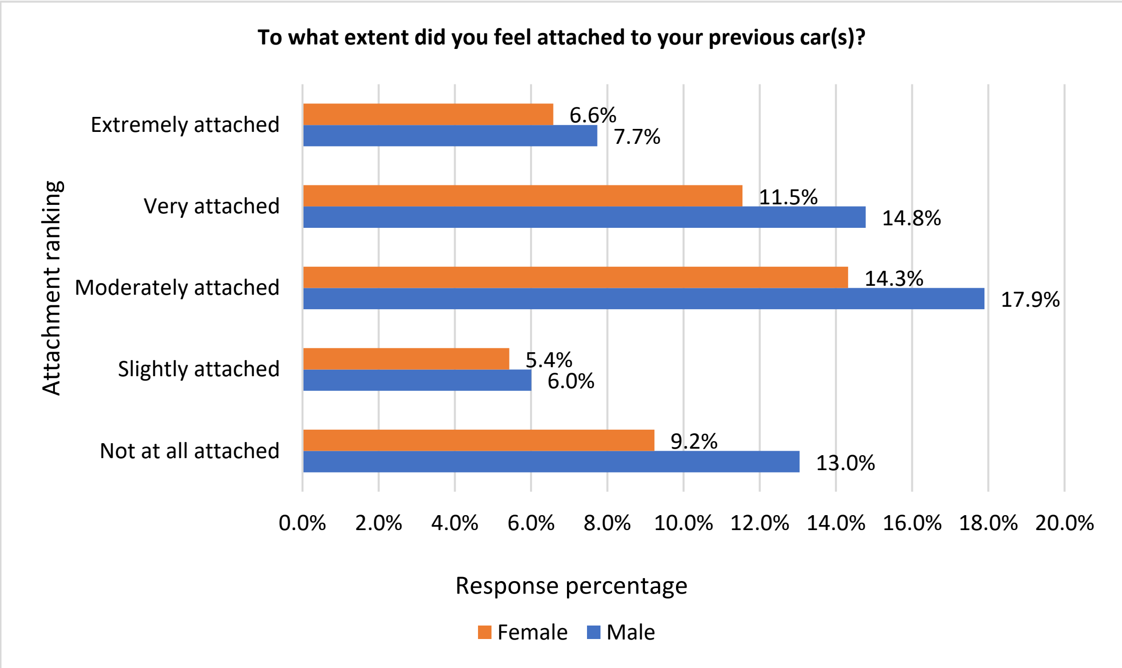
Appendix V. Repair and Maintenance Tasks. Observed Responses. Gender Proportion.



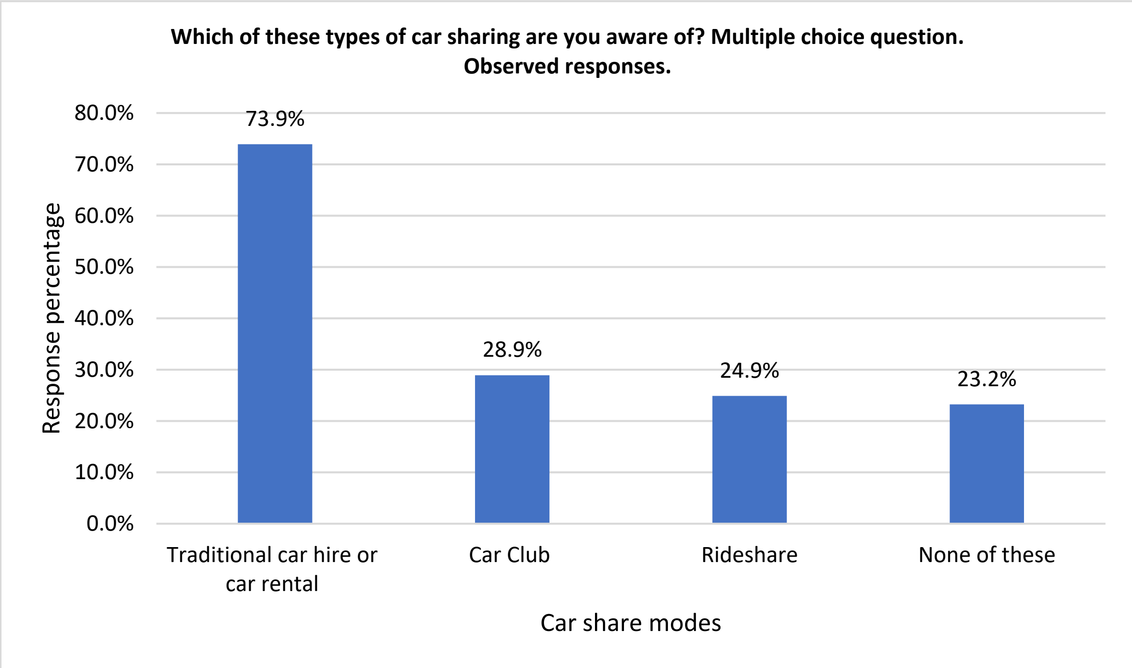


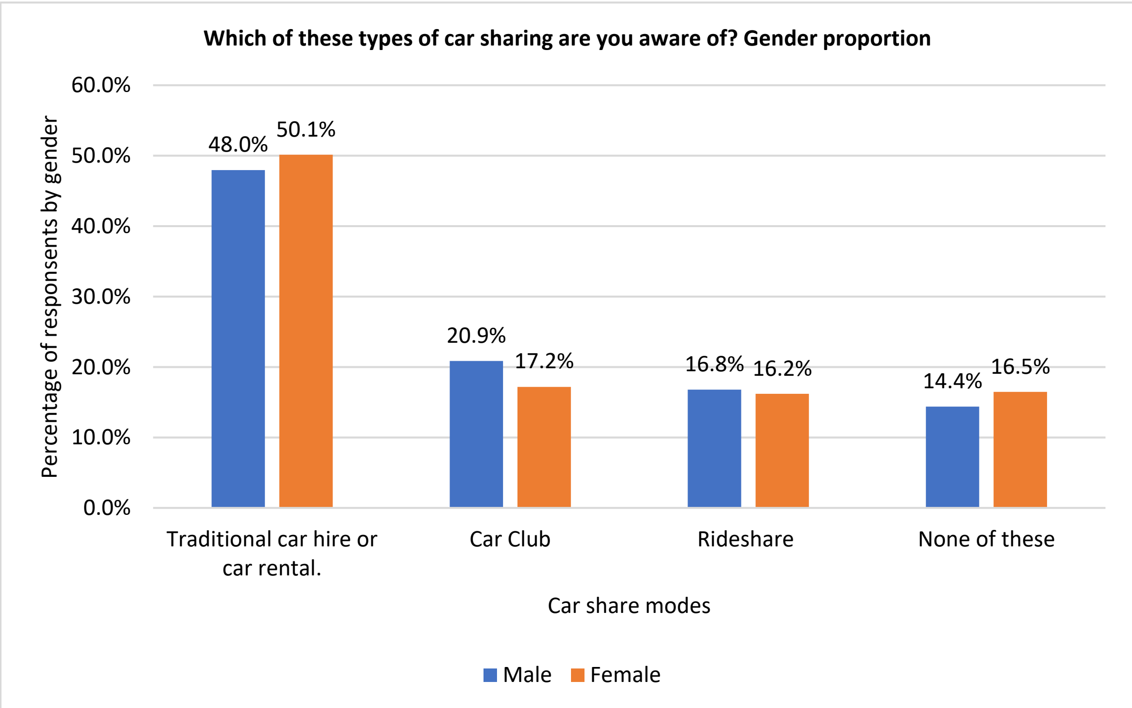
Appendix W. Car Attachment. Responses Distribution. Gender Proportion.



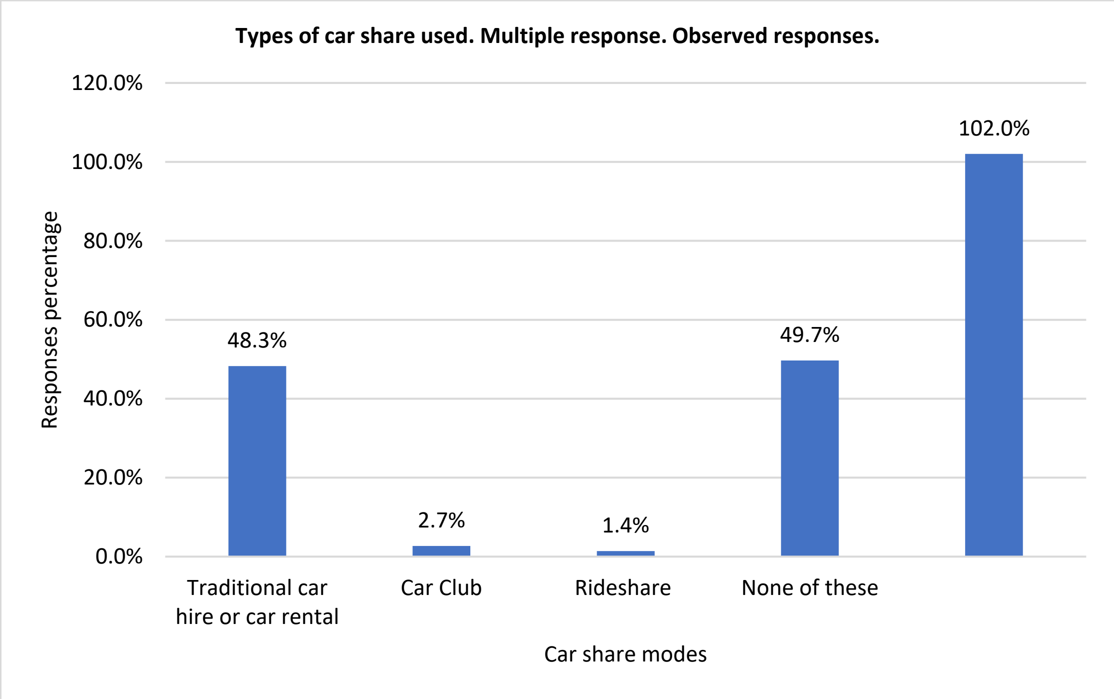


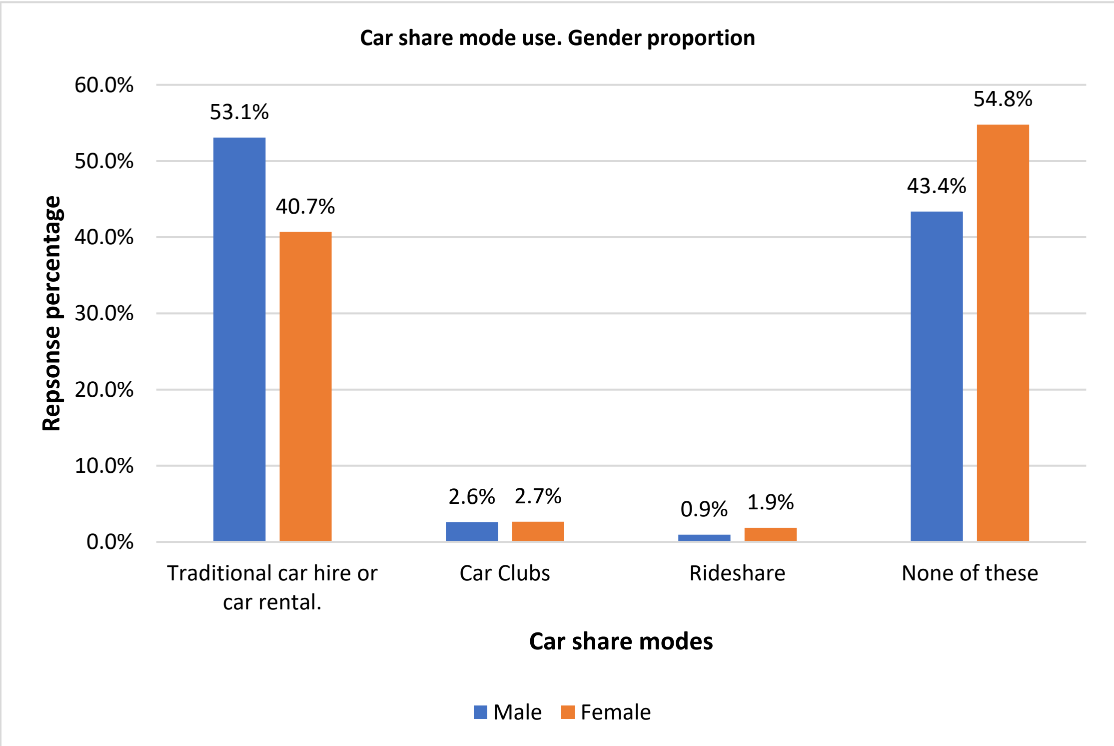
Appendix X. Car Share Awareness. Observed Responses. Gender Distribution.



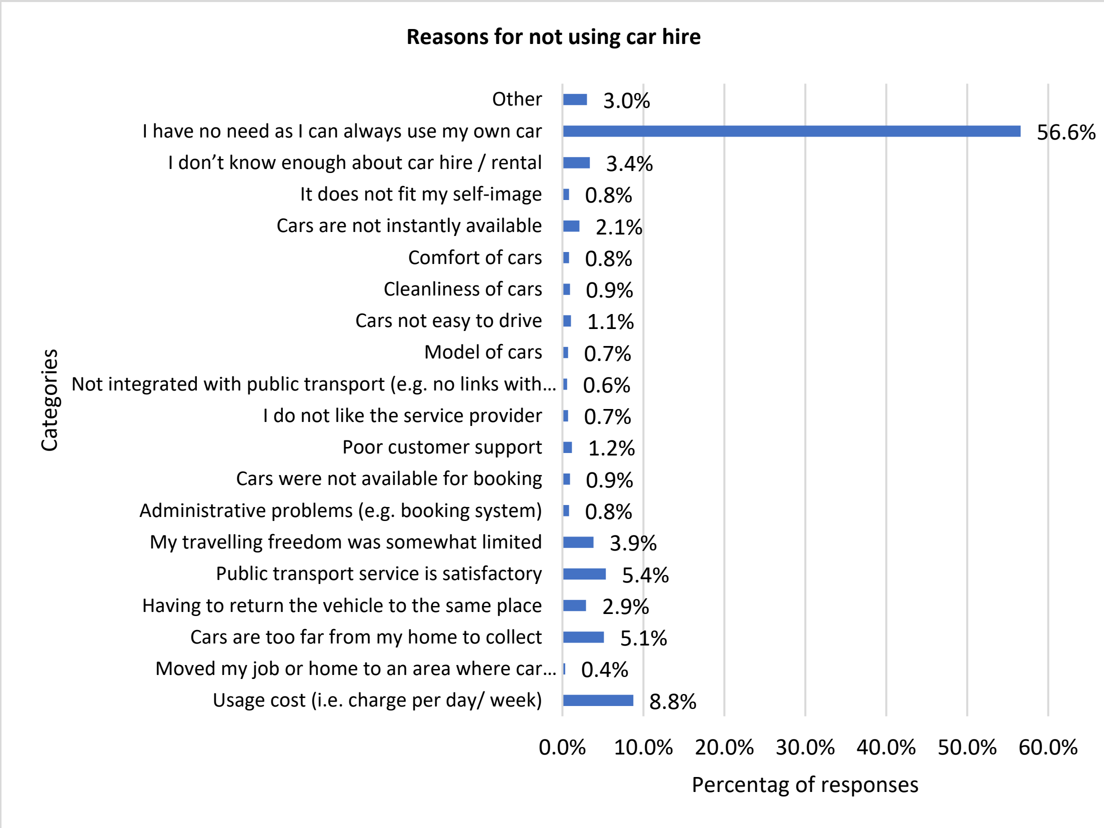


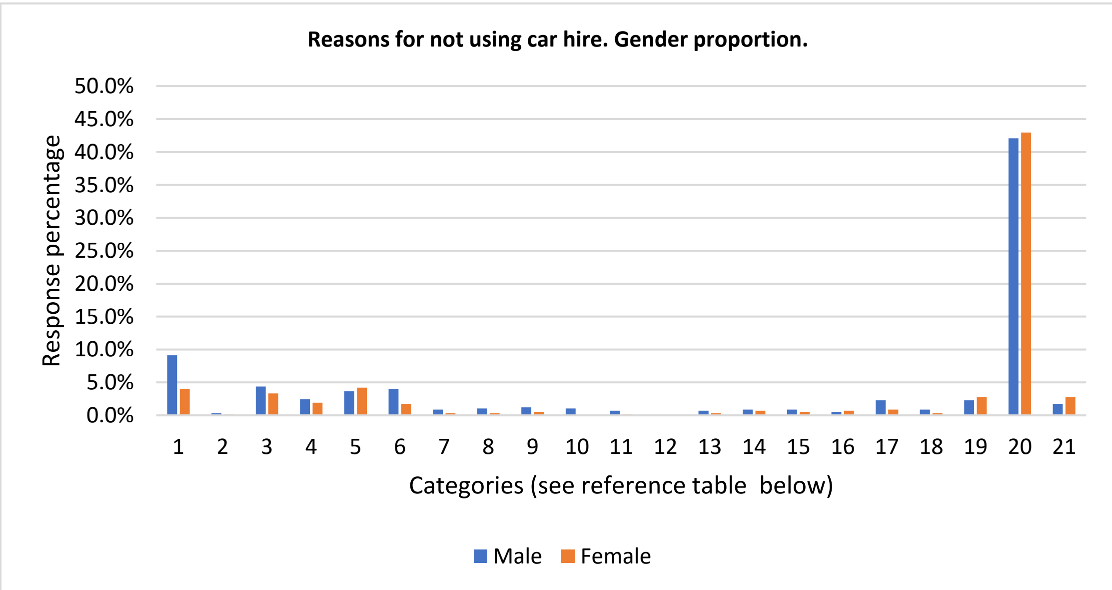
Appendix Y. Car Share Use. Observed Responses. Gender Distribution.





Appendix Z. Reasons for Not Using Car Share (Car Hire, Car Clubs, Rideshare). Observed. Gender Distribution. Reference Table. Statistical Tests.

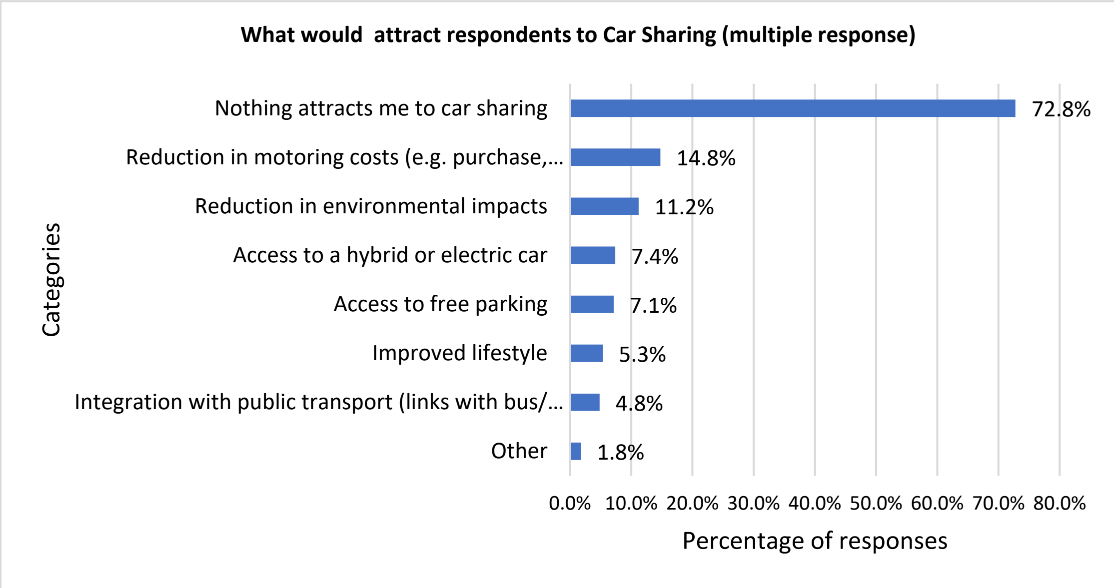


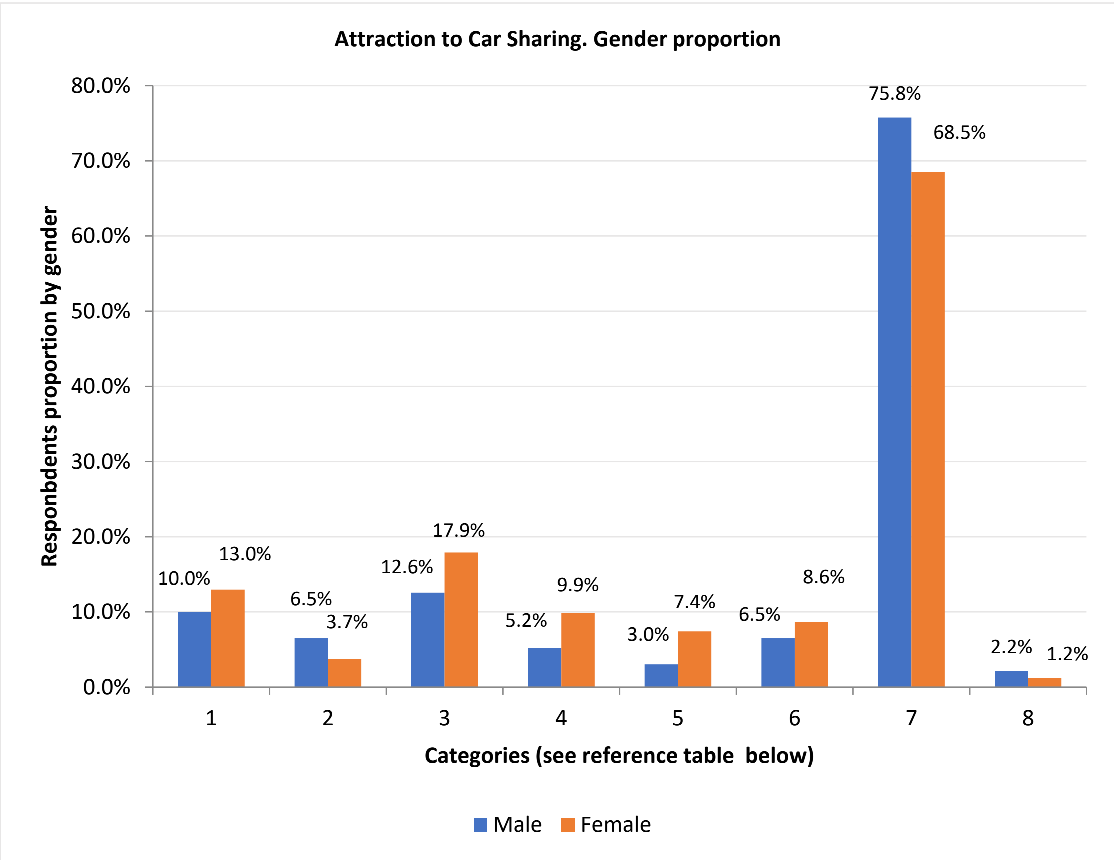


Reference	Reasons for not using car hire	Male	Female
1	Usage cost (i.e. charge per day/ week)	9,1%	4,0%
2	Moved my job or home to an area where car hire/rental is not available	0,4%	0,2%
3	Cars are too far from my home to collect	4,4%	3,3%
4	Having to return the vehicle to the same place	2,5%	1,9%
5	Public transport service is satisfactory	3,7%	4,2%
6	My travelling freedom was somewhat limited	4,0%	1,8%
7	Administrative problems (e.g. booking system)	0,9%	0,4%
8	Cars were not available for booking	1,1%	0,4%
9	Poor customer support	1,2%	0,5%
10	I do not like the service provider	1,1%	0,0%
11	Not integrated with public transport (e.g. no links with bus/ train/ tram)	0,7%	0,2%
12	Technical problems with cars (e.g. damaged cars, entry cards)	0,0%	0,0%
13	Model of cars	0,7%	0,4%
14	Cars not easy to drive	0,9%	0,7%
15	Cleanliness of cars	0,9%	0,5%
16	Comfort of cars	0,5%	0,7%
17	Cars are not instantly available	2,3%	0,9%
18	It does not fit my self-image	0,9%	0,4%
19	I don’t know enough about car hire / rental	2,3%	2,8%
20	I have no need as I can always use my own car	42,1%	43,0%
21	Other	1,8%	2,8%
		81,2%	68,9%

Chi-Square Tests						
Reasons for not currently using car hire		**Value**	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Usage cost (i.e. charge per day/ week)	Pearson Chi-Square	12.449a	1	0.000		
Moved my job or home to an area where car hire/rental is not available	Fisher's Exact Test				1	0.505
Cars are too far from my home to collect	Pearson Chi-Square	.798a	1	0.372		
Having to return the vehicle to the same place	Pearson Chi-Square	.334a	1	0.563		
Public transport service is satisfactory	Pearson Chi-Square	.265a	1	0.607		
My travelling freedom was somewhat limited	Pearson Chi-Square	5.244a	1	0.022		
Administrative problems (e.g. booking system)	Fisher's Exact Test				0.450	0.231
Cars were not available for booking	Fisher's Exact Test				0.286	0.147
Poor customer support	Fisher's Exact Test				0.340	0.176
I do not like the service provider	Fisher's Exact Test				0.030	0.016
Not integrated with public transport (e.g. no links with bus/ train/ tram)	Fisher's Exact Test				0.373	0.191
Technical problems with cars (e.g. damaged cars, entry cards)	No response					
Model of cars	Fisher's Exact Test				0.686	0.350
Cars not easy to drive	Fisher's Exact Test				1.000	0.509
Cleanliness of cars	Fisher's Exact Test				0.725	0.370
Comfort of cars	Fisher's Exact Test				0.723	0.492
Cars are not instantly available	Pearson Chi-Square	3.557a	1	0.059		
It does not fit my self-image	Fisher's Exact Test				0.450	0.231
I don’t know enough about car hire / rental	Pearson Chi-Square	.373a	1	0.541		
I have no need as I can always use my own car	Pearson Chi-Square	.976a	1	0.323		
Other	Pearson Chi-Square	1.540a	1	0.215		

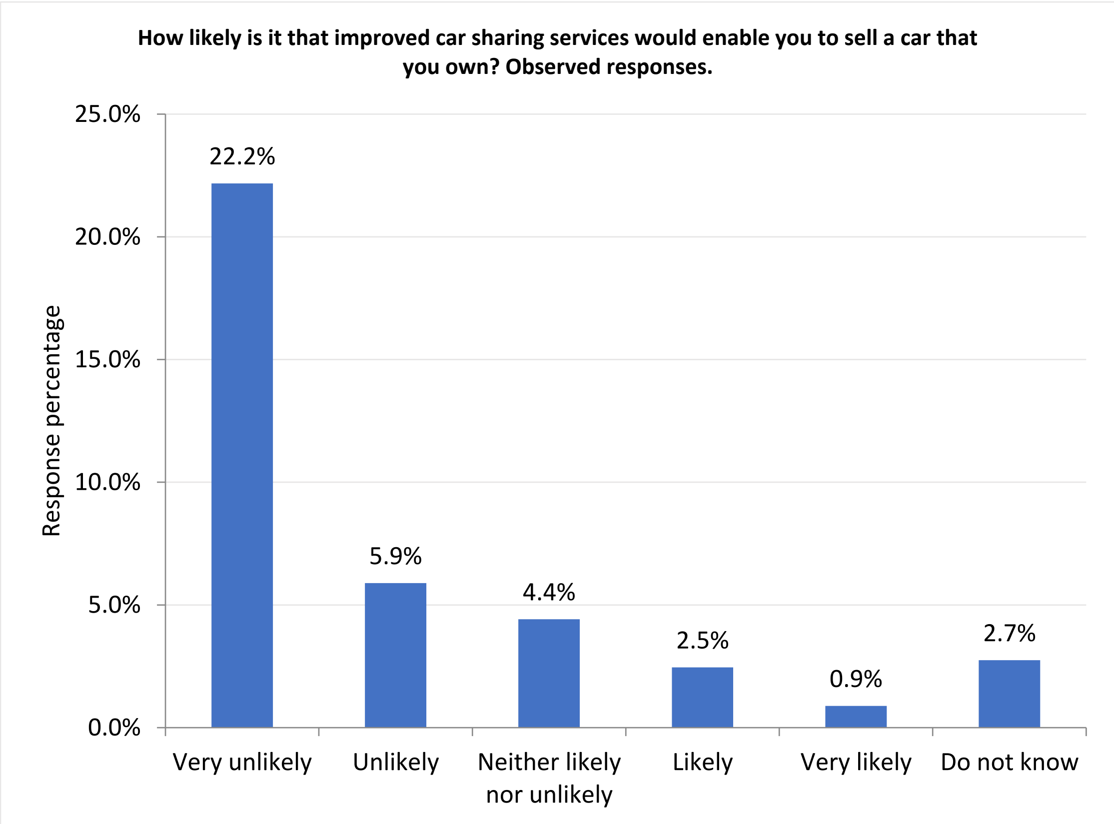
Appendix AA. What Would Attract Respondents to Car Sharing. Observed Responses. Gender Proportion.





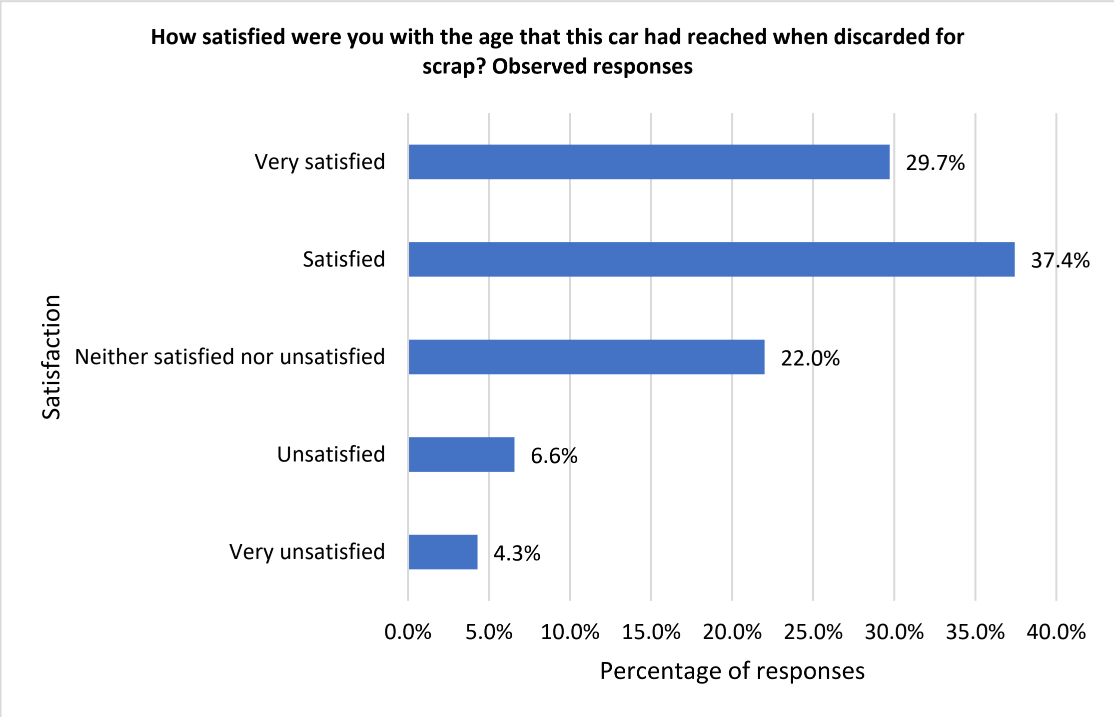
Reference	Categories
1	Reduction in environmental impacts
2	Improved lifestyle
3	Reduction in motoring costs
4	Access to free parking
5	Integration with public transport
6	Access to a hybrid or electric car
7	Nothing attracts me to car sharing
8	Other

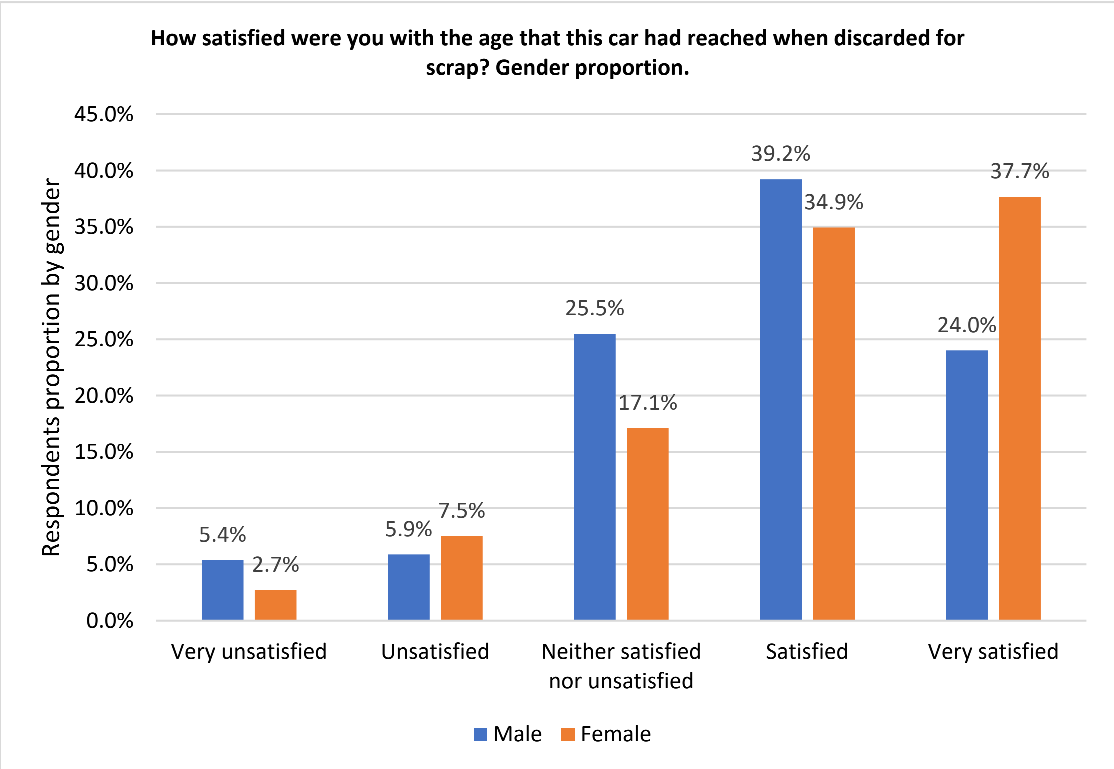
Appendix BB. Likeliness of selling car if car share service improved. Observed Responses. Gender Proportion.



Appendix CC. Satisfaction with discarded age of car when scrapped.

Observed responses. Gender Distribution.





Appendix DD. Trimming outliers. Perceived average age of UK passenger cars. Adapted from Hoaglin and Iglewicz (1987).

Q1	Median	Q3	g	outliers cut-off point	
				Lower threshold	Upper threshold
12		17	2.2	1	28
Q3 - Q1	5				
g1	11				

Appendix EE. Trimming outliers. Average mileage of UK passenger cars. Adapted from Hoaglin and Iglewicz (1987).

Q1	Median	Q3	g	outliers cut-off point	
				Lower threshold	Upper threshold
100000		150000	2.2	-10000	260000
Q3 - Q1	50000				
g1	110000				

Appendix FF. Trimming outliers. Ideal average age of passenger cars in the UK. Adapted from Hoaglin and Iglewicz (1987).

Q1	Median	Q3	g	outliers cut-off point	
				Lower threshold	Upper threshold
14		20	2.2	0.8	33.2
Q3 - Q1	6				
g1	13.2				

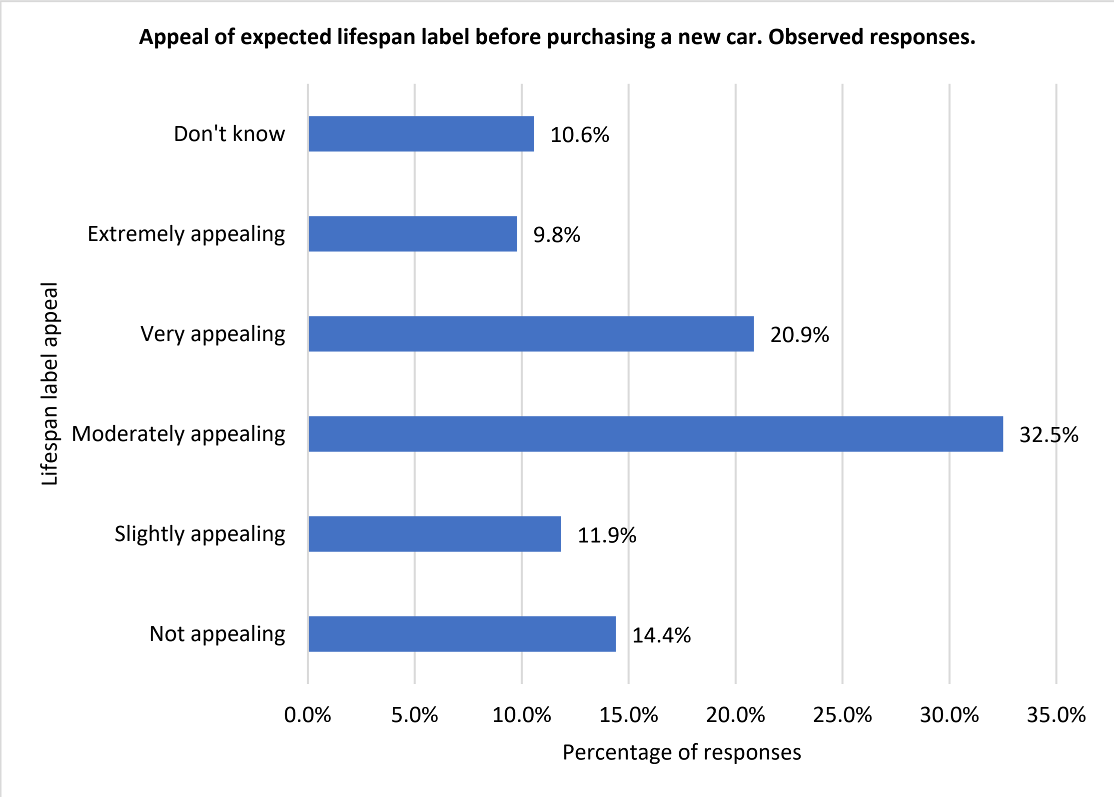
Appendix GG. Trimming outliers. Ideal UK car average mileage. Adapted from Hoaglin and Iglewicz (1987).

Q1	**Median**	**Q3**	**g**	**outliers cut-off point**	
				Lower threshold	**Upper threshold**
100000		200000	2.2	-120000	420000
Q3 - Q1	100000				
g1	220000				

Appendix HH. General Car Purchasing Criteria. Wilcoxon Mann-Whitney U tests.

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Brand Importance when purchasing	127269.000	244639.000	-0.484	0.629
Reliability Importance when purchasing	129312.500	246682.500	-0.044	0.965
Durability Importance when purchasing	123848.500	267228.500	-1.316	0.188
Size Importance when purchasing	120948.000	264328.000	-1.928	0.054
Length of warranty Importance when purchasing	120947.000	264327.000	-1.897	0.058
Features/ High specification Importance when purchasing	120429.500	237799.500	-1.991	0.047
Appearance/ styling Importance when purchasing	127578.000	270958.000	-0.419	0.675
Price Importance when purchasing	123173.000	266553.000	-1.543	0.123
Engine performance Importance when purchasing	126446.000	269826.000	-0.676	0.499
Fuel efficiency Importance when purchasing	122167.000	265547.000	-1.720	0.085
Comfort Importance when purchasing	126112.500	269492.500	-0.773	0.440
Environmental impact Importance when purchasing	112852.500	256232.500	-3.652	0.000

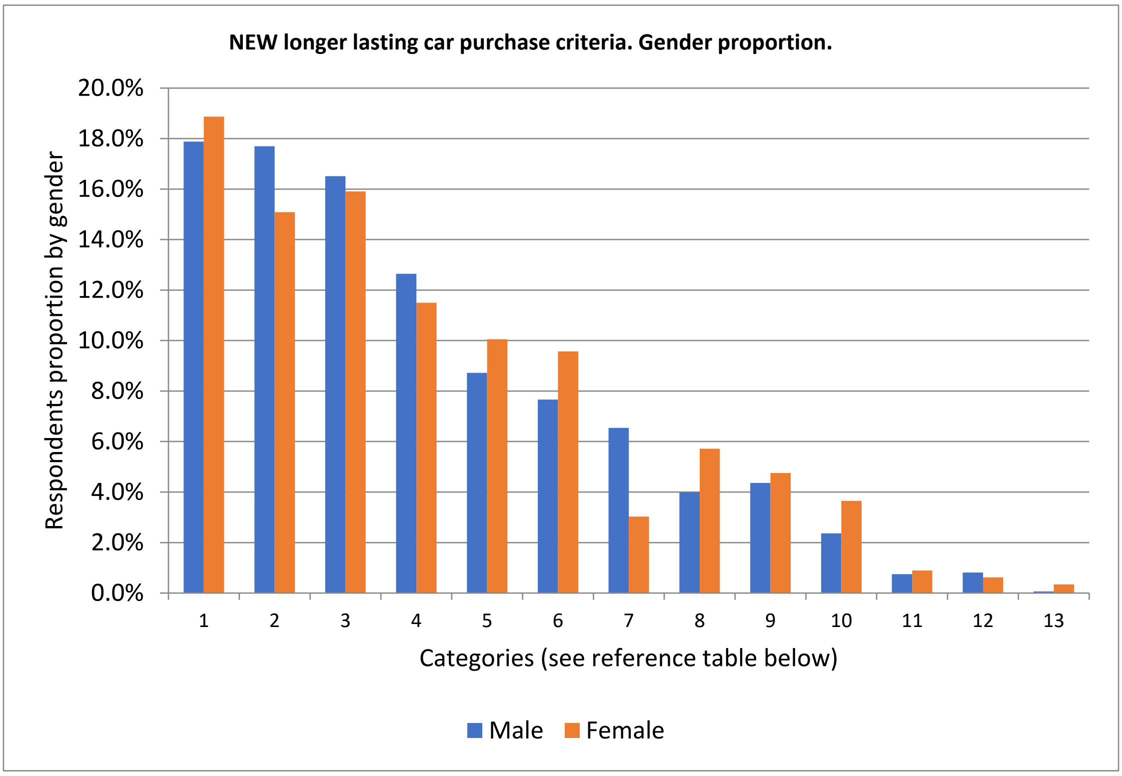
Appendix II. Passenger Car Lifespan Label. Observed Responses. Gender Distribution.



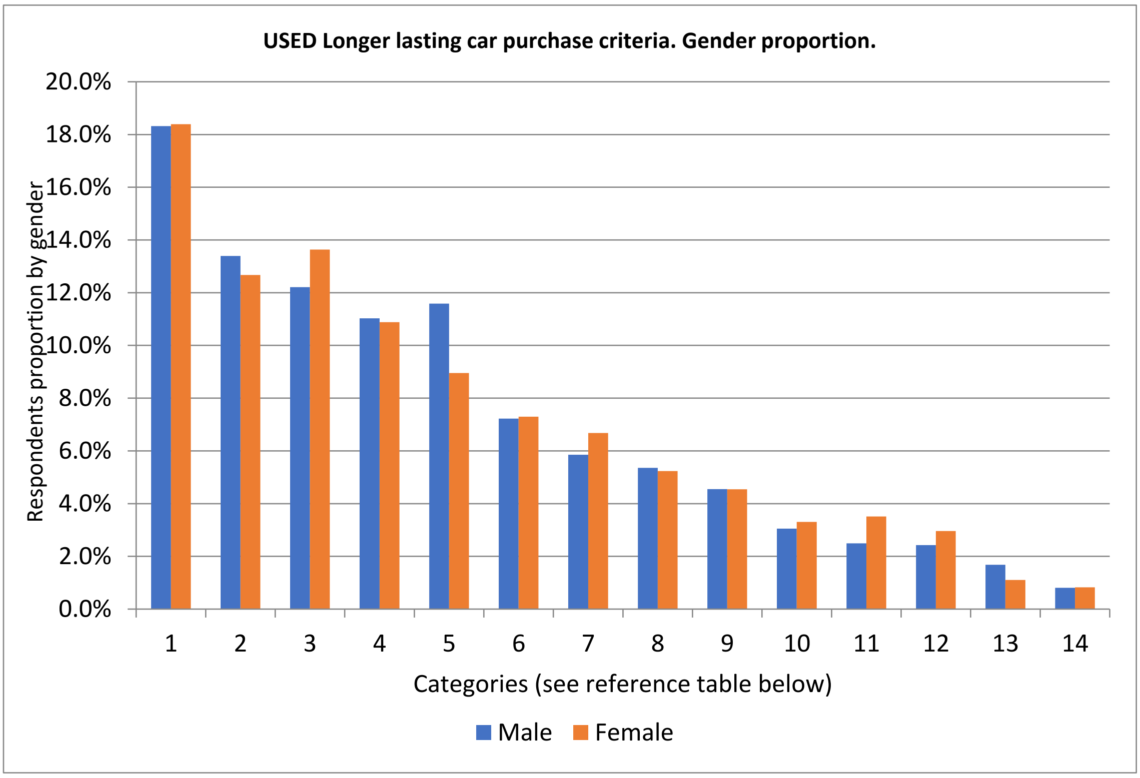
Appendix JJ. General Purchase Criteria Importance Table.

Criteria	Most common answer	%
Reliability	Extremely Important	73.7
Fuel efficiency	Extremely Important	51.4
Durability	Extremely Important	49.1
Comfort	Extremely Important	42.2
Price	Very Important	60.2
Size	Very Important	42.3
Engine performance	Very Important	36.6
Length of warranty	Very Important	35.2
Appearance/ styling	Moderately important	33.4
Features/ High specification	Moderately important	33.1
Brand	Moderately important	31.1
Environmental impact	Moderately important	29.6

Appendix KK. NEW and USED Longer Lasting Car Purchasing Criteria. Gender Distribution. Reference Tables.



Reference	NEW LLC car Category	Male	Female
1	Price	17.9%	18.9%
2	Manufacturer's reputation	17.7%	15.1%
3	Length of warranty	16.5%	15.9%
4	Previous experience with manufacturer	12.6%	11.5%
5	Expert reviews	8.7%	10.1%
6	How it feels during a test drive	7.7%	9.6%
7	Quality of the interior components	6.5%	3.0%
8	User reviews	4.0%	5.7%
9	Style	4.4%	4.8%
10	Advice from friends, family or colleagues	2.4%	3.7%
11	Advice from seller	0.7%	0.9%
12	Other	0.8%	0.6%
13	Brochure in showroom	0.1%	0.3%



Reference	USED LLC car Category	Male	Female
1	Price	18.3%	18.4%
2	Mileage of used car	13.4%	12.7%
3	Length of warranty	12.2%	13.6%
4	Age of used car	11.0%	10.9%
5	Manufacturer's reputation	11.6%	9.0%
6	How it feels (interior quality, test drive)	7.2%	7.3%
7	Previous experience with manufacturer	5.9%	6.7%
8	Visual condition	5.4%	5.2%
9	Expert reviews	4.5%	4.5%
10	User reviews	3.1%	3.3%
11	Advice from friends, family or colleagues	2.5%	3.5%
12	Style	2.4%	3.0%
13	Advice from seller	1.7%	1.1%
14	Other	0.8%	0.8%