"Policy Guidelines for Integrated Sustainable Transport Planning to meet Greenhouse Gas Targets for Wellington, New Zealand and Possible Effects on the Built Environment"

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POLICY GUIDELINES FOR INTEGRATED SUSTAINABLE TRANSPORT PLANNING TO MEET GREENHOUSE GAS TARGETS FOR WELLINGTON, NEW ZEALAND AND POSSIBLE EFFECTS ON THE BUILT ENVIRONMENT

By

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"We can't solve problems by using the same kind of thinking
we used when we created them"

Albert Einstein

Abstract

The increasing concentration of greenhouse gases (GHGs) in the Earth's atmosphere is resulting in an increase in the temperature of the Earth. The accumulation of GHGs is due to emissions from burning of fossil fuels for energy generation and transportation, from industrial and manufacturing processes, as well as from agriculture and other activities. To meet the requirements of the Paris Climate Agreement, to which New Zealand is a signatory, will require emissions to be cut by at least 80% from current levels by or before 2050.

The transport sector through its reliance on oil accounts for approximately 15% of overall greenhouse gas emissions. Global CO_2 emissions from transport have grown by 45% from 1990 to 2007. At the same time the International Energy Agency (2013) state that by 2050 under a Business-as-Usual scenario global urban passenger mobility will more than double. Around half of the global population is now living in urban regions, i.e. where the environment is largely comprised of buildings and their connecting infrastructure, and this same half contributes 70% of global carbon emissions while more than 60% of the global gross domestic product is created by the revenue of only 600 cities.

In order to see whether the demands for transport and the requirement of the Paris Agreement can be met simultaneously, the approach in this study is to establish goals for CO_2 emissions reduction together with Business-as-Usual as a benchmark, and then to see how, and the extent to which, existing mobility services for the city of Wellington could be supplied within these targets. The forms of transport that might be needed for provision of these mobility services are also described. The bottom line of this study is that we are dealing with a long run problem and now is the time to think of what structure (in terms of built environment, technological improvement and behavioural changes) should be adopted for Wellington's transport at the earliest possible time since this structure will determine energy and emissions intensities for many years to come.

While it may not be desirable or feasible to entirely remove motor vehicles for the sake of sustainability the baseline situation (Business-As-Usual) should not be permitted as much acceleration as it is currently showing. Improving vehicle efficiencies, substituting lower carbon fuels for existing fossil fuels, shifting and avoiding strategies, human behavioural improvements, and national, regional and local policy frameworks all need to work together

for mitigation of emissions. Coordinated policies within the transport portfolio, combining land use and transport agencies are needed which will produce outcomes perhaps only after 10 to 20 years to meet objectives of the sustainable transport journey towards a greener future.

This research explores the possibility of significantly lower emission urban transport without significantly curtailing mobility services in terms of per capita distance travelled while meeting the overall level of emissions that will satisfy the requirements of the Paris Climate Agreement. It does this for a single city in a particular geographic location but its findings have implications for cities across the world.

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Dedication

This thesis is dedicated to my (late) father Ramzan Shaikh and my (late) mother Zubaida Ramzan (May Allah rest their souls in eternal peace), who always had a giant vision in their lives and who taught me always to think above the sky's limits. I have just attempted the first step. Without their sacrifices, financial and moral support from my cradle to getting to University I would be nothing.

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List of contents

Abstract i

Acknowledgements iii

Dedication iv

List of tables ix

List of figures xi

List of Abbreviations xii

Chapter 1 | Introduction 1

1.1 Research aim 2

1.2 Research scope 3

1.3 Significance 5

1.4 Structure 7

Chapter 2 |Greenhouse gases, CO_2 emissions and emissions from transportation 11

2.1 Natural temperature phenomenon 12

2.2 Global warming 14

2.3 Greenhouse gases and CO_2 emissions 16

2.4 Emissions from transportation 18

2.5 Why the focus on carbon emissions? 20

2.6 Transport and climate change 21

2.7 Stabilisation and its cost 23

2.8 Conclusion 24

Chapter 3 |Research question 26

3.1 Black gold reserves; point of concerns 26

3.2 Looking for alternatives; is it a correct choice? 27

3.3 Car ownership, oil and inequality 27

3.4 Is there a relationship between mobility and GDP growth? 32

3.5 Economic prosperity and urban development 34

3.6 Low carbon world 37

3.7 Current system of transportation 43

3.8 Fuels, economy and alternatives 44

3.9 The gap in knowledge 46

Chapter 4| New Zealand and Wellington region transportation emissions 47

4.1 New Zealand a recently discovered country 47
4.1.1 New Zealand's geographic profile 47
4.1.2 New Zealand's greenhouse gases profile 48
4.2 Relation of CO_2 emissions and VKT: 52
4.3 Why a city-based consideration? 56
4.4 Wellington, coolest little capital 57
4.5 Region's demographics and social characteristics 58
4.6 Wellington region VKT and carbon emissions 60
4.7 Wellington region's transport; the existing situation 62
4.7.1 Wellington region's light passenger vehicles 62
4.7.2 Wellington region's public transport framework 65
4.8 Transport in the Wellington region by 2050 66
4.9 Wellington transport; a consolidated overview up to 2050 71
Chapter 5|Technical aspects of sustainable transport 76
5.1 Transport emission mitigation measures 76
5.2 Technological strategy (technical mitigation measures) 78
5.3 Car technology 79
5.4 Saving fuel in oil powered cars 80
5.4.1 Saving fuel in oil powered cars – shared mobility 80
5.4.2 Saving fuel in oil powered cars – weight reduction 80
5.4.3 Saving fuel in oil powered cars – hybrid drivetrains 82
5.5 Transport-as-a-service 83
5.6 Other possibilities 84
5.6.1 Other possibilities - road expansion 84
5.6.2 Other possibilities – Transport Demand Management 86
5.6.3 Other possibilities - CO_2 emissions control by traffic signal system 87
5.6.4 Alternative fuels for existing vehicles - biofuel potential 87
5.7 Alternative energy – electric vehicles 90
5.7.1 Particulates from EVs 95
5.7.2 EVs in Norway 96
5.8 EVs in New Zealand 97
5.9 Freight transportation 101
5.9.1 Fuel efficiency standards for heavy vehicles 101
5.9.2 Fuel efficiency standards for light commercial vehicles 102

5.10 Effect of technology 103
5.11 Technical scenarios 104
5.11.1 First technical scenario 104
5.11.2 Second technical scenario 106
5.11.3 Third technical scenario 109
5.12 Conclusions 111
Chapter 6 | Non-Technical aspects of sustainable transport 113
6.1 Non-Technical aspects - *what does this mean*? 113
6.2 Non-Technical strategy 114
6.3 The need is mobility not necessarily private cars 116
6.4 Heavy vehicles non-technical measures 117
6.5 The urban situation 118
6.6 Role of urban public transport 118
6.7 Public transport in an international perspective 120
6.8 Public transport trends 122
6.9 Emissions reductions by way of public transport 124
6.10 Integrating public transport and urban planning 126
6.11 Wellington public transport past and present 128
6.12 Non-motorised transport modes 130
6.12.1 Walking 132
6.12.2 Cycling 133
Chapter 7| Built environment & sustainable urban planning 137
7.1 Sustainable transport and urban planning 137
7.2 Urban mobility and regional prosperity 140
7.3 Land use policies 140
7.4 Built environment effects on vehicle usage 142
7.5 Compact city + sustainable transport = healthy environment 143
7.6 The built environment and Wellington's active & public transportation 145
7.6.1 Local effects; walking and cycling 146
7.6.2 Cycling 146
7.6.3 Local effects; congestion and light rail 149
7.7 Other public transport considerations 151
7.8 Built environment effect on travel behaviour 152
7.9 Conclusions 152

Chapter 8|Results and discussion 156
8.1 Light passenger vehicles vision 2050 156
8.1.1 Other ways of travelling 159
8.2 Light commercial vehicles vision 2050 160
8.3 Heavy commercial vehicles vision 2050 162
8.4 Wellington region bus transportation Vision 2050 164
8.5 Wellington regional rail transportation vision 2050 165
8.6 Consolidated overview "Wellington Transportation Vision 2050" 166
Chapter 9 |Future prospects and recommendations 171
9.1 Wellington region's future prospects 171
9.2 Timeframe needed for changes 172
9.3 How these proposals are different from the current transport system 174
9.4 Traffic congestion in Wellington; what does it cost? 176
9.5 Foreseeing the Region's Future 177
9.6 Sustainability parameters 178
9.7 Policies practice 180
9.8 Policy framework 182
9.9 Proposed planning policies that may help to achieve the scenarios 184
9.10 The way forward 186
9.11 The role of cities 189
9.11.1 Technical measures 190
9.11.2 Nontechnical measures 191
9.11.3 Driverless cars 191
9.12 How much can Wellingtonians save by taking public transport? 192
9.13 Recent Case Studies reveal the lack of awareness of the need to reduce emissions 193
9.13.1 Case study 1 "Let's Get Wellington Moving" 193
9.13.2 Case study 2 "Wellington Trolley buses" 194
9.14 Freight transport 195
9.15 The future of Wellington region's transport 198
Chapter 10 |Conclusion 199
10.1 Answers to research questions 200
10.2 The way forward 202
10.3 Concluding remarks 204
Bibliography 206

List of tables

Table 2.1: Stabilization level chart CO_2e 13

Table 3.1: Projections of passenger car ownership rates to 2040 (per 1,000) 26

Table 3.2: Top twelve OPEC member countries in terms of their share in production 28

Table 3.3: Top twelve countries in terms of Human Development Index ranking 29

Table 3.4: Brief presentation of previous studies in the field of transport and carbon emissions 35

Table 3.5: Global renewable energy resources base 42

Table 4.1: New Zealand's transport generated emissions past and present profile 1990 – 2015 47

Table 4.2: Wellington region's transport past, present and future 59

Table 4.3: Wellington region's public transport past and present 61

Table 4.4: Wellington region transport profile (Business-As-Usual) 63

Table 4.5: Wellington region's detailed actual and projected emissions profile 2000 – 2050 64

Table 4.6: Wellington region's consolidated transport review 68

Table 4.7: Wellington region's transport generated emissions overview during 2000/01 – 2012/13 69

Table 4.8: Wellington region's transport generated emissions overview during 2000/01 – 2014/15 70

Table 5.1: Average travel speed from to Wellington following construction of new roads/expressways 79

Table 5.2: First scenario for Wellington 2050 (No power train changes) 97

Table 5.3: Second scenario – LPVs – Improved fuel efficiency with certain percentage of EV introduction 99

Table 5.4: Second scenario – LCVs – improved fuel efficiency with certain percentage of EV introduction 99

Table 5.5: Second scenario – HVs with limited entering compared with past trend 100

Table 5.6: Third scenario – LPVs improved fuel efficiency with increased percentage of EV introduction 101

Table 5.7: Third scenario – LCVs improved fuel efficiency with increased percentage of EV introduction 102

Table 5.8: Third scenario – HVs with limited entering compared with past trend 102
Table 6.1: Comparison of four countries' total transport sector and per capita transport sector CO_2 emissions 111
Table 6.2: Car ownership aspiration index in selected countries 111
Table 6.3: Wellington region public transport CO_2 emissions and boarding profile 117
Table 6.4: Greater Wellington region rail transportation profile 118
Table 7.1: Changes over time in the fuel efficiency of cars in the United States 132
Table 7.2: Modes of travel to work in the Wellington region; a comparison between years 2006 & 2013 135
Table 8.1: Light passenger vehicles vision by 2050 143
Table 8.2: Light commercial vehicles vision by 2050 146
Table 8.3: Heavy commercial vehicle vision by 2050 148
Table 8.4: Wellington region bus transportation vision by 2050 149
Table 8.5: Wellington region train transportation vision by 2050 150
Table 8.6: Consolidated overview of transportation vision 2050 151

List of figures

Figure 2.1: Concentrations of Greenhouse gases from 0 to 2005 12

Figure 2.2: Global mean temperature change (^{0}C) 14

Figure 2.3: Emissions of carbon dioxide and reduction target (CO_2e) 14

Figure 2.4: Two way relationship between climate change, environment and sustainable development 16

Figure 2.5: Relationship between transport, mobility and greenhouse emissions 20

Figure 3.1: Moving towards a green trajectory 31

Figure 3.2: Transportation driven urbanisation and climate change 32

Figure 4.1: New Zealand's total GHG emissions (1990 – 2015) 46

Figure 4.2: Consumer energy demand share by sector 47

Figure 4.3: New Zealand light fleet per capita travel 2000/01 to 2014/15 50

Figure 4.4: New Zealand light mode travel per capita 2000/01 to 2014/15 50

Figure 4.5: VKT per person for selected OECD countries and rank from lowest (1) to highest (30) 51

Figure 4.6: Average light vehicles age in years 52

Figure 4.7: Wellington region VKT (million km) 56

Figure 4.8: Wellington region demographic and fleet overview in terms of annual percentage increases since 2001 56

Figure 5.1: The existing urbanisation based transportation cycle 73

Figure 5.2: A comparison among EVs and hybrid vehicles 86

Figure 5.3: Comparison of EVs and different vehicles driving range before recharging or refuelling 91

Figure 5.4: Comparison of carbon emissions from different vehicles (Kg CO_2e per km) 92

Figure 5.5: Total cost of vehicle at 120,000 km total travel 92

Figure 6.1: Actual and preferred travel mode share of Wellington region 123

Figure 6.2: Difference between preferred and actual travel mode of Wellington region 123

List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASB	Australian Bureau of Statistics
ASEAN	Association of South East Asian Nations
AV	Autonomous Vehicles
BAU	Business as Usual
BOQ	Bills of Quantities
BPEV	Battery Powered Electric Vehicle
BRANZ	Building Research Association of New Zealand
Cap	Capita
CASBEE	Comprehensive Assessment System for Built Environment
CBD	Central Business District
CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CoP	Conference of the Parties
CNG	Compressed natural gas
E85	Internal combustion engine vehicle that can operate on up to 85% biofuels
EC	Energy Consumption
ECF	European Cyclists Federation
EECA	Energy Efficiency and Conservation Authority
EF	Ecological Footprint
EIA	Energy Information Administration
ETS	Emission Trading Scheme

EU	European Union
EV	Electric Vehicle (comprising both BEVs and PHEVs)
GHG	Greenhouse Gases
GJ	Gigajoule
GWP	Global Warming Potential
GWRC	Greater Wellington Regional Council
HDV	Heavy Duty Vehicle
HDI	Human Development Index
HEV	Hybrid electric vehicle
HFCV	Hydrogen fuel cell vehicle
HICEV	Hydrogen internal combustion vehicle
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITF	International Transport Forum
LCA	Life Cycle Analysis
LCE	Life Cycle Energy
LNG	Liquefied natural gas
LPG	Liquid petroleum gas
LPV	Light passenger vehicle (cars, SUVs and MPV less than 3,500 kg)
LULUCF	Land Use, Land use Change and Forestry
MBIE	Ministry of Business, Innovation and Employment (New Zealand)
MfE	Ministry for the Environment (New Zealand)

MoT	Ministry of Transport (New Zealand)
MPV	Multi-Purpose Vehicle
Mtoe	Million tonnes of oil equivalent
NRC	National Research Council
NZH	New Zealand Herald
NZME	New Zealand Ministry for the Environment
NZTA	New Zealand Transport Agency
NZ	New Zealand
OECD	Organisation for Economic Collaboration and Development
OPEC	Organisation of Petroleum Exporting Countries
PHEV	Plug-in hybrid vehicles (use both electricity and petroleum as fuel)
PPM	Parts Per Million
PPMV	Parts Per Million Volume
PPSK	Persons Per Square Km
PT	Public Transport
RES	Renewable Energy Systems
RUC	Road User Charges (NZ road taxes paid by non-petrol powered vehicles)
SUV	Sport Utility Vehicle
STATSNZ	Statistics New Zealand
tCO_2e	Tonnes of Carbon dioxide equivalent
TEU	Twenty-foot [container] Equivalent Units
TOD	Transport Oriented Development
TTW	Tank To Wheel
UNFCCC	United Nations Framework Convention on Climate Change
UK	United Kingdom

UN	United Nations
USA	United States of America
VKT	Vehicle kilometres travelled (annually)
WBIEG	World Bank Independent Evaluation Group
WCC	Wellington City Council
WTT	Well To Tank

Chapter 1 | Introduction

The Solar System comprises the Sun and nine orbiting planets, but according to human understanding, the creator of this Universe, GOD, has granted life only on this planet Earth and granted uncountable resources for the benefit of human beings. By taking it for granted, humans have been carelessly polluting the planet by anthropogenic activities (Ledley et al., 1999). The planet Earth rotates on a fixed path around its star, the Sun, just as the wheels of a vehicle run over the fixed road or rail networks. This transport brings development for "quality of life", fuelled by non-renewable resources at the cost of damaging sustainability in the form of global warming by greenhouse gas (GHG) emissions.

Substantial worldwide growth has occurred in the transport sector in the past two decades in the form of increased vehicle ownership, public mobility and freight movement. No one can deny that economic prosperity is reliant on human mobility and freight transportation but adverse effects like increased fossil fuel consumption, pollution and public health issues need serious attention. Transport is a key factor in the overall energy consumption of the built environment as it links users and buildings. Around half of the world population is now living in urban regions and contributing 70% of the global carbon emissions while more than 60% of the universal gross domestic product is created by the revenue of only 600 cities (UNHSP 2011). A study conducted by Dobbs et al., (2011) suggests that there will be a paradigm shift in economic prosperity by the year 2021, with growth of 136 new cities from the developing regions alone, consequently ecosystem damage will occur more rapidly as well as additional emissions of greenhouse gases, often from transport. To counter this growth in urban transport emissions, Fouracre et al. (2003) demonstrate the environmental benefits from transferring people from private to public and non-motorized transport. Similarly Mees (2014) found that TOD (transit oriented development) would be a good system for encouraging public transport ridership but they considered that traffic congestion and high parking fees would make it unworkable.

Increases in economic growth tend to enhance the purchasing power of individuals and hence lead to increasing private vehicle ownership especially in urban areas (WEC 2011). Thus, it is estimated vehicle usage will be doubled by the year 2040 (ExxonMobil 2013). This trend

increases energy consumption and the resulting emissions, with carbon dioxide (CO_2) expected to increase by 30% by the year 2030 (IEA 2008).

The transportation system and its infrastructure are directly associated with three main sectors - Environment, Economy and Society -which are assumed by organisations such as the OECD to be linked and related to sustainability (Strange and Bayley, 2008).

The specific transport framework relevant to a particular society is characterized by the approach needed to support national authorities to achieve their objectives such as a prosperous economy, but at the same time a sustainable transport network is now increasingly necessary worldwide, not only for the safety of the environment by avoidance of more emissions of CO_2 but also because society needs to become aware of a coming shortage of conventional sources of energy globally (Enerdata 2016) (EIA 2016) (World Energy Council 2013) (IEA 2013) (Toni Pyke 2017). What could be described as "war footing" efforts may be needed to slow initially and then eventually to reverse the global growth of anthropogenic CO_2 emissions and GHGs. There is compelling pressure to get started immediately and to adjust as the future becomes apparent. The costs of stabilising CO_2 emissions are real but affordable whereas delay would not only be perilous but also more expensive (Stern 2006).

1.1 Research aim

The concept of "sustainability" was recognised as a steering principle for human persistence when concern was raised about the way in which utilization of natural resources for economic growth occurred at the expense of environmental degradation. In 1713 the idea of sustainability was developed by Carlowitz in his book on forest sciences which argued that there should be a balance between forest growth and logging (Keiner 2005). In 1987, the Brundtland Commission presented the modern definition of sustainability in their report "Our Common Future" (Brundtland Report 1987) as meaning no compromise on the ability of future generations to meet their needs. To supplement that definition, models of sustainability have been developed, of which the best known are the weak and strong models. In the weak model the Economy, Society and Environment are seen as three equal and

interacting fields. The implication is that damage to one can be offset by improvements in the other two. According to the 3-nested-dependencies model (which is also known as the strong model) if the environment is damaged there will be no human society, because society can only exist within a working natural environment which provides the air, climate, food, water, etc. If human society is damaged there will be no economy as the economy is a product of society. On this basis the environment takes priority over anything else as without a functioning environment there is nothing (Willard 2010). The strong and weak models have also been presented as two possible approaches to sustainability by New Zealand's Parliamentary Commissioner for the Environment (PCE, 2002: 34-35). In a report the Parliamentary Commissioner stated fifteen years ago.

> *"A number of models have been designed to represent the integration of environmental, social and economic dimensions of sustainable development. The one that the Parliamentary Commissioner for the Environment supports as representing the limits within which the economy and society must operate if we are to function in a sustainable way is the strong sustainability model..."*
>
> (PCE, 2002: 7)

It is proposed therefore in this research to adopt the viewpoint of the strong model of sustainability, in which avoiding damage to the environment is seen as the primary task. By giving priority to this environmental aspect of human life the main motivation of this research task is to seek mobility strategies founded on low carbon development in order to bring about benefits in mitigation while allowing adaptation and economic development.

1.2 Research scope

The United Nations Environment Programme has stated the need to limit global temperature rise to no more than 1.5 or at most 2^0C compared with the pre-industrial level to prevent serious social, economic and environmental problems by 2100 (UNEP, 2010) and these figures have been confirmed by the Paris Climate Agreement. The CoP21, United Nations Framework Convention on Climate Change (UNFCCC), 21st session of the Conference of

Parties was held in December 2015 in Paris, France. After lengthy deliberations, 196 countries (New Zealand is one of the signatories) successfully negotiated the legally binding Paris Climate Agreement with the global goal of holding temperature increase to below 2^0C above pre-industrial levels, with parties agreeing to make efforts to keep it below 1.5^0C (Climate Action, 2015) New Zealand's target is to reduce its GHG emissions to 30% below 2005 levels by 2030 (New Zealand Government, 2015, 1). In a national inventory report submitted to the UNFCCC in April 2015, the Transport sector is stated to have contributed more than 17% of New Zealand's total greenhouse gas (GHG) emissions by sector in 2013 (New Zealand Government, 2015, 3).

Research by Nsaliwa et al (2015) has found that regarding greenhouse gas emissions, a New Zealand household's choice of personal transport, in terms of both mode (private car, bus, train) and technology (internal combustion, battery electric), plays a much greater role in household-related emissions than the choice of whether to live in a "zero energy" or a conventional dwelling. This is because in New Zealand dwellings are serviced largely by electricity sourced to a considerable extent from renewable hydroelectricity, whereas transport relies largely on oil. This finding is supported by the fact that road transport, fuelled by oil, provides the largest share of New Zealand's CO_2 emissions (as compared to 17% of total GHG emissions as stated in the previous paragraph), "The main contributors to total carbon dioxide emissions were road transport (37.4 per cent)...and public electricity and heat production (15.4 per cent)" (New Zealand Government, 2013, 55).

The research carried out by Tran (2014) makes clear that it is possible to have lower emission transport without curtailing mobility demand. That research, with its focus on three very different cities, also suggests that it would make sense to focus on a city, rather than on a whole country, so that the full implications of the possible range of mobility options can be considered in order to understand the effects of local circumstances and the possible impacts of transport choices on the physical form and structure of the city. Wellington is the city in New Zealand which has the largest percentage of commuters using public transport, so it can be argued to be the city most favourably inclined towards alternatives in the transport field.

Wellington City Council has proposed a transformation of the city to a "Low Carbon Capital" (WCC, 2016) and a key part of this transformation will need to come from the transport sector as this is such a large component of total emissions.

> *"Approximately 25 percent of commuters to Wellington's four cities used public transport, compared with 4 percent of commuters to the Auckland metropolis from surrounding districts. 1 percent of people travelling to work in Christchurch from surrounding districts used public transport."*
>
> (Goodyear and Ralphs, 2009, 1).

This research will look at land transport in the Wellington region in line with the declared targets of the Paris Climate Agreement and the city's declared aim of being a Low Carbon Capital. It will study the relationships between the various components of the transport system (technology, behaviour and energy mix) and built environment, the mobility services it provides and climate-related emissions. The scope is to find ways to support and enhance sustainable infrastructure development in Wellington, New Zealand to strengthen economic prosperity and social and environmental wellbeing while meeting the requirements of the Paris Climate Agreement. The Paris requirements will be considered not in terms of the New Zealand Government's proposed emission reductions, but in terms of the reductions that would be needed if a 1.5 degree temperature rise is to be avoided, as stated in the Paris Agreement.

1.3 Significance

Existing studies (Shaheen S. & Lipman T. 2007) (Bastani et al., 2012) (Zahabi et al., 2012) (Saboori et al., 2014) (Basu et al., 2015) (Ratanavaraha & Jomnonkwao, 2015) fail to reveal what combination of technical and behavioural measures could or should be used to meet a particular transport emission target depending on current demand for mobility. The proposed way to do this in this thesis is to start from the total CO_2 emissions required globally to meet a particular target and apply the percentage emissions reduction needed to meet the target emission levels on a global scale to the existing transport-related emissions for Wellington.

The research is based on creating scenarios to meet pre-determined transport emissions targets for Wellington. A scenario is here defined as

"...a small bespoke set of structured conceptual systems of equally plausible future contexts, often presented as narrative descriptions, manufactured for someone and for a purpose, typically to provide inputs for further work"

(Schnaars, 1987) (van der Heijden, 2005) and (Ramirez et al., 2008).

However, in order to be able to produce scenarios to compare possible future transport options it is essential to have targets against which possible reduction methods can be tested. As a recent Arthur D. Little/UITP report states (Audenhove et al, 2014, 26) "...in all too many cases, urban mobility plans look like "Christmas wish lists" with no relation to desired outcomes, including the greenhouse gas emissions reductions that might be required to limit global temperature rise. The data from the IPCC (Intergovernmental Panel on Climate Change) make it clear that the necessary emissions reduction targets are not "easy" targets. Even to achieve a temperature rise of no more than 2 degrees requires an average reduction in emissions of 70% (Banuri and Weyant, 2001) while Hanson et al's (2008) target of 350 ppm (parts per million by volume, also called ppmv, which refers to the concentration of CO_2 in the atmosphere), which they state is needed to avoid severe climate problems in the future, would effectively require moving to a zero emission society, since the current level of CO_2 is more than 400 ppm.

Atmospheric CO_2 concentrations are currently rising by 2 ppm annually (Moriarty and Honnery, 2008) from a level of over 400 ppm currently (Earth System Research Laboratory, 2017). It must also be pointed out that as made clear by Banuri and Weyant (2001) although a target may be fixed, in terms of the limit of CO_2 concentration in the atmosphere, the measures needed to achieve it will increase in severity as population rises. As they point out " to achieve a 450ppmv concentration target, average carbon emissions per capita globally need to drop from about 1 tonne today to about 0.3 tons in 2100". This is of great significance, the current emission level of around 400 ppm might be assumed to mean that no change in behaviour is needed if emissions are to be stabilised at 450 ppm, an increase of 50 ppm, whereas even to stabilise the concentration of carbon dioxide in the Earth's atmosphere at this increased figure by 2100 will require a 70% reduction of current emissions according to the IPCC.

In the light of the discussion of CO_2 concentration and temperature rise, it is proposed in this research to study the effects on transport in Wellington of carbon dioxide reductions to a value of 80% below the year 2000 level by 2050, keeping in mind that projected population increases over time mean that in order to meet a fixed target for CO_2 in the atmosphere per capita emissions will need to fall on an annual basis in line with annual population increase. The research question can be posed formally as follows:

If CO_2 emissions have to be restricted to meet CoP21 what will this mean for mobility in Wellington, a small city in the developed world?

The reasoning behind the choice of this research question is set out in greater detail in chapters 2 and 3.

1.4 Structure

This thesis comprises ten chapters, which are structured in the manner presented below:

Chapter 1: Introduction

This Chapter 1 Introduction is a discussion regarding the nature of the problem. It states the aim of the thesis as well as the research scope, its significance and a general outline of the contents of the thesis to deal with the gap in knowledge that is identified.

Chapter 2: Greenhouse gases, CO_2 emissions and emissions from transportation

This chapter contains a literature review covering global warming and increased atmospheric temperature, greenhouse gases (GHGs) and carbon dioxide equivalent emissions, CO_2 emissions from transportation and effects of transportation emissions on climate change, relative levels of emissions from each transportation mode (light passenger, light commercial, heavy trucks, buses, rail, seaborne and air transportation) are summarised in general terms.

Chapter 3: Research question

This chapter provides an overview of transport generated emissions in New Zealand. More specifically the Wellington region's CO_2 emissions from transportation during the years from 1990 to 2015, projected emissions level by 2050 and targeted reduced level, estimated population, growth in gross regional product, annual travel demands by various modes and other factors are highlighted. Why the city based approach is adopted and the extent to which it may be an effective way to achieve the national emissions reduction target is also discussed.

Chapter 4: New Zealand and Wellington region transportation emissions

In compliance with the Paris Climate Agreement's targeted 80% reduction of the year 2000 CO_2 emissions level this chapter determines the historical record emission levels of the year 2000 and year 2015 transportation generated emissions levels for the Wellington Region and provides the reasoning behind opting to consider land transport only. It sets out a theoretical framework and a tentative methodology. The chapter determines the emissions contribution from each sector of existing land transport and its required share in meeting the reduction target. Tools and techniques available to be used for mitigation are logically described based on aspects of different existing studies.

Chapter 5: Technical aspects of sustainable transport

This chapter considers the full range of technical strategies, meaning changes to the technology of vehicles and their fuels. It covers not only changes to existing vehicles and fuels but also new vehicle technologies and lower or zero-carbon energy sources. It considers both private and public passenger transport as well as freight transport. In addition the effects of possible interactions between technical options are discussed as well as likely time frames for their introduction and accompanying policy implications.

Chapter 6: Non-technical (behavioural) aspects of sustainable transport

There is a broad range of non-technical aspects of CO_2 emissions mitigation covered in this chapter, including ways to reduce on-road Vehicle Kilometres Travelled (VKT) by reducing the travel demand, lower trip lengths and increasing vehicle occupancies, Shared Mobility is also covered, shifting from private to more energy efficient public transport options that generate fewer carbon emissions as well as consideration of changes to freight options including rail. As well as vehicles the chapter looks at ways to promote walking and encourage cycling, telecommuting and virtual contact.

Chapter 7: Built environment and sustainable urban planning

Many CO_2 mitigation measures are associated with the built environment and attributed to sustainable urban planning. Beside the possible technical and behavioural aspects this chapter considers to what extent and how the built environment can play a role in working towards a "green smart cool capital". Urban planning significantly contributes in non-technical strategies by framing a ground for action. The chapter explores the extent to which changes in the built environment and sustainable infrastructure could potentially assist in reducing CO_2 emissions to meet the required 80% regional reduction target.

Chapter 8: Results and discussion

This chapter sets out a number of scenarios for land transport in the Wellington region that bring together the findings of the Technical, Behavioural and Built Environment chapters. It demonstrates the interaction between these various factors, their impact on possible travel if emissions reductions are to be achieved and the effect of rising population for the Wellington Region.

Chapter 9: Future prospects and recommendations

The overall results and findings are described in this chapter. The regional implications and particularities are considered in the discussion of findings of the proposed scenario solutions.

The chapter also discusses possible cost implications and the likelihood of acceptance of the proposed measures.

Chapter 10: Conclusion

The final chapter recommends some policy measures that could be used to move transport in the Wellington region towards following the findings of the research. It also suggests further research that could be carried out to provide a more detailed understanding of the initial findings and their possible application in a wider context.

Chapter 2 |Greenhouse gases, CO_2 emissions and emissions from transportation

"We have not inherited the land from our fathers; but have borrowed it from our children"

Dennis J. Hall

Michigan Natural Resources (1975)

The comparison of human development before and after the development of powered vehicular movement is hard to measure. There is a question however of whether this vehicular movement is bringing us towards improvement or whether ancient human societies were able to have a 'good economy' by maintaining their environment to keep the best possible society. Is the way in which human society has developed in terms of modernization, based on digging up precious and finite resources, something keeping us moving forward or in reality, taking us towards the end of civilization? It is hard to decide whether it is overall beneficial and it may be even harder to come to terms with the idea that it may not be beneficial.

The wheel is possibly the biggest technological invention of human history. It was invented around 3500 BC initially for use in making pottery and 300 years after that, the wheel started being used for light carriages (Ratner 2016). Now wheels are omnipresent in human society, facilitating transportation and commerce which have not only expedited evolution in every walk of life but also given various pathways to explore different development dimensions.

When nature's resources, goods and services are under-priced they are likely to become over used and abused as well and nature's invisible hand that is supposed to automatically balance the demand and supply becomes functionless (WWF 2017). A realistic approach is necessary to understand that nature has a finite capacity and resources to supply human demand are not limitless if planet Earth's ecological sustainability is to be maintained. This approach urges society to realize the need to reduce consumption, improve technology, change behaviour, think sensibly and save today so as to allow future generations to be able to continue to consume tomorrow.

In terms of the Earth's resources, the exploration, extraction, processing, usage, and after-usage environmental impacts of finite energy resources play a critical role in the progress of human beings, in gross national production, and the physical future of our planet. The finite fossil fuel reserves provide nearly 80% of the primary energy consumed annually, of which around 58% is consumed by the transport sector in the world (Salvi et al., 2013). The problem is not only that there are likely limits to the extraction of limited fossil fuel resources but also the situation becomes worse by continuous emissions from manufacturing industries, power stations and the transport sector damaging the nature of the world. In the transport sector the tailpipe emissions from conventional vehicles with internal combustion engines urge global attention for alternative energy production corresponding to zero emissions 'from well to wheel'. These aspects of resource use are discussed in greater detail in the following sections.

2.1 Natural temperature phenomenon

The measurements of the Earth's average surface temperature over the past 100 years reveal an increase of 1.4^0F or 0.8^0C with a more rapid increase observed over the past 35 years. An increase of 0.8^0C may feel unnoticeable in the case of daily or seasonal fluctuation, but it creates imperative changes as a permanent average increase of the entire planetary temperature. This can be more easily understood by the fact that the estimated increase in average temperature between today's climate and an ice age is only 9^0F (5^0C) (NAP 2012).

As a natural phenomenon when the Sun's energy hits the Earth's surface, most of it is absorbed and some of it is then re-radiated in the form of infrared energy outward from the warmed surface of the Earth. If the greenhouse gas "blanket" in the atmosphere were thin enough then this infrared radiation would easily escape to space and the Earth's average surface temperature would be maintained. But the existing situation is somewhat different as the greenhouse gas volume is increasing in the atmosphere making the blanket thicker, trapping heat and causing the surface temperature to rise. Although carbon dioxide in many other natural processes is produced and absorbed in many conditions in the form of the carbon cycle like photosynthesis, respiration, weathering of rocks, volcanic eruptions and waste and decay of dead organisms (NAP 2011) CO_2 emissions by anthropogenic activities

such as deforestation, cement production and burning of fossil fuel are manifold and are increasing.

Environmental scientists have studied the composition of air bubbles trapped in ice cores from Greenland and Antarctica and found that in the 2,000 years before the Industrial Revolution, the CO_2 volume in the atmosphere was steady and it began to rise sharply after beginning of the industrial revolution from 1800s (NAP 2011).

Now that scientists and environmentalists have complete records to show how much coal, petroleum, and gases are burned in different countries and regions each year it is relatively easy to calculate how much CO_2 is being emitted from different sectors and how much it is being absorbed by the land surface and the oceans. A careful analysis shows that about 45% of the CO_2 emitted by anthropogenic activities remains in the atmosphere.

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Figure 2.1: Concentrations of Greenhouse gases from 0 to 2005.
Source: Division on Earth and Life Studies, National Academy of Science (NAP 2011)

The forensic examination of the chemical fingerprint of carbon from fossil fuels shows that fossil carbon contains radioisotope carbon-14 (a form of the carbon that decayed naturally over decades ago) and when scientists measured carbon-14 volume in the atmosphere it was found that the large majority comes from the combustion of fossil fuels. The CO_2 emissions from volcanic eruptions are about 200 million tons per year whereas anthropogenic activities

are causing 36 billion tons (i.e. 36,000 million) each year and out of this 85% comes from burning of fossil fuels (NAP 2011).

Given the long atmospheric lifetime of carbon dioxide and the time lags in the climate system, environmentalists and scientists are concentrating on the long term ramifications on Earth's climate as some effects of 21st century human anthropogenic activities would appear to be likely to cause climate change for more than 100,000 years (NAP 2011b).

2.2 Global warming

Two centuries ago at the beginning of the industrial revolution, the atmospheric concentration of CO_2 was 280 ppm, it crossed the 400 ppm level in May 2013 (UNFCCC 2013). UNFCCC, 2013 (United Nations Framework Convention on Climate Change - it has near universal membership and is the parent treaty of the 1997 Kyoto Protocol) in a report warned that;

> *"With 400 ppm CO_2 in the atmosphere, we have crossed an historic threshold and entered a new danger zone. The world must wake up and take note of what this means for human security, human welfare and economic development."*

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Table 2.1: Stabilization Level Chart (CO_2e)
Source: NRC 2011

In a 'Business-As-Usual' scenario in the absence of CO_2 mitigation policies to control emissions, the world's GHG emissions may rise to 59 Gt CO_2e per year by 2020 (a Gigatonne, Gt, is a billion tonnes) compared to 35.3 Gt in 2013, and would likely mount to 87 Gt CO_2 per year by 2050 which is relatively a 70% increase from 2010. If this trend continues the global average temperature would be likely to increase by 4°C by 2100 compared with 1900 and keeping below the 2°C upper limit set out as the target in the Paris Climate Agreement would be utterly impracticable (Olivier et al. 2014 p.6). Hence, the lower the CO_2 emissions in the immediate future, the longer the time before reaching an "emission budget" limit, taking immediate action makes it easier to take action later to stay within the 2°C limit.

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Figure 2.2: Global mean temperature change (^{o}C)
Source: NRC 2011 [National Research Council (2011) "Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia" The National Academies Press, Washington]

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Figure 2.3: Emissions of carbon dioxide and reduction target (CO_2e)
Source: NRC 2011 [National Research Council (2011) "Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia" The National Academies Press, Washington]

Today, for every 15 - 20 $GtCO_2$ emitted, the concentration of carbon dioxide in the atmosphere rises by a further 1 ppm (Stern, 2006). To keep the atmospheric carbon concentration limited to a relatively safe 350 ppm (see Table 2.1 above) means both technical and behavioural aspects are likely to be needed to mitigate the issue, so it is very clear that sustainable transport, which is the focus of this thesis, needs to deal with proper balancing between environmental, social and economic standards of living.

2.3 Greenhouse gases and CO_2 emissions

Briefly the phenomenon of global warming can be described as the Earth continually receiving radiation from the Sun and the Earth giving off Infrared radiation, most of which escapes to outer space. Some of the infrared radiation is increasingly trapped by the blanket formed by the greenhouse gases in the atmosphere which ultimately is increasing temperature in the phenomenon commonly known as global warming or as climate change.

The aggregation of greenhouse gases (GHGs) (CO_2 and non CO_2 gases) in terms of their carbon dioxide equivalent (CO_2e) is known as the GHG Footprint. It is a measure of the impact of direct and indirect anthropogenic activities on the environment produced by greenhouse gases. Carbon dioxide equivalent (CO_2e) is the unit used for comparing the radiative forcing

or global heating effect of a GHG to that of carbon dioxide. It is the amount of carbon dioxide by weight that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are calculated by multiplying the weight of the gas being measured by its respective Global Warming Potential (GWP) (VijayaVenkataRaman et al. 2011) (Ramachandra et al. 2015). Global Warming Potential takes into account both the warming effect and the lifetime in the atmosphere of different greenhouse gases. The 100 year GWP is mostly used which is equal to the ratio of the warming effect (radiative forcing) from 1 kg of a greenhouse gas to 1 kg of carbon dioxide over 100 years (Stern, 2006). This is driving temperature rise, warming oceans, and declining Arctic sea ice, shrinking ice sheets and other climate change related issues (VijayaVenkataRaman et al. 2011).

Humanity is failing to realize that this situation is a continuous threat to the web of human life. The increase in Earth's temperature impacts the dynamics, functioning and structure of ecological networks and thereby impacts on the human race. It also adversely affects water availability, food security, human health and well-being. To maintain Earth's sustainability, it is necessary that production and use of materials must be slower than the materials can be reproduced by the natural world and similarly the waste discharge, which includes GHG emissions, must be at a slower pace than the wastes can be absorbed into the environment (Wackernagel and Rees, 1996).

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Figure 2.4: Two way relationship between climate change, environment and sustainable development.
Source: Redrawn from IPCC (2007)

There are many natural as well as anthropogenic factors contributing to the GHG footprint. The natural factors include plate tectonics, solar outputs, orbital variations, volcanism and ocean variability (IPCC 2014), whereas the anthropogenic human activities include increases in CO_2 emissions from burning fossil fuel, deforestation, the cement manufacturing process and land use mismanagement. Climate change somewhat more severely affects developing countries, though they make less contribution to the warming situation, by aggravating the existing social inequalities of resources use and some of the other social factors leading to instability, conflicts, displacement of people and changes in living standards (IPCC 2001).

2.4 Emissions from transportation

The history of transportation is as old as humanity. From the basic movement of humans emerged the demand for different modes of transportation not only for movement of people but also for their goods. The growth in population on different continents has increased the distances between people, which has ultimately caused the development of the current transportation system comprised of roads, railways, airways and waterways.

Personal freedom is a dimension of mobility. Mobility has key socioeconomic features and lack of mobility infrastructure can lead to social exclusion (Kenyon et al., 2002). Cities are the powerhouse of economic prosperity and development and at the same time constitute a critical part of the transport system which in cities consists largely of an increasing number of vehicles (mainly private cars) causing environmental pollution, traffic congestion and road accidents. On the other hand, transport is also necessary to maintain living standards through the smooth mobility of people and goods.

Tailpipe emissions of vehicles are the main cause of transport generated environmental pollution and global warming and in many developed countries vehicle generated emissions cause up to 60% of total air pollution (Guo et al., 2007).

Globally GHG emissions rose by 61% from 1970 to 2005 or by roughly 1.4% per year. Over the same period, world population has risen by 77% (calculated using data from Worldometers, 2017) and the world per capita GDP has risen by just over 800% (calculated using data from The World Bank, 2017) showing that the carbon intensity of human society has fallen in spite

of population growth and material progress. What the simple figure of global GDP does not show is that although the poor have got absolutely richer, they have also got relatively poorer over the same period, as the wealthy countries have enriched themselves at a much faster rate (Vale and Vale, 2009: 22).

CO_2 emissions largely dominate the global GHG emissions and have risen 86% between 1970 and 2005 or 1.8% per year. Of the estimated 45.4 Gt of GHGs (CO_2 equivalent) emitted globally in 2005, approximately 59% (27 Gt. CO_2 eq.) resulted from the combustion of fossil fuels. The transport sector accounts for approximately 15% of overall greenhouse gas emissions (ITF 2010). The way that the data are presented in many tables of emissions, with “Energy supply” or just “Energy “ as separate sectors, does tend to distort the figures. If energy production, particularly electricity, were allocated to the sectors where it was used the figures would be likely to show a different ranking for transport, probably increasing its share of emissions relative to other sectors. In 2015 the transportation share of energy related emissions was 23% with 7.5 billion tonnes of CO_2 emissions coming from fossil fuel combustion by the transportation system which makes transport the second largest source of CO_2 emissions after power/energy supply which contributes 45.5% (IEA, 2015). The OECD and non-OECD countries' inhabitants emitted around 2.8 tonnes and 0.5 tonnes of CO_2 per capita respectively and keeping in view the growing demands for transport in developing countries it is likely this level will increase until it becomes comparable with OECD countries. Total fossil fuel related CO_2 emissions increased from 20.9 Gt in 1990 to 28.8 Gt in 2007, of which transport accounted for 4.58 (1990) and 6.63 (2007) Gt, representing an increase of approximately 45% (IEA, 2009). Despite attempts at controlling the increases, according to the World Energy Outlook 2009, transport emissions could rise to 9Gt by 2030 which will boost the global energy related CO_2 emissions to over 40 Gt. (OECD/ITF, 2010, 6). The point here is to show the projected rate and scale of increase in emissions from transport. The connections between the level of emissions and the likely resulting global temperature rise are discussed below.

In the IEA projections to 2030, it is estimated that strongest growth in overall CO_2 emissions will come from the energy sector but it will come from transportation in the OECD countries (IEA 2005). In 1973 the transportation sector worldwide used 45.4% of oil production with around 20% used for industries whereas by 2012 the share of oil demand for transportation

increased to 63.7% (IEA, 2014, 33). In the IEA 2013 Report world oil use is expected to surpass 100 million barrels of oil per day in total in the 2020-2025 time frame (Miller, 2014, Chapter:1 p.6). In 2010, of all anthropogenic CO_2 emissions, about a quarter came from the global transport sector. By consuming 47 million barrels per day of fossil fuel this sector released 8.8 billion tonnes of CO_2. If this trend remains unchanged then by 2030 CO_2 emissions from the transport sector will increase by roughly two thirds, to 15 billion tonnes with oil consumption of 78 mb/d. If mitigation policies were adopted in transportation it is estimated this would reduce CO_2 emissions by 2.2 billion tonnes thus saving 11 mb/d, whereas with "best practice measures" (technical change and behavioural policy) it is estimated that the CO_2 emissions could be reduced by a further 4.4 billion tonnes thus saving 21 mb/d, which is almost equivalent to a 30% reduction in CO_2 and a 27% reduction in oil consumption (Miller, 2014).

According to the International Organization of Motor Vehicle Manufacturers (OICA, 2012) (Voelcker, 2014) more than I billion motorized vehicles are driven on the roads globally and it is estimated that this number would reach 2 billion in the next decades and therefore by 2050 CO_2 emissions are expected to increase by more than 70% compared with CO_2 emissions in 2010 (Amir and Abdul, 2015).

According to IEA records, average GDP per capita during the last decade has increased by 75%, while in some regions/countries such as China, India, Southeast Asia and Eastern Europe this growth has doubled. This abrupt growth has caused a surge in passenger travel and freight movement in general. Road and rail modes of transport in terms of passenger and freight travel have increased by 15 trillion annual person kilometres and freight tonne kilometres which is 40 % higher than the 2000 level. It is also estimated that by 2050 this trend will reach around 115 trillion passenger and freight tonne kilometres which is double the 2010 level. The role of non OECD regions in this growth is expected to be about 90 % (Dulac 2013).

2.5 Why the focus on carbon emissions?

There are many other gases emitted by human activities, but the particular reason for emphasis on carbon dioxide (CO_2) is that it remains in the atmosphere for very long time

periods, even hundreds of years and contributes to global warming and climate change (Archer 2008).

Since the realization of its long term effects on the environment various regional, national and international policy making and industrial associations have undertaken and are further planning to undertake a range of measures to mitigate carbon dioxide emissions. Thanks to all these strong mitigation measures, the recent record shows a reduction of about 9% in total GHG emissions i.e., from 5564 million tonnes of carbon dioxide equivalent (CO_2e) in 1990 to 5045 in 2007. But during the same period the human created CO_2e from the transport sector has increased from 19% of the total in 1990 to about 25% in 2008 (Janic 2014) Unsurprisingly the growing number of vehicles on the road has substantially contributed to this, traffic volume has increased from 2433 million vehicle kilometres in 1995 to about 3061 million in 2009 (EEA 2010).

2.6 Transport and climate change

In the early 1970s the global think-tank Club of Rome's publication "The Limits to Growth" (Meadows et al. 1972) provided a statement of the finite nature of the environment and humankind's relationship with the earth, predicting that:

> *…if the present growth trends in world population, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached within the next hundred years.*

Computer modelling forward from 1970 was used by Meadows et al to generate their predictions of the future state of the world. The work of Graham Turner at CSIRO in Australia has shown that between 1970 and now, reality has followed these predictions exactly (Turner G. 2008).

The easier access of people to cities and towns afforded by modern transportation systems helps to develop urbanization. Between 2000 and 2010, the world's urban population increased by 650 million people (UNDESA 2012) and urban passenger travel increased by nearly 3 trillion annual passenger kilometres during the same period. It is estimated that 70% of the global population (around 6.3 billion people) will be living in cities by 2050. The 18% of

the world's population living in developed countries account for 47% of global CO_2 emissions while the other 82 % account for the remaining 53% (UN HABITAT 2011).

Figure 2.5: Relationship between transport, mobility and greenhouse emissions.
Source: Author

The determination of energy related CO_2 emissions is based on;

CO_2 emissions from energy = Population X (GDP per head) X (energy use/GDP) X (CO_2 emissions/energy use)

(IEA 2014b)

According to the International Energy Agency, based on data from the International Transport Forum, in non OECD countries (mostly with emerging and developing economies) by 2050 it is estimated that passenger mobility will be increased five to six times, while for the same period freight volume will be increased by four to five times as compared to 2000 levels (IEA 2014 Edition). Since this increase in passenger and freight transport will be powered largely by oil it will contribute to climate change.

Many proposals relating to transport for a more sustainable or "green" environment seem to fall far short of what may be required if emissions are to be reduced to the level required. As shown in Table 2.1: Stabilization Level Chart (CO_2e) from Section 2.2 above, CO_2e in the atmosphere needs to be reduced to 350ppm to have a good chance of avoiding excessive

temperature increase, but it is already over 400ppm. In this context suggestions such as "leave the car and use public transport instead" for mobility purposes, combined with better land use design and planning associated with non-motorised transport infrastructure which are claimed to minimise congestion and reduce travel time for other productive activities (McKinnon 2008) and UNEP (2008) suggesting measures to curtail the operational expenditures by improving the efficiency of freight transport do not appear to come close to achieving sufficient reduction in transport emissions.

2.7 Stabilisation and its cost

Global warming is a common problem for all of humanity, which must be tackled by joint efforts considering long term tasks and frameworks based on mutually reinforced approaches at national, regional and international level. Just as each individual takes an individual footprint share from the earth, in the same way, each one must participate in fighting against this problem.

According to the Stern Review Report (Stern 2006), if no immediate actions are taken then the costs and risks of climate change will cost equivalent to 5% of global GDP loss per year in the case of an optimistic approach whereas in a pessimistic approach these damages could rise to 20% of global GDP per year. According to Stern, the stabilisation of greenhouse gases in the atmosphere at a level of 550 ppm CO_2e by 2050, compared with only 280 ppm before the industrial revolution (or in other words when humans started to measure development in terms of mechanisation) would cost only 1% of global GDP per year. If we remain busy only on thinking or depending on others to take responsibilities and leave others to take actions then the possibility to stabilise at 500-550ppm CO_2e may become impossible. It should also be pointed out that this level proposed by Stern may be too high a level of GHGs to avoid severe climate change

Although no region or part of the world will be unaffected by climate change it is in the poorest countries where people would be more disturbed. It is estimated that by 2100, especially in South Asia and sub-Saharan African countries (where the life of a common person is already terrible) up to 220 million people could fall below the $2 per day poverty

line and not only this an additional 165,000 to 250,000 children could die if climate change mitigation measures are not adopted (McMichael et al., 2006).

2.8 Conclusion

In 2006, 25% of greenhouse gas emissions worldwide came from transport which is an increase by 6% from 19% of GHG emissions in 1971. In 2006 there were more than 715 million cars in the world for around 6300 million people that is an average ownership of 113 cars per 1000 persons. 65% of the world population lived in countries with fewer than 20 cars per person, 18.5% in countries with 20 to 200 cars and the remaining 16.5% in countries with more than 200 cars per 1000 persons (World Bank 2006). Car owners do not merely use the car as they use other home appliances rather they want to enjoy driving therefore they are not only looking for fuel efficiency but are also keen for comfort, safety, internal space, and carrying capacity as well. Because of this whatever gains have been already achieved in engine efficiency are usually balanced by heavier vehicles and their demand for power steering, air conditioning, safety, and entertainment and information systems. Moriarty and Honnery (1999) found that considerable fuel efficiencies were possible with smaller, slower and lighter weight passenger cars. For the Wellington region and other environment conscious cities Moriarty and Honnery offer a good example of the Japanese “Kei car” category which is promoted by offering users lower taxation costs. These are small cars with reduced luggage and passenger capacity which run at a speed of 30 km/h and would be ideally suited for the average distance travelled by Wellingtonians.

All over the world the private vehicles’ share has become dominant in surface transportation systems compared to bus and rail transportation. Some of the obvious reasons are private vehicles can give faster door to door access than public transport and non-motorised transport, they offer privacy, time saving, they are convenient to carry shopping and heavy luggage, offer freedom from timetables and besides some trips are either not feasible to undertake or inconvenient by public transport. Perhaps for a car owner, there is also a psychological factor of balancing the unavoidable mandatory road user cost and fixed costs for example registration, insurance and depreciation by more annual vehicle travel, the

feeling that if they have paid to own the car then they ought to use it. Behind the logical analysis of whether all these are genuine and valid arguments or not the necessary reduction in transport generated carbon emissions will need to correspond to deep reductions in car passenger km. To take up some of the private car passenger km with public transport its CO_2e emissions in kg/ passenger km must be less than for private cars. Like private vehicles' dominance in surface transport (except in Japan where rail travel is dominant in public transport), bus travel accounts for 75% of the public transport passenger km share in 1990 and is projected to increase to 81% in 2020 (Schafer A., and Victor D., 2000)

The ultimate dilemma is to reduce to the maximum extent carbon emissions from private and public transport movement. This can be expanded into being represented as the product of the interaction of the following four factors:

i) Maximum extent reduction in private vehicles travelling (VKT)

ii) Increase of the vehicle occupancy rate (Passenger km/ vehicle km)

iii) Increase in the primary energy efficiency from well to wheel (covering the life cycle of the fuel including its end use in the vehicle).

iv) Decreased carbon intensity of the fuel/ energy mix.

Chapter 3 |Research question

"I believe those that produce the least emissions in autos will also be those who have the greatest success worldwide" Angela Merkel

(FindsGood 2016)

3.1 Black gold reserves; point of concerns

Is it possible that the assumptions from chapter 2 that energy demand for transport will continue to increase may not occur due to the non-availability of adequate supplies of oil? Based on an in-depth review from various studies and analysis of future oil supplies databases in light of major supply forecasts, (Sorrell et al. 2010) (Sorrell et al. 2010b) conclude that before 2030 conventional oil production will peak and there is the chance of a peak before 2020. In a similar study Bentley et al. (2007) strongly argued that peaking in oil supply will occur no later than 2020 and mentioned some flaws in other economic analyses and oil supply forecasts. Another opinion from Hook et al. (2009) suggests that the rate of decline of production from oil fields shows that they have already passed their production peak, with a decline in production from 3% per year in the 1960s, steadily increasing to an average decline of 12.5% per year for the fields that peaked in the 2000s, in spite of oil recovery capacity enhancement.

The projected increase of global oil supply is given by Jakobsson et al. (2009) as being from 80 million barrels per day (Mb/d) in 2005 to 105 Mb/d in 2030 according to the IEA or 103 Mb/d according to the US Energy Information Agency based on assumptions concerning rates of decline in production from existing fields, the same conclusion is drawn by Sorrell et al. (2012). Whenever the peak of oil production may be, the importance of this fuel was realized during the 1970s' global oil crisis. Irrespective of whether its reservoirs may (or may not) be sufficient to be able to supply fuel to vehicles, the wheel moves on in the sense of its effects on our planet.

3.2 Looking for alternatives; is it a correct choice?

One school of thought as a response to the likelihood of declining availability of oil is to look for alternative renewable energy options to fuel existing vehicles, such as liquid biofuels. The question to be asked is why is reduced mobility not being considered in an on-line society, why is the search for other fuels being undertaken before confirming the availability of new sources and their ability to meet projected demand, as well as that they will not have harmful effects? This is particularly so in the case of fuels that need to be grown on farm land which could mean fuel crops taking precedence over food crops. The life cycle analysis (LCA) of biofuels has been subject to considerable controversy and uncertainty (Voet et al., 2014). The variation in LCA studies' results is because of a number of reasons including difference in assumptions, the method adopted for calculation, real world differences and inclusion or exclusion of biogenic CO_2 emissions, resulting in a wide variation in conclusions drawn on biofuel performance. As well as concerns over biofuel production and land use change there is uncertainty around issues such as the "fossil rebound" (there is expectation that adding one litre of biofuel supply to the market will only displace some fraction of a litre of fossil fuel use) and other indirect impacts (changes to agriculture could affect emissions sources such as livestock, fertilizer use, and rice paddies, while changing the uses of wastes and residues could have knock-on effects such as increasing demand for other fuels). Is there sufficient fertile land to produce biofuel in addition to the land required for basic food cultivation? If so from where will water for irrigation of the crop come? In addition there is a critical difference between how biofuel could be produced sustainably and how biofuel would actually be produced if and when expansion is driven by policies or the market, which could favour more profitable fuel over more essential food (Wicke et al., 2012) (Hannon et al., 2010) (Gnansounou et al., 2009).

3.3 Car ownership, oil and inequality

According to the OPEC World Oil Outlook 2014 (OPEC 2014) in 2011 there were 940 million passenger cars in the world out of which two thirds of cars were in OECD countries. The ownership of cars in developing countries has increased very sharply from 6 percent of 210

million in 1970 to 28 percent of 940 million in 2011 and this trend is likely to be growing more and more in future. In terms of car ownership on average 489 people owned a car out of 1000 in 2011 in the OECD. But if talking about the figure for people living in developing and underdeveloped countries, the car ownership is less than 1 car per 50 people in this group of countries with a total population of 2.5 billion people (OPEC 2014 Page: 94 Figure 2.7)

Is the large number for car ownership in OECD countries due to their development or did they develop because of mobility on vehicle wheels? Is it necessary to own a car for rapid development? To some extent this appears not to be the actual reason or the only ground for development. Take the example of China, one of the fastest growing countries, where people own comparably fewer vehicles than is the case in several European and South American countries with more car ownership and less rapid development. In 2011 Chinese owned 53 cars per 1,000 people which is very low in comparison with OECD countries. Other examples are Japan, France and the Netherlands with more GDP growth and less share of private vehicle ownership than the United States.

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Table 3.1: Projections of passenger car ownership rates to 2040 (per 1,000)
Source: OPEC (2014) "World Oil Outlook 2014 Report Table 2.2"

The private car is more than a necessity it has now become a global trend to own personal vehicles not only for transport but as status symbols as well as demanding faster, more comfortable, and more luxurious vehicles which are perceived as able to provide more convenience than public transportation. The key findings of some studies (Beirao G. and Cabral S. 2007) (Luigi dell'Olio et al. 2011) (Redman et al. 2013) show that to increase public transport usage, the service should be improved up to the levels of service required to attract potential commuters and particularly car users. Sustainable urban transport systems do not require the complete elimination of private cars that of course is not expected. However, a shift from part of current private vehicle travel to use of public transport by improving the public transport system image and service level to make it attractive to potential users is the main intention. The high private car ownership and or easy access to a private car is a key restraint for the possibility of public transport increasing its influence. The detailed knowledge and understanding of the demands of both public transport users and also of non-users is critical to attract those with higher potential for switching modes (i.e. those people who have access to public transport but who do not make use of it). Because of lack of this culture of public transport use the world vehicles fleet increased from about 50 million vehicles to 580 million vehicles between 1950 and 1997, growing five times faster than the growth in population (Braker et al. 2007). For example in China vehicle sales increased from 0.7 million (2001) to 1.1 million (2002) and 1.7 million (2003). China with 13.6 million per year domestic vehicle sales has now become the world leader (BBC News, 2010).

In a realistic approach, it may not be feasible to entirely remove private motor vehicles from the Earth for the sake of sustainability. However if emissions are to be reduced below the level that will cause severe climate disruption the baseline situation (Business-As-Usual) could not be allowed to continue with as much acceleration as it is showing at present. Improving vehicle efficiencies, optimum developed systems, substituting lower carbon fuels for existing fossil fuels, shifting and avoiding strategies, human behavioural improvements, and national, regional and local policy frameworks are forms of potential mitigation that may all be needed to avoid climate disruption on a large scale and to save the scarce resources of the Earth, the only planet to show the existence of life.

Currently the world's transport sector consumes 59% of total oil production while transport's dependency on oil is predicted to increase to 63% by 2040 (OPEC 2014 Report Page: 89 figure

2.1) but this is not bringing much benefit to the countries which provide the oil. As shown in Tables 3.2 and 3.3, if the top twelve oil producing countries in terms of the percentage they supply of OPEC's oil output (OPEC's share is 81 percent of oil production) (see table 3.2) are compared with the top twelve developed countries ranked by the United Nations' Development Programme(UNDP) "Human Development Index (HDI)"(http://hdr.undp.org/en/content/human-development-index-hdi) , a measure of overall social development (their development being based to a very large extent on the fuel supplied from the oil producing countries) the lowest GDP per capita of a developed country is more than the highest GDP per capita of an oil producing country, except in the case of Qatar and Kuwait, both of which are very small countries.

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Table 3.2 Top twelve OPEC member countries in terms of their share in production.

One tool which is used to measure environmental impact by means of the ecological assets required for production of the resources which a country needs to meet its consumption and the land required to absorb its wastes, especially carbon emissions, is the Ecological Footprint (Global Footprint Network 2017). The Ecological Footprint is measured in terms of the land area in global hectares (a global hectare is a hectare of land of globally average productivity)

required to provide all of a country's goods and services. The greater the area, the greater the environmental impact. The Ecological Footprint of the majority of oil producing countries (except for UAE and Qatar) is far lower than the Ecological Footprint of developed countries meaning that in general the oil producing countries are causing less damage to the environment than the countries that buy their oil. Similarly the motor vehicles fleet and associated CO_2 emissions, both measured per capita, are much higher for developed countries than for the fuel supplying oil exporting countries.

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Table 3.3 Top Twelve countries in terms of Human Development Index Ranking.
Sources: http://www.opec.org/opec_web/en/data_graphs/330.htm
http://hdr.undp.org/sites/default/files/hdr14-report-en-1.pdf
http://data.footprintnetwork.org/
http://databank.worldbank.org/data/reports.aspx?Code=NY.GDP.PCAP.CD&id=1ff4a498&report_name=Popular-Indicators&populartype=series&ispopular=y
http://www.nationmaster.com/country-info/stats/Transport/Road/Motor-vehicles-per-1000-people
CO2 (IEA): CO2 emissions from fuel combustion, OECD/IEA 2014 edition
OECD/ITF 2015 "ITF Transport Outlook 2015" International Transport Forum.

Having made themselves relatively wealthy by using the oil they buy from the oil producers, the developed countries then enrich themselves further by exporting vehicles. According to an OPEC report (OPEC World Oil Outlook 2014 Report Page: 90 figure 2.3) the oil demand (for the transportation sector) of developing countries will be increased from the level of 55% of developing countries' total oil demand in 2011 to 65% of developing countries' total oil

demand in 2040 which means the car manufacturers of developed countries will sell more vehicles to developing countries. The same trend is seen in Eurasia (OPEC World Oil Outlook 2014 Report Page: 90 figure 2.4) where oil demand will reduce by 5% for electricity generation and increase in transportation from 44% to 49% in 2040.

The non-OECD countries also suffer more oil-based pollution. The gasoline derived sulphur content in the air is very high in the Middle East and some African countries where oil is extracted, as compared to other regions where oil/diesel is used but not produced (OPEC World Oil Outlook 2014 Report Page: 239 figure 5.14) similarly the on-road diesel sulphur content in the air of Middle East, African countries and some of the Latin American countries is more than 500 ppm whereas in North America, Europe and Oceania countries the content is less than 15 ppm (OPEC World Oil Outlook 2014 Report Page: 240 figure 5.15)

3.4 Is there a relationship between mobility and GDP growth?

To support investment in transport for freight movement and services is crucial for economic prosperity. On the supply side freight transport volume is considered to be strongly correlated with economic growth whereas on the demand side the passenger car is the driving factor. But there are examples demonstrating that high GDP could also be achieved by transportation systems that are less dependent on the private car (Jewell et al., 2007).

In a 'green mobility' environment cities and regions could consequentially separate car use from economic prosperity to overcome pollution issues by sustainable infrastructure and city planning. A well planned and efficient patterned smart city like Amsterdam or Tokyo as shown in the following figure 3.1 provides low carbon transport (public transport), makes cycling/walking viable and is less dependent on private cars and their related infrastructure. Individuals' travel time savings through the availability and use of an interconnected, efficient and affordable transport network and lower traffic congestion would be available for productive use. Perhaps as a result of cost saving by reduced fuel use and transport time, companies can curtail their expenditures and increase their profit margin. Studies show (McKinnon 2008) (UNEP 2008) that efficiently designed improved transport networks significantly reduce operational costs with added benefits of reduced carbon pollution. Also

investment in sustainable transport, through its potential to raise government investment, benefits the overall economy (Chmelynski 2008).

Following its late 19th century "break-neck speed" adoption of modern technology , Japan became the world leader in high speed trains when in 1964 its first high speed railway reduced by two hours the journey time (from six to four) between Tokyo and Osaka. The new railway connected two densely populated cities (40 million people in greater Tokyo with 20 million in Osaka) which made rail travel competitive with air travel and helped to make day trips between these cities possible (The Economist 2014). Making such performance in the public transportation sector, Japan has shown 28% GDP (Purchasing Power Parity) growth from US$ 4682 in 1990 to US$ 5986 in 2015 and at the same period there is a reduction from CO_2 emissions intensity from 0.22 kg/GDP (PPP) in 1990 to 0.19 CO_2 emissions/GDP (PPP) in 2015 (IEA 2017). Japan is also showing the benefits of urban public transport. Tokyo is one of the cities like Amsterdam and Madrid which are successfully placed in the most efficient pattern towards a green economy in terms of making the least use of private cars as shown in the following figure 3.1.

Also at the urban scale of transport the Singapore Mass Rapid Transport system is one of the cleanest and most efficient urban train networks. More than 100 stations, part underground and part elevated, heavy duty escalators and modern information displays provide daily services to 2.6 million riders to keep them away from private car ownership (City transport 2017). It can be seen from Fig 3.1 that Singapore also does much better than many American and Australian cities in reducing its share of private car use, and unlike many of these cities it has a plan to improve even further. The city has the ambitious target to have 70% of trips taken during the morning peak commuting to be on public transport by 2020 which is 21% up from the 2008 level. To make this possible government has made huge investment in its public transport infrastructure with easy and fast connections between bus and rail services. Restraints on car licenses and restrictions on conventional less efficient cars with a vehicle quota system support this target. All these actions across all individual categories make Singapore top performer city in the Asian Green City Index followed by Hong Kong (The Green City Index 2012).

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Figure 3.1: Moving towards a green trajectory
Source: UNEP (2011)

With relatively similar level of per capita GDP as London and Berlin and with very much lower car use, Hong Kong is recognised as having one of the best Mass Transit Systems, which because of its punctuality record and efficiency is known as the gold standard in the transport industry. This is one of the most profitable urban train services where passenger fares exceed its running costs (City transport 2017).

3.5 Economic prosperity and urban development

The development of society is an interlinked cycle. Economic prosperity brings about income increase, income increase gives rise to car ownership and road transport demand which strengthen suburbanisation and ultimately give rise to longer trip lengths. As a result car dependency increases and also road demand. The whole situation ends up causing severe congestion hence not only more energy is consumed but also there is more pollution, more accidents and more greenhouse gases.

If critical analysis is made of the life cycle of development from a sustainability angle, it can be seen that while transport and infrastructure development of a society should bring economic and social prosperity by providing accessibility to services and facilities in truth it is not so. The existing transport systems and policies are creating more air pollution, traffic congestion, road fatalities and accidents and transport related social exclusion (Markovich and Lucas 2011) (Mackett and Brown 2011) (Essen et al., 2011). To compare the scale of road traffic deaths to other forms of mortality, in 2013 the USA had 32,719 road traffic deaths, a rate of 10.6 per 100,000 people (WHO, 2015: Table A2, p270). In the same year the USA had 33,636 deaths resulting from firearms, a rate of 10.63 per 100,000 people (CDC, 2015).

If a framework were designed to show how transport relates to current development it might be as shown in Figure 3.2 below, with transport driving urbanisation and development which then drive climate change.

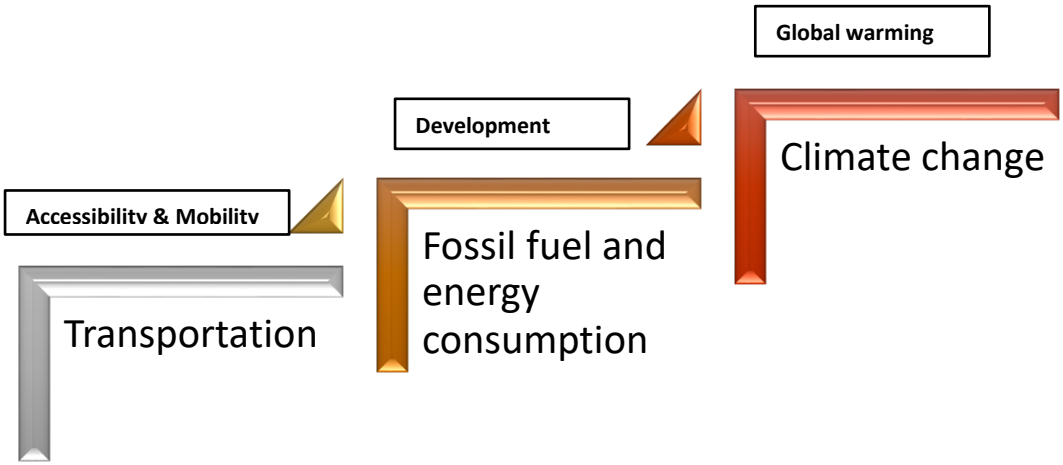

Figure 3.2: Transportation driven urbanisation and climate change.
Source: Author

The rapid motorization of global society together with poor land use planning in urban areas accelerates suburbanisation thus causing the formation of slum urban areas. A vicious circle of motorisation and suburbanisation have transformed transport related global environmental problems. Before the invention of supersonic aircraft, sports utility vehicles, luxurious cars with different added features and high engine capacities to support heavy vehicle bodies, high powered motorcycles and other ways of making transport faster, human beings were surviving and there were developments in every walk of life. Climate change

became a worsening problem when humans started to take transportation beyond basic mobility and accessibility and now speed and global warming are increasing together. No one seems to realise that the faster speed of transportation may be giving advancement in development but on the other hand is also causing disruption of the same development by way of global warming and its effects (de Decker, 2008). One might wish to ask why do not industrialists and car manufacturers and buyers too, who are also living on the same planet in the same environment and about to face the same after effects, understand that to slow the numbers and the speed would also reduce global warming instead of leaving the task of fighting against greenhouse gas emissions to the environmentalists and scientists?

Urban expansion and the resulting pressure produced on urban infrastructure is now become an international challenge. It is estimated that by 2050 around 6.3 billion of the world population will be living in cities (UNDESA, 2012). The increased population growth is associated with increased travel demand. This is why transport planners now tend to focus on integrated transport planning and land use changes and their effects on travel behaviour. Residential expansion through suburban developments in North America, Australia and New Zealand has created sprawl combined with a lack of local facilities which has restrained people's ability to walk or cycle for their daily travel requirements (Stevenson et al. 2016).

The International Energy Agency in a report (IEA 2013b) presented that by 2050 under a Business-as-Usual scenario global urban passenger mobility will more than double whereas the increase in some fast growing regions like Southeast Asia, South Asia and the Middle East will be ten times during the same period. Despite vehicle technology improvements and fuel economy measures, under this Business-as Usual scenario urban annual transport energy consumption is expected to increase by 80 % by 2050 (IEA 2013b).

The widely-used term sustainable development is inevitably associated with the need for a sustainable transportation system. An approach where economic development has to be limited by social and environmental constraints is discussed by Journard and Nicolas (2010). A similar approach is presented by Daly (1996) stating that there is a limit to the scale of the economy, set by the need to sustain the carrying capacity of the ecosystems and resources of the Earth, with a fair distribution of resources and output from the economy among generations. Brown et al. (2006) used the concept of the "triple bottom line" stated as 'people, planet and profit'. The problem with this approach is that it is easy for the profit side

to become dominant in the current economic system meaning that this concept may become a tool for companies to demonstrate their "green credentials" without doing very much to reduce their real impact on the environment.

A more economically-focused view of sustainable transport (Schipper et al. 1994, p.16) is "providing transportation services as long as those using the system pay the full social costs of their access, without leaving unpaid costs for others (including future generations) to bear". This appears to cover the reality of the situation as long as there is an agreed way to calculate the "full social costs".

Confirmed by Jeon & Amekudzi (2005) and then Perschon (2012), who carried out detailed reviews of various definitions and mission statements, overall the objectives of sustainable transport are seen as stability of the social, economic and ecological system with improvement of human quality of life. Whether these things are compatible or possible under the current growth-based economic system remains to be seen.

3.6 Low carbon world

Climate change was politically addressed at the international level in Rio de Janeiro, Brazil at the Earth Summit in 1992. The summit set out a framework for stabilizing atmospheric temperature increase to not more than 2°C. Since then CO_2 emissions reductions with a particular emphasis in the transport sector have been widely debated by governments and international decision makers (FIA mobility 2015). For the first time in over 20 years of UN negotiations, CoP 21 (21st session of the Conference of Parties) in the December 2015 Paris Climate Conference the world appeared to achieve a legally binding and universal agreement on climate. The Paris Agreement is one of its kind as an international climate agreement extending mitigation obligations to both developed and developing countries. The first formal commitments to reduce GHGs were set under the Kyoto Protocol in two commitment periods but the Kyoto Protocol is potentially limited in its ability to address global emissions (IEA 2016). In response to post-2020 mitigation contributions to the Paris Agreement, 170 countries (representing seven billion population responsible for 90% of energy related CO_2

emissions) submitted their Intended Nationally Determined Contributions (INDC) in the lead up to CoP21. The first round of actions is based on when parties formally approve the agreement prior to the second round for the 2025-2030 period which will be updated by 2020. Under the Paris Agreement each country's INDC begins from 2020 but according to IEA scenarios the energy sector emissions must be controlled by 2020 for a reasonable chance of limiting temperature rise to below 2°C (IEA, 2015b).

The Paris Agreement's collective aim is to control the increase in the global average temperature to well below 2°C above pre industrial levels and to make immediate efforts to limit the temperature increase to 1.5^{o}C. Signatory parties are bound to bring about immediate global peaking of GHG emissions and then to undertake rapid reductions from this peak to achieve a balance between anthropogenic emissions by sources and mitigations of GHGs in the second half of this century (UNFCCC 2015).

Major cities have frameworks to curtail their own carbon footprint and climate negotiations have focused on setting rational targets to drive national actions. Technology, innovation, socio economic boundaries and international political conditions appear to be coming together to make possible a low carbon future. Nevertheless transport currently accounts for 22% of total energy related CO_2 emissions but because of the rapid growth in traffic volume and its total dependence on fossil fuels, transport needs immediate attention. The transport sector is the fastest growing sector among all emissions sources and land transport is a major carbon contributor. According to (ITF 2015) CO_2 emissions from global land transport will grow by between 30% and 110% by 2050 depending on fuel prices and urban transport patterns. This is why the transport sector is so critical in achieving mitigation targets and a more sustainable environment. The continued growth in transport demand corresponding to oil consumption and resulting CO_2 emissions especially in the developing world is a global issue free from boundaries, demanding boundaries to be set round it urgently. Cumulative CO_2 emissions between now and by 2050 will strongly influence the extent of climate change by the end of the century in 2100.

S.No.	Studies	References	Description	Focus
1.	IPCC methodology	El-Fadel M., & Bou-Zeid E., (1999)	Motor Vehicle Emission Inventory model predicted emissions from different vehicles and scenarios. Two different mitigation approaches.	GHG emissions, fleet technology, average speed and travel volume.
2.	Rule Based Evolution	Gupta (1998), Den Elzen et al. (1999), Berk & den Elzen.	Analysed the implications of a number of alternative Multi Stage approaches for the differentiation of future climate commitments under two alternative global emission profiles.	Per capita GDP (PPP).
3.	World Energy Projections	Criqui and Kouvaritakis (2000), Blanchard et al. (2001, 2003)	Elaborated the model for the purpose of analysing the impacts of technological change and key exogenous hypotheses on population and economic growth.	Per capita GDP (PPP), GHG emissions per capita.
4.	GHG emissions: Implications for KP.	Lutter (1994), Baumert et al. (1999),WRI(2002) OECD IEA (2003)	Developing countries' participation in the Kyoto Protocol to limit GHG by adopting limits which could offer economic gains to developing countries.	Population, GDP, GHG projections
5.	"Hybrid" instrument	Ellerman and Wing (2003)	Elucidate the difference between restricting CO_2 emissions via absolute limits & intensity based caps which are indexed to GDP.	GDP, GDP projection.
6.	Multi sector approach	Jansen et al. (2001)	Compares the costs with the burden differentiation of emission mitigation.	GHG emissions, GDP
7.	Innovative engine & veh. Technology	Shaheen S.A., & Lipman T.E., (2007)	Automotive fuel technologies, ITS and mobility management strategies that can reduce the demand for private vehicles.	GHG, CO_2, Vehicle technology & mobility management
8.	Potential of energy demand	Yan X. and Crookes R.J. (2008)	Assess the future trends of energy demand and the effectiveness of possible reduction measures.	Fuel tax and biofuel promotion
9.	Carbonless footprint:	Frank L.D., Greenwald M.J., and Winkelman. S., (2009)	Active transportation to meet health and GHG emissions goals.	CO_2 emissions and Climate Stabilization
10.	Cost and CO_2 emissions of electric cars	Vliet O.V., and Brouwer A.S., (2010)	Efficiency, cost and CO_2 emissions of future electric cars (EV) in the Netherlands.	GHG, life cycle costs
11.	Empirical effects of gasoline tax on CO_2 emission.	Kim Y.D., Han H., & Moon Y.S., (2010)	Appropriate price elasticity of gasoline as carbon tax to mitigate GHG emissions.	Gasoline Tax and CO_2 emission
12.	Emissions scenario using PET.	Neill B.C., Dalton M., Fuchs R., Jiang L., and Pachauri S. (2010)	Assessment of the implications of demographic change for CO_2 emissions using an economic growth model.	CO_2 emissions and GDP
	Effects of carbon tax on CO_2 emissions	Lin B., Li X. (2011)	Mitigation effects of the five European countries by using the method of difference in difference.	Per capita CO_2 emissions, GDP per capita and Carbon Tax

S.No.	Studies	References	Description	Focus
13.	Activity based longitudinal panel survey	Moreno L.F., & Gosselin M.L. (2011)	Impact of individual & household socio economic & transit supply characteristics around the residence & work place.	Transit system and Urban travel CO_2 emissions
14.	Alternative fuel & reduction pathways.	Heywood J.B., Hope C., (2011)	Stochastic technology and fleet assessment model to quantify the emission and fuel use for a realistic pathway.	Fuel consumption and GHG emissions
15.	Biofuels, HEV, PHEV & FCEV	Nguyen T.D., Das S., (2011)	Increasing engine efficiency and transition to low carbon fuels separately. Decarbonisation of fuels is also suggested in this study for large reduction in GHG emissions.	Low carbon fuels, Carbon intensity
16.	Opportunities to improve fuel efficiency & economy.	Badruddin I.A., Mekhilef S., Silitonga A.S., (2011)	Fuel economy standards, labels and technologies as potential fuel savings measures.	Oil demand, GHG emissions and Vehicular advanced technologies
17.	Effects of carbon tax on CO_2 emissions	Lin B., Li X. (2011)	Mitigation effects of the five European countries by using the method of difference in difference.	Per capita CO_2 emissions, GDP per capita and Carbon Tax
18.	Analysis of several model scenarios	Bueno G. (2012)	Mobility in a decarbonized world should be more efficient when moving people & freight & organized by way of high occupancies of vehicles.	GHG emissions, Energy consumption
19.	GHG emissions & urban form.	Moreno L., Patterson Z., Barla P., Harding C. (2012)	Impact of urban form and transit accessibility on GHG emissions by introduction of emerging green technologies.	GHG emissions & CO_2 emissions
20.	Policy scenarios for the transport sector of China	Yang S., Liu Q., Tu J., Jaccard M. (2012)	Effective policy measures for reducing CO_2 emissions workable for implementation.	CO_2 emissions & transportation
21.	Impacts of factors on CO_2 emissions	Lu Y., Zhang J., & Wang T., (2013)	Divisia index approach used to explore the factors on the CO_2 emissions from road transportation.	CO_2 emission and Road freight transportation.
22.	Fully modified bi-directional approach	Sapri M., Baba M., (2013)	Relationship between CO_2 emissions, economic growth, road sector energy consumption.	CO_2 emission, road transport, OECD Countries
23.	Optimization methods for green transport	Demir E., Bektas T., & Laporte G. (2013)	Green freight transportation by route planning of vehicle emission models for the Netherlands.	Road freight and CO_2 emission
24.	Eco friendliness of road transport	Kirschstein T., and Meisel F., (2014)	Macroscopic models which estimate emissions designed for transport planning purposes in Germany.	GHG and CO_2
25.	Multi criteria approach for CO_2mitigation.	Javid R.J., Nejat A., & Hayhoe K., (2014)	Analytical Hierarchy process to rank road emissions mitigations strategies including reduce, avoid and replace strategies.	CO_2 emissions and Transportation planning

S.No.	Studies	References	Description	Focus
26.	Estimate the energy demand	Baeza C.C., & Pardo C.S., (2014)	Mitigation scenario "BRT" considers a modal shift from private car trips to a BRT system.	Sustainable transport & GHG emission
27.	Impact of built environment on the lifecycle.	Waygood E.D., Sun Y., Susilo Y.O. (2014)	Comparison of transportation CO_2 emissions produced over a family's lifecycle across five different built environments to determine their sustainability.	Transportation CO_2 emissions,
28.	Relationship between transportation variables	Mishalani R.G., Goel P.K., Westra A.M., & Landgraf A.J. (2014)	Model of CO_2 emissions per capita as a function of various transport variables using data of urban areas in the U.S.	CO_2 emissions & Urban passenger transportation
29.	Strategic approach to sustainable transportation	Basu R.J., Bai R., Palaniappan P.K. (2014)	Enumeration and heuristic approach in terms of solution quality and computational time based on the results of sample problems considered.	Sustainable transportation and carbon footprint
30.	CO_2 emissions in the transportation sector & policy mitigation	Ratanavaraha V., and Jomnonkwao S., (2015)	Forecasting of the CO2 amount released from transportation using 4 techniques: log-linear regression, path analysis, time series, and curve estimation.	Variable used size of the population, GDP.
31.	Model to predict GHG emission	Hao H., Geng Y., Li W., & Guo B. (2015)	Framework reflecting the future trajectories of GHG emission from freight transport sector.	Energy consumption, GHG emission & freight transport

Table 3.4: Brief presentation of previous studies in the field of transport and carbon emissions.

A review of the literature (see Table 3.4) reveals that most existing studies of transport emissions have taken an economic focus. They have tried to relate CO_2 or GHG emissions with gross domestic product (GDP) (expressed either in US$ or in terms of Purchasing Power Parity) but they do not consider the pressing question of how much transport may be possible in the carbon restricted world that will result if the Paris Climate Agreement is followed in practice by its signatories. Studies that look at reducing emissions are also based very much on the status quo (Waygood E.D., Sun Y., Susilo Y.O. (2014). Truly sustainable transportation, transportation that plays its part in the required reduction of carbon emissions to meet the Paris Agreement, may mean there is a need for fundamental changes in existing transportation and urban planning practices, to change the focus from transport to mobility. This might imply, for example, that it would be preferable to build small-scale local shops near where people live rather than to require them to drive to large out-of-town shopping centres.

As John Whitelegg (1993) states,

> *"It is the ease of access to other people and facilities that determines the success of a transportation system, rather than the means or speed of transport. It is relatively easy to increase the speed at which people move around, much harder to introduce changes that enable us to spend less time gaining access to the facilities that we need"*

If transport is to respond to the Paris Climate Agreement there is also a need to quantify what level of emissions reductions from transport, or from other sectors of the global economy, may be required to meet the Paris target. The Paris target is expressed in terms of global temperature rise, no more than 2°C and ideally no more than 1.5°C, while concentration of CO_2 in the atmosphere is usually expressed in parts per million (ppm) or parts per million by volume (ppmv) and the relationship between atmospheric concentration and possible temperature increase is not precise. The Intergovernmental Panel on Climate Change (IPCC 2007) refers to

> *"...the likelihood of exceeding an equilibrium temperature threshold of 2°C above pre-industrial levels [is] based on a range of published probability distributions for climate sensitivity. To render eventual exceedance of this exemplary threshold 'unlikely' (<33% chance), the CO_2-equivalent stabilisation level must be below 410 ppm for the majority of considered climate sensitivity uncertainty distributions (range between 350 and 470 ppm)."*

The IPCC also some time ago linked the scale of necessary reductions to population growth

> *"...stabilization of CO_2 concentrations in the atmosphere at 450, 550, 650, and 750ppmv would require limiting fossil-fuel carbon emissions at about 3, 6, 9 and 12 billion tonnes, respectively, by 2100 and further reductions thereafter to less than half current global emissions. If, for example, the world population stabilized at about 10 billion people by then, an average carbon emission per capita of 0.3, 0.6, 0.9, and 1.2 tonnes of carbon would be required to achieve the 450, 550, 650, and 750ppmv limits, respectively. We make no assumption here about how these emissions would or should be allocated globally, but simply report that the average by 2100 must work out to these levels to achieve the stabilization objectives. Thus, to achieve a 450ppmv*

concentration target, average carbon emissions per capita globally need to drop from about 1 tonne today to about 0.3 tonnes in 2100..."

(Banuri and Weyant, 2001, 89)

These statements from the IPCC show the scale of the likely reductions in carbon dioxide emissions that could be needed to meet the Paris Climate Agreement target. In terms of transport such reductions would be a very significant change. The possibility of being able to make significant changes in the environmental impact of transport was revealed in the PhD research of Tran Thuc Han in the VUW School of Architecture. She found that comparing personal transport between three apparently very different cities (Wellington, Hanoi in Vietnam and Oulu in Finland) in all three places people's land transport provided a similar annual travel distance but the transport modes in the three cities had very different environmental impacts in terms of energy use and hence emissions (Tran, Thuc H., 2014). This research made clear that it is possible to have significantly lower emission urban transport without curtailing mobility services in terms of per capita distance travelled.

3.7 Current system of transportation

Adequate, reliable and economical transport is essential, although not in itself sufficient, for social and economic development, as clearly expressed in a study of rural areas in developing countries (Carapetis et al. 1979). Worldwide the present system of transportation consumes more than half of entire global fossil fuels and after its uses emits around a quarter of the energy related CO_2 (OECD 2005 CO_2 Emissions from Combustion 1971-2003) which is projected to increase by 1.7 per cent a year from 2004 to 2030 (IEA/OECD 2006). Land transport accounts for roughly 73% of the sector's total CO_2 emissions, followed by aviation (11%) and Shipping (09%). More than 80% of the predicted growth in transport emissions is expected to come from road transport in developing countries (IEA 2009). This extreme use of fossil fuels is causing adverse effects in the environment and 80% of the air pollution of urban areas is related to transport emissions. In addition 1.27 million fatal traffic accidents per year and severe traffic congestion are also damaging society. If this scenario continues without any significant improvements the number of vehicles on roads will be around 2 to 3

billion by 2050. Not only road vehicles but also increasing air and water transportation are enhancing CO_2 emissions to a great extent.

In the twenty-first century, transportation has changed the world in ways which were unimaginable 100 years ago. While the price which we are paying now may seem minor, in future the cost may be much higher for such benefits. The after effects, just as the aftershocks of an earthquake, might be very calamitous in developing countries where even now 90 % of the road fatalities occur (Aiza A., 2007).

Green growth is desirable but the current rapid unrestrained growth in vehicles volume and the manner in which transport has expanded in recent years is undermining the economic and social growth it is supposed to enable. Instead of enjoying the outcomes of socio economic growth, development and urbanisation are starting to suffer, the economic cost of air pollution, road fatalities and accidents and traffic congestion in many developing countries is from five to ten per cent of GDP (Dalkmann and Sakamoto 2011).

3.8 Fuels, economy and alternatives

So far insufficient attention has been given to educate the public to think and make sensible decisions about fuel economy when choosing to buy a car. The vehicle owner seldom seems to bother to think about the fuel economy of vehicles when buying a vehicle and there is little quantitative assessment of the value of fuel economy, although in some countries, including New Zealand, there is mandatory labelling of vehicle fuel economy at the point of sale (EECA, 2017).

Fuel economy labels cover conventional fuels. If it comes to finding substitute alternatives for fossil fuels, biomass with other options for electric vehicles like hydropower, nuclear, wind and solar energy are possible alternatives but whether they are cheap and safe in production as well as able to offer long term mobility preservation is still debatable and their feasibility is still under consideration. Simply depending on a policy of use of bioenergy and other renewable and often intermittent energy sources, before their full maturity, is an absolutely unrealistic approach to achieve no more dependency on fossil fuels for transportation use in the future vehicle fleet. Another option as alternative is coal, the largest of the conventional

fossil fuels in terms of reserves. If combined with Carbon Capture and Storage (CCS) some suggest coal could be the most suitable substitutionary option subject to technical viability and proof of environmental acceptability (Azar et al. 2006). However, coal is not a viable fuel for replacing oil without the intervening step of changing the fleet to electric vehicles and it also would require that CCS could be made to work.

In 2010, total global primary energy consumption was 550 exajoules (1 Exajoule is equal to 174 million barrels of oil equivalent), of this total the fossil fuels share was 80%, bio energy (wood combustion) 11.3%, nuclear 5.5%, hydro 2.2% and the remaining from other renewable energy sources (Post Carbon Institute 2012). Total world energy consumption has increased at a rate of 2.1% per year from 10020 Mtoe in 2000 to 13903 Mtoe (571 EJ) in 2016 and for New Zealand per year increase is 1.4% from 17 Mtoe in 2000 to 21 Mtoe in 2016 (Enerdata 2017).

Because of a limited supply of biomass energy for conversion into transport fuel, solar and or wind may be significantly more reliable and feasible to replace the fossil fuels. According to the WEA (2000), the annual solar energy potential ranges from 1600 to 50,000 EJ/Year, depending upon some constraints, the practical potential may be less than the presumed level. For wind energy, its resources roughly have an estimate equivalent to around 500,000 TWh/Year with a practical potential of at least 50,000 TWh/Year (6000 EJ/Year) (Johansson et al. 2004). But there are some physical restrictions to rectify before it may be possible to make solar, wind and geothermal energy options feasible (Andersson and Jacobsson 2000).

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Table 3.5: Global renewable energy resources base.
Source: Johansson et al. 2004

As Table 3.5 shows, renewable energy sources have the technical potential to provide far more energy than the total of 550EJ consumed in 2010 or the 571EJ in 2016. What is far less clear is the extent to which these sources, which with the exception of biomass generally produce electricity, can provide energy for transport which currently uses oil.

3.9 The gap in knowledge

The gap in existing knowledge lies in the lack of understanding of the linkages between the desired mobility services of urban populations, to access work, education, shopping and leisure activities and the need to meet the overall level of emissions that will satisfy the requirements of the Paris Climate Agreement. Research to date has not explored what types of transport services might result from the need to cut CO_2 emissions and how these services could work in the existing fabric of the built environment.

There is currently a lack of research that comprehensively interconnects the dynamics of mobility to urbanization, to development (social and economic) and to climate change. The aim of this research is to see what combination of transport technology and/or transport behaviour could be most influential in achieving more sustainable mobility.

This approach is summarised in the following research question

If CO_2 emissions have to be restricted to meet CoP21 what will this mean for mobility in Wellington, a small city in the developed world?

The approach in this study is to establish goals for CO_2 emissions reduction (one being to meet the CoP21 target of no more than 2^0 C of warming) together with Business-as-Usual as a benchmark, and then to see how, and the extent to which, existing mobility services could be supplied within these targets. The forms of transport technology, transport behaviour and built environment changes that might be needed for provision of these mobility services will also be discussed in later chapters.

Chapter 4| New Zealand and Wellington region transportation emissions

"Building cities is big business, and the way we govern our cities is as important as running the nation"

Ludo Campbell-Reid, an urban strategist and design champion

(Dominion Post 2017)

4.1 New Zealand a recently discovered country

4.1.1 New Zealand's geographic profile

New Zealand is a long, narrow, hilly and mountainous country located in the southwest Pacific Ocean between 33^0 and 55^0 south latitude. It consists of two main islands and has 268,021 sq. km total land area which is similar in size to Japan or the United Kingdom. At 15,000 km New Zealand's coastline is one of the longest in the world and it has a relatively large maritime economic zone of 4.1 million sq. km. Around half of New Zealand's land area is arable land and a quarter is under forest cover. Lakes and rivers cover 1% of the land area, and are valuable sources of hydroelectric power but most of the rivers are seldom navigable [http://www.treasury.govt.nz/economy/overview/2016/02.htm]. Australia is the nearest land mass, located on the Eastern side of New Zealand at a distance of more than 2,000 km. New Zealand's climate is influenced by its latitudinal zone with westerly winds and surrounded by ocean. The average annual rainfall range is 600 to 1600 mm and average annual temperatures range from 10^0 C in the southern part to 16^0 C in the northern part of New Zealand. It is expected that in the future annual rainfall will increase up to 5% by 2040 and 10% by 2090 in the west, whereas it will decrease up to 5% by 2090 in the east. No big temperature variations between summer and winter seasons occur except to the east of the mountain ranges where it goes up to 14^0 C. The last 100 years' temperature data show that New Zealand's average annual temperature has increased by about 1^0 C. Projected climate change suggests annual temperature could rise by 1^0 C by 2040 and by 2^0 C by 2090 (MfE 2013 page 23).

New Zealand's economy is based on the provision of services and manufacturing while the export oriented primary sector plays a key role with 8% contribution to New Zealand's GDP. Due to the critical economic importance of the primary sector, climate conditions can have a significant effect on New Zealand's economy (MfE 2013 page 28). Of New Zealand's total food production 85% goes to the international market which makes it an export dependent economy (MfE 2013). During the period of the last ten years, two droughts have led to reduced agricultural productivity. The 2008 and 2013 droughts cost the economy NZ$ 2.8 billion dollars and NZ$ 1.5 billion dollars respectively. The global recession of 2008 badly affected New Zealand's economic growth, which resulted in an economic downturn and also an emissions reduction from the transport sector due to the reduced economic activity (MfE 2013 page 29).

4.1.2 New Zealand's greenhouse gases profile

New Zealand as a developed country and member of international associations like OECD (Organisation for Economic Cooperation and Development) and ASEAN (Association of South East Asian Nations) has been claimed to be playing an important role in a global strategy against climate change and has contributed at both a domestic and international level with various measures to address this global issue. Though New Zealand's total emissions are only about 0.15% of total world emissions, in 2012 GHG intensity in terms of population was 17.2 tonnes CO_2e per capita, the fifth highest in the world. New Zealand's emissions profile has different aspects compared with other developed countries. For example more than 75% of electricity is generated from renewable sources, although this has not reduced the per capita emissions as much as might be expected. On average, developed countries' agricultural emissions constitute around 12% of total emissions whereas, with most of it for export, New Zealand's agricultural sector emissions are 48%, four times larger than those of other developed countries. New Zealand's net emissions (emissions from agriculture, the energy sector (including transport), industrial processes and product use (IPPU) and waste minus emissions from LULUCF Land Use, Land Use Change and Forestry) (http://unfccc.int/essential_background/glossary/items/3666.php) under the UNFCCC

(United Nations Framework Convention on Climate Change) were 38 Mt CO_2e in 1990 which was increased by 18.4 Mt CO_2e to 56.4 Mt CO_2e in 2015 (MfE 2017).

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Figure 4.1: New Zealand's total GHG emissions (1990 – 2015)
Source: (MfE 2017)

New Zealand's gross GHG emissions increased by 15,581 kt CO_2e from 64,573kt CO_2e in 1990 with average annual growth of 0.9% to 81,155 kt CO_2e in 2015 showing more than 24% increase, although as shown in Fig 4.1 the 2015 figure is lower than the figure in 2005-2006. The categories which dominated contributions to emissions were road transportation and manufacturing industries and construction (MfE 2017). In 2015, two main sub sectors of the energy supply sector contributed 59% of total carbon dioxide emissions (not total GHG emissions as shown in Fig 4.1), that is transport, which with more than 40% share in CO_2 emissions contributed 14,593 kt CO_2 and manufacturing industries and construction with 19% share of New Zealand's CO_2 emissions which emitted 6,810 kt CO_2.

With regard to total GHGs as opposed to CO_2 only, the energy sector with around 58% share in New Zealand's net GHG emissions emitted 32,455 kt CO_2e in 2015. With a 41% share of the total energy sector, the road transportation sector alone contributed 13,282 kt CO_2e. The growth in the energy sector contribution was more than 36% from 23,748 kt CO_2e in 1990 to 32,455 kt CO_2e in 2015 with the leading share from road transportation emissions. Between 1990 and 2015, the growth in emissions mainly is due to road transport which increased by 5,814 kt CO_2e (78%) from 7,468 kt CO_2e level in 1990. Total emissions from New Zealand's

transport sector were 14,728 kt CO_2e, (emissions from international marine and aviation transportation are reported as memo items and are not included in New Zealand's total emissions) making up 44% of the emissions from the energy sector which is equivalent to 17% contribution of national gross emissions coming from transport. With more than 90% share of transport emissions, road transport contributed 12,811 kt of CO_2e emissions (MBIE 2015). Transport related emissions are summarised in Table 4.1.

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Table 4.1 New Zealand's transport generated emissions past and present profile 1990 – 2015
Source: Ministry of Transport 2017, New Zealand Government.

Because of New Zealand's isolated position in the Pacific Ocean and given the importance of main industries like tourism and exports to the national economy, international aviation and shipping are critical but they are beyond the scope of this study, with its focus on the city of Wellington.

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Figure 4.2: Consumer Energy Demand Share by Sector
Source: (MBIE 2014)

In 2014, the industrial sector consumed 38% of the bulk of consumer energy (the category which includes all energy used by final consumers) followed by 36% for the transport sector as shown in fig. 4.2

The Climate Action Tracker Policy Report, which looks critically at what nations are doing with respect to climate change, states that unlike China, the U.S.A., and the European Union, New Zealand's climate policy is projected in the opposite direction to an appropriate climate policy framework (Climate Action Tracker 2015).

New Zealand's INDC (Intended Nationally Determined Contribution) 2030 target under the Paris Climate Agreement indicates that New Zealand's actions are not following a fair approach to reach a pathway towards a global temperature rise of no more than 2^0 C and if the same trend were to be adopted by other developed countries, then global warming would exceed 3^0 C or even 4^0 C (Climate Action Tracker 2015, page 1).This is because to control the fastest growing emissions sources of transport and industries which together produce more than half of emissions, currently no policies exist in New Zealand. Instead of decreasing New Zealand's per capita emission which is currently 17.1 tonnes of CO_2e per capita, the trend is set to surpass the U.S.A. per capita emissions (20.6 tonnes of CO_2e per capita) which reflects the failure of current policies of burden sharing and equity. New Zealand has comparatively few and relatively light policies in place for emission control and the per capita emissions rate would be even higher if it were not for the high proportion of hydroelectricity in total primary energy supply.

A challenge for any country, including New Zealand, is to mitigate carbon emissions while keeping GDP growth. During the last couple of decades the emissions in the energy sector have increased by 25% with major contributions from the transport sector (58% growth) and fossil fuel electricity generation. (Climate Action Tracker 2015, page 20). In 2012, the energy sector (excluding transport) contribution in GHG emissions was 24% whereas transport accounted for 19%. Since 1990 in New Zealand, 40% increase in transport generated emissions made it the largest source of emission increase (Climate Action Tracker 2015, page 21).

4.2 Relation of CO_2 emissions and VKT:

Vehicle activity level, also known as traffic volume, is expressed as vehicle kilometres travelled (VKT). VKT is used as a measure of the road network, for transportation planning, computing energy consumption and estimating vehicle emissions (DoIT 2011). Annual VKT at the national level is the number of kilometres travelled in a country by all vehicles during a year and it is expressed as (EIA 2005):

Traffic Volume (VKT) = Number of vehicles x Distance travelled.

VKT can be characterised as the pressure road transport puts on the environment. The Transportation Research Board (Canada) identifies the annual VKT as one of the most important indicators and it has an indirect correlation with environmental indicators such as GHG and air quality (The Calgary City 2010). This measure (VKT) is widely used at national and international level and also by the OECD to compare the progress of different member countries towards environmental sustainability (MfE 2009). VKT depends on population growth, vehicles entering into the fleet, and household travel. Now per New Zealander there are more vehicles than there were in 2001. In 2015, there were 770 light vehicles for every 1000 people in New Zealand compared to 660 in 2001. In 2001, 3.3% of New Zealanders had no access to vehicles which decreased to 2.6% in 2013 and 11.9% had access to two motor vehicles which increased to 12.7% in 2013. In the Wellington region 4.4% had no access to vehicles in 2001 and no change in 2013 but two vehicle ownership increased from 10% in 2001 to 11.5% in 2013 (MoT 2016).

Vehicle engine technologies, fuel use and vehicle kilometres travelled are three important components of addressing the transport CO_2 emissions (Cervero & Kockelman, 1997).

The chart in Fig 4.3 shows that New Zealand light travel (i.e. excluding public transport and heavy freight trucks but including both light passenger and light commercial vehicles) per capita VKT has reduced from 8702 km in 2000/01 to 8629 km in 2014/15, a decreasing trend of 0.05% per year. If this trend continues then it is estimated that by 2050 the national light travel per capita will be about 8500 km per year. This travel dropped in 2006 and from 2009 to 2013 due to increased fuel prices during these periods otherwise the travel increase would have been more as shown in the trend of increase from 2014. A similar trend is observed for

light travel per vehicle from 13,178 km in 2000/01 to 11,251 km in 2014/15 with 0.9% per year decrease and based on the trend it is estimated to fall to around 7500 km in 2050. For light passenger (those vehicles comprising no more than eight seats and used for the transport of passengers) travel per capita the decreasing trend is 0.3% per year from 7368 km in 2000/01 to 7087 km in 2014/15, suggesting the level may fall to around 6,500 km in 2050. New Zealand has an increasing percentage of vehicle ownership and this increase in vehicles per capita is the reason for the decline in travel per light vehicle (MoT, 2015). Contrary to all these trends, the light commercial travel per capita has increased from 1,333 km in 2000/01 to 1,542 km in 2014/15 and with this increased trend of 1% per year, it is estimated that by the year 2050 this level will increase to 2100 km. This national light fleet average annual travel per vehicle type is shown in the following Fig 4.3.

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Figure 4.3: New Zealand light fleet per capita travel 2000/01 to 2014/15
Source: MoT (2015) table 1.4 to 1.7

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Figure 4.4: New Zealand light mode travel per capita 2000/01 to 2014/15.
Source: MoT (2015) table 1.4 to 1.7

In 2002, New Zealanders drove the greatest distance per person within the OECD after the U.S.A, averaging 11,200 km of travel over that year, partially due to a small population scattered across a large land area. Norway and Finland with similar demographic characteristics, that is population density and total population, had a VKT per person of 7300 and 9400 respectively. New Zealand total VKT (as opposed to per capita VKT) is likely to continue to increase with population increase and GDP growth just as it has done for many years unless drastic changes (technical and non-technical) can be introduced to shift towards more sustainable transportation (MfE 2009).

Overall this decreasing national trend in light travel is somewhat different in the Wellington region. During the same period the region's VKT level increased from 3429 million km in 2000/01 to 3708 million km in 2014/15 which shows 0.5% per year increase. Following this trend by 2050 it might rise to 4500 million km. Though the regional share in the national contribution has decreased by 0.85% per year from 9.9% share in 2000/01 to 8.7% share in 2014/15, this might be due to a comparatively lower regional growth rate than that for the

national total VKT which grew by 1.5% per year from 34,813 million VKT in 2000/01 to 42,530 million VKT in 2014/15 (MoT 2015).

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Figure 4.5: VKT per person for selected OECD countries and rank from lowest (1) to highest (30).
Source: MfE (2009)

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Figure 4.6: Average light vehicles age in years
Source: MoT 2015, New Zealand Government.

The New Zealand vehicle fleet is relatively old among OECD countries by International standards. New Zealand light vehicles, on average, are nearly four years older than Australian vehicles and an even wider gap exists compared to other countries such as five years older than Canadian vehicles.

In environmental terms, it can be argued that an older fleet minimises the life-cycle impact of the embodied energy of manufacturing the vehicle, by spreading it over a longer period. However, an older fleet can also be argued to delay the introduction of more efficient vehicles to the point where they affect the fleet average performance.

4.3 Why a city-based consideration?

Under the current economic paradigm mobility underpins a country's economy and is a substantial contributor to its GDP. On the other hand it is inconceivable to achieve long-term sustainability in cities where transport is based largely on the private car using oil as fuel. Ideally a transport system is needed that is capable of delivering the required capacity and performance while utilizing inexhaustible energy resources and at the same time, is compatible with the desired lifestyle as well as clean and affordable. This research seeks to establish the extent to which such a truly sustainable transport system is technologically feasible and behaviourally possible while also being affordable. It is likely that existing government policies and social attitudes would require significant changes if the vision and mission of sustainability are to be turned into accomplishment. New Zealand ratified the Paris Agreement on 4th October, 2016 (New York time) (Ministry for the Environment, 2016) so these changes will have to be addressed or the country will have to explain to the other Paris signatories why it has failed to act.

To grasp what will need to be done for transport to meet the reductions implied by the Paris Agreement it makes more sense to look at a city rather than a whole country. Studying transport in a single city can provide a clearer view of what changes might be needed. A recent report from Arthur D Little and the International Association for Public Transport, UITP, states

> *"There is also often a poor interlinking of urban mobility strategy and other urban strategies. For example, if a city is committed in its environmental strategy to reduce*

CO_2 emissions, it should ask what contribution transport should make to achieve this goal."

(UITP 2014)

The city of Wellington for example, the capital of New Zealand, has put in place a policy to reduce its emissions by 80% compared to 2001 (WCC, undated). This research attempts to identify what combinations of transport technology, transport behaviour, changes in transportation mode and changes to the built environment could be most effective in achieving more sustainable mobility. This approach is summarised in the research question as "If CO_2 emissions have to be restricted to meet the Paris Agreement what will this mean for mobility in Wellington, a small city in the developed world?" An initial study, taken from a Wellington household perspective rather than from a city perspective, suggested that it would be possible to achieve a 70% reduction in a household's transport footprint compared with the average, through a combination of reduced use of a small or fuel efficient car combined with considerable increases in walking and public transport use (Vale and Vale, 2013, Table 3.6, p66)

4.4 Wellington, coolest little capital

The Lonely Planet travel guide described Wellington, New Zealand as "the coolest little capital in the world" (New Zealand Herald, 2010). In a recent global study of 47 developed cities, done by Deutsche Bank, in terms of the cost of living, pollution, house prices and climate, Wellington has been ranked the best place to live in the world. Even with this best quality of life in the world, more action is needed in the growing competitive market of city planning (New Zealand Herald, 2017).

Wellington has the highest median income in the country and the local economy has grown 21% since 2011, hosting new technology businesses and becoming a web and digital businesses hub in New Zealand with more than $2 billion contribution to GDP (The Dominion Post 2017).

4.5 Region's demographics and social characteristics

The Wellington region (the administrative jurisdictions consist of Wellington City, Lower Hutt City, Upper Hutt City, Porirua City, South Wairarapa Districts, Carterton Districts, Masterton Districts and Kapiti Coast District) is located in New Zealand's lower North Island. The Wellington Region encompasses the southern-most parts of the North Island with more than half a million population and land area of 805,500 hectares, the population density is 0.63 persons per hectare (id Community 2017).

Mobile emissions contribution from the region is 37% of the total gross emissions which showed a 3% decrease in total emissions from 3,906,324 tCO_2e in year 2000 to 3,793,147 tCO_2e in 2013 (URS 2014). Transport emissions have increased by 5%, decreased petrol and marine fuel usage were balanced by increased aviation fuel usage from year 2000 to year 2013 (URS 2014 page 73). Contrary to the reduction in the region's overall emissions, mobile emissions have increased by 2% from 1,368,161 tCO_2e in 2000 to 1,393,724 tCO_2e in 2014 (AECOM 2016). In terms of transport modes, emissions from bus, train, and marine have decreased by 5%, 6% and 7% respectively while a significant increase of about 46% was from the Wellington region domestic air transportation (URS 2014 page 75) and (URS 2014 Appendix H).

It is not always straightforward to find reliable data, for example, in the AECOM 2016 report on GHG inventory carried out for the Wellington City and Regional Councils , the increase for domestic aviation in the Wellington region is only 11% from 190,383 tCO_2e in 1990 to 212,138 tCO_2e in 2013 (AECOM 2016 Appendix B). In comparison it is surprising to see an entirely different situation in MoT 2014 data (MoT 2014 table EI 001) which shows more than 27% decrease in national domestic aviation emissions from 1183 kt CO_2e in 2000 to 855 kt CO_2e in 2013.These kinds of variations in data sources even for similar subjects (in this case domestic aviation) raise questions of reliability and of which data should be used. In this particular case the discrepancy in aviation data is not a problem as the main focus in this research is the Wellington region's land transport emissions only, on the grounds that this is by far the largest component of transport emissions. On this basis the emissions from two other regional transport sectors, aviation and marine, though important in the overall regional reduction

target, can be left for future research. Land transport is both the largest part of total transport emissions and also the part which can possibly be influenced by urban design and planning.

In the Wellington region a recent report shows the transport generated emissions contribution has increased to 39% of total gross emissions in 2014/15 with 29% of total emissions being from petrol usage for road transport (AECOM 2016). The increased contribution from the transportation sector is a concern in this study, although the maximum growth occurred during the middle of the last decade and it has now reduced, it is still higher than the year 2000 level.

Between 2000 and year 2014, the Wellington region population increased by 12% while the Gross Regional Product (GRP) increased by 26%. Despite this increase in population and GRP, petrol use for road transport is trending slowly downward. This decoupling of economic activity, fuel use and resulting greenhouse gas emissions indicates that the region is becoming more energy efficient and less emissions intensive in both per capita terms and per unit of GRP (AECOM 2016 page vi). The region's total energy use during this period remained relatively unchanged in spite of population increase. The total energy use which was 11,095,717 MWh (Megawatt hours) in the year 2000 decreased by 2.3% to 10,832,001 MWh in the year 2014 but during the same period gross energy consumption by transportation increased by 4.4% from 5,619,973 MWh in 2000 to 5,867,733 MWh in 2014 (AECOM 2016) in spite of the reduction in use of petrol. This phenomenon also indicates the independence of emissions and energy use. This trend shows some overall reduction in energy intensity (the energy intensity is calculated by dividing the total energy consumption including coal, gas, electricity, heat and biomass of a country or region by its Gross Domestic Product) during this period and an increase in energy output.

Besides national compliance with the Paris Climate Agreement, Wellington city is also a member of the International Compact of Mayors and obliged to report emissions in accordance with the Global Protocol for Community Scale Greenhouse Gas Emissions reporting by the standard template (AECOM 2016 page 1). As there is no fossil fuel production within the Wellington Region emissions from transmission and distribution of fossil fuels are assumed to be negligible and are not reported in the New Zealand National Inventory. Therefore only combustion of fossil fuels by each mode of transportation is considered in estimating mobility emissions (URS 2014).

Overall the Wellington region emissions profile is quite similar to the New Zealand emissions profile (URS 2014).

4.6 Wellington region VKT and carbon emissions

The following discussion and data show that the per capita travelling trend has declined in New Zealand due to increase in population but overall travel in km has increased and the same trend is observed for the Wellington region. This is the main reason for taking the regional VKT as the base for future estimation and related CO_2e emissions calculations. Possible variation in travel per capita during this period makes for uncertainty with regard to CO_2e emissions.

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Figure 4.7: Wellington region VKT (million km)

New Zealand travel VKT is comprised as follows 76% consists of light passenger, 16% is light commercial, 6% is trucks and 2% is buses and motorcycles (MoT 2015, fig 1.3a page 7). By taking the same modal percentages of travelling for the Wellington region light passenger VKT in 2050 is calculated as 4500 * 0.76 = 3420 million VKT, light commercial 4500 * 0.16 = 720 million VKT, Truck 4500 * 0.06 = 270 million VKT and Buses/Motorcycles 4500 * 0.02 = 90 million VKT. (These figures are shown later in table 4.4)

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Figure 4.8: Wellington region demographic and fleet overview in terms of annual percentage increases since 2001
Sources: Ministry of Transport (2014) "The New Zealand 2013 vehicle Fleet: Data Spreadsheet" New Zealand Govt. Wellington.
AECOM (2016) "Community Greenhouse Gas Inventory for Wellington City and the Greater Wellington Region 2000 -2015" Wellington City Council and Greater Wellington Regional Council, Wellington.
URS (2014) "Greenhouse Gas Inventory for the Wellington Region" URS New Zealand limited, Wellington.
Stats NZ (2016) "Stats NZ (2016) Regional Gross Domestic Product: Year ended March 2016 New Zealand's regional economies 2016, New Zealand Govt., Wellington.

Fig 4.8 shows some demographic and fleet characteristics of the region and the annual percentage increase in all the various factors for each year compared to the figure in 2001. On that basis, by 2015 the population had increased by 12% compared with 2001 and by 2013 the transport generated CO_2 emissions had increased by 10% but for the same duration total regional vehicles had increased by 32% and of course this is all associated with regional economic prosperity growth of 26%.

It is pertinent to note from fig 4.8 that during 2005 to 2007 vehicle ownership increased and during this period bus boarding declined and then resumed its increase. In 2010 and 2011 there was a steady level of increase in private vehicle ownership and a minor increase in bus boarding. Then after 2012 the same increased trend is shown in private car ownership with corresponding but lower increase in bus boarding. Total VKT also shows a direct relation with increased car ownership both are substantially increased after 2014. Regional population growth rate is more or less steady with around 0.9% per annum. This also shows that regional GRP growth also encourages more car ownership.

The Community Energy and Emissions Initiative (CEEI) methodology for GHG emissions calculation as outlined in the report "Assessing Vehicular GHG Emissions: A Comparison of Theoretical Measures and Technical Approaches" used fleet size, average fuel efficiency and VKT as follows.

GHG Emissions = Number of Vehicles X Average Fuel Efficiency X Average VKT X Unit Emissions

(Pacific Analytics 2008)

Unit Emissions is the average CO_2 emissions factor per tonne-km by transport mode (Tonnes CO_2 emissions = litres x kg CO_2 per litre of fuel)

The above equation indicates that to achieve control over GHGs from transportation without changing the vehicle ownership rate, the possibilities are either to either limit VKT or to improve the fuel efficiency.

4.7 Wellington region's transport; the existing situation

4.7.1 Wellington region's light passenger vehicles

Table 4.2 below gives some basic details of the Wellington region's transportation situation showing figures for years 2000/01 and 2014/15 based on three different authoritative data sources - "Ministry of Transport data sheet" Govt. of New Zealand, "Greater Wellington Region 2000 – 2015 report" AECOM Wellington, and "Greenhouse Gas Inventory for the Wellington Region" URS Report prepared for Wellington City Council.

Figures from all these sources show variations in each variable. For the purpose of this research, Ministry of Transport data seem preferable out of the three sources for light passenger vehicles and for public transport as well. For almost every variable the MoT figures are higher than those from the other sources, but the figures are considered to be likely to be the most accurate as they are from a national government ministry and on that basis will be able to be compared with data for other parts of New Zealand. For example land transport emissions from MoT data show a value of 1.23 Mt CO_2e for 2000/01 which with an 80%

reduction will need to decrease to 250,000 tCO_2e by 2050. This initial value is 13% higher than the URS report level of 1.09 Mt CO_2e which gives a reduction target of less than 220,000 tCO_2e by 2050 shown in table 4.2.

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Table 4.2: Wellington region's transport past, present and future.
Sources:
Ministry of Transport (2014) "The New Zealand 2013 vehicle Fleet: Data Spreadsheet" New Zealand Govt. Wellington.
AECOM (2016) "Community Greenhouse Gas Inventory for Wellington City and the Greater Wellington Region 2000 -2015" Wellington City Council and Greater Wellington Regional Council, Wellington.
URS (2014) "Greenhouse Gas Inventory for the Wellington Region" URS New Zealand limited, Wellington.
Stats NZ (2016) "Stats NZ (2016) *Regional Gross Domestic Product: Year ended March 2016* New Zealand's regional economies 2016, New Zealand Govt., Wellington.

Population figures are more or less similar in the three datasets and taking an average of all three sources shows around 0.9% per annum growth in population, a growth of 12% in the period 2000 to 2015. The Wellington region ranks third in size out of the 16 regions in New Zealand (Stats NZ 2013). If it is assumed that the annual growth trend remains the same then the estimated regional population by 2050 will be around 650,000.

With 80% gross regional product growth from $17,447 (million) in 2000/01 to $31,488 (million) in 2014/15 (Stats NZ table 1), the Wellington region's share of national GDP is 13.5%, the second highest after the Auckland region's share of 37.2% (Stats NZ Table 5). Significant variations in GRP figures occur between all three datasets as shown in table 4.2.

A significant difference is shown in the region's per capita transport emissions due to the 15% difference in reported total emissions from transportation in the year 2014/15 (MoT's 1.58 Mt CO_2e level compared to the URS report's 1.38 Mt CO_2e) shown in table 4.2. Significant growth is observed in the region's total vehicle travel in VKT which increased by more than 8% from 3429 million Km in 2000/01 to 3708 million km in 2014/15 as shown in table 4.4 below.

If Ministry of Transport data only is considered, it shows that between 2000 and 2015 there was 12% population growth combined with 8% regional VKT growth which produced 16% emissions growth (from 1.23 Mt CO_2e in 2000/01 to 1.43 Mt CO_2e in 2014/15) in land transportation while comparatively there was less growth in total transport emissions of 12% from 1.41 Mt CO_2e to 1.58 Mt CO_2e during the same period as shown in table 4.2. Comparatively there was more growth between 2001 and 2015 in land transport emissions than in total mobility growth and twice the increase in land transportation emissions than in the VKT growth. This needs immediate attention, particularly in the light of the Paris Climate Agreement and is also another reason to focus in this study only on land transport. For the same period, the other two data sources show a similar trend for land transport emissions and a small increase in total mobility emissions. The 80% growth in gross regional product reflects the Wellington region's economic prosperity with more than 30% growth in vehicle fleet size caused by the entry of 78,900 vehicles including more than 52,000 new or used light vehicles on the road between 2000/01 to 2014/15.

4.7.2 Wellington region's public transport framework

A well-managed public transport network supports economic growth and regional production by providing stress free, easy and safe low cost access between homes to and from work, shopping, study, play other recreational and social services. An efficiently running and properly operated public transport system can increase productivity up to 23% over other modes like private vehicles (NZTA 2013).

Table 4.3 illustrates the Wellington region's past and present public transport situation.

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Table 4.3: Wellington region's public transport past and present
Sources:
Ministry of Transport (2015) "The New Zealand 2015 vehicle Fleet: Data Spreadsheet" New Zealand Govt. Wellington.
AECOM (2016) "Community Greenhouse Gas Inventory for Wellington City and the Greater Wellington Region 2000 -2015" Wellington City Council and Greater Wellington Regional Council, Wellington.
URS (2014) "Greenhouse Gas Inventory for the Wellington Region" URS New Zealand limited, Wellington.
Stats NZ (2016) "Stats NZ (2016) *Regional Gross Domestic Product: Year ended March 2016* New Zealand's regional economies 2016, New Zealand Govt., Wellington.

More than 65% of commuters in the greater Wellington region used public transport (MoT 2015b). The main feature of this trend is with around two thirds of people commuting by public transport and 27% growth in bus boarding and 30% growth in passengers travelling from 2000/01 to 2014/15, there was no increase in emissions during the same period, rather a 5% decrease from 7053 tCO_2e in 2000/01 to 7014 tCO_2e in 2014/15 as shown in table 4.3.

A similar trend is observed in the Wellington region's train transportation which showed growth of 21% in passengers boarding and 24% growth in total passenger-km travelled. Overall there is 25% growth in total public transport passengers travelling during the same period.

From the URS and AECOM datasets it is shown that during 2000/01 to 2014/15 the emissions from buses which were around 7000 tCO_2e are 0.6% and 0.5% of land transport and total transport emissions respectively. By taking the MoT total land transport emissions level and applying the 80% reduction of the year 2000 bus emissions level, means the emissions from buses should be around 3,000 tCO_2e by 2050. To achieve this emissions reduction, a provision is needed to accommodate more buses in the fleet to provide boarding to those passengers who will be willing to shift from private vehicles to public transport, but at the same time if buses in general have more passengers on each trip lower per passenger - km emissions can be achieved.

Freight transport is discussed briefly below and in greater detail in chapter 5 and particularly section 5.11.

4.8 Transport in the Wellington region by 2050

For this study a critical aspect is to estimate the size of the Wellington region vehicle fleet by 2050 keeping the same trend for vehicles entering and leaving the fleet as the existing situation. For the estimation of vehicles by 2050 the Simple Growth Factor Method is used, except for buses which are discussed below. The Growth Factor method is based on economic projections and has been used for urban transportation planning in the United States (Weiner E. 2016).

$$Y = a\,(1 + r)^{X}$$

$$r = \left(\frac{Final\ reading}{Initial\ reading}\right)^{(1/\text{Number of years})} - 1$$

Where

Y is the year

a is the initial reading

r is the annual growth factor

x is the number of years

(TRB 1996)

Using the above equations gives the following results:

Light passenger; light passenger growth rate was 1.8% per year from 2000 to 2015 which means the fleet size may grow to 530,000 private cars by 2050.

Light commercial; during the same period the light commercial growth rate was 1.9% per year which gives 70,000 light trucks and vans by 2050.

Motorcycles; Compared to other modes, the motorcycle fleet increased by a rate of more than 5% per year and is estimated to surpass 75,000 motorcycles by 2050.

Heavy vehicles; with 1.8% growth rate for heavy vehicles from 2000 to 2015, it is estimated that the fleet will grow to around 14,000 trucks.

Buses; with 4% growth rate, the number of buses increased from 456 to 769 from 2000 to 2015. Contrary to other modes, buses will not be assumed to increase at the same pace up to 2050. It is assumed here that the bus fleet will be limited to an electrified network of 1,000 high capacity buses by 2050.

Table 4.4 below shows an overview of the Wellington region transport profile from 2000/01 to 2014/15 and estimated data assuming business as usual by 2050. Table 4.4 shows that the increase in CO_2 emissions from the road fleet overall was 16% during the period 2000/01 to 2014/15, that is instead of a reduction to achieve the 80% targeted level of reduction, there

has been a 1.2% per year increase. The Business As Usual trend rises to 2,000,000 tonnes of CO_2 emissions.

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Table 4.4 Wellington region transport profile (BAU)
Source: MoT (2015)

For the estimation of the 2050 CO_2 emissions level, which is based on the 2000 CO_2 emissions level, two approaches are considered. Average light passenger share in CO_2 emissions is 64% of regional total land transport emissions (MoT 2014). This percentage of contribution when applied to the MoT figure for land transport CO_2 of 1,236,962 tonnes in 2000 gives around 800,000 tonnes CO_2 emissions for light passenger vehicles and applying the 80% required reduction gives a target of 160,000 tonnes CO_2 emissions. On the other hand the figures given in AECOM (AECOM 2016) and URS (URS 2014) reports show that the emissions from land transportation are 1,096,636 tonnes CO_2 emissions and 64% of this figures gives 702,000 tonnes CO_2 emissions level by 2050 and this lower emissions level gives a 2050 target of 140,000 tonnes of CO_2 emissions. Based on these two figures the target level for this study is taken as 160,000 tonnes CO_2 emissions level to be achieved by 2050 from the LPV fleet. Each year population increases and with it the likely size of the LPV fleet, meaning that any target becomes harder to reach each year. In a business-as-usual situation by 2050 an LPV fleet of 440,000 vehicles with the current (year 2015) average emission for light vehicles entering the fleet of 180 gm/km and current annual travel in Wellington of 12,231 km (MoT, 2015b) would emit more than 900,000 tonnes of emissions, compared with the target of 160,000 tonnes

CO_2. The question is how can these emissions be reduced sufficiently to meet the required target and what might this mean for current patterns both of vehicle ownership and of use?

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Table 4.5 Wellington Region's detailed actual and projected emissions profile 2000 – 2050
Sources:
Ministry of Transport (2014) "The New Zealand 2013 vehicle Fleet: Data Spreadsheet" New Zealand Govt. Wellington.
AECOM (2016) "Community Greenhouse Gas Inventory for Wellington City and the Greater Wellington Region 2000 -2015" Wellington City Council and Greater Wellington Regional Council, Wellington.
URS (2014) "Greenhouse Gas Inventory for the Wellington Region" URS New Zealand limited, Wellington.
Stats NZ (2016) "Stats NZ (2016) *Regional Gross Domestic Product: Year ended March 2016* New Zealand's regional economies 2016, New Zealand Govt., Wellington.
*** Difference in range is because if CO_2 emission is calculated in terms of estimated VKT it gives 50 gm CO_2/km while 80% reduction of year 2000 emissions level of 320 gm CO_2/km gives 60 gm CO_2/km.**
Note: Table 4.5 boxes with green colour shows positive/favourable trend towards economy and environment whereas boxes with grey colour are unfavourable.

Carbon emissions produced from vehicles are proportional to the amount and type of fuel consumed by those vehicles. Other harmful emissions can be reduced by redesign and re-engineering of engine

and drivetrain systems but CO_2 emissions are directly produced on the basis of the fuel consumed (MoT 2015 page 11). On average New Zealand fleet CO_2 emissions are comprised of 65% from light passenger, 15% from light commercial, and 20% from the heavy fleet (mainly trucks and buses) (MoT 2015, fig 1.10 page 11). As a part of the strategy for this research, this proportion of carbon emissions will be allocated to the annual travel of each mode of transportation and it is presumed that the estimated VKT (million km) of year 2050 should not emit more than the allocated CO_2 emissions for each mode which together will make up the total permitted emissions. The degree to which this core strategy can be achieved by technical (engine design and vehicle technology, including alternative fuels) changes and non-technical (behavioural changes, shift to public transportation, non-motorised transportation, eco driving and built environment changes) changes is determined in the following chapters of this thesis.

4.9 Wellington transport; a consolidated overview up to 2050

Table 4.6 below gives a consolidated overview of the region's transport from year 2000/01 to 2014/15 and year 2050 estimated figures as the target based on 80% reduction of 2000 emissions level. No detail of regional based fleet transport emissions by mode is available from any dataset so to overcome this issue, MoT national data that is "CO_2e emitted from domestic transport per capita" for each mode of transportation was used by multiplying by the Wellington region's population to calculate land transport and total transport emissions. An average of the last five years of New Zealand land transport fleet share of CO_2 emissions shows light passenger contribution of 64%, light commercial 15%, heavy fleet 20%, buses 0.6% and motorcycles 0.4% (MoT 2016, page 11). This contributing percentage is used to establish the projected possible emissions in 2050. For the calculation of 2050 targeted level, out of the three datasets shown in the table, MoT data (because of source reliability and availability of detailed records of other associated variables) is mostly used. For example as per the MoT record, light passenger vehicles, with an average 82% share in number in the land fleet, contribute 64% of emissions and accordingly the targeted emissions level by 2050 for this mode is 160,000 tCO_2e. Light commercial with 10.5% share of the fleet, is responsible for 15% of total emissions and is required to reduce to 37,000 tCO_2e level whereas the heavy vehicles (heavy goods trucks and buses) with 2.5% share in the fleet for heavy vehicles and 5% motorcycle share are responsible for 19.6% and 0.4% respectively of land transport

emissions (MoT 2015, Vehicle Fleet table 1.10), and need to reduce to a level of 50,000 tCO_2e from heavy vehicles emissions and 3,000 tCO_2e emissions from buses by 2050.

By following these proposed reductions for the year 2050 the current road transport emissions level of 1,236,000 tCO_2e with 80% reduction target will be limited to 250,000 tCO_2e included in the total transport emissions projected reduced level of 285,000 tCO_2e from transportation services to meet mobility demand for an estimated regional population of 650,000. From the URS report and the AECOM report datasets, for a population of 610,000, these levels would be 220,000 tCO_2 to 270,000 tCO_2 that is 30,000 tCO_2e less in land transport emissions and 15,000 tCO_2e in less in total transport emissions level compared with MoT emissions records.

Tables 4.7 and 4.8 are a detailed calculation of carbon emissions contribution percentage by mode of transportation each year, and they show some small deviations between the two datasets. Data from the URS report show a decrease from 82% in 2000 to 78% in 2013, of land transport emissions' contribution to total transportation emissions. Road emissions with 98% share of land emissions have maintained their contribution but a decrease in the road transport share of total emissions from 81% to 76% has occurred over the same period. This decrease is offset by increase over the same time in the emissions related to domestic air travel. The decrease in the road emissions share even with 52,000 new and used light vehicles entering the fleet is due to the fact that the fleet fuel economy for new vehicles entering the fleet had improved from 220 gm CO_2/km in 2005 to 181 gm CO_2/km in 2015 (MoT 2015 page 56). It is also observed that compared to the light vehicles trend, public transportation, that is the buses and trains emissions contribution, has been maintained at the same low level making this option more sustainable to accommodate the load of additional passengers boarding public transport and changing from private vehicles.

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Table: 4.6 Wellington region's consolidated transport review

i Based on MoT (EI004) (tonnes of CO_2 eq emitted from road + rail and multiplied by corresponding year Wellington population i.e. 2.75 + 0.06 = 2.81 x 440200 = 1,236,962)
ii Based on MoT (EI004) (total tonnes of CO_2 eq emitted from transport multiplied by corresponding year Wellington population i.e. 3.22 x 440,200 = 1,417,444)
LP = Light Passengers, LC = Light Commercial, HV = Heavy Vehicles, T = Trucks, B = Buses
*** Note: In column 2 year 2000/01 the two percentage shows that;**
Light passenger fleet share is 82% of total regional fleet contribute 64% CO_2 emissions of total land transport generated CO_2 emissions. Light commercial fleet share is 10.5% in total fleet size gives 15% CO_2 emissions (more than the fleet size). Heavy vehicles fleet (including trucks and buses) size of 7.5% emits share of 21% of CO_2 emissions (20% from trucks and 1% from buses).

URS Report Transport Emissions Data

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Table 4.7: Wellington region's transport generated emissions overview during 2000/01 – 2012/13

AECOM Report Transport Emissions Data

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Table 4.8: Wellington region's transport generated emissions overview during 2000/01 – 2014/15

Chapter 5|Technical aspects of sustainable transport

5.1 Transport emission mitigation measures

From a worldwide perspective, it is evident that decarbonising vehicles and fuels is an essential strategy (AASHTO undated). Transport and infrastructure development of a society should bring economic and social prosperity by providing accessibility to services and facilities but existing transport systems and policies are creating more air pollution, traffic congestion, road fatalities and accidents and transport related social exclusion. Transport pollution is not only a global climate problem. Traffic pollution aggravates asthma, and levels of obesity in children are on the rise because playgrounds, parks and recreational locations are being converted into roads and infrastructure to accommodate increasing demand of traffic volumes and this situation prevents the new generation from having healthy physical activities and social interaction (GLC undated). Black carbon emissions, largely from the use of diesel engines, not only contribute to climate change but these emissions are also a main cause of 3.2 million early deaths annually (Fulton and Replogle 2014). Road safety is another critical challenge. According to WHO records about 1.24 million people die every year on the world's roads plus another 20 to 50 million who sustain nonfatal injuries as a result of road traffic crashes (IBRD 2014). Current car-based transport systems also have a major impact on those who do not own a motor vehicle, whose mobility is walking and or cycling. They directly face air and noise pollution created by the richer car owners.

The vehicle itself has little involvement in creating direct harmful effects apart from road accidents (injuries and fatalities) but burning of derivatives of crude oil i.e., petrol and diesel in conventional vehicle internal combustion engines is causing CO_2 emissions and other air pollution, particularly particulates. A recent study also shows that apparently clean vehicles (Electric Vehicles) which are generally heavier than fossil fuelled vehicles, require harder brake application, resulting in more particulate matter (PM) emissions. The study suggests that an increase in the number of EVs could contribute more to this type of pollution than fumes from diesel exhausts (Loeb 2017). This aspect is further discussed later in this chapter.

The framework for representing existing transport development and its related effects might be as shown in Figure 5.1 below:

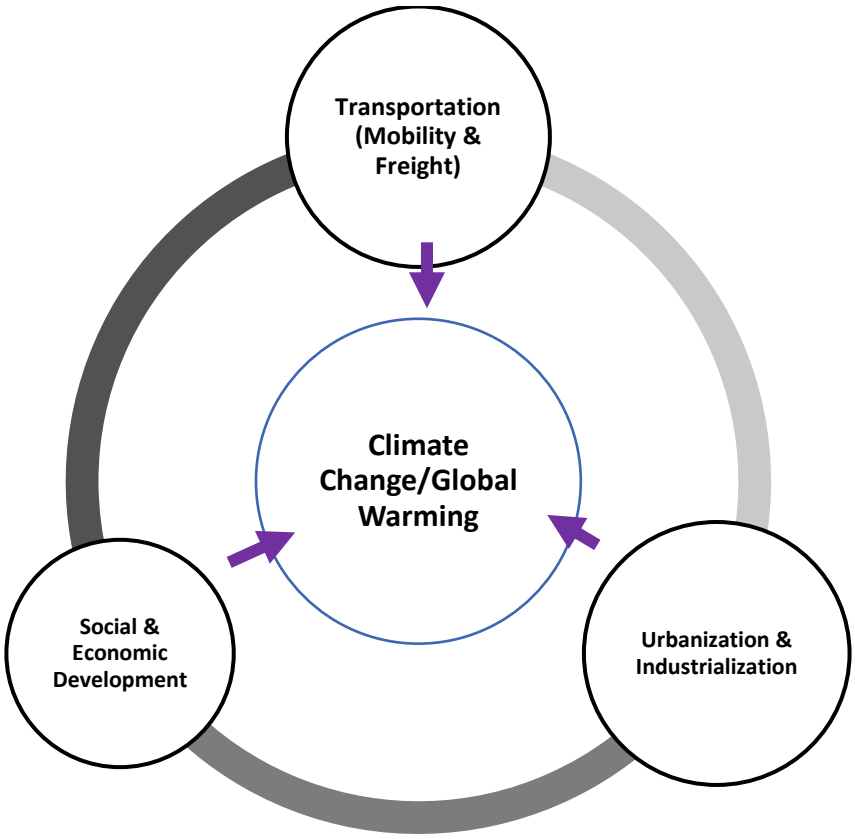

Figure 5.1: The existing urbanisation based transportation cycle.
Source: Author

The emissions from oil-based fuels have driven interest in diverting production to more fuel efficient innovative technologies including electric-petrol/diesel/gas hybrid vehicles (HyV), hydrogen vehicles (HV), battery electric vehicles (BEV), and hydrogen fuel cell vehicles (HFCV) (IPTS 2008). The conventional petrol/diesel/gas vehicles (internal combustion engine vehicles, ICEV) are not only causing environmental pollution by emitting greenhouse gases and particulates but they are also depleting the crude oil reserves which otherwise perhaps should be saved for future generations for optimum utilization for the greater benefit of humanity.

5.2 Technological strategy (technical mitigation measures)

Carbon dioxide emissions are directly proportional to the amount of fuel used by vehicles and the energy used for their production (MoT 2016c). This means that carbon emissions are not only associated with engine fuel combustion technology, car manufacturing and raw materials used in the process are also playing a critical role.

In a recent study a long run bi-directional relationship between energy consumption/CO_2 emissions, and economic growth was found. (Saboori et al., 2014). The authors concluded that policies with a focus on more efficient use of energy combined with moves to use biofuels, renewables, nuclear energy and biofuels could bring considerable benefits in mitigating GHG emissions. Energy consumption is a requisite factor for prosperity in each country and plays a key role in a country's economic growth. Various studies have shown a dynamic relationship between energy consumption, carbon emissions, and economic growth. Ang (2010) found this relationship in the economy of France. Ozturk and Acaravci (2010) examined a similar positive relationship in East European countries and Al-Mulali and Binti Che Sab (2012) found the same relationship in Sub Saharan countries. A very similar significant relationship has been found for Pakistan (Nasir and Rehman, 2011) and for BRIC group countries (Brazil, Russia, India and China) (Pao and Tsai, 2010). Saboori et al., (2014) by taking annual long run time series data for World Development Indicators for OECD 27 member countries and using the Fully Modified Ordinary Least Squares model reveal a highly significant positive long-run relationship between economic growth and CO_2 emissions from the transport sector in all the OECD countries. The results of all 27 member countries show that economic prosperity and rapid growth of a country's transport infrastructure in the form of road expansion and car ownership lead to higher energy consumption, resulting in more carbon emissions from the transport sector as this sector is mainly dependent on fossil fuel consumption.

Carbon emissions from vehicle tailpipes and global climate change from carbon dioxide emissions generated from transportation similarly can be considered a bi-directional challenge which could be tackled with approaches coming both from the direction of technology and also from the direction of behaviour. These approaches could include projected technical developments to conventional vehicles including increased vehicle

internal combustion engine efficiency and reducing weight of vehicles and materials used in vehicle manufacturing, while behaviour might include transport demand management, shifting private vehicle passengers to public transport modes, encouraging cycling and walking, changes in driving behaviour, adoption of a more sustainable built environment and amendments in existing regulations and implementation of new driving rules.

5.3 Car technology

Private vehicles are generally the first targets of measures to reduce emissions from the transportation sector. The most effective way to control carbon emissions from motor vehicles is to improve vehicle fuel economy (Shaheen and Lipman 2007). The conventional ICE car has run on roads for over 100 years and huge amounts of expertise and resources have been utilised in its manufacturing technology but less effort has been made concerning its energy consumption. Fuel economy of passenger cars has stagnated despite constant betterment in technology, as fuel economy seems to have become secondary to other vehicle attributes. This becomes clearer from looking at a publication which provides a comparison of all the cars of the world in 1958, and gives their fuel consumption. At that time there were at least 20 models with fuel consumption of 5 litres per 100km or less, with one as low as 2.9 (international Automobile Parade, 1958). Since 1958 vehicle safety, comfort, and cost of purchase have improved significantly and this can be expected to continue over time, but there has been little improvement in fuel economy. Fuel economy, while very important, is not the whole of the picture, it is estimated from a full life cycle analysis of a car that around 15% of the total CO_2 emissions over its life are generated from manufacturing and disposal (King 2007).

The main efforts towards the development of more efficient conventional automobiles are based on trying to eke out the energy from fuel to the maximum possible extent, because 70% of the fuel's chemical energy is lost due to the thermodynamic, friction, and pumping losses in the internal combustion engine. Around 15% of wastage takes place in auxiliary systems and accessories, transmission and idling when the vehicle is at rest, and only 15% of energy reaches the wheels to accelerate and maintain the desired vehicle speed (Lutsey, 2012).

5.4 Saving fuel in oil powered cars

5.4.1 Saving fuel in oil powered cars – shared mobility

A simple behavioural option for emissions reduction could be through car sharing, meaning here having more passengers in one vehicle. It is listed here under technical strategies as the first way to save fuel in conventional vehicles because it is one of the simplest ways of achieving savings, although it is a matter of behaviour rather than technology. One car with five people in it could travel 50km with the same emissions as five similar cars each with one occupant each travelling 10km. High population density in the city centre makes Wellington well suited for car sharing. Average private vehicle occupancy of Wellington is 1.58 (MoT 2015 Table TV010). From a 2013 survey, around 15 % of Wellington residents do not own a car, while non-ownership increases to 45.6 % amongst residents of the suburb of Te Aro (WCC 2016b). In 2010 a study based on data from 6,000 car sharers found that the average number of vehicles per household dropped from 0.47 to 0.24 and in addition the average fuel economy of car sharing vehicles used by respondents was more efficient by 3.6 km per litre than the average vehicle that respondents had given up when they took up car sharing. This survey also found that car sharers also used more public transport, bicycles and walking (Shaheen S. 2012).

An ITF study (ITF, 2016) shows that using well organised shared mobility could reduce the size of today's fleet by 3% but this would not necessarily reduce VKT so this may not be a useful strategy.

5.4.2 Saving fuel in oil powered cars – weight reduction

It is clear that conventional cars can vary widely in terms of their fuel consumption when tested under standard conditions to remove the effect on fuel consumption of driver behaviour. The United States Department of Energy publishes a list of fuel consumption data for cars available in the United States, including "best" and "worst" figures and using a standard test protocol (US Department of Energy, 2017a). Out of the conventional petrol cars the best in mid - 2017, including models of the Toyota Yaris and Ford Fiesta, have a combined

city/highway fuel consumption of 35mpg (miles per US gallon) or 6.7 litres per 100 km, while the worst use three times more fuel, offering only 12 mpg (19.6 litres per 100 km). This latter category includes models from Ferrari, Aston Martin and Lamborghini.

There are ways that conventional passenger cars' and light vehicles' efficiency can be improved and one option is clear from the US Department of Energy figures above, the Yaris and Fiesta are both relatively small and smaller, lighter cars tend to be more fuel-efficient. A critical aspect of fuel savings in a car is weight reduction as 10 % reduction in vehicle weight can give the possibility of 7 % fuel saving at the same performance level (EEA 2006). In addition reducing aerodynamic drag (reshaping the vehicle's front cross sectional area) by 10 % can save 2 % fuel consumption in each case (EEA 2006).

It has been argued that one of the main reasons for increased CO_2 emissions is increase in the mass of the private vehicle. The average weight of private vehicles has increased by 40 % from 1000 kg in the year 1975 to 1400 kg in 2015 (OECD/ITF 2017). More mass means the vehicle consumes more fuel and results in more CO_2 emissions. Reduction in vehicle mass could be beneficial in fuel savings and make mitigation measures easier to decrease carbon emissions. The increase of the average vehicle weight is recorded in almost all vehicle segments especially the most recent hybrid and electric vehicles are typically heavier than conventional vehicles (Ricardo AEA 2015). The 2018 model of the Nissan Leaf EV weighs between 1,544 and 1,595kg (Nissan UK, 2018) while a similar size petrol Toyota Corolla weighs 1,280 kg (Toyota NZ, 2018).

There are a number of ways to reduce the weight of vehicles without compromising their safety standards. For example, Lotus Engineering has designed a vehicle with 38 % reduction in vehicle weight at a cost of less than $US1,000 through the use of lighter materials and improved design features (Lotus Engineering 2010). The Lotus Company is planning that such vehicles will start being produced by 2020 and these vehicles will be commercially available in the market by 2030. A study by the International Aluminium Institute shows 6%-7% fuel savings if light passenger car mass is reduced by 10% (Ifeu 2016). ICCT 2017 has provided the same values for mass reduction including engine downsizing (ICCT 2017).

It is estimated that in the European Union manufacturing of new lighter private cars with vehicle mass reduced to the earlier level of 1000 kg and new light commercial vehicles with

reduced vehicle mass of 1100 kg could offset a total of 39 % of CO_2 emissions through a combination of reduced mass (18% emissions reduction) and greater fuel efficiency of engine and drivetrain (21% reduction) by 2050 compared to 1990 levels (OECD/ITF 2017). It is argued that the increased cost of purchasing a more fuel efficient lighter weight vehicle is ultimately offset by savings in fuel consumption and emissions. Around 85 % of the weight-related future CO_2 emissions reduction would come from lighter light passenger vehicles (OECD/ITF 2017). The European Union has a 60 % reduction target for transport generated CO_2 emissions by 2050 compared to the 1990 level.

5.4.3 Saving fuel in oil powered cars – hybrid drivetrains

Fuel economy of vehicles that use oil as their fuel can be improved further through the use of hybrid technology in which an electric motor combined with the engine acts as a generator to save energy from braking and store it in a battery for use later. The best known example is probably the Toyota Prius. Toyota have sold ten million hybrids since the introduction of the first version of the Prius in 1997 (Toyota UK, 2017). It was stated in 2007 that the midsize hybrid system vehicles currently running on roads in the USA reduced fuel consumption by 40 to 80 % at an additional retail price of about $2,500 to $5,000 (Keefe et al. 2007). These figures are in comparison with conventional vehicles in the USA. The report assumes a conventional car with fuel economy of 25 USmpg (9.4 l/100km) and 36 USmpg (6.5l/100km) for urban and highway driving respectively, compared with a hybrid at 40mpg (5.9l/100km) and 45mpg (5.2l/100km) (Keefe et al, 2007, Table 6, p10). Under the same system of measurement the 2017 best-performing conventional hybrid car (i.e. not a “plug-in” hybrid with a battery that can be recharged from outside the car) in the United States, the Hyundai Ioniq Blue, achieves 57 mpg urban and 59 highway, which is 4.1 and 4.0 L/100km respectively, a significant improvement over the 2007 figures for hybrid cars (US Department of Energy 2017b). This is roughly 40% better than the current best conventional cars (Yaris and Fiesta, see above) which have a combined city/highway fuel consumption of 35 mpg (miles per US gallon) or 6.7 litres per 100km. It is possible that in future more improvement in the entire system may be able to provide more fuel saving at a reasonable price but it will be a long time before hybrid technology is a significant part of the fleet. Toyota’s figure of ten million hybrids

sold over twenty years sounds impressive but it is very small compared with worldwide annual car sales of over 70 million a year since 2014 and 2017 sales estimated at nearly 80 million (Statista, 2018). This makes clear the failure of the "free market" to deliver solutions to climate change, manufacturers have had the ability to make much more fuel efficient cars for twenty years but there has been little or no incentive for them to make them because governments generally have been unwilling to take action by demanding improved fuel efficiency.

That the combination of lighter weight and hybrid technology can achieve better fuel consumption is demonstrated clearly by the Volkswagen XL1, claimed to be the world's most fuel efficient car. This is a diesel electric hybrid two seater that achieves fuel consumption of 110 km/litre, (0.91L/100km) (VW, 2013) and emits ten times less greenhouse gas than the average U.S car (InsideClimate News 2014). The car is a "high-tech lightweight design" with a carbon fibre reinforced polymer body shell to reduce weight and a diesel-electric plug-in hybrid drive train using an 800cc twin cylinder diesel engine. Volkswagen's achievement may bring competition to impel others to make a vehicle at least equal to it if not better, but such performance will not represent the fleet average by 2050. The XL1 is claimed to emit only 21 grams of CO_2 per km (VW, 2013). The XL1 serves to demonstrate what could be achieved if manufacturers chose to focus on fuel consumption performance but is unlikely to become mainstream. Only 200 were built in total and the car cost £100,000 in the UK but quickly sold out (Auto Express, 2014).

5.5 Transport-as-a-service

The findings of a recently published U.S. report based on detailed evaluation of data from market and economic analysis shows that 95% of passenger miles travelled could be shifted onto a new business model called "Transport-as-a-service" that is on-demand driverless EV fleets (Arbib and Seba 2017). In this way an American will have mobility service at a cost of US$3,400 and would save an average of US$5,600 compared with otherwise normal spending of US$9,000 per year on a privately owned conventional vehicle.

Besides several prospective features that include 30% reduction in oil demand, 50% reduced current oil prices and 70% decrease in car manufacturing, it is claimed that this system after ten years of its regularisation will drastically cut 90% in CO_2 emissions from private passenger vehicles. But on the other side this strategy is silent on some critical aspects of driverless EVs' full life cycle, for example basic infrastructure required for manufacturing and operation of EVs, increased demand of electricity, and EVs' residual sales value. The figure of 90% is not at all likely unless per capita travel decreases, as these vehicles are not technically likely to have lower emissions than conventional electric vehicles and in many places, as shown in section 5.7, EVs have higher emissions than gasoline vehicles due to the fuels used for electricity generation. There is nothing in the technology of driverless vehicles that makes them capable of the emissions reductions that are claimed for them in this report.

5.6 Other possibilities

5.6.1 Other possibilities - road expansion

The ever increasing transport demand in urban areas is causing various problems especially more fuel consumption, traffic congestion, environmental deterioration and accidents. (Sharif et al. 2012).

For the purpose of meeting growing transport demand, the approach of expansion of road infrastructure may appear to reduce traffic congestion and since highway fuel consumption is always lower than urban fuel consumption this might lead to lower overall fuel consumption. A study carried out on this approach by Black (1997) concluded that solutions to transportation problems using this approach may decrease congestion but lead to increased crashes, generate parking problems, and lead to increased fuel consumption hence more pollution. A similar study by Nelson and Editor (2000) concluded about this approach that the more a solution attempts to accomplish several objectives simultaneously the more it may aggravate other problems. Building roads is unlikely to result in reduced CO_2 emissions.

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Table: 5. 1 Average travel speed from to Wellington following construction of new roads/expressways. Source: George (2017)

In addition, large-scale investment either on new road construction or on road widening and then the continuing expenditure on maintenance does not appear to guarantee reduced congestion and increased traffic flow. Measurements made following construction of the new Kapiti Expressway show that along State Highway 1 between Wellington and the Kapiti Coast traffic is moving slower than before the new road was built at a cost of $630 million (George, 2017). Data show that average travel speed from Waikanae to Wellington airport during the morning peak using the new road reduced from 48.8 km/h in 2016 to 44.3 km/h in 2017. This reduction in average speed is not solely a function of the new expressway. Across the Wellington region average travel speed has dropped for example between Petone and Wainuiomata in Lower Hutt, between Paremata and Haywards Road, and between the suburb Karori and Bowen Street near Parliament in the CBD. Wellington City Council's General Manager Strategy accepts that there is wide conjecture as to the reasons for this increased congestion. It might be that more people are driving and people who are driving are doing more trips. The findings are summarized in Table 5.1 above.

5.6.2 Other possibilities – Transport Demand Management

Another approach to transport emissions reduction is known as Transport Demand Management (TDM) which is based on enhancing transportation system diversity and efficiency (Todd, 2006). Transportation Demand Management (TDM) is a technique of strategies which enhance the efficiency of a transportation system overall instead of considering the movement of private motor vehicles alone. It is considered here as a "technical" strategy although it could equally be considered as a behaviour modification technique. In a TDM strategy the priority is given to higher value trips and lower cost modes of travel over lower value trips and higher cost modes of transport (Ferguson, 2001). Examples of high value vehicle trips are freight movement, business travel, emergency and medical services (GWRC, 2005). Cost can be assessed in terms of emissions cost as well as financial cost when assessing which modes of transport to encourage. In TDM some form of road pricing method is generally used to influence peak travel demand and time of travel. After successful implementation of a comprehensive TDM strategy there would be changes in journey time meaning that lower cost/lower emission bus services would become quicker and more reliable with reduced travel time for high value trips and priority users. (GWRC 2005). Modern research is strongly arguing that for the quality enhancement of transportation systems, management strategies such as TDM offer the best approach, (in this case for developing countries) (Sohail et al. 2006). (Rassafi and Vaziri, 2005) Transport Demand Management instead of being based on expansion of roads and transportation infrastructure is a way of shifting travel attitudes, saving resources which otherwise would be used for expanding roads. Hence for developing countries, for obvious reasons, it is better and more cost effective to prevent the problems than to treat them (Qureshi and Huapo, 2007). The same argument could apply to a developed country where TDM could be used instead of more road construction.

TDM policy tools aimed at discouraging private vehicle usage like reduced provision of parking spaces, increased parking fees, cordon tolls etc. and encouraging techniques like improved public transport services, reduced public transport fares and free bus passes have been seen to have potential in affecting people's mode choice (Sullivan & O'Fallon 2003). In their study

Sullivan and O'Fallon found that although only 3% of commuters would choose to change to some form of car sharing, 24% would change to public transport. However two thirds of those surveyed would continue to drive. This indicates that TDM may be feasible for shifting some drivers from private vehicles to public transport but is less able to increase occupancy to make private vehicles more fuel efficient because a vehicle is transporting more people (Sullivan & O'Fallon 2003 page15).

5.6.3 Other possibilities - CO_2 emissions control by traffic signal system

Emissions savings can also be made in the operation of traffic systems. An efficient traffic signal control system is also claimed to be a potentially helpful contributor in CO_2 emissions reductions, for example in a study done in Kawasaki City, Japan found that a well-designed and operated signal system results in 7% CO_2 emissions reduction (Oda et al., (undated). In the USA, a new traffic signal tool "SensMetrics" has been developed which is used to improve traffic flow utilizing real time data and increase safety at intersection. It is claimed by its promoters that it gives 40% reduction in traffic delays and up to 22% reduction in emissions (Sensys Networks 2017).

5.6.4 Alternative fuels for existing vehicles - biofuel potential

One possible answer to the carbon emissions from fossil fuels is to replace them with plant derived (biomass) fuels. The plants will take carbon from the air to grow and when the fuel is burned the carbon will be released back into the air where it can be used by the next crop. This cyclic process differs from the use of fossil fuels where carbon is taken from the earth's crust and released into the atmosphere. Any liquid fuel produced from a biomass is known as biofuel. The most common types of biofuels are corn grain ethanol and biodiesel. Because of their easily synthesized properties these are commercially produced to use as vehicle fuels but neither of them is capable of replacing the existing infrastructure for supplying the fleet of passenger vehicles designed for petroleum based fuels (NRC 2013). Biofuel life cycle assessments show that up to 20 percent reduction in greenhouse gas emissions can possibly

be achieved by biofuel usage (Farrell et al., 2006) (Hill et al., 2006) (Hertel et al., 2010) (Mullins et al., 2010).

Searchinger et al (2008) on the other hand suggest that studies which show that biofuels have a positive effect on reducing carbon emissions have failed to take account of the carbon that is emitted as a result of farmers worldwide responding to the signals they receive from the market. Searchinger et al argue that if more crops are grown for fuel this will cause the price of food to rise, higher prices can be earned for food crops and this encourages farmers to convert land which is currently forest or grassland into new cropland to replace the land whose crops are being converted into biofuels instead of being used for food. Alternatively farmers may bring additional land into cultivation in order to grow fuel crops. Either way, this means that the existing carbon sequestration effect of the land is changed. If land is being cropped the carbon that the plants take out of the air is not stored in the plants but gets back into the air after the crops are eaten. Eventually there may be a carbon benefit as the carbon saving due to using biofuel instead of oil gradually covers the carbon sequestration lost by converting wild land into crop land, but this can take a long time. Producing ethanol from maize in the United States reduces emissions by 20% compared to using oil if the land-use change is not taken into account, but with the land use changes there is an increase of emissions for the next 167 years (Searchinger et al, 2008)

Many car manufacturers produce “flex fuel” vehicles able to run on biofuels or conventional oil but the number of biofuel fuelling stations is limited and up to now the cost has always been higher than petrol of an equal energy content. Ideally a biofuel would need to reduce life cycle greenhouse gas emissions by half compared with petroleum based fuels to take full benefits. For this biofuel would have to be produced from cellulose. The quantity of biofuel needed for smooth supply also depends on huge initial capital to build the biofuel refineries which is further associated with the need for a guaranteed raw biomass supply and a guaranteed number of potential users. Economic analysis shows that the conversion facilities need to be as near as possible to where the crops are grown. The primary barrier to displacing petrol with biofuels is the capital and infrastructure required such as an additional product pipelines network to transport the biofuels from the conversion facilities to the distribution system (NRC 2011). Greenhouse gas emissions from the production of biofuels and the time

profile required for carbon mitigation are also concerns, as discussed by Searchinger et al (2008).

Substituting biofuels for oil in the current fleet may not be straightforward. Most of the car fleet in New Zealand is made up of Japanese manufactured vehicles (TERNZ 2006 page 21) and Japan does not use biofuel to a significant extent, thus compatibility of current vehicles is uncertain (Greater Auckland 2017). Normally two types of biofuel are considered, ethanol blends and biodiesel blends. Usually ethanol blends with petrol are used as a substitute for petrol. These blends are marked with a suffix of E and a number which represents the percentage of ethanol in the blend. Biodiesel biofuels are blended with mineral diesel as a substitute for fully mineral diesel. These blends are similarly marked with a suffix of B where the number represents the percentage of biodiesel in the blend. Up to 10% of carbon emissions could be mitigated by E5 and B5 blends both of which are permitted without labelling. In the New Zealand fleet all petrol powered vehicles are able to accommodate an E3 and E5 blend without causing risk. Biodiesel blends have fewer complaints than ethanol blends and blends of 20% or less do not reveal any problem (TERNZ 2006).

It is observed that a higher ethanol proportion in fuel carries some risks especially for ordinary engine vehicles. The worldwide fuel charter has specified a 10% ethanol limit. This restriction agreed among countries including New Zealand does not allow ethanol blends above 10% to remain in the current mainstream conventional engine market. Blends with ethanol proportion above 10% that is E10 and above, have mostly been used in Brazil and require vehicle modifications whereas in Australia the use of E20 blends in unmodified vehicles has revealed several problems with engine working and material compatibility (TERNZ 2006 page 8). Other problems are associated with the use of ethanol blended and biodiesel blended fuel including fuel system components corrosion and degradation, fuel system blockage, engine operations and fuel usability etc. (Orbital Engine Company 2002) Biodiesel blends higher than B5 are more likely to cause issues for light and heavy vehicles of early nineties models. All latest model vehicles available in New Zealand are E10 compatible and can be used without risk (TERNZ 2006 page 19).

Biodiesel B20 blends have been widely used in the USA and some European countries. The biodiesel proposed in New Zealand is different than that used in USA and Europe. US biodiesel is based on edible soybean, European is based on edible oilseed rape whereas New Zealand

biodiesel is based on waste tallow that has a higher melting point and is more susceptible to cold weather problems (Worley Consultants 1985). New Zealand has also developed a biodiesel standard compatible with other international standards and allows B5 blend which probably will have no operational difficulties. But some evidence has recorded that shelf life of biodiesel is lower and it is more susceptible to microbial growth (Taylor et al. 1997).

5.7 Alternative energy – electric vehicles

The CO_2 emissions from generating electricity from renewable energy resources including wind, solar PV, hydro, biogas and geothermal is very low compared to fossil fuels, only one fifteenth to one hundredth of the amount of CO_2 to generate the same amount of electricity (Karyono 2014). Most renewable energy sources are used to make electricity so for CO_2 control and less dependence on fossil fuel resources, the electrification of land transport is potentially of great importance (Nanaki and Koroneos, 2016). It is generally believed that, in terms of reducing oil demand, emission reduction and environmental protection transport electrification has significant advantages compared to alternatives (Wu and Zhang, 2017).

The barriers for electric vehicle (EV) deployment include initial vehicle cost, range, battery charge time and battery life uncertainty, charging infrastructure, vehicle model choices and understanding of the technology (NRC, 2015). The potential for EVs to achieve significant CO_2 emission reductions is also significantly dependent on the energy sources of electricity production. A moderately efficient EV can achieve emissions of 50 gm of CO_2 per km, around half to one third the emissions of fossil fuelled efficient cars which emit between 100 to 150 gm/km of CO_2 (Nanaki and Koroneos, 2016). These efficient conventional cars are already up to 50% better than average conventional cars, which in the United States are said to emit around 205 gm of CO_2/km (WEF, 2018:13).

Whether or not an EV brings benefits in emissions terms is highly dependent on location. If the batteries of an electric car are charged from solar, wind, hydro or even nuclear electricity its carbon dioxide emissions might be much lower than if it is charged with electricity made by burning coal, but how much of a difference does this make? In the various US states coal provides between 96% of electricity in West Virginia and 0% in Idaho and Rhode Island

(Nunez, 2015). The US Department of Energy (2017c) has a website for comparing vehicle emissions in different states based on the mix of energy sources that each state uses to generate its electricity. In West Virginia, a state with nearly all its electricity coming from coal, the lowest emission option is a hybrid (gasoline-electric) car with annual emissions of 6,258 pounds of CO_2 equivalent compared with 11,435 pounds for a conventional gasoline car, 9,451 pounds for a battery electric car and 9,260 pounds for a plug-in hybrid (a plug-in hybrid is a hybrid car with a larger battery that can be charged from the electricity mains rather than solely from energy recovered from the car's motion). On the other hand in one of the non-coal-using states, Rhode Island, which gets nearly all its electricity from natural gas, the figures are quite different, with the battery electric car having 4,122 pounds of emissions, the plug-in hybrid 5,899, the hybrid 6,258 and the conventional gasoline car 11,435 pounds respectively. In the other non-coal state, Idaho, 59% of electricity comes from hydro and the figures are quite different again, with the battery car at 970 pounds, the plug-in hybrid at 3,911 the hybrid again at 6,258 and the conventional car at 11,435 pounds (all data from US Department of Energy, 2017). These figures are all based on average vehicles of each type and average annual mileage driven so they could vary quite considerably.

A Norwegian study found similar results (Holtsmark and Skonhoft, 2014). The EVs Nissan Leaf and Tesla S (with 60 kWh and 85 kWh battery) and petrol-electric hybrids Toyota Prius and Lexus ES 300h are of similar sizes respectively. The study shows that the Prius consumes 0.047 l/km of fuel, the equivalent of 110 gm CO_2/km (0.44kWh) whereas the Lexus has consumption of 0.059 l/km, equivalent to 137 gm CO_2/km (0.55kWh). The Leaf consumes 0.21 kWh/km with a driving range of about 115 km and the Tesla S consumes 0.38 kWh/km (it consumes more due to its larger size and greater weight of its battery).

Using a global electricity mix balance that is 40% coal, 25% gas, 5% oil and 30% renewables, CO_2 emissions from the Leaf are given in the text of the paper as 113 gm CO_2/km (not as shown in the chart, which is also taken from the same paper), that is more or less equal to emissions from the Prius. In the same mix condition, the CO_2 emissions from the Tesla S are around 120 gm CO_2/km, only slightly lower than the emissions from the petrol driven Lexus ES 300h.

A different source also shows a similar comparison among three EVs, the Tesla S, Nissan Leaf, and Renault Zoë with different power generation sources including fossil fuel generation,

mixed electricity generation (similar to Holtsmark and Skonhoft), solar, wind, and hydro and corresponding carbon emissions from each condition and average fuel consumption. The Nissan Leaf in the mixed energy condition emits 71 gm/km CO_2 (Olivier Willemsen 2016) (A similar comparison is available at http://www.nextgreencar.com/emissions/make-model/nissan/leaf/). These comparisons both make the point that emissions from EVs depend on the energy generation source, or in other words the emissions level from EVs running on fossil fuel generated electricity is very much the same as emissions from conventional vehicles (Ji et al 2012).

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Figure 5.2: A comparison among EVs and hybrid vehicles
Source: (Holtsmark & Skonhoft 2014)

The figures cited above reveal that whether an electric car makes sense in terms of its emissions will depend not only on which car you buy but also where you plug it in. In none of the US states discussed here is an electric car a zero emissions option, although it comes quite close in Idaho because of the high percentage of renewable energy in the electricity grid in this state. This is the key point here, electric cars make sense for emissions reductions

according to the percentage of renewable energy in the electricity grid from which they are charged. However even given this, it has been argued that promoting electric cars may not be of benefit to the environment. In spite of the fact that 98% of Norway's electricity comes from renewable sources, largely hydro (Ministry of Petroleum and Energy, 2016) the study mentioned above based in Norway, where government policy has been to promote electric vehicles very aggressively with a range of subsidies and benefits, such as free charging stations, free parking and the right to use bus lanes, suggested that the only long term solution to reducing transport emissions is to bring in policies that restrict all car use. The promotion of electric cars has resulted in more two car households and more people giving up public transport in favour of driving (Holtsmark and Skonhoft, 2014). This implies that in the long term the technical solution apparently offered by the introduction of EVs may not be able to provide transport emissions reductions on the scale required to meet the Paris agreement.

Uptake of a higher number of EVs also brings new challenges such as the possible need for increased electricity generation and a strengthened distribution grid and the development and building of new infrastructure for charging. The extent of these issues is determined by the timing and pattern of charging EVs (Parks et al. 2007).

Increasing social and political pressure to reduce GHG emissions, limited fossil fuels and on the other side recent development in the capacity and manufacturing of batteries have increased sales of BEVs which had almost doubled in some countries in 2012 but sales overall are still at a very low level compared to conventional vehicles (Jochem et al., 2015). In this same study it is found that, for some countries, as noted above for some states in the USA, the introduction of EVs will not necessarily decrease CO_2 emissions.

It is always desirable to have electricity generation available when electricity is demanded and generation has to be adjusted accordingly. But the increase in renewable electricity generation sources like wind, solar and hydro sources has changed the situation and the supply may need to incorporate storage systems to make the best use of the inputs from renewables. Controlled charging of electric vehicles is a demand measure through which additional electricity demand can be shifted to off peak times or times of high renewable generation. Using controlled charging the emission for an EV (based on one calculation approach) is about 58 gm CO_2/km whereas with an uncontrolled charging strategy (that is

direct charging as and when required) the emissions reach 110 gm CO_2 /km and this level of emission is already achieved by efficient conventional vehicles today (EEA, 2013).

In addition it is over-simplistic to talk of EVs as though all EVs are the same. The comparison from Holtsmark and Skonhoft (2014) starts to make this clear, showing that emissions from the Tesla S are always higher than those from the Nissan Leaf. The United States Department of Energy (2017c) shows that the best petrol cars in mid-2017 have a combined city/highway fuel consumption of 6.7 litres per 100km, while the best hybrid achieves 4.1 litres per 100 km. The US Department of Energy also publishes equivalent figures for battery electric cars, (US Department of Energy, 2017d) which, unlike petrol-electric hybrids or plug-in hybrids, use electricity as their sole fuel source. The published figures give a mpg equivalent, to show how far a car could go on a quantity of fuel with the same energy content as a (US) gallon of gasoline (US Department of Energy, 2017e). On this basis the combined city/highway figure for the best electric car, the Hyundai Ioniq Electric, is 136 mpg (1.7l/100km) and the least good all-electric car is the BYD E6 with a figure of 72 mpg (3.3l/100km). So for the year 2017 the best gasoline (hybrid) car and the best electric car available in the United States were both versions of the Korean Hyundai Ioniq. These figures show that it is simplistic to say “electric cars good, petrol cars bad” because it all depends on a number of factors. What the figures demonstrate is that battery electric cars go further on a given amount of energy than conventional cars burning oil. The worst electric car at 3.3l/100km equivalent is twice as good as the best petrol cars at 6.7l/100km and the best EV is four times as good. The worst electric car uses twice as much energy as the best electric car. As discussed above, a low energy consumption per km for an electric vehicle may not necessarily result in low emissions, the emissions will depend on how the electricity is generated meaning that in many cases an EV may have higher emissions than a car which uses oil.

Even the EVs with lowest emissions achieved through using renewable electricity during their lifecycle are affected by the higher emissions during their production phase. The production of an EV emits about 10 tonnes of CO_2 and the production of conventional vehicles emits 6 tonnes, the overall CO_2 emissions during the whole product lifetime of both technologies amount to about 20 tons of CO_2 (US Department of Energy, 2017e). This applies when the vehicles are manufactured in places where the energy generation mix consists of the average US mix of thermal electricity generating plants and where the charging of the EVs is from

average US electricity. Detailed life cycle analysis shows that during the manufacturing process of EVs more greenhouse gases are created than for ICEVs (internal combustion engine vehicles), with the manufacturing of EVs having emissions in the range of 87 to 95 g CO_2-eq/km compared to 43 g CO_2-eq/km for manufacture of a similar size ICEV (Hawkins et al (2012). Hawkins et al found that an EV charged with EU average electricity would offer life cycle emissions savings of between 10% and 24% compared with diesel and petrol ICEVs, but that "performing the calculation assuming a lifetime of 200,000 km for the ICEV and assuming a battery replacement within the lifetime of the EV would result in lower GWP [global warming potential] impact for the diesel ICEV with respect to the EV charged with European average electricity." In another study Hawkins, Gausen et al (2012) carried out a Life Cycle emissions analysis related to an EV's production, its components and driving over the whole lifetime of the car which shows that its greenhouse gas emissions are only 9 to 29% lower than emissions from conventional fossil fuel engine vehicles (Hawkins et al. 2012). However this will depend crucially on the source of electricity used to charge the EV.

In a study for the USA, even if all small cars including small SUVs and small commercial vehicles, plus half of all mid-size passenger cars were replaced by BEVs this would reduce emissions from light duty vehicles by less than 7.5% compared with the 83% reduction below 2009 levels needed to achieve the overall targeted emissions reduction of 80% below 1990 level. Savings in gasoline would be less than 25%. In addition if all gasoline vehicles were replaced by either BEVs or PHEVs, then there would be a reduction of less than 25% of GHGs with oil savings of less than 67% (Sandy Thomas, 2012). Thomas sees the answer as hydrogen fuel cell vehicles but the paper is published in the *International Journal of Hydrogen Energy* so this may not be entirely coincidental. The relative effectiveness of using fuel cells would depend, as for the BEVs, on the mix of electricity used to create the hydrogen.

5.7.1 Particulates from EVs

In accordance with World Health Organisation guidelines on air quality, a UK study has argued that pollution from traffic particles will be about 90% from non-exhaust sources, that is from braking in particular, by the end of 2020. This source is probably growing in absolute magnitude as traffic increases. These emitted particulates are of varying sizes that can

penetrate the human body and enter the bloodstream when inhaled. It is common understanding that EVs are clean vehicles and environmentally friendly but manufacturing aspects of EVs mean they tend to be heavier (14.6% to 28.7%) than comparable fossil fuelled vehicles and they consequently need harder braking causing more brake wear, tyre and road surface wear etc. resulting in greater particulate matter emissions than conventional vehicles as wear takes place to brake pads, tyres and road surfaces. It is claimed the next generation of diesel vehicles will have few or no particulate emissions because of particle filters on the exhaust making them more environmentally friendly (also per km carbon emissions from diesel engines are less than for petrol engines) so switching to electrification will no longer be such a good option. A PhD student at Imperial College London has researched that even if EVs come with lighter weight they still need to have tyres and brakes so switching to EVs is no more than change of fuel type. Hence either petrol, diesel or electric regardless of whether they are private or public transport the particulate problem exists and to address it using public transport is a part of the solution (Loeb 2017). This is one of the reasons why in this study more emphasis is given to reducing the distance travelled and changing to other modes rather than depending entirely on vehicle electrification. This is similar to the argument of the Norwegian study cited earlier (Holtsmark and Skonhoft, 2014) that found that overall private car use needs to decrease. This is particularly of interest because the recommendation is made despite the Norwegian government's strong commitment to EVs and the country's very high percentage of renewable electricity production.

5.7.2 EVs in Norway

Norway as the "EV capital" has the largest number of EVs per capita in the world. Since 2012, the purchase of EVs has almost doubled every year from 10,000 EVs in 2012 to around 80,000 EVs in 2015 (Aasness A. Marie & James Odeck 2015). The reason behind this abrupt growth in EVs is a number of EV incentives that Norwegians receive from their government like exemptions from taxes, toll charges and parking fees, and free access to transit lanes. These are obvious savings that ultimately make EVs much more economical to purchase and use. Norway is one of those countries where electricity is generated almost entirely by renewables and for only 5 million inhabitants EVs seem to offer a positive option for greenhouse gas

mitigation. Nissan Leaf and Tesla S are the dominant EVs on Norwegian roads with almost zero CO_2 gm/km and no marginal external cost per km. The detailed five years period analysis of operational cost of EVs and conventional vehicles including depreciation, maintenance and energy etc. is €343.00 and €615.00 per month respectively which attracts an individual to the increased purchase and use of EVs in Norway (Aasness A. Marie & James Odeck 2015).

5.8 EVs in New Zealand

Transport generates twice as much greenhouse gases as stationary energy and is one of the fastest growing components of New Zealand's emissions profile (MfE 2014). The Dominion Post newspaper in an article titled "Just how green are EV machines" dated September 23, 2017 reported EV registrations in New Zealand had reached more than 4500 and it is expected EV registrations will reach 5000 before the end of the year. The scale of this can be seen if it is compared with the figure of 3.3 million passenger cars/vans on 30 November, 2017 (NZTA, 2018). In this article, it is stated that the Hyundai Ioniq (the least expensive EV currently on sale new in New Zealand) does not consume any of the "dreaded fossil fuels" and does not emit any exhaust fumes meaning tailpipe CO_2 emissions are nil. Later this article states that by 2018 New Zealand electricity generation will move from 85% to 90% renewable which is already high by world standards. The entry model Ioniq EV retails for around $60,000 with the Elite version at $66,000 in comparison with a conventional petrol engine vehicle from the same manufacturer, which costs $35,000 for an entry model to $40,000 for an Elite model. One of the barriers to EVs, that is limited range, will no more exist when a new model of Hyundai with range of 450 km and at more reasonable prices will be launched by next year (2018) and with an increased number of fast charging stations being installed throughout New Zealand. Cost of batteries is falling so quickly that it is presumed that within 15 years EVs might be less expensive than conventional fossil fuel engine vehicles (The Dominion Post 2017).

Most of the developed and developing member cities of "Rockefeller Foundation's 100 Resilient Cities Network" (Wellington is also a member of this network and has recently joined the global Compact of Mayors) have identified electrification of the vehicle fleet as one of the most impactful potential areas for carbon mitigation from transportation.

"Electric vehicles can drive us into a cleaner, more sustainable energy future. The IEA has shown that if global warming is to be limited to 2 degrees, at least a fifth of all vehicles on roads by 2030 should be electric."

Fatih Birol, Executive Director of the International Energy Agency
(WCC 2015)

The BEVs that came onto the market during 2011-16 are limited to 100 – 200 km mileage range but since 2014 driving range has increased to over 450 km for some vehicles which is near to the driving distance for conventional fuel vehicles. Possibly due to increasing battery capacity and scale, this mileage will be increased in the future (Sigurd Magnusson 2016, page 8).

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Figure 5.3: Comparison of EVs and different vehicles driving range before recharging or refuelling.
Source: Sigurd Magnusson 2016, page 8

Fig 5.4 compares the emissions from a range of vehicles, a BEV, a PHEV, a hybrid and some petrol and diesel cars. The lowest emitter is the Nissan Leaf BEV with 28 CO_2e gm/km. This is

due to low greenhouse gas emissions from New Zealand's electricity generation which has a high percentage of renewable energy.

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Figure 5.4: Comparison of carbon emissions from different vehicles (Kg CO_2e per km)
Source: Sigurd Magnusson 2016, page 12

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Figure 5.5: Total cost of vehicle at 120,000 km total travel.
Source: Sigurd Magnusson 2016, page 13.

On average New Zealanders' daily travel is less than 40 km with working day travel 28 km, so presumably a battery electric vehicle can cover average daily travel demand (EECA 2012). EVs are incentivised by exemption from road users' charges until June 2020 by the New Zealand Government (RUC 2012).

Charging an EV for 160 km of travel takes 12 to 6 hours from a regular plug point or a charger connected to the main switchboard respectively (Kieran Devine 2014). 85% of house garages have a power outlet where EVs can be charged and most power retailers offer lower cost packages during off peak times, which will reduce the running costs (EECA 2012). The main electricity transmission system authority Transpower has confirmed that the national electricity grid is substantially capable to meet the increased demand of EV charging (Hawkins et al 2012).

Around half of cars are second hand imported to New Zealand (Mark Gilbert 2014) EVs could be promoted financially if government were to introduce regulations and provide incentives. For example, carbon tax levies could be increased on conventional vehicles including second hand imports, depending upon engine size and fuel efficiency. Taxes on petrol could also be used and the revenue generated by these taxes could be recycled to subsidise EVs. Exemption from import duties, discounted CBD parking fees and extension in RUC grace period are some of the examples that could be applied to encourage the uptake of EVs (NZ Customs Service 2016).

One critical aspect that must be considered in the formation of any vehicle policy is that the process of design, building, testing before launching a new model, government certification and creating complex production tools especially with new power train, needs 5 to 7 years. Again to record the carbon emissions effects, once the new automobile comes into the market, needs sufficient time (OICA 2007). The carbon emissions related to the manufacture of electric vehicles will not occur in New Zealand since it has no vehicle manufacturing, but they will have an effect globally and need to be taken into account.

5.9 Freight transportation

For the Wellington region transportation is not only about moving people. As Wellington is a relatively large city situated in the lower North Island of New Zealand it forms a hub and this geographical location not only makes it the bridge between the North and South islands but also greatly contributes to the local and regional movement of goods and services, requiring an interconnected efficient freight transportation system and connections to road, rail, ship and air infrastructure.

5.9.1 Fuel efficiency standards for heavy vehicles

In many countries heavy freight trucks play a vital role in the economy by transporting goods from one city to another city/cities to feed the markets. Intercity buses provide services of mass transportation via highways within shortest possible time. In the United States the CO_2 emissions of heavy trucks and buses combined make up 46.5% of road transportation emissions, with the other 53.5% coming from light vehicles and motorcycles (Miller and Facanha 2014). At the global scale the combined share of buses, 2 and 3 wheel vehicles and rail is 6% and freight trucks' share is 23% of total world transportation energy (IEO 2016).

For the reduction of fuel consumption in heavy trucks, re-engineering of design and mechanical changes are needed. For example drag coefficient can be reduced by cab reshaping, closing the cab and trailer gap etc. and such types of changes can reduce fuel consumption by 12 % (Cooper 2000). It is expected that by 2020, new heavy goods vehicles (HGVs) are to be 15-17% more fuel efficient than they were in 2014 (Tim Breemersch & Lars Akkermans 2014). Improvement in HGV transmissions system in mechanical automation and gear shifting has a potential of 5-7%. HGV auxiliaries system can also be improved with a tentative potential of 1.5-1.7% reduction, low rolling resistance tyres and regular tyre pressure balancing can give benefit of 3-4% fuel efficiency. Aerodynamic improvement involves HGV body modifications that is cab's nose, chassis panels and trailer front fairing changes can improve up to 3-4%. Reducing axle friction 0.5% can save fuel consumption and weight reduction can reduce consumption by 0.5-0.9%. Increase of heavy duty vehicle allowed weight for freight loading can also be an added advantage for fuel saving. New HGVs

featured with all these changes and improvements are expected to run over highways by 2020.

So far Japan is the only country which has introduced fuel efficiency standards for heavy vehicles, from 2006. Other developed countries like the United States and the European Union also started the work from 2009 but their efforts are at an initial level whereas Japan has successfully implemented fuel economy standards in heavy duty vehicles (Kojima and Ryan 2010). The reason behind this lack of adaptation of standards to heavy duty vehicles is that most policy makers are of the opinion that as heavy duty vehicles are commercially operated, they are already guided by costs and probably efficiency measures would have been made.

In an Auckland based study it is shown that CO_2 emissions per VKT by heavy goods vehicles is around 630 gm/km of (Denne & Atkins 2016). Keeping in view the continued manufacturing development in truck technology it is claimed that in the near future conventional heavy vehicles with carbon emissions around 300 gm/km will easily be available for freight movement (21st Century Truck 2013). Although Wellington Regional Council has no direct regulatory control over HGVs and freight movements they could propose to the national government for the formation of such policy to make it mandatory for transporters either to go for long haul shipment by rail or using coastal shipping.

5.9.2 Fuel efficiency standards for light commercial vehicles

The European Union had set out a target for light commercial vehicles that new vans would not emit more than 175 gm of CO_2/km by 2017 but in 2016, the light commercial vehicles sold in the EU emitted 163 gm of CO_2/km, below the 2017 target which was already reached. The EU has decided the emissions limits target for 2020 which is 147 gm CO_2/km. The EU strictly follows its legislation and penalties are imposed, with an excess emissions premium for each LCV, if a manufacturer's fleet exceeds its limit value (Climate Action 2017). A recent study found that CO_2 emissions from the LCV fleet in the EU would decrease towards the level of 140 gm CO_2/km by 2025 and 135 gm CO_2/km by 2030 under the prevailing conditions. This reduction of the CO_2 emissions from LCVs would be achieved by the use of conventional

powertrain technology. With hybrid technologies the CO_2 emissions level of 78 – 97 gm CO_2/km for LCVs will possibly be achieved (Ernst et al 2015).

If central government in New Zealand follows policies similar to those of the EU for strict import control of those LCVs manufactured under this restricted CO_2 emissions level it could be possible to maintain the targeted regional emissions level from the LCV fleet in the future.

The effect of possible technical changes in public transport will be considered in chapter 6 which looks at the effect of transport behaviour, as deciding to use public transport rather than the private car is considered here as a change in behaviour.

5.10 Effect of technology

Three proposed scenarios will be used to ascertain the degree to which changes in the technology of private vehicles might be able to meet the emission reductions required by the Paris agreement while maintaining the expected future transport requirements of people in Wellington. The First Scenario (No powertrain changes, improved fuel efficiency) means Business-As-Usual, continued existence of the current fossil fuel dependent system with no major changes in vehicle technology, no broad shifting in transport modes and also no notable changes in land use. This will be used to set the benchmark for what the situation would be if current trends were continued.

The Second Scenario (Improved fuel efficiency with certain percentage of EV introduction) is to some extent based on the introduction and promotion of innovation and advanced car technologies based on continued, but more efficient, use of conventional fuels leading to minimum usage of fossil fuels in more efficient engines combined with increased penetration of full battery electric vehicles (BEVs).

The Third Scenario (Greater fuel efficiency and far more dependence on EVs) assumes widespread penetration of BEVs and light weight fuel efficient vehicles available by 2050 with substantial dependence on renewable primary energy sources for new cars as the primary option.

5.11 Technical scenarios

In the first instance under the technical strategy category of this research the methodology considers whether the targeted level of 250,000 tonnes of CO_2 emissions could be achieved by jointly controlling VKT and introducing fuel efficient technologies.

5.11.1 First technical scenario

The First Technical Scenario is intended to determine if a continuation of current trends will be able to meet the reduced emissions target. It is based on a combination of the trend shown by existing developments in fuel efficiency of internal combustion engines combined with some restriction on vehicle kilometres travelled (VKT) if fuel efficiency alone is not able to achieve the targeted emission level. The following table 5.2 gives an overview of this scenario based on the figures from table 4.2 which is estimated for year 2050 keeping the same trend from 2000 to 2015 calculated from the data given in the Ministry of Transport website (MoT 2015) and now used below for all the three scenarios of each mode of Wellington region transportation.

The scenario under this strategy is that by 2050 light passenger vehicles with CO_2 emissions of 75gm/km will have formed the average for vehicles in the fleet under the "controlled carbon emissions" heading.

The proposed fleet average target of 75 g/km is chosen here as one that is probably achievable. The past record of average CO_2 emissions of light vehicles entering the fleet in New Zealand (MoT, 2016: p55) shows gradual improvement over a period of ten years in vehicle technology in terms of reduction in CO_2 emissions from 225 gm/km in 2005 to less than 170 gm/km in 2015.

If this trend continues at the same rate, conventional vehicle technology could be expected to improve with average fleet emissions of less than 100 gm/km by 2050. So this further technological development to 75 g/km is likely to be achieved although it less clear whether such vehicles will come to form the fleet average by 2050. The figure of 75 gm/km is assumed here to see the effect here of a reasonably ambitious target for the improvement of conventional vehicle technology and to be able to determine whether this technical advance

on its own is likely to be able to offer a way to meet the emissions level required by the Paris Agreement.

Wellington Region	2050								
	Fleet	VKT million (Estimated)	Ideal limit CO_2 tonnes (1000)	VKT million (Projected)	Per year per veh travel (km)	CO_2 emissions (gm/km)	VKT million (Projected)	Per year per veh travel (km)	CO_2 emissions (gm/km)
Road Fleet	690,000	4500	250	***Controlled Carbon Emissions***			***Controlled Vehicle Travelling***		
Light passenger	530,000		160	2100	4000	75	1590	3000	105
Light commercial	70,000		38	275	4000	140	210	3000	200
Truck	14,000		50	250	18000	200	110	8000	450
Buses	1,000		0.3 - 8	42 mil passenger boardings		N/A	42 mil passenger boardings		N/A

Table 5.2 First Scenario for Wellington 2050 – no power train changes

This very high level of technical performance in terms of emissions (75 g/km) would allow a per year per vehicle travel limit of only 4000 km in order to stay within the emissions limit. The current distance travelled per light vehicle per year (not available broken down into passenger and commercial) is 11,251 km in 2014/15 (MOT, 2015). This means that even with the widespread deployment of very much more efficient internal combustion engines, travel will have to be reduced by over 60%. A private vehicle with 75 gm/km CO_2 emissions and each vehicle per year travelling 4000 km gives a total of 2100 million VKT to limit light passenger emissions to 160,000 tonnes CO_2. Even with the entire LPV fleet made up of vehicles that are in emissions terms 25% better than the best available, not the average, in 2017, the first scenario makes clear that oil powered driving would need to be severely restricted if Wellington is to meet the emissions reductions required by New Zealand's signing of the Paris Climate Agreement.

Under the “controlled vehicle travelling” heading the fleet average emission for LPVs is taken to be the best of current (2017) practice at 105 gm/km. With this assumption annual travel per vehicle would have to be no more than 3000 km.

Similar to LPVs, in the first scenario, to keep to the limit of 38,000 tonnes CO_2 emissions, it is assumed that the estimated fleet of 70,000 LCVs will need to be limited to 4000 km per year per vehicle travel to give a total of 275 million VKT assuming 140 gm/km CO_2 emissions from fuel efficient LCVs or to 3000 km per year per vehicle travel to a total of 210 million VKT with 200 gm/km CO_2 emissions. That is assuming no power train changes (continuing the use of oil for fuel) and keeping the same past fleet entering trend. Heavy vehicles, in the first scenario, for a 14,000 truck fleet size and projected emissions limit of 50,000 tonnes CO_2 could be allowed either 18,000 km per year per vehicle travel with fuel efficient trucks that emit 200 gm/km CO_2 or 8,000 km per year per vehicle travel with 450 gm/km CO_2 emissions for a total of 110 million VKT, again without power train changes.

The situation of buses is different from the other modes as it is assumed that the bus fleet will provide transport services to a greater number of passengers meaning that CO_2 emissions per passenger-km are reduced to a great extent. It is projected that a fleet of 1000 buses will provide boarding to around 42 million passengers for 288 million passenger-km travelling and depending upon the energy supply sources and power train types, by 2050, it is estimated that 300 to 8,000 tonnes of CO_2 emissions share will be contributed by the bus mode of public transportation.

5.11.2 Second technical scenario

The second scenario assumes that electric vehicles (EVs) will form a percentage of the light vehicle fleet by 2050, following the Cabinet Economic Growth and Infrastructure Committee proposal, New Zealand Government (CEGIC (undated)).

The Second Scenario is based on moderate policies for changing car ownership by assuming 30 % of vehicles on the road by 2050 are EVs. The current vehicular growth is 1.8% per year, calculated as follows.

$R = (286{,}263/217{,}143)^{1/15} - 1 = 1.8\%$

Wellington Region *Second Scenario*		2020 Fleet	2030 Fleet	2040 Fleet	2050 Fleet	2050 per year per veh trav	2050 VKT million	2050 CO_2 ton	CO_2 gm/km
Light Private Vehicle LPV		310,000	370,000	440,000	530,000				
2 %	E V	6,200							
98 %	Conventional Vehicles	303,800							
10 %	E V		37000						
90 %	Conventional Vehicles		333,000						
20 %	E V			88,000					
80 %	Conventional Vehicles			352,000					
30 %	E V				159,000	7000 km	1111 vkt	27,000	25 gm/km
70 %	Conventional Vehicles				371,000	4000 km	1484 vkt	133,000	90 gm/km

Table 5.3 Second scenario – LPVs - Improved fuel efficiency with certain percentage of EV introduction

By assuming the same ownership growth of 1.8% per year the projected total passenger vehicles fleet by 2050 will be 530,000. This scenario assumes that 30% of the fleet by 2050 is comprised of EVs. It also assumes that each of the remaining conventional vehicles has an average emission of 90 gm/km, not as low as for the first scenario, but more in line with the trend of reduction over time that has been achieved in the fleet to date. This conventional fleet's projected emission is 133,000 tonnes of CO_2 provided that each conventional vehicle travels only 4,000 km per year, less than half of the current distance. The remaining fleet will be made up of 30% of EVs that is 159,000 with 7,000 km for each EV's travel per year which gives 1111 million VKT assuming average emissions of 25 gm/km for each EV. The total number of EVs will emit 27,000 tonnes of CO_2. The results of this scenario as applied to light private passenger vehicles are shown in Table 5.3.

Wellington Region *Second Scenario*		2020 Fleet	2030 Fleet	2040 Fleet	2050 Fleet	2050 per year per veh trav	2050 VKT million	2050 CO_2 ton	CO_2 gm/km
Light Commercial Vehicle		40,000	47,000	57,000	70,000				
1 %	E V	400							
99 %	Conventional Vehicles	39,600							
05 %	E V		2,350						
95 %	Conventional Vehicles		44,650						
15 %	E V			8,550					
85 %	Conventional Vehicles			48,450					
25 %	E V				17,500	8000 km	140 vkt	8,000	60 gm/km
75 %	Conventional Vehicles				52,500	4500 km	234 vkt	30,000	130 gm/km

Table 5.4: Second scenario – LCVs - Improved fuel efficiency with certain percentage of EV introduction

The same strategy is adopted for commercial vehicles with less share of EVs than assumed for the passenger vehicles. The current growth rate of light commercial vehicles is 1.9% per year and by 2050 the estimated fleet increases to 70,000. The introduction of electrified light commercial vehicles is slower than private vehicles and 75% of the fleet will be conventional light commercial vehicles. With restricted annual travelling of 4500 km and 130 gm/km CO_2 average emissions its share will be around 30,000 tonnes of CO_2. The electrified light commercial fleet of 17,500 will have 8000 km per year travel and 60 gm/km carbon emissions, its share of emissions will be 8,000 tonnes of CO_2. The results for light commercial vehicles are shown in Table 5.4.

Contrary to the assumptions made for light passenger and light commercial vehicles, instead of the introduction of EVs for heavy transport, in the second scenario for heavy vehicles the fleet growth rate will be kept to 75% of the current trend that is 1.3% per year. For this growth rate the projected fleet by 2050 will consist of 10,000 heavy vehicles. Vehicular movement will be 17,000 km per year which gives 170 million vkt and total emissions of 50,400 tonnes of CO_2.

Wellington Region *Second Scenario*	2020 Fleet	2030 Fleet	2040 Fleet	2050 Fleet	2050 per year per veh trav	2050 VKT million	2050 CO_2 ton	CO_2 gm/km
Heavy Vehicles	8,200 *(8,400)*	8,500 *(10,000)*	9,000 *(12,000)*	10,000 *(14,000)*	17,000	170 vkt	50,000	300 gm/km

Table 5.5: Second scenario – HVs with limited entering compared with past trend.

Note: The italic figures in table 5.5 show estimated HV fleet size keeping the past entering trend.

The past ten years' travel per vehicle record of New Zealand shows that heavy vehicles travel decreased from 24,253 km per year in 2001 to 22,335 km per year in 2010. The average heavy vehicle travel during this period gives 23,000 km per year travel but using the same technique of future travel estimate gives heavy vehicles travel of around 17,000 km per year subject to this trend of decline continuing (MoT 2013b). The reason behind taking a growth rate at 75% of normal rate is to assume a future policy framework of gradual shifting of freight cargo load from road traffic to the railway network under mandatory obligations. The details of this policy measure are discussed in chapter 8.

5.11.3 Third technical scenario

According to the Electric Vehicles in New Zealand Fact Sheet from the Ministry of Transport (New Zealand Government 2016b) EVs accounted for 1,015 vehicles at the end of January 2016 in a fleet of 3.1 million. The Ministry has set a target of doubling the number of electric vehicles in New Zealand every year, to reach approximately 64,000 by 2021. This is claimed to be about two percent of New Zealand's current light vehicles fleet *Electric Vehicles Programme Overview Ministry of Transport* (New Zealand Government 2016b). In 2001 the total light vehicle fleet was 2,562,480 and by 2015 total light vehicle fleet was 3,524,672 giving a per year increase of 2.2% for New Zealand as a whole.

By following the same strategy the Wellington region's future conventional vehicles fleet size and share of EVs, annual travel per vehicle, VKT and emissions from each mode are estimated. The increment for New Zealand is 2.2% whereas for Wellington it is taken as 1.8% as Wellington region's growth is lower than New Zealand (MoT 2015). The table assumes that 60 % of the 530,000 fleet will have shifted to EVs by year 2050 that is about 318,000 vehicles with the remaining 212,000 vehicles likely to be conventional vehicles. The assumed growth, in EVs by 2050 is well below the Ministry of Transport's proposed doubling rate, which if continued after 2021 would see the entire fleet comprised of EVs before 2030. The point is that the total fleet of 530,000 vehicles in 2050 needs to emit no more than 160,000 tonnes of carbon emissions. It is presumed that emissions from EVs will not be more than 25 gm/km and from conventional vehicles emissions may be up to 90 gm/km as assumed for the second scenario.

Wellington Region *Third Scenario*		**2020 Fleet**	**2030 Fleet**	**2040 Fleet**	**2050 Fleet**	**2050 per year per veh trav**	**2050 VKT million**	**2050 CO_2 ton**	**CO_2 gm/km**
Light Private Vehicle		310,000	370,000	440,000	530,000				
2 %	E V	6,200							
98 %	Conventional Vehicles	303,800							
10 %	E V		37,000						
90 %	Conventional Vehicles		333,000						
30 %	E V			132,000					
70 %	Conventional Vehicles			308,000					
60 %	E V				318,000	9000 km	2800 vkt	71,000	25 gm/km
40 %	Conventional Vehicles				212,000	5000 km	1000 vkt	90,000	90 gm/km

Table 5.6: Third scenario – LPVs Improved fuel efficiency with increased percentage of EV introduction

New Zealand motorists currently drive on average 29 km per day and average commutes in urban centres are about 22 km per day. (New Zealand Government 2016c). Average per year vehicle travel in year 2050 is calculated to be 14km per day driving for conventional vehicles and 26 km for EVs. This means that even in this scenario the distance travelled by internal combustion cars that are twice as efficient as the current average will have to be half the present figure, while EVs could allow travel close to the current figure. The total per year conventional vehicles travel will be 1000 million VKT if they drive 14 km per day and if the emissions limit is 90 gm/km they will produce 90,000 tonnes of CO_2 while EVs with 26 km per day driving gives 2800 million VKT and estimated emissions will be 71,000 tonnes of CO_2 provided that each car's emissions provision is 25 gm/km.

Wellington Region *Third Scenario*		**2020 Fleet**	**2030 Fleet**	**2040 Fleet**	**2050 Fleet**	**2050 per year per veh trav**	**2050 VKT million**	**2050 CO_2 ton**	**CO_2 gm/km**
Light Commercial Vehicle		40,000	47,000	57,000	70,000				
2 %	E V	800							
98 %	Conventional Vehicles	39,200							
10 %	E V		4,700						
90 %	Conventional Vehicles		42,300						
30 %	E V			17,100					
70 %	Conventional Vehicles			39,900					
50 %	E V				35,000	14000 km	490 vkt	29,000	60 gm/km
50 %	Conventional Vehicles				35,000	7,000 km	245 vkt	31,000	130 gm/km

Table 5.7: Third scenario – LCVs Improved fuel efficiency with increased percentage of EV introduction

In the third scenario 50% of the LCV fleet will consist of electrified light commercial vehicles and the rest of the fleet will be conventional commercial vehicles with improved fuel efficient technology. The electrified commercial vehicles fleet of 35,000 will be allowed a VKT of 490 million with each LCV's per year travel being 14,000 km and assumed LCVs CO_2 emissions limit is 60 gm/km while the remaining 35,000 conventional LCVs with 7,000 km per year per vehicle travel will make 245 million VKT with 130 gm/km CO_2 emissions and share of 31,000 tonnes CO_2 emission by 2050.

Wellington Region *Third Scenario*	**2020 Fleet**	**2030 Fleet**	**2040 Fleet**	**2050 Fleet**	**2050 per year per veh trav**	**2050 VKT million**	**2050 CO_2 ton**	**CO_2 gm/km**
Heavy Vehicles	8,000 *(8,400)*	8,300 *(10,000)*	8,800 *(12,000)*	9,500 *(14,000)*	20,000	190	52,000	280 gm/km

Table 5.8: Third scenario – HVs with limited entering compared with past trend.

Note: The italic figures in table 5.8 show estimated HV fleet size keeping the past entering trend.

In the third Scenario the heavy vehicles growth rate is restrained at 50% of the current growth rate which gives a projected fleet of 9,500 vehicles with vehicular movement of 20,000 km per heavy vehicle per year at an emissions level of 280 gm/km for a limit of 52,000 tonnes of CO_2. This limited vehicle growth is possible with restricted conditions like mandatory transportation of freight by rail and imposition of levies of carbon charges by road transportation.

5.12 Conclusions

One of the significant findings of these three scenarios is that they make very clear that the current push to introduce autonomous or self-driving vehicles (see, for example, PWC, 2016) will not make any difference to emissions. The emissions from transport are a product of the individual vehicle performance in terms of fuel economy and the VKT. There is nothing inherent in the concept of an autonomous vehicle that makes it more fuel efficient than a non-autonomous one and it seems likely that the introduction of such vehicles would tend to increase, rather than decrease, people's desire to travel. Where a saving could be made is if the introduction of such vehicles reduced the total fleet size, in which case the embodied energy and emissions of manufacturing the vehicles would be taken out of the equation. However, these emissions are not considered in this thesis, only the operating emissions, as the manufacturing emissions do not take place in New Zealand. A recent report comes to the same conclusion in respect of the autonomous vehicle

> *"…it does not fundamentally change how we define transport problems; rather, it reinforces existing automobile-oriented transport planning."*
>
> (Litman, 2017: 19)

A similar conclusion was reached in a recent report from the United States, showing that autonomous vehicles could offer a range in energy demand compared to the current situation from a 60% reduction to a 200% increase (Stephens et al, 2016: 32-33).

One problem of the second and third scenarios, with their reliance on the introduction of electric powered cars and light commercial vehicles to reduce emissions, is that this relies on manufacturers elsewhere producing such vehicles. New Zealand, like Norway another country with renewable electricity, does not manufacture vehicles. As discussed above, the research by Holtsmark and Skonhoft (2014) and the US Department of Energy (2017) in terms of vehicle operation emissions and by Hawkins et al (2012) and Hawkins, Gausen et al (2012) including manufacturing emissions that EVs may not offer emissions reductions when operated in places that do not have a high percentage of renewable electricity. Manufacturers will manufacture EVs only if they have a market for them which means that they will promote their sale worldwide as an "environmentally friendly" alternative to petrol cars whatever the effect on emissions. This global approach to vehicle manufacturing and sales does not have an impact with petrol vehicles as petrol is the same worldwide and so are emissions from it, but electricity can vary from 100% renewable to 100% coal generated with corresponding effects on the emissions associated with EVs. The use of EVs in areas with high carbon electricity could result in increased emissions compared to those from petrol vehicles. This suggests that the uptake of EVs in New Zealand to reduce emissions could ironically result in increased global emissions because the rest of the world has not moved to low-carbon electricity generation.

Chapter 6 | Non-Technical aspects of sustainable transport

6.1 Non-Technical aspects - *what does this mean*?

To meet the mitigation of GHG emissions targets will require drastic changes over the coming years both in technology as well as in the way that technology is perceived and utilised by single car owners and society as a whole if a reduction of 80% in emissions is to be achieved. Nevertheless, major barriers still exist to implementing potential policies, in particular the current lack of realisation at the individual level of the social and political need to take serious measures for avoiding climate change and for government to be willing to lead in promoting and enforcing moves towards a more sustainable transport future. At the wider scale, consideration needs to be given to the technological state of low carbon alternatives and globally to the effect of the rapid increase in the use of vehicles especially in developing countries.

It is possible that the latest technology will go some way towards reducing the target gap but this alone may not be enough. Some forthcoming technologies, such as driverless cars, by making it easier to travel, do not appear to be likely to offer the necessary reduction in travel-related emissions. They will tend to encourage motorized travel by making it easy, and it is not technically possible that the emissions of such vehicles can be appreciably lower than those of vehicles with human drivers. There is nothing inherently more energy efficient about a self-driving car, if the effect of self-driving cars is to increase VKT then the result will be increased emissions. The gap in emissions reductions that is left once possible technological changes have been implemented needs to be filled by implementing schemes which are aimed at changing transport behaviour. The possible outcomes and effects of these changes are likely to be large, but they could be subject to considerable lifestyle adaptations linked to perception of the degree to which quality of life is improved by their uptake. At least the advantage of such adaptations is that they could be easily implemented on a quicker timescale than technological changes and they could well be a no-cost option or could even save money rather than having a cost. Not only this, behavioural changes also potentially reduce other transport related externalities particularly congestion (Proost 2000).

A different school of thought could assume that any attempt to control the trend of individual car trips will restrict freedom and compromise perceived quality of life. Indeed, private car driving may provide an individual with a sense of status symbol, comfort and privacy, as well as appearing to offer time saving and a perception of convenient transportation. In this situation to talk about rational transport could seem like sanctions on the individual "right to choose". It is therefore necessary to examine what might be acceptable behavioural changes in the life of an individual member of society. This acceptability will play a vital role before implementation of a transition from present to rational transport, as it may be difficult to persuade people to compromise on perceived living standards for the sake of "sustainability". On the other hand, to what extent should individual behaviour choices, in transport or in anything else, be allowed if their effect is to compromise the future of the planet through compromising the nation's ability to meet the requirements of the Paris climate agreement to which New Zealand is a signatory?

6.2 Non-Technical strategy

A sustainable transport system cannot be achieved by a single method or policy. It needs a mix of measures, policy packages and a series of integrated strategies. In terms of the technical approach the future framework will have to be based on disruptive innovation in the full life cycle of vehicles from manufacturing to disposal, but it may be that the focus on vehicles needs to change as well.

> *"Over the past 80 years we have been building cities for cars much more than for people. If only children had as much public space as cars, most cities in the world would become marvellous … The world's environmental sustainability and quality of life depends to a large extent on what is done during the next few years in the [Developing World's] 22 mega cities. There is still time to think different…there could be cities with as much public space for children as for cars, with a backbone of pedestrian streets, sidewalks and parks, supported by public transport."*
>
> Enrique Penalosa, former Mayor of Bogota, Colombia
>
> (Enrique P 2009)

In a recent study (Dalkmann H. & Sakamoto K. (2011) it is stated that green transport is capable of reducing transport greenhouse gas emissions by 70% by allocation of less than 1% of global GDP in restructuring of public transport infrastructure.

Another study states that if we could double the public transport share worldwide then around 170 m tonnes of oil out of 2300 m tonnes (transport used 63% of 3650 m tonnes of oil in 2012) (IEA 2014) and 550 m tonnes of CO_2 equivalent out of 7187 m tonnes of total CO_2 emissions from transportation in 2012 would be saved. In addition urban traffic fatalities would reduce by 15% and risk of obesity and heart disease would be reduced by 50% in addition to a two-fold increase in number of jobs in public transport operators (UITP 2014). Expansion of public modes of transportation helps a 20% reduction in pkm mode share of light duty vehicles (Gouldson et al., 2015). Public transport provides more transport capacity at economical cost.

By 2050, it is estimated that urban transportation will consume more than 17% of available bio capacities in the earth which is five times more than the 1990 consumption level. Average time an urban commuter will spend is 106 hours per year in traffic jams by 2050 that is twice the 2010 rate (Arthur D Little 2014 page 9). However, this is still less than 30 minutes per day. The impact of transport has increased rapidly in recent years which is well described by Arthur D Little in the form of the accounting framework that is known as Triple bottom line with three aspects of sustainability that is Economic, Social and Environment, categorized below as Profit, People and Planet.

> ***"Planet:*** *At a time when sustainability of resources and the environment is increasingly at the forefront of one's mind, a logarithmic increase in the use of motorized transport raises the specter of a vast rise in air and noise pollution and CO_2 emissions. Indeed, it is predicted that by 2050 urban mobility systems will use 17.3% of the planet's bio capacities, five times more than they did in 1990.*
>
> ***People:*** *An inevitable consequence of an unreformed and under-invested urban mobility system is gridlock. By 2050, the average time an urban dweller will spend in traffic jams will be 106 hours per year, twice the current rate, with all that entails for the quality of life of the average citizen.*

Profit: *Unless far-sighted decisions relating to service expansion and innovation are made now, the cities of the future stand to sleepwalk into a situation where they have insufficient public transport, overloaded infrastructures, a default expansion of motorized means of transport and a concomitant parking capacity problem. Given that urban infrastructure is a key factor in luring businesses to cities, this would be highly damaging commercially."*

6.3 The need is mobility not necessarily private cars

From one viewpoint, it appears to make sense to give preference to private motor vehicles as on the road the numbers of cars are high compared to public transport vehicles and it appears possible to save fuel by promoting their smooth running flow. However it may be that technical measures to reduce energy consumption of private cars may not, on their own, provide sufficient reduction in emissions. To divert local inhabitants towards greater use of public transportation and to make it attractive as well, preference must be given to buses and rapid mass transit systems. To some extent electric vehicles are helpful in CO_2 emissions but as shown in chapter 5 electricity is not necessarily "green" by nature. The conventional fossil fuel sources and the renewable energy resources used for electricity generation all have specific environmental profiles and carbon footprints. According to the Austrian Transport Ministry, electric cars emit 76 to 262 grams per passenger-kilometre of greenhouse gases, similar to diesel or gasoline cars, whereas a significant emissions reduction is possible from public transport with a range from 17 to 48 grams per passenger kilometre (UITP 2013). The emissions related to electric cars will depend on the mix of fuels used to generate electricity in a particular country and the resulting carbon emissions. This is why using life cycle carbon footprint for the selection of sustainable transport infrastructure projects is essential. In addition, individual electro-mobility is not able to tackle congestion problems, a traffic jam of electric vehicles is still a traffic jam. As shown in chapter 5, even in Norway with its strong government support for EVs there are still researchers suggesting that private personal vehicles, even if electric, may not provide a satisfactory long-term solution to transport.

The transport sector besides supporting economies directly through vehicle sales also creates employment opportunities from manufacturing vehicles to shipments, fuel extraction to

supply, development of transportation infrastructure to its maintenance. But it is claimed that "green transportation" could provide more jobs. A number of studies have concluded that one billion US dollars investment in public transport could generate 36,000 new jobs which is respectively 9 % and 19 % higher than the jobs created by either conventional road maintenance or new road projects (STPP 2004) (EDRG 2009).

Because of considerable uncertainty regarding both the likely rate of change and the level of emissions reduction that can be achieved by vehicle technology, by itself technology cannot be the single way to deal with this dilemma. This is even stated by a motoring organisation, the Royal Automobile Club in the UK (RAC 2002).

It has been claimed that a litre of fossil fuel saving by reduced VKT provides more benefit than the same litre of saving provided by shifts to more efficient or alternative fuel vehicles. This is because reduced private vehicle travel provides social, economic and environmental benefits like fewer road accidents, less expenditure on parking fees and road user costs, reduced traffic congestion and pollution. It is likely that new technology or more fuel efficient vehicles could stimulate more vehicle travel resulting not only in more traffic congestion and parking costs but also having impacts on gains that could be achieved by reduced emissions. This does not mean that more efficient vehicles or alternative fuel options are useless. In the first instance mitigation of carbon emissions and fossil fuel savings should be the priority but mitigation needs to be considered in context with other associated factors and impacts. This underlines the need for a framework for developing policies, technologies and infrastructure for the future delivery of transport services that meets with regional and international emissions reduction targets (Litman 2005).

6.4 Heavy vehicles non-technical measures

It is not only in passenger transport that non-technical measures can be applied. A European study gives some non-technical/ non mechanical potential measures showing that more than 15% CO_2 emissions reduction from heavy vehicles is possible through non-technical means. Proposals include a new EMS (European Modular System) under which with greater maximum loading capacity, vehicles, if provided with obstacle free circulation, can reduce CO_2 emissions by 7%. Driver training on eco driving principles also makes it possible to reduce fuel

consumption by 5%. Optimum load adjustment if utilised properly and mutually operated between service providers can be of further benefit to reduce CO_2 emissions by 4%. In addition, some other measures like biodiesel and blended biofuel could offer 4% reduction, road maintenance to minimise rolling resistance could achieve 3% and "harmonised platooning" (one truck closely following the other in an organised and preferably centrally coordinated manner essentially forming a road train, to reduce drag and CO_2 emissions) can give 2% CO_2 emissions reduction (Tim Breemersch 2017). Further savings could come from shifting freight away from road transport.

6.5 The urban situation

According to UN population figures in 2007, more than a half of the world's population have migrated to urban areas and this proportion is set to increase to 60% by 2030 and 67% by 2050. Today, urban travel kilometres are 64% of all travel kilometres and urban travel is expected to increase three fold by 2050. A study conducted by Siemens Megacity Challenges found that mobility with 27% was the main reason of attracting investment in cities, three times more than the second highest factor that is security (Audenhove and Oleksii 2014).

6.6 Role of urban public transport

It has been argued that the rapidly growing public demand for urban mobility could only be met by green compact cities designed in a sustainable urban style and supported by an integrated land use and transport system which makes cities not only liveable but offers socio economic development (Porter et al., 2013). This urbanisation pattern is claimed to bring social as well as economic development because this transportation system produces less environmental impact than that which results from a motorised car dependent living style.

Increasing the use and easy access to public transport where it exists and providing public transport options where they are not available are tools for potentially reducing the rate of growth in private vehicle VKT. A well planned green public transport system properly organised with respect to the local demand and conditions and with stakeholders'

coordination can help take society into a more favourable ecological world in reality. To make this dream come true proactive integration between sustainable transportation and other urban policies is required to be both established and maintained. To keep this world ecologically viable there is no other option to a low carbon, low energy and technologically efficient environmentally friendly transportation network. The use of public transportation modes is one of the best options.

To some extent motorbikes as seen in many cities in Asia might seem a good alternative for those who could not afford a four wheel car, but motorcycles' emissions of CO_2 are not negligible. They form a small part of transport with just 1.6% share in total carbon emissions from transportation (WBCSD 2010). Small motorcycles have fuel consumption of around 2.9 to 4.0l/100km which is not much lower than a small efficient car which can be around 5.0l/100km. In addition two-wheel motorized mobility is more risky with a considerable number of accidents and fatalities (Canet and Allen 2013). Cars and motorcycles emit 3.5 times more greenhouse gases per passenger than public transport (Arthur D Little 2014) and if this trend continues then it is estimated that greenhouse gases will increase by 30% by 2025 compared with 2005 levels.

Contrary to this, public transport is claimed to be one of the best ways of curtailing CO_2 emissions as public transport consumes about 3 to 4 times less energy per passenger per kilometre while transporting large numbers of people in addition to using much less road space. For the same passenger capacity a kilometre of double track railway occupies a third of the land area of a motorway (UIC/CER, 2015: 25). A 3.5 metre wide "transport corridor" in a city can carry 2000 people an hour if they are driving cars in conventional mixed traffic, but 9000 in buses and 22,000 in trams if the corridor is in the form of a road. A similar corridor width can transport 100,000 people an hour if they are on suburban trains rather than in road vehicles. The same corridor can also be used as a roadway for non-powered transport, accommodating 14,000 cyclists or 19,000 pedestrians an hour (Hickman et al, 2011: 55). This helps to demonstrate why the private car, often with only one occupant, is not a very efficient way of moving people around cities, it needs too much space. A German study published in 1993 found that even then each car had an area of road and parking of 200m^2 devoted to it (UPI, 1993).

6.7 Public transport in an international perspective

Public transport plays a vital role in the transport system. The commonest form of public transport is the bus, (A&S Transportation 2016) (Richard Cross 2016) which can offer a greener and cheaper way of meeting transport needs with least burden on traffic flow. The fuel efficiency and carbon emissions of all public transport, including buses, are strongly influenced by patronage, that is more the numbers of people travelling by bus the lower the emissions per passenger and the less the private car travel. Penetration of hybrid, electric and fuel cell technology buses to the maximum extent on a priority basis is also required. Hybrid buses, which are claimed to reduce CO_2 emissions by 30-40 % compared to conventional buses, are already available but high upfront cost needs to be reduced for quicker uptake (DoT 2009).

The present growing situation is "we need to do everything we can to get people out of cars" (de Jong 2008). Some countries make use of deliberate policy to get people out of cars. As an example, Bangkok's car ownership is high at 399 per 1000 population as compared to other more economically developed countries of the same region like Singapore with 152 per 1000 (Amin N. 2009 page 5). This is a good example of contrasting scenarios between motorization and level of economic development. Singapore is a trend setter in this case because of the government's determined intervention. The Singapore Government first motivated people with economic incentives and afterwards when the required results were not achieved then enforced quantitative restrictions. A public oriented easily accessed mass transit system is not only the main reason which contributed to a reduction in the buying as well as usage of light duty vehicles. Singapore introduced a Vehicle Quota System (VQS), with a mechanism called Certificate of Entitlements (CoE) in 1990, and each interested vehicle owner has had to compete under specified vehicle categories. This system was successful to reduce vehicle growth to 3% per annum compared with 6.8% per annum in the three years prior to the implementation of the VQS scheme. The existence of an efficient and economical public transport system was also available to the public as a viable alternative to car ownership given the restrictions on ownership (Omar and Rahman 2006). However, this policy has not resulted in significantly lower overall CO_2 emissions per capita. At 10.3 tonnes per capita Singapore compares poorly with countries such as Germany (8.9 tonnes per capita) New Zealand (7.7

tonnes per capita) or the United Kingdom (6.5 tonnes per capita), none of which have such controls over car ownership (WBG 2017). On the other hand, the percentage of total CO_2 emissions represented by transport in Singapore is low at 15.2% in 2014 compared with 21.4% for Germany, 44.9% for New Zealand and 28.5% for the UK (World Bank Group, 2017b). Fig 6.1 compares the per capita transport emissions of the four countries.

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Table 6.1 Comparison of four countries' total transport sector and per capita transport sector CO_2 emissions.
Source: (IEA 2014)

These figures show that thanks to its car ownership policies Singapore is performing quite a lot better in terms of per capita transport emissions than countries such as Germany and the UK which do not have such policies. All these countries however are significantly better than New Zealand. Like New Zealand, Singapore has a very low figure for its total transport emissions because it is a small country.

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Table 6.2 Car ownership aspiration index in selected countries.
Source: (Amin N, 2009 table 2.1 page 4)

The Aspiration Index (AI) (Fig 6.2) has been developed on the criteria of current ownership as well as a person's future intention to buy a private vehicle. Singapore and New Zealand are in the medium level of the AI. (Amin N. 2009 page 4). This index shows that people in lower income countries aspire to own private cars, to a greater extent than those in wealthier countries, which suggests that there is still considerable demand for car ownership, even in places such as Hong Kong and Singapore which have very good public transport systems. This also suggests that voluntary systems for restricting car ownership may not be sufficient to achieve the desired result of steep reduction in emissions.

The other dominant factor that increases the demand for and use of private cars is the construction and expansion of new roads, where supply creates its own demand. In Bangkok during the late 1990s, 176 km of expressways were constructed in an attempt to counter the severe traffic congestion and this is reflected in the relatively high car ownership. Similarly more investment in road construction in China caused increase in highway and expressway mileage and both these countries' car ownership aspiration is high as shown in fig 6.2, which means that demand is being created (Amin N. 2009).

Using public transport may need to be inculcated from an early age. In a comparative study (Buehler and Pucher 2012) it was proved that German children generally use more public transport (or walk or bike) for their trips to and from school as compared to American students. The lack of American school children's culture of using public transport probably develops an opposite trend in their personality to use of public transport later in life, whereas German children are used since an early age to travel in public transport on their daily trips to school and hence use more public transport as adults.

6.8 Public transport trends

To attract people to use public transport it has to be perceived as providing quality of service. Quality of service is the satisfactory performance perceived to be provided to the users by a public transport system and the elements that comprise it can be grouped into different classifications: Public Vehicle elements, Transport system elements, and Passengers' elements (TRB 2003). In general the most significant parameters of an existing public

transport system are the condition of basic infrastructure, prevailing fares, frequency of movement, physical conditions of public vehicles and accessibility. There are some additional features which are also considered like reliability, safety, comfort, environmental impact, etc. (Dragana and Ivanovic 2013).

The improvement of quality of a public transport system is very crucial from two perspectives; from users' and also from non-users' point of view to shift them from using their own private vehicles to public transport although they may not have been using public transport for a long time, or perhaps never before. Improving the level of quality from the users' perspective needs to be substantial to motivate people towards public transport and to persuade them to shift from passenger car transport. There might be some reasons or deficiencies in the public transport system because of which these services are only used by those who are not able to afford to own two or four wheel private vehicles which means the users are there by virtue of dependence and not by choice. The rectification of weaknesses of the public transportation system and subsequent improvements will be likely to attract more non-users. Hence for an efficient public transportation system accurate determination of the users' demands and assurance of continuous improvement up to a perceived satisfaction level are undeniably essential. To achieve public transport that satisfies both economic and environmental conditions for social benefits, the ideal situation is that all the elements of public transport service quality should be met from existing and potential users' perspective, for the cause of sustainability.

The public transport user normally faces a big problem which is common everywhere particularly where buses share the road with private cars and other vehicles. To get the optimum results of bus transit more lanes should be created as for Bus Rapid Transit systems so that passengers save travelling time and they are attracted to bus transit. Light Rail Transit is more attractive to the public because shorter travelling time is possible as LRT is often based on a separate right of way which is congestion free, unlike buses which have to share the roads with other vehicles. No doubt the bus is still the most common form of public transport because of its features like lower operating cost and route flexibility (Hensher 1999). But on the other side LRT is also becoming a priority of the public because of speed, high capacity, safety and being more environmentally friendly (no local emissions from the electrically powered vehicles) (Kim et al 2007) (Martinelli 1996) (Williams 1976).

There are various studies on LRT systems that show how this mode of transit can play a critical role in urban development (Hass-Klau et al., 2004) (Vuchic 2005). The LRT system can get more public attraction than the bus, if it can have shorter headways, long route coverage and fares as low as reasonably possible.

Another factor which keeps the general public away from use of public transport particularly in developing countries is that bus services in these countries usually remain overcrowded, slow, inefficient, unscheduled, comfortless and even dangerous (Kashirsaga et al., 2008) and because of this even those people who cannot afford to buy a car will seek to obtain one by some other way like leasing or on a loan basis, because they strongly prefer a car specially for family travelling.

6.9 Emissions reductions by way of public transport

The target gap that is left once possible technological changes have been implemented will need to be filled by implementing schemes which are aimed at changing transport behaviour. The public transport sector has competency and willingness to act and is ready to make a difference with respect to global warming caused by the transportation system (APTA 2017). Public transport's carbon footprint is inversely proportional to the global carbon footprint the more that public transport replaces private transport. For public transport to become citizens' preferred mode of choice, first it has to become a focus of understanding of bureaucrats in transport controlling authorities, a focus of politicians, of the transport industries' investors and also the mode of choice of decision makers implementing sustainable urban policies. There is more likely to be good public transport if the policy makers use it than if they all drive to work.

In terms of climate change mitigation, no major investment is required for new technologies as shown in the "Moving Cooler" study (Cambridge Systematics 2009) and McKinsey (2009) that an integrated transport system based on comprehensive policies can result in savings to the economy as well as emissions reductions. A similar study carried out by the World Bank (2009) on Mexico showed that improving the efficiency of bus networks, rail freight and efficient vehicle inspection schemes showed large net savings.

UITP (International Association of Public Transport), at its 2009 World Congress in Vienna, suggested a vision for the transport sector that if the share of public transport were to increase by double worldwide by 2025 with associated cycling and walking it would avoid only around 8% of the total emissions of 7187 million tonnes of CO_2 from transportation. There would also be the possibility of 15 % reduction in accident fatalities and the incidence of heart disease and obesity will be halved whereas double the number of jobs related to development, operation and maintenance of public transport will be created (Arthur D. Little 2014) identified some key dimensions for sustainable urban mobility systems. Further UTIP in 2012 elaborated its vision of doubling public transport into a campaign known as "Grow with public transport" and highlighted some of the features like enhancing green growth, controlling climate change and forming more liveable cities that are brought about by increased public transportation (http://www.uitp.org/grow-public-transport). However, if a doubling would give only an 8% reduction in CO_2 emissions it is clear that much more needs to be done.

Another study using an integrated macroeconomic model for detailed quantitative analysis suggests that if a budget provision of around 0.34% of global GDP is allocated for public transport infrastructure and efficiency improvement of road vehicles it could reduce the volume of road vehicles by 27% to 35% and reduce the share of transport provided by private vehicles by 30%. It is claimed this could reduce carbon dioxide emissions in 2050 compared with Business as Usual by slightly more than 8 gigatonnes through a decrease in energy consumption between 16% to 31% without affecting current employment. Rather there would be an increase in opportunities and markets (UNEP 2011). Transport-related emissions were 7187 m tonnes (7.2 Gt) of CO_2 in 2012 (UITP 2014b) (IEA 2014b). This shows the effect of the likely increase in transport demand and makes clear the nature of the problem, since the projected saving in emissions of around 8 gigatonnes by 2050 is greater than current total transport emissions of 7.2Gt.

In the case of Business-As-Usual (BAU) in transport it is estimated that energy use and carbon emissions will increase by 50% by 2030 and around 80% by 2050 with highest emissions contribution from light passenger vehicles followed by aviation and heavy vehicles with 56%, 18% and 16% shares respectively. Overall transportation emissions will increase to 25% of global energy related CO_2 emissions by 2050. In terms of load among all transport modes,

light passenger vehicles will remain on top with an increase in share from 47% in 2010 to 62% in 2050, while with decreasing share of buses from 25% to 15% there will no big variation in passenger rail load (6-7%) and similar trend of 10% in aviation. For freight transport there would be a slight decline in rail and an increase in road freight (UNEP 2011).

In 2011, a survey was conducted by UTIP Observatory of Employment which calculated that the urban public transport sector accommodated about 7.3 million job opportunities worldwide and local authorities employ about 300,000 people worldwide in public transport. The expansion of public transport, as well as provision of more "green job" creation would simultaneously embrace clean energy, boost efficiency, and limit GHG emissions in cities through modal shift to public transport. (http://www.uitp.org/sites/default/files/cck-focus-papers-files/fp_green_jobs-EN.pdf)

According to the United Nations Environment Programme (UNEP) and the International Labour Organization (ILO), green jobs are defined as follows:

> *"We define green jobs as work in agricultural, manufacturing, research and development (R&D), administrative, and service activities that contribute substantially to preserving or restoring environmental quality. Specifically, but not exclusively, this includes jobs that help to protect ecosystems and biodiversity; reduce energy, materials, and water consumption through high efficiency strategies; de-carbonize the economy; and minimize or altogether avoid generation of all forms of waste and pollution."*
>
> *(UNEP 2008)*

('Green Jobs: Towards decent work in a sustainable, low-carbon world', a report commissioned and funded by UNEP, as part of the joint UNEP, ILO, the International Organisation of Employers (IOE) and the International Trade Union Confederation (ITUC) Green jobs initiative, and published in September 2008.)

6.10 Integrating public transport and urban planning

To get the maximum output from the integration of public transport and spatial development the relation between them must be pro-actively based on strategic delivery and functional project design. Strategic delivery is related to making policy logically, politically and

functionally viable. Stakeholders' coordination is essential to get political support and enable a project's justification. Project design refers to the assurance of feasibility of construction and operation to achieve the environmental, economic and social objectives (IEA 2013).

Surviving in the 21st century while maintaining ecological stability needs to be based on a sustainable move forward where minimum energy resources utilization with least CO_2 emissions is the requisite factor. This is indispensable for the assurance of human society flourishing into the future. The development of liveable sustainable cities should be formulated on socially reasonable and ecologically viable carbon footprint evaluation. Green cities inhabitants' mobility use will need to be shared instead of individually owned by users in an interconnected system with walking, cycling, public transport, rapid mass transit, etc. Ideally the landscaping/ urban planning of such cities would be designed in such a way that households can conveniently access a diversified portfolio of integrated transport networks.

One challenge will be to implement this approach in existing cities as there will be little possibility of building new cities that incorporate such ideas. Even when opportunities for change may exist, the chosen policy tends to be business as usual. A local example particularly relevant to this research is the "Let's Get Wellington Moving" study to develop an overall transport system for Wellington which was recently carried out by Wellington City Council, Greater Wellington Regional Council, and the NZ Transport Agency. All of the four options presented as a result of the 2017 "Let's Get Wellington Moving" study state "No significant change to greenhouse gas emission at a regional level" (Let's Get Wellington Moving 2017). This is a shocking situation and reveals the extent to which New Zealand planners, politicians and policy-makers are very far from taking the need for emissions reductions into their thinking, even when planning long-term transport infrastructure.

Various scenarios show that a low carbon, green sustainable transport sector can reduce GHGs generated by the transport sector by 70%. Minor reallocation of just 0.16 % of global GDP in promoting public transport systems and improving energy efficiency of road vehicles would also reduce the volume of road vehicles by one third by 2050 which otherwise, in a business as usual scenario, would increase from 800 million to around 2.5 billion. The transportation system is responsible for 23 % of global energy related CO_2 emissions which makes a strong argument that for the well-being of the Earth there is a pressing need for an efficient green sustainable transportation system but unluckily the current global investment

patterns are still heavily skewed towards supporting the motorisation model of development (Dalkmann and Sakamoto 2011b).

Savings may apply also at the small scale. For example, through efficient traffic management giving priority and better operating conditions for public transport, a reasonable quantity of fuel consumption can be saved. For example giving priority at traffic signals and reserved lanes increase speed on a busy bus route by 5km/h and saves 20 % energy consumption (in urban traffic conditions energy consumption is inversely proportional to the average speed) resulting in less greenhouse gas emissions (UITP 2009 page 8, figure 3).

6.11 Wellington public transport past and present

The focus in the technical approach to emissions mitigation discussed in chapter 5 is given to various factors associated with light passenger, light commercial and heavy commercial vehicles in different aspects to curtail CO_2 emissions in every possible way. In the non-technical approach to carbon mitigation, the strategy is to shift from private vehicles to bus and train, with minimum possible CO_2 emissions and powered by renewable energy sources, by increasing regional boarding. Based on the year 2000 public transport fleet size, boarding and corresponding CO_2 emissions and percentage increase during 15 years, estimated figures are calculated for 2050 as shown in the following table.

Des-cri-pti-on	2000					2015					2050			
	Fleet	Passenger Km	Passenger boarding	CO_2 tonnes (tCO_2e) URS	CO_2 tonnes (tCO2e) AECOM	Fleet	Passenger Km	Passenger boarding	CO_2 tonnes (tCO_2e) URS	CO_2 tonnes (tCO2e) AECOM	Fleet	Passenger Km	Passenger boarding	CO_2 tonnes (tCO_2)
Bus Fleet	456	134 million	19 million	6972	7053	769	169 million	24 million	6964	7014	1000	288 million	42 million	2000
TPC	44 km/head	_	_	_	_	50 km/head	_	_	_	_	58 km/head	_	_	_
Train	_	242 million	10 million	12136	12265	_	305 million	12.8 million	11918	10981	_	468 million	20 million	8000

Table 6.3: Wellington region public transport CO_2 emissions and boarding profile (TPC = Travel per capita)

The best mode in terms of low-emissions travel during the period from 2000 to 2015 appears to be bus transportation, since bus passenger boarding during the same period increased by 26 % (24-19 = 5/19 = 0.26) at the same level of CO_2 emissions. If the bus boarding trend remains the same then the projected bus boarding by 2050 will be 38 million (24-19 = 5/19 =

0.26/15 = 0.017 per year * 35= 0.61 + 1 = 1.61 * 24 = 38 million) and bus passenger kilometres will be 288,000,000 km which gives average per head travel per trip of 288,000,000/38,000,000 = 7.45 km. For the projected population annual bus travel per capita is 38,000,000/650,000 = 58 km/head. But if the trend of bus travel per capita for the scenario of a shift from private to public transport is considered, annual patronage is assumed to increase by 2% instead of normal growth of 1.7% which gives projected bus travel per capita of 64 km/head (42,000,000/650,000 = 64 km/head). According to this assumption bus boarding will increase to 42 million (0.022 * 35 = 0.77 + 1 = 1.77 * 24 = 42 million) around double the year 2015 bus boarding. An interesting aspect of this is that average per head travel will be decreased because of those passengers who commute for shorter distance instead of using private vehicle.

Per capita bus boarding = 19,000,000/440,000 = 44 km/head and 24,000,000/478,137 = 50 km/head. Projected bus passenger km by 2050 (169,199,616 -134,048,686 = 35,150,930/134,048,686 = 0.26 = 0.26/1 = 1.7% per year = 288 million km). For each person boarding a bus average travel in year 2000 was 134,048,686/19,795,687 = 6.77 km and by 2015 it increased to 169,199,616/24,331,408 = 7.00 km.

Description	2000				2015				2050		
	Boarding	Passenger km million	CO_2 tonnes tCO_2e AECOM	CO_2 tonnes tCO2e URS	Boarding	Passenger km million	CO_2 tonnes tCO_2e AECOM	CO_2 tonnes tCO2eURS	Boarding and projected boarding	Passenger km	CO_2 tonnes
Train Boarding	10 million	242	12265	12136	12.8 million	305	10981	11918	20 million 23.4 million	468 million	8000
Average per passenger travelling	242/10 = 24 km	_	_	_	305/12.8 = 24 km	_	_	_	468/23.4 = 20 km	_	_
Average per capita travelling	23.1 km/per	_	_	_	26.7 km/per	_	_	_	30 km/per 36 km/per	36 km/per	_

Table 6.4: Greater Wellington region rail transportation profile.

The train boarding increased by 26% during the period 2000/01 to 2015/16 whereas both consultants' studies (AECOM & URS) show that the decrease in CO_2 emissions over the same period is 10.4% (10,981–12,265 = 1284/12265 = 0.104) and 1.7% (12136-11918 = 218/12136=0.17). Average per passenger travel (distance per trip) is more or less the same during this same period but the figure for annual train travel per person increased from 23 to

26.7 km per person. The average trip leg travelled by each passenger is 24 km in 2000 which is the same in 2015.

By keeping the same trend of increase in train boarding the estimated train boarding by 2050 is 20 million but by keeping the same trend of per capita travelling the projected passenger travel km is (26.7-23.1/23.1 = 3.6/23.1 = 0.01 per year = 1.35 x 26.7) 36 km/person, and the required boarding to be projected by year 2050 is 23.4 million. For this projected boarding, the total passenger km need to increase to 468 million and for this enhanced boarding the per passenger trip leg is 20 km. This means that the estimated population by 2050 of 650,000 will comparatively travel more in numbers and for shorter distances. If the CO_2 emissions reduction rate remains the same as it has been from 2000 to 2015 then it is estimated that by 2050 carbon emissions from the train network would be reduced to around 8000 tonnes CO_2. The current percentage contribution of carbon emissions from electric rail is around 20% and from diesel 80% of total emissions from Wellington regional rail network (AECOM 2016). If the entire Wellington region passenger rail system is shifted to complete electrification with the diesel engines made obsolete this will presumably make it easy to achieve the target of 2500 tonnes CO_2 emissions for the rail network. In order to make it a sustainable network it would be relatively easy to shift the existing diesel rail system into electrification. It is needed only on the Wairarapa Line beyond Upper Hutt and as far as Masterton so does not require a completely new electrified network to be installed, only an extension of what is already there. This critical feature of the rail network is an added advantage compared to road transportation where a change in the fleet from oil to electric requires huge investment for a new fleet and its infrastructure. This seems to be a reasonable, affordable and easy way to deal with rail-related emissions.

6.12 Non-motorised transport modes

Shifting from private cars to public transport is a relatively “normal” way of reducing carbon dioxide emissions. It still requires the use of vehicles and fuel sources and the behaviour change required to use public transport need not be great as regards the individual making the choice. Climate change cannot be avoided entirely, but the most severe impacts of climate change can be avoided by sustainably reducing the amount of heat trapping gases released

into the atmosphere. The Third Assessment Report published by the IPCC in 2001 states, “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities”. Unequivocally, though not completely, it is possible to mitigate climate change and GHG emissions to a certain level, by changes in the actions of those who are responsible for their production. However, we do not need sustainable transportation only for reversing climate change or reducing global warming but also for developing a more stress free, healthier green environment by discarding automobiles or at least controlling their use to an absolute minimum. Many efforts and actions have been performed in different parts/regions of the world in various ways for CO_2 emissions adaptation but often these are one-shot attempts, piecemeal or are partially like showpieces which are not repeated, that is why their results are often not long lasting of effective at a wider scale. Many of these mitigation measures were implemented as policy rules whereas for consistent outcomes their adaptation should be behavioural changes as an attitude of citizens, society, political leaders and governments. Citizens’ unwillingness to respond and politicians’ procrastination because of fear of losing votes so far appear to be among the main reasons in failure to set emissions limits. One of the main reason of deficiencies of successful implementation or failure in achieved results is lack of alternative modes of transportation which ultimately diverts urban residents to private car ownership. Many do not even have some basic essential amenities such as walkways, bikeways and easy access to public or mass transit whatever it is available (Amin N. 2009).

Shifting from private vehicles and even from public transport to non-motorised transport i.e., cycling and walking, could be considerably helpful in CO_2 emissions control. In the Netherlands, with 47% of trips by non-motorised transport this mode plays a significant role up to a distance of 7.5 km for cycling and walking up to 2.5 km (Ribeiro et al. 2007). There is still large potential to revive interest towards cycling and walking with strong policies and cultural dedication as in the Netherlands, with the cycling share about 40% and walking share about 25% for accessing trains (Ribeiro et al. 2007)

6.12.1 Walking

The cheapest, healthiest, most environmentally friendly and space efficient way to travel is walking. It is recommended for health that people should walk 10,000 steps a day, which is a distance of 8 km (NHS Choices, 2014). Normally a human while walking covers 1312 steps in 1 km (Kyle's Converter 2017). It is somewhat surprising that 30% of private car trips in New Zealand are for less than 2 km (NZTA, 2016), a distance that could be easily walked any time during day or night, with additional economic, health and social benefits for individuals in particular and society in general (LTSA, 2000). The effect is made worse due to the fact that cars use more fuel for short trips when the engine is not warmed up (Vale and Vale, 2013: 68-69). As time passes New Zealanders are undertaking fewer journeys per capita where walking is the only transport mode, it is recorded that there were 400,000 fewer walk-only trips in 1997/98 than in 1989/90 in spite of an increase in population. The number of walk-only trips rose slightly between 2005 and 2012 but the overall trend during the last decade shows a decreasing trend of 0.3% per year whereas there was a threefold increase in population growth of 0.9% during the same period. The development of a dedicated walkway network for a community of 50,000 people would cost less than one km of motorway (NZTA, 2016).

For a short distance walking is a natural, healthy and affordable for everyone mode of travel and at the same time a compulsory component of the vast majority of public transport trips as the transport user has to walk to and from the bus stop or the railway station. Walking is a crucial aspect of sustainable transport. Basic infrastructure like paths and streets helps to motivate the public to start walking. It can be the most preferable way of moving around specially if services and resources are suitably located, which links it closely to the built environment. The public will definitely find it more attractive if the authorities provide them a safe walking access interconnected with all buildings and destinations. By providing some basic elements like street lights, trees, protection from traffic and, particularly, convenient ways to cross the road, the walking environment can be enhanced.

The Ministry of Transport has found that the amount of walking done per person per week in New Zealand varied by main urban centre or rural area. People living in main urban centres walk more than those living in rural areas. In urban areas primary school children of age group 5 – 12 walk for 56 minutes against 38 minutes' walk per week in rural areas. A similar trend is

observed for age groups 13 – 17 years and 18+ years - people in these two groups walk 105 minutes against 83 minutes and 57 minutes against 36 minutes per week in urban and rural areas respectively (New Zealand Govt. 2015b page 12) Although "on an average surveyed day" 77% of people reported walking less than 100 metres (page 5) average walking is 50 minutes for males and 54 minutes for females per week. Given that the average walking speed is given in the Household Travel Survey as 4.4 km/h (page 7) this gives an average daily walking distance of 545 metres or just over 700 steps a day, not nearly far enough as recommended for health.

6.12.2 Cycling

For short distances the fastest way to travel is cycling. Like walking, cycling is also an emission free, healthy mode of transit with door to door travel and with speedier movement than walking. If safe, easy accessed and comparatively short cycling ways connecting all buildings and commercial centres are provided then generally the public especially younger age groups could be more attracted and perhaps diverted from motor vehicles. This non-motorised mode of transport combines low cost travel with good exercise. The CDC recommendation (US Centers for Disease Control and Prevention) for moderate exercise is 8 km of bicycling (Gotschi & Mills, 2008, 29). Bikes are an enjoyable and clean way of getting around a city. The hilly terrain of the Wellington region might be a hurdle to shift a major share of short trips to cycling, but electric bikes could be good to overcome this problem. Electric bicycles offer multi-dimensional advantages of easy handling, cheaper and environmentally friendly transport for longer distance travel with easily overcome inclines and wind pressure and provision of load carrying capacity. These make this option an alternative to private cars for shorter trips as well as sensible choice for recreational activities (Wachotsch et al, 2014). The European Cyclists Federation (2011: 10) found that the CO_2 emissions of both pedal powered and electrically-assisted bicycles were similar due to the additional food eaten by the pedal cyclist compared with what they would need to eat if sitting in a car.

This transport mode (pedal and electric bicycles) could potentially replace up to 50% of the current car traffic load as almost half of car trips are less than 6 km (NZTA 2011). Adopting the Dutch culture of walking and cycling for shorter distances could reduce car travel to 10 to

12 km per day travel from the current 22 km of average per day travelling (EECA 2015) in cities. This would then mean that car travel would fall to only 10 km which would potentially go a considerable way towards meeting the emissions target.

There is a growing number of people cycling in Wellington and it is suggested that people tend to cycle if safe, fully separated and barrier protected cycle infrastructure is provided (WCC 2014). Nearly 50% of people who do not cycle said that lack of safe infrastructure and fear of those motorists who drive unsafely are the main barrier to cycling. And 76% of people over the age of 18 say they would consider cycling for all purposes subject to the provision of safe and barrier protected cycle infrastructure. There is clearly a large percentage of people who wish to cycle but because of a number of reasons do not cycle. To encourage such people, in Sweden, free cycles are provided for six/twelve months and a similar program has been introduced in France, where people are paid if they cycle to work. (WCC 2014 page 6) Such attractive schemes in the Wellington region if introduced, could be very successful at increasing the numbers of people using cycling as a regular transport mode.

A recent travel mode survey of Wellington city shows (fig 6.1) the difference between preferred and actual travel modes. There are 6% more than the percentage who walk who would like to be walking and there are 22% (the difference between preferred and actual mode share) who would like to cycle but are using another mode to get to work (WCCC 2014 page 9). Interestingly the data also show that only just over 25% of people wish to drive although more than 40% are driving, suggesting that there could be uptake of alternatives to driving if they were perceived as being more available. Indeed the gap between preferred mode and actual mode is greatest for cycling which gives the impression that improved facilities could attract many more cyclists. A model of cycling of Wellington residents shows that there are 9% hesitant cyclists and 12% likely cyclists that could be started cycling if issues are resolved (Nylund K.L., Asparouhov T., and Muthen B.O., 2007). The important factor for hesitant cyclists is the slope or hilliness of a cycle route followed by directness and road condition while likely cyclists need flat routes, fully segregated from other road traffic and the shortest possible route.

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Fig 6.1: Actual and preferred travel mode share of Wellington region.

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Figure 6.2: Difference between preferred and actual travel mode of Wellington region.
Source: WCC 2014

The first bike sharing scheme was introduced in 1965 in Amsterdam city as a way to reduce road traffic and since then bike sharing has been growing worldwide and by 2013 more than 700,000 members of the public are using it in different parts of the world (ITDP undated). The growing trend of public bicycle sharing systems can add low cost and easy use to other benefits of cycling. For example the privately owned Urban Public Bicycle sharing programme

in Hangzhou city in China is the world's largest bike sharing program serving 280,000 riders daily, complementing the city's extensive bus system (metropolis 2016). This system has had a considerable effect on public transport, with the city's passenger share ratio of public transport increasing in twenty years from 7.8% to 22.2%. A similar kind of service has started in Auckland named Nextbike which uses technology and bikes from Nextbike GmbH. For the Wellington region this kind of bike sharing could complement GO Wellington buses and Metlink trains (Nextbike 2017) [http://www.nextbike.co.nz/en/]. In addition to public bike rental the company also provides cycle skills education and driver coaching on rider behaviour.

If reasonable pedestrian friendly walking and biking pathways are provided it could not only motivate the public to shift towards walking and cycling but also be very supportive in reducing the use of private cars. Various studies show cycling should be adopted as a culture and when the public start using more cycling then a safer environment will develop for cyclists. One researcher (Jacobsen, 2003) developed a growth rule that if the number of cyclists doubles, the risk per cyclist reduces by 34% and if the cycling number halves, the risk per cyclist increases by 52%. But before this increasing trend is generated it is necessary to provide high quality cycle paths, pedestrian crossings, cycle stands and ancillary facilities with provisions of comforts during different weather.

A study by the UK Department for Transport, 2006 showed that for shopping trips 51 trips/person/year are undertaken by walking as compared to 82 trips by private car as drivers and 42 as passengers. Whereas the length of walking trips averaged one km, car travelling distance was 8.4 km as driver and 10.9 km as passenger (Department for Transport 2006). This also links to spatial layout. As the figures above show, people will walk an average of 1 km to shop, but will drive around 10km for the same activity. To make walking more attractive to people it appears that facilities may need to be located closer to where people live as proposed by Tran (2013) who compared transport in Hanoi, Vietnam with the situation in New Zealand. However the idea for reducing transport by providing facilities closer to where people live runs counter to the market-driven trend for out-of-town shopping centres and large supermarkets. This shows the complex interlinked nature of transport, behaviour and the economic system of society.

Chapter 7| Built environment & sustainable urban planning

7.1 Sustainable transport and urban planning

There are many current suggestions for reducing the emissions from transport by means of changing the built environment (USDE, 2013:13) (Urban Land Institute, 2009) (Frank et al., 2007) (Cervero, R., & Kockelman, K. (1997) (Boarnet, M.G., & Crane, R. (2001) (Zhang, M. (2004)) (Ewing, R., & Cervero, R. (2001), changing technology and/or changing behaviour (Bristow et al., 2004) (Todd Litman 2015) (Department of Transport 2009) (Proost S. 2000). What is not known is the relative effectiveness of any of these measures in reducing emissions. In spite of the large number of studies such as those cited above, there is a lack of research that comprehensively connects the dynamics of transportation to urbanization and industrialization, to development (both social and economic) and to climate change.

Future land use infrastructure planning could play a critical role in average distance reduction as well as decreasing number of vehicle trips. Land use planning by shaping the city infrastructure to minimise vehicle use has potential for GHG reduction. To densify cities can not only minimise vehicle trips but also reduce pollution and traffic congestion. Singapore and Hong Kong are good examples of slower motorization by following land use planning (Sperling D., and Salon D., 2002). It has been estimated that appropriate design and urban shaping could reduce motorised passenger travel (pkm per capita) by as much as 7% in OECD and 25% in developing countries (Gouldson et al., 2015). Sustainable design of the built environment will also encourage walking and cycling besides bringing public transport stops closer to where people live making them more easily accessible to the general public. Pleasant outdoor urban planning and well connected commercial and residential structures are a growing demand for zero emissions smart cities. In such a pattern of urbanisation people drive 20 to 40 % less and the street network is designed to be better interconnected. Density is increased by building more homes as townhouses and by building offices, shops and other destinations up rather than out. It will be a realistic approach to assume that compact development can give 30% savings in VKT. This reduction in VKT could reduce total transportation related CO_2 emissions by 7 to 10% in 2050. Hence land use changes alone can contribute up to 10% excluding other measures (Ewing et al. 2007). Another study conducted by the National Research Council in

the United States found that greenhouse gas emissions could be reduced by more than 10 percent by 2050 if 75 to 90 percent of new urban development were compact in form rather than a continuation of existing patterns (Green and Baker 2011 Page xi]

In practice the purpose of transport is to provide access from home to work, education, business, goods and services, friends and relatives etc. There are defined tools and techniques to improve such access at the same time attempting to mitigate adverse environmental and social impacts and reducing traffic congestion. Urban areas with "sustainable" transport networks and infrastructures are claimed to be vibrant, liveable and sustainable cities (Lautso et al., 2004).

Transport sustainability enhances a healthy environment, supports society's standards and strengthens the economy by changing paradigms, giving priority to non-motorised and public transport and avoiding unthinking car use. It is easy to have an urban plan with a focus on "modern" transportation infrastructure (which tends to mean roads) but it is better to design a city for the public than for cars. Urban mobility and urban planning integrated into comprehensive city and regional planning can reshape urban development. Unfortunately, in developing countries in particular, the possible role of urban planning in changing travel behaviour has never been considered because urban planning professionals have not been given any kind of commanding role in influencing transport policies. Often in developed countries as well it appears that transport policies are similarly heavily weighted in favour of the car.

Sustainable transport, as an application of the concept of sustainability to transport, originally grew out of concerns to minimise the harmful environmental effects associated with increasing use of transport (particularly automobiles). However, in recent proposals (Song et al 2016) (Ye & Titheridge 2017) (Newton 2017) (Wang & Zhou 2017) the concept has evolved to require a more explicit link to the achievement of the "triple bottom line", rather than purely addressing environmental concerns in the context of transport. In other words, the goal of sustainable transport needs to express how transport integrates, influences and affects broader social, economic and environmental outcomes.

Another key theme in applying sustainability to transport is the need to recognise the explicit links between transport and land use planning. It has long been accepted that both transport

and land use planning are inherently linked and that activities in one area can affect the other. So, for example, the planning of new and existing urban communities needs to take account of the transport infrastructure that supports the community. Likewise, the planning of transport infrastructure needs to take account of the needs of the communities it serves. Accordingly, in applying the concept of sustainability to transport, as an example the work of the transport legislation review in the State of Victoria, Australia, proceeded on the basis of developing an overarching legislative framework based on “integrated and sustainable” transport (Pearce and Shepherd 2011). The problem with this sort of approach is that it seems to ignore the fundamental changes that are likely to be needed to achieve a truly sustainable future and focuses instead on a "business as usual" attitude to transport. This will be insufficient to avoid the negative environmental impacts that the world faces from current practices. The scale of the problem can be seen in the fact that, due to population growth and increases in demand, even major changes in the technical efficiency of transport will result in transport-related emissions at best remaining steady by 2030, not in them falling (Miller and Facanha 2014).

The University of Plymouth Centre for Sustainable Transport (CST 2016) provides a widely accepted definition of a sustainable transportation system that states:

A sustainable transportation system is one that:

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy;
- Limits emissions and waste within the planet’s ability to absorb them, minimizes consumption of non-renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

This definition is open to question in the light of the severe emission reductions that seem to be needed for transport to meet the targets of the Paris Agreement. It fails to consider that

there may be differences between “access needs” and wants, it does not acknowledge that “choice of transport mode” may be a problem (for example if people choose high-emission modes of transport) and it assumes that a “vibrant economy” and limits to emissions can both be achieved simultaneously. In general it reads like a definition designed to avoid offence rather than a call to action.

7.2 Urban mobility and regional prosperity

Many empirical studies have found that urban developments have significant effect on urban mobility, even if residents’ socio-economic factors are taken into account (Frank 1994), (Frank, L.D. and Pivo, G., 1994) (Ewing 1995), (Ewing et al. 1996), (Kitamura et al. 1997), (Stead 2001).

Especially in the developing world, wealthy and upper middle class families are relocating to new automobile oriented gated enclaves, whereas the poor class stay in the distant periphery. This trend often results in concentrating the poor in low lying slum areas far from the nearest markets, commercial centres and job places, with problems of transport to reach opportunities for work. Many progressive city governments like Bangkok, Manila, Seoul and Singapore have proved substantial performance improvement through strategic development that interlinked urban and public oriented transport planning (Hayashi 2004). These metropolitan authorities deal with both traffic congestion and urbanisation through the adoption of transit oriented development by encouraging more sustainable travel modes which reduce car use and congestion which results in more sustainable development, higher land values, increased tax revenues and above all happier public/society.

7.3 Land use policies

Many factors come together to exacerbate climate change related to transport; including those closely related to the built environment such as urban sprawl and rapid urban growth, as well as population growth, rapid motorisation, and lack of proper traffic management systems. For an individual, accessibility to physically unconnected activities such as

workplace, market and schooling is the primary concern (Bertolini et al, 2003). Land use and built form policy interventions, if considered with priority given to accessibility, could have a significant effect on the decision making of an individual's travel patterns by shaping a proposed system of mobility services. Land use policies aimed at reduction of car use by individuals and at transport mode selection related to environmental issues have been discussed in many empirical studies (Newman, et al, 1989) (Calthorpe, 1993) (Williams et al, 2000) (Dixon et al., 2003) (Holden et al, 2005) (Hickman, R. et al 2007) (Chen et al, 2008) (Kelbaugh, 1996). Various studies have emphasised that compact development instead of urban sprawl could have the capacity to reduce growth in vehicle miles travelled and improve behaviour towards achieving more environment friendly transport (Cervero et al, 1995) (Levinson et al, 1997) (Schwanen, T., et al 2004). Other studies (Janic, 2014), (Dowling, 2013) and (Dell'Olio, 2012) have also mentioned that prospective changes in vehicle technology and cultural amalgamation could also reshape future forms of urban mobility.

Increased buying power and economic growth do not seem to be resulting in reduced trips and reduced travel distance. High level of economic growth, increasing individuals' income, expanding urbanization, variations of recreational and social activities, unequal distribution of materials and energy resources and growing number of private cars with increasing population have increased transportation demand (Saboori et al., 2013). Integrated land use transport planning encompassing such diverse areas as land use planning, mass transit corridors, regulation of fuel consumption and vehicles and information technology for drivers' guidance needs to be formulated to assist in bringing about shifting of current passenger load from private to public or to non-motorised transport and to rail and water transport for freight. To make all these measures, both technical and behavioural, feasible and workable, policies and procedures at the macro level will need to be established. The density of metropolitan areas and land use development patterns and availability of transportation means play a critical role in determining energy consumption, travel behaviour and carbon emissions in every society (Brown et al., 2008). A well planned, properly organised, systematically operated, efficiently maintained sustainable transport system requires integrated policies which justify and encourage denser, walkable and transit friendly communities. This could assist in reducing vehicle miles travelled by making possible reliable,

affordable, convenient and energy efficient travel options for commuters, providing alternatives to the private car.

7.4 Built environment effects on vehicle usage

The density of land use and easy access to public transportation have been found to define vehicle miles travelled (Holtzclaw 2004). Another study showed that mixed land use, dense residential areas and job/house balance are associated with shorter trips as well as with less vehicle ownership (Burer et al., 2004). In a comparative study among different metropolitan areas with varying residential densities it was found that a household in a neighbourhood with 1,000 fewer housing units per square mile drives almost 1,200 miles more and consumes 65 US gallons of fuel per year more compared with its peer household with a higher density neighbourhood (Golob & Brownstone 2008). Increase in population is responsible for only a quarter of the increase in VKT driven over the last decades and a large share of the growth can be traced to the effects of a changing built environment, comparatively longer trips and the increasing trend of solo drivers meaning energy is being consumed for development three times faster than would be due to population growth alone. This pattern of development has raised CO_2 emissions from mobility (Ewing et al., 2007). One reason for this trend is generally that incomes have grown and the real cost of vehicle buying has declined making this factor one of the contributors to the growing traffic congestion faced by many urban areas.

Many built environment and travel behaviour studies show that VKT is strongly related to destinations' accessibility and street network design. A number of studies, including (Crane 1996) (Kockelman 1997) (Cervero & Kockelman 1997) (Boarnet & Crane 2001) (Cervero 2002) (Zhang 2004) (Cao et al. 2009) provide empirical results on associations between the built environment and travel behaviour and influence on travel choices. Ewing & Cervero (2001) for example showed that a doubling of density can reduce vehicle trips and VKT by 5%, all else being equal.

Strategies to promote compact urbanism may be effective at reducing per capita vehicle emissions and providing energy savings associated with reduced driving resulting in a better environment for walking and cycling (Frank et al., 2007). Land use patterns and design of the

built environment play a key role in shaping travel behaviours, mode choice, numbers of trips and trip length for each purpose of journey. Compact design does not imply very high density but rather well planned blended urbanism, gross neighbourhood density in the range of 1500 – 4000 persons per square km is a reasonable range for the successful reductions in VKT (Porter et al., 2013). These figures which are converted from a range of 4,000 to 10,000 people per square mile in this paper seem surprisingly low, working out to only 15 to 40 people per hectare or roughly 5 to 13 dwellings per hectare. This can be compared with a study in Australia, a country of low density development similar to the United States, which categorized a gross density of fewer than 11 dwellings per ha as "very low density" (Government of South Australia, 2006, 6).

A comprehensive study conducted in King County, Washington, by Larry Frank of the University of British Columbia (Frank et al. 2007b) found that residents of walkable communities drive 26% fewer miles daily than those living in sprawling areas. Similar types of studies and meta-analysis show that households living in areas with twice the density, diversity of uses and compact design of interconnected streets drive about a third less than residents of low density sprawl. A better built environment can also be better for physical health. Different studies done after 2002 have found significant links between built environment and obesity (Ewing et al., 2007).

Another study from the United States found that the most common reasons given by residents for moving into a new housing project were 20% for new appealing design followed by 17% for nearby public transport stop (Switzer 2002). This shows that even in a car-oriented society like the United States, public transport proximity can be an important factor among other factors like the project price and design and larger community.

7.5 Compact city + sustainable transport = healthy environment

A national economy is collectively based on healthy metropolitan economies which need to make transit options available to their residents. In order to ensure that transportation systems help to provide a competitive edge, every government should consciously aim to reduce energy consumption by improving the people movement and freight transit by

multiple means within and between cities and rural areas. To reduce emissions people and goods cannot stop travelling altogether nor should they but some can change how they travel.

In the U.S.A., the transportation sector has been for some time one of the major sources of emissions, causing one third of the nation's carbon emissions and leading to the United States ranking first among major world economies in per capita carbon dioxide emissions, at roughly double those of the United Kingdom and Germany (Marland et al. 2004) (EIA 2017). Interestingly, in 2008, cumulatively travel had a record decline by more than 42 billion vehicle miles, attributed to very high gasoline prices (US DoT 2008). Hence high fuel prices were driving vehicle owners to use public transport, or it may be concluded that possibly people were changing from cars to public transport.

One approach to built environment design which may be able to reduce transport emissions is Transit Oriented Developments (TOD) which feature higher density and easy access to a transit system serving the urban and surrounding community. TODs offer potentially lower household transportation expenses by reducing energy consumption and traffic congestion. TOD households are twice as likely to not own a car at all, and generally own half as many cars as similar households not living in transit rich metropolitan areas (Arrington, G.B., and Cervero, R., 2008). Research shows that households that live in TODs or surrounding neighbourhoods spend just 9 % of their budget on transportation, while the shares of other spending are more or less equal, as compared to 25 % on transport for those who do not have similar kind of services and are dependent on their private vehicles. For low income families, this 16 % saving in terms of transportation is very beneficial, otherwise transport costs would eat up a lion's share of their annual income (U.S. DoT 2007).

In order to reduce travel adverse effects, higher density urban developments to some extent could have an impact as residents have more chance to walk and cycle to work, school and shops, but only if such developments include these facilities as well as providing housing. It is argued in Transport Oriented Development (TOD) strategy that urban areas with higher densities consume less energy for transportation but for a successful TOD, offices, business and commercial centres, recreational and social locations must be near the city centre and integrated with active (walking and cycling) and public transport infrastructures as well. Hence an entire redesign and reshape of existing structures may be needed which is not workable in many existing cities. Also the current trend in many countries of high rise

residential condominiums may not lead to notable fuel savings until residents choose to avoid private vehicle travel and shift to active and public transport. (Vale & Vale 2013: 67).

7.6 The built environment and Wellington's active & public transportation

Wellington is more like a European city with New Zealand's highest proportion of public transport commuters, 25% of Wellingtonians use public transport for the journey to work, but still a larger number of Wellington commuters use private vehicles to get to work. Ministry of Transport, New Zealand data show that around 94% of the total distance travelled by New Zealanders was by private vehicle as driver or passenger (Vale & Vale 2013 page 65) (MoT 2009) . Using a fuel efficient private vehicle for this movement could help as part of a strategy to reduce severe adverse effects but a real issue is the technical and manufacturing changes which occur as a result of producing the latest model each year – which seems to mean increasing body and engine size and providing more auxiliary systems without improvement in fuel consumption. A chart from the United States compares fuel economy in a range of common cars as shown in Table 7.1, demonstrating that there has been very little improvement and in some cases performance has got worse.

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Table 7.1: Changes over time in the fuel efficiency of cars in the United States (in US mpg urban/highway) from http://i.imgur.com/vdtfb.png accessed 15 Jan, 2018

The same is true of electric vehicles, the 1910 Detroit Electric with Edison nickel-steel batteries offered a guaranteed range of 100 miles (160 km) per charge (Johnson, 2018) similar to the modern Nissan Leaf. It is likely that the best way to reduce emissions from private cars may be less to hope for improvements in technology and more to put emphasis on non-motorized forms of transport.

7.6.1 Local effects; walking and cycling

Walking infrastructure makes it possible to ensure more social space for access to shops and work to or from home. Walkability is the term used to describe measurement of the degree of the pedestrian friendliness of an area. Walking develops definite improvements in health and social interaction as well as reducing air pollution. Walkability and cycling are the basis of a sustainable city that provides useful types of travel to shopping, work and school (Rafiemanzelat, R., et al. 2016). Transformations of the built environment of urban areas are causing the decline of walking. Sprawling of metropolitan areas is leading to more use of motor vehicles which increases VKT associated with vehicle transportation. Walkability is also defined as the extent to which the built environment is friendly to the presence of people for walking, living, shopping, visiting, enjoying or spending time in an area. The mayor of London defined walkability in “Making London a walkable city” as the extent which walking is readily available to the consumer as a safe, connected and pleasant activity (Fitzsimons 2013).

7.6.2 Cycling

The model of cycling given in the “Cycling demand analysis” survey (WCC 2014) shows six classes of Wellington residents - that is Non cyclists (24%), safe cyclists (33%), recreational cyclists (17%), likely cyclists (12%), hesitant cyclists (9%) and dedicated cyclists (5%). Among these classes there are two classes that can be attracted to come forward and switch to more cycling.

The non-cyclists group are those who have never cycled and are highly unlikely to consider cycling. Non-cyclists are more likely to be age 50 plus and commuting by public or private transport is likely to be their preferred option. Safe cyclists are strongly oriented towards cycling and will continue cycling subject to the provision of secure and protected cycling infrastructure. The recreational cyclists group are inclined more to cycle for recreational reasons than to use motor transportation and are strongly influenced by proper cycling infrastructure. A small dedicated group of only 5% are passionate about cycling and unconcerned even if circumstances are not favourable for cycling.

Hesitant cyclists are those who are much more likely to cycle under ideal cycling conditions (that is the condition where they are fully segregated from traffic and have the shortest possible on-road route between two points). For hesitant cyclists, route slope is by far the most important aspect and they will be very unlikely to cycle on either short or long steep sections. Likely cyclists with 12% weighted share are people who are intending to cycle even in the current cycling conditions subject to having a working bicycle and would cycle more often if infrastructure was improved. These aspects show the target population that is most likely to cycle.

Overall, based on various characteristics, respondents indicated on-road infrastructure improvements (55% influence) and more considerate drivers (45% influence) are key factors that inspire cycling behaviour. All these series of characteristics and route choice will take a long time to come to reality particularly if the necessary changes to existing road infrastructure are not paced rapidly. So far the reported barriers as indicated by both cyclists and non-cyclists are lack of well-designed and maintained road network, risk from private vehicle drivers who drive unsafely, poor or improper street lighting and slippery road surface. Many of these, particularly the first, are built environment related factors that could be improved by design.

In order to see how current legislation may be affecting the ability to provide a denser built environment that encourages walking and cycling and reduces the use of private cars, it is useful to consider Wellington's Minimum Parking Requirement (MPR) rule. The rule means developers are supposed to build a minimum number of off street car parks (one or two parks per dwelling) with any new development. While there is no MPR requirement within Wellington's city centre (CBD) this rule is applied to new developments across the rest of the

city (WCC 2016). This MPR should be phased out or at least changed to accommodate EVs only as a vehicle electrification incentive.

Journey to work in the Wellington Region

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Table 7.2: Modes of travel to work in the Wellington region; a comparison between years 2006 & 2013
Source: Statistics New Zealand (www.stats.govt.co.nz) available at https://profile.idnz.co.nz/wellington/travel-to-work?EndYear=2001 viewed on 23rd January 2018.

The space that is gained from residential and commercial plots by not providing parking, rather than creating excess space that incentivises car ownership over other sustainable transport options, can enable greater transport choice that is only possible when it becomes easier for residents to not own a private car. Not providing a mandatory parking space with

each development emphasises that you are not assumed to want to own a car. Walking in Wellington with 17% of journeys to work is already very high at the national level (table 7.2).

In addition there is a need to enhance safe and convenient tracks to develop a cycling trend by combining increased public motivation as well as supporting infrastructure. At the same time there is a need to promote car/ride sharing services that could potentially free up parking space. Recent Australian research shows that a fully operated car sharing vehicle can remove up to 10 private vehicles from city streets with multi benefits of reduced traffic volume, fuel saving and less pollution. A similar USA study shows such a sharing program can remove as many as 15 cars from the road (PBA 2015). Lower population density residents are less likely to walk with twice as many (21.5%) obese compared with those who live in higher population density environments (obesity 11.7%). The findings of this study recommend that a walkable environment is attractive for more physical activities and lower chances of obesity prevalence with less driving (Frank et al. 2007). Hence individuals of neighbourhoods in a less car dependent environment, with proximity to CBD and efficient public transport are more physically active than residents of more car dependent neighbourhoods.

7.6.3 Local effects; congestion and light rail

Wellington's "Wall Street" Lambton Quay, with 38,000 people's workplaces is the highest density of employment in New Zealand in terms of workplace address (Auckland Transport 2014). Lambton Quay and Wakefield Street are claimed to be congested with too many buses causing traffic jams in Willis Street and Victoria Street and the situation will be worsened as public transport trips are forecast to increase by 22 percent by 2030. This situation will be even worse when the Transmission Gully motorway opens and 11,500 more cars will be entering onto Wellington roads every morning (GWRC 2015).

Some of the possible options to reduce this congestion are double decker buses instead of existing single decker buses, no doubt this change will increase capacity but commuters' boarding time will be increased which could result in more bus congestion. The operating speed of a bus is affected by its size. A smaller bus/van can usually accelerate and manoeuvre

more smoothly in traffic than a larger vehicle and due to smaller number of passengers its dwell time at bus stops will obviously be less. In the case of buses of larger size and larger commuter numbers the speed is reduced or even negated by the congestion resulting from the large numbers of larger size buses frequently stopping due to the need to pick up and set down commuters. Additional costs for more complex construction of the vehicles, greater headroom in depots and managing other overhead obstructions like utility cables are some of the drawbacks of double deckers (www.ppiaf.org available at https://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/UrbanBusToolkit/assets/1/1d/1d8.html].

It has been proposed to build (Greater Wellington 2015) a dedicated lane electric light rail line to serve the city's most saturated routes from the existing city railway station to Newtown in the first phase and then extend to Miramar and Island Bay. In the next phase it would be extended to Johnsonville and Tawa. Though a light rail network is comparatively more expensive than the bus fleet, because of its carrying capacity of 400 – 500 passengers per vehicle each vehicle could provide service equal to several buses so could be the revolutionary change that Wellington needs. Light rail vehicles are directly energised by renewable electricity (as were the city's trolley buses which were removed by the Regional Council at the end of 2017) which means zero emissions and no diesel released carcinogenic particles into the air. This city needs electrified public transport rather than reverting to diesels. Some additional features of light rail are as follows;

i) On average there would be an 11 minute travel time saving (13 minutes total trip time) with increased reliability between the Wellington Railway Station and Kilbirnie and 7 minute travel time saving (11 minute total trip time) between Newtown and the Wellington Railway Station.

ii) A reduction in private vehicle traffic in the CBD during weekdays as well as reduced air pollution and congestion.

The modern technology has made light rail costs much cheaper reducing the cost difference from the bus network (Greater Wellington 2015).

7.7 Other public transport considerations

An American study found that if a commuter shifts from a 32 km round trip as a single occupant car driver to public transportation he or she can reduce annual CO_2 emissions by 2180 kg per year which is equal to a 10% reduction in overall anthropogenic GHG by a family of two adults in a household with two cars. A potential saving of 30% of CO_2 emissions can be achieved by eliminating one car and shifting to public transportation (APTA 2008). Of course, it all depends on what car and what form of public transport. If New Zealanders opt for public transportation as a part of the solution and start travelling by public transportation they can easily save energy consumption instead of travelling in private vehicles and will also be reducing the country's dependency on imported foreign oil. In a study carried out by UITP, it was found that some collective measures like increasing the public transport speed, priority at traffic signals and reserved lanes/corridors can also achieve substantial results. For example an increase of 5 km/h bus speed on a busy lane can save 20% energy consumption and surely attracts more commuters (UITP 2012). In addition, public transport consumes 3.4 times less energy per passenger kilometre than private vehicles and this gap can be increased more during congestion hours when public transport vehicles have higher occupancy.

Similar to a private vehicle, a bus driver should also adopt an "Eco driving" style to reduce fuel consumption and CO_2 emissions. Smart, smooth and safe driving techniques can give up to 5-10% fuel savings. Some additional features are that as a result of Eco driving culture drivers are less tired and can react more sensibly to avoid accidents, and for the bus it offers increased tyre life, less body wear and tear, and increased gear box and engine life. An 8km bus test trip showed that drivers who had Eco driving training and were using the techniques while driving used the brake 838 times compared to 1,120 times for those who were untrained. A study by Geneva, Switzerland Public Transport services found that 40% fuel saving is possible by such "soft" driving behaviour (UTIP 2012). Eco driving of buses in Geneva directly helps the planet by saving 1,600 tonnes of CO_2 that is equivalent to annual CO_2 emissions from 512 private cars with mileage of 8 litres per 100 km driving 15,000 km per year.

The Wellington region's public transport share is the highest of New Zealand but Vienna, Austria with 36% of public transport against car riding share of 31% of all journeys is one of

the highest shares of any city in the world. The key factor of this higher percentage is that around 96% Viennese are living nearby to a bus stop (UITP 2012).

Although with the highest single motor vehicle ownership (44.7%), the highest no motor vehicle ownership level (13.5%) and the highest level of public transport users, Wellington may be considered to be performing well, overall the use of a private vehicle to reach the workplace is still the preferred mode of transportation across New Zealand (Quality of life project 2007). The majority of employed residents across 12 large cities use private cars to travel to work with the highest level of 72.7% in Manukau to the lowest level of 45.1% in Wellington. To a considerable extent this may be a result of lack of provision of other modes, for example only Auckland and Wellington have a suburban rail network and this limits choice even for people who might wish to choose public transport. Demand for private transport may not reflect a choice so much as a lack of choices.

7.8 Built environment effect on travel behaviour

The built environment can have a significant effect on travel attitudes that frame travel behaviour to establish travel mode (Lin et al., 2017). Sustainable land use planning can help to resolve traffic issues and pollution problems in metropolitan cities through compact urban form to enhance green transportation. A household with private car ownership is more likely to prefer driving than walking and cycling, males especially are more intent on driving private cars and less likely to prefer walking and cycling than are females (Lin et al., 2017). With the highest single car ownership percentage the Wellington Region still needs more emphasis to maintain its higher ranking of public transportation. For example the car loving metropolitan area of Oslo has travel behaviour more positive towards public transportation and more restrictive in regards to their private motor driving (Lin et al., 2017).

7.9 Conclusions

Regional zoning for mixed use areas, so that residences, schools, stores and businesses are closer together to reduce the need for driving and building public transportation, sidewalks,

and bike paths to increase lower emission transportation choices could be of benefit to Wellington. The Moving Cooler study (Urban Land Institute, 2009) found that VKT can be reduced by 2% to 13% based on built environment changes with gross densities of at least 1500 people per square km. Once suitable density exists, it generates destinations close to walk to, and reasonably competitive transit alternatives from a travel time and cost standpoint. The existing Wellington built environment, particularly in the comparatively dense CBD, could be assumed to be able to provide the conditions to promote reductions in VKT by making easier the choice of modes of transport other than private cars and commercial vehicles. In a nutshell, planning policies will need to encourage a built environment which degrades those factors which currently combine to lock in car dependent travel behaviour. It is expected that a large earthquake in the Wellington region which may result from movement of the Wellington Fault could be expected to be of about magnitude 7.5. Because of these geological conditions of the region, densely populated development is not as feasible as elsewhere (Kos 2010). In Wellington, buildings have to be more resilient to earthquake than buildings in other New Zealand cities. Seismic loadings for new buildings in Wellington must be one third higher than the standard for buildings in Christchurch and three times the standard for buildings in Auckland (Langridge et al. (undated)). In Wellington 92% of the population live within 500 metres of a public transport stop so could potentially contribute to reduction of private car VKT if Wellington CBD and the nearby periphery were converted towards greater public transport use (MoT 2018). This can potentially reduce the regional all day travel time delay which is increasing from 0.37 minutes delay per km in 2012 to 0.45 minutes delay per km in 2015 (MoT 2018b) and at the same time it would be helpful in increasing public transport trips share from the current 17.1% of trips to work in Wellington (Mees et al 2010).

A study by Cervero & Kockelman (1997) and a similar study Ewing R. & Cervero R. (2001) showed five factors which make a combined contribution in reduction of vehicle kilometres travelled in total of 33%.

> ***Density*** (population size of a given urban area) has an inverse relationship with vehicle ownership rates and VKT per capita (P. Newman & Kenworthy, 1989).
>
> ***Diversity*** that provides a mix of land use activities such as shops, schools, offices and residential areas which should be situated close to each other can reduce VKT.

Design of regional road networks also influences residents' travel behaviour through patterns which provide access between different suburbs and links to a pedestrian and active transport oriented network.

Destination access measures how easily and to what extent opportunities are available within a given travel time. It is desirable to maximize the amount of opportunities available to Wellingtonians within a given travel time from their homes and other destinations.

Distance Simply increasing access will not reduce VKT if other transport modes which are easy, cheap and time competitive with cars are not available. Distance is a key factor in making other modes competitive

Implementing these five parameters in future regional development planning would assist as evolving approaches in providing support for greater control of increase in private car travel.

As suggested in USDE, (2013:13) a range of 1500 – 4000 people per square km has been found to act as the threshold for the most meaningful reductions in automobile travel but due to geographical and terrain condition as well as the scattered dwellings of Wellington region it is suggested that to achieve a limited 5% of reduction in VKT will be a big achievement in reducing CO_2 emissions through built environment-related changes. In Wellington, 30% of workers commute from peripheral urban areas of Porirua, Kapiti and the Hutt into central Wellington City (Reid P. 2015). In order to support the "say no to private car" culture the optimal density should be 35 people/ha or 6-7 dwellings per acre at minimum (requiring 13 dwellings per ha at New Zealand's average household size of 2.7 people) (Ewing et al., 2002; Newman, 2007)

Energy intensity is strongly dependent on vehicle occupancy. Energy intensity is a measure of the energy efficiency of a nation's economy, calculated as units of energy per unit of GDP (IEA 2014 Edition)]. The more the energy saving rises the more energy intensity is reduced. CO_2 emission from a fuel efficient car is 95 gm CO_2/km (EAMA 2017) and if there are four passengers travelling in the car than per passenger km CO_2 emissions equate to 23 gm of CO_2 per kilometre per person. This CO_2 emission is more or less equal to the CO_2 emission per

passenger kilometre from a diesel urban bus that travels at peak time with 65% occupancy (Vale, 2001). So if bus occupancy is less than 65% than a fully occupied car can be more environmentally friendly than public transport, at the same time a car may be able to provide additional features like convenience with regards to availability, speed, transfer and luggage handling.

In the specific case of this research Greater Wellington Region Council should regularly monitor occupancy rates and needs to increase private as well as public vehicles' occupancy. The New Zealand Travel Survey (NZTS) shows that average vehicle occupancy rate has reduced from 1.75 in 1989/90 to 1.69 in 1997/98 (Sullivan and O' Fallon 2003). This would fit well with research (Vigar et al., 2000; Goodwin et al., 2012) which concluded that instead of following the traditional engineering approach for demand prediction, the available road space should be better managed. The original research by Goodwin et al was carried out in 1989 and provides an interesting comparison with today. Four reasons are given for management of road space - pragmatic, economic, environmental, and engineering. The available road space has to be properly linked to realistic and acceptable amounts of traffic and there should be consistency with all other aspects of transport policy. If the existing road capacity is getting worse then it is a question of building new roads or increasing the capacity of those that exist. Attention should be given first to more productive use, such as improving vehicle occupancy. Construction of new roads should always be within the financial and political constraints or in the case that public transport is not able to provide a feasible alternative. Hence new roads may be required for new industrial and residential developments whereas the provision of new road capacity for car access to existing areas, especially to city centres/CBDs, is not justified. Emphasis needs to be given to improvement of road surface quality, maintenance of potholes, and overall improvement of lighting and associated facilities that are considered in Goodwin et al's research to be more important than the provision of new roads. Instead of new roads being the first option it is more rational to consider the need for new roads as the last option once all other possibilities have been considered (Goodwin et al. 2012)

Chapter 8|Results and discussion

8.1 Light passenger vehicles vision 2050

The conventional internal combustion engine vehicle is involved in creating harmful effects through the emissions resulting from its manufacture, but the majority of its harmful effects occur when it runs over the road. It emits CO_2 from burning of derivatives of crude oil causing air pollution and the use of road vehicles also results in road accidents. CO_2 emissions are directly proportional to the amount of fuel consumed by vehicles and the energy used for their production. The greater the car production and use the more energy is consumed and the more carbon dioxide emissions are created. In New Zealand, the annual VKT trend is direct proportional to car ownership and because of economic growth and higher employment rate, per capita car ownership in New Zealand is 4th highest in the world (MoT 2015) (World atlas 2016). A bidirectional relationship (potential impact of the energy consumption on the environment and economic growth) between CO_2 emissions, economic growth and energy consumption is found (Ang 2010) (Saboori et al., 2014). In the same way carbon emissions from vehicle tailpipes and global climate change from carbon dioxide emissions generated from transportation can be considered a bi directional challenge which could and should be dealt with through a combined technical and behaviour approach. VKT as a measure of the road network is characterised as the pressure road transport puts on the environment. New Zealand's average VKT of around 11,000 km is higher than Norway's and Finland's VKT per person of 7,300 and 9,400 respectively though they have similar demographic characteristics. In New Zealand there is a need for VKT to be curtailed by restricted car use and a shift to active and public transport. Because of their lion's share of 76% in land transportation emissions, LPVs have to be the first targets of measures to reduce fuel burning and emissions. Over 100 years huge amounts of expertise and resources have been utilised in improving the manufacturing, safety, comfort and cost of purchase of the private car rather than reducing its dependency on fossil fuels and the resulting carbon emissions.

A critical aspect of this research has been to estimate the likely size of the region's vehicle fleet by 2050 keeping the same trend for vehicles entering and leaving the fleet as in the

existing situation. As shown in chapter 4 table 4.4, with 1.8% per year growth rate the fleet size will grow to 530,000 private cars by 2050.

In the earlier chapters that is 5, 6 and 7 different aspects of transport in Wellington have been discussed with the focus respectively on technical, non-technical and built environment changes that could be used to reduce transport emissions. This chapter considers possible strategies to be adopted to achieve the estimated required CO_2 emissions level of no more than 250 thousand tonnes of CO_2 emissions a year from the Wellington region land transportation sector.

Light Passenger Vehicles Vision 2050							
Scenarios	**Conditions**	**Fleet**	**VKT million (Projected)**	**Per year per vehicle travel (km)**	**CO_2 emissions per vehicle (gm/km) (Permissible)**	**CO_2 emissions generated tonnes 1000 (Expected)**	**Total CO_2 emissions from LPV tonnes 1000 (Targeted)**
1st scenario	Controlled Carbon Emissions	530,000	2100	4000	75	160	160
	Controlled Vehicle Travelling	530,000	1590	3000	105	160	
2nd scenario	30 % of Electric vehicles	159,000	1111	7000	25	27	160
	70 % Conventional vehicles	371,000	1484	4000	90	133	
3rd scenario	60 % of Electric Vehicles	318,000	2800	9000	25	71	160
	40 % Conventional vehicles	212,000	1000	5000	90	90	

Table 8.1: Light passenger vehicles vision by 2050.

The study here is broken down into the various sectors that make up land transport in the Wellington Region. Table 8.1 presents the results applied to three possible scenarios for Wellington's light passenger vehicles by 2050. In table 8.1 the private car fleet is expected to rise from 286,000 in 2015 to 530,000 in 2050 as a result of economic prosperity and population growth. Three scenarios are presented for assumptions about the amount of private car use and types of engine powertrain. In the first scenario it is assumed that two approaches are followed for conventional vehicles without change in engine type, in order to limit emissions from private vehicles to no more than 160,000 tonnes per year as their share

of the required reduction in total transport emissions. The two approaches are controlled carbon emission and controlled vehicle travel. In the controlled carbon emission approach it is assumed that by 2050 the most fuel efficient vehicles will have average CO_2 emissions of no more than 75 gm/km.

To meet the emissions target even such vehicles, which represent better than the very best of currently available technology for fossil fuel engines, can be allowed to travel only 4000 km per year which means car owners should use their private vehicles on average to drive only 11 km per day. Various policies and regulations for managing are suggested in chapter 9 in order to keep Wellingtonians within the range of 11 km per day. If commuters chose other means of travel to and from work the 4000km annual travel limit would allow one weekend trip of just under 80km.

In the controlled vehicle travel approach a further reduction in car use is necessary if the owner has a less fuel efficient vehicle. Daily travel of only 8km is allowed to a car owner if the CO_2 emission of their vehicle is 105 gm/km. The projected VKT are 2100 million and 1590 million in controlled carbon emissions and controlled vehicle travelling conditions respectively. However, in both approaches the estimated CO_2 emissions level is 160,000 tonnes from light passenger vehicles in 2050. These figures make clear the likely effect of the necessary emissions reductions and the inability of internal combustion engines to form part of an acceptable solution to the need to reduce emissions. Even the very best technology requires very severe reduction in private car use compared with what people consider normal today.

The second scenario for light passenger vehicles is based on the assumption that by 2050 there will be some proportion of electric as well as conventional vehicles. As discussed in detail in chapter 5 the scope and possibilities of acquiring EVs especially in the New Zealand perspective, as it is in national planning to increase renewable power generation capacity, make EVs a feasible option on one hand and likely to be favourable in meeting emissions mitigations. The second scenario proposes a moderate EV uptake by 2050 of 30% of the entire LPV fleet with the rest consisting of conventional fuel efficient vehicles with 90 gm/km CO_2 emissions (representing the best available in 2018) responsible for 133,000 tonnes of CO_2 emissions. Though the share in the fleet of conventional vehicles is 70% there will be car usage restriction of average 11 km per day for fossil fuel vehicles whereas EV owners will have a

liberty of usage close to double that of the conventional vehicles. If the EVs are charged from power generated from renewable sources they are likely to have close to zero emissions, but a provision of 25 gm/km is kept in table 8.1 to allow for not all electricity being from renewable sources by 2050. This means that the fleets of EVs will probably contribute 27,000 tonnes which with the fossil fuel vehicles makes a total of 160,000 tonnes of anthropogenic emissions.

The third scenario is rather more stringent in its assumptions and has more share of EVs than for conventional vehicles with a proportion of 60% and 40% respectively. Again EVs will have liberty of usage up to 25 km per day with emissions share of 71,000 tonnes against less than 15 km per day for conventional vehicles with 90,000 tonnes of emissions. Based on the required reduction in CO_2 emissions there can be no more than total emissions of 160,000 tonnes of CO_2 emissions from the region's light passenger vehicles fleet.

It can be seen that in order for drivers in 2050 to be able to have annual travel that is anything like what they use today, it would be necessary to introduce electric vehicles into the fleet as rapidly as possible. Currently there are only 6000 EVs in the whole of New Zealand (Moodie, 2017). To achieve the necessary fleet penetration in Wellington by 2050 (given the low figure for the whole country and assuming starting from a situation of no EVs in 2018 in the Wellington region) would require annual EV sales in Wellington of around 10,000 a year from now until 2050. New Zealand new car sales in 2017 were 108,608 (MIA, 2018). New Zealand population in June 2017 was 4,785,100 people (StatsNZ, 2018). The population of the Wellington region at the same date was 513,900 (StatsNZ Infoshare, 2018). Taking Wellington car sales as a proportion of national sales based on population size gives a figure for 2017 of 11,664 new cars sold in the Wellington region. The implication of this is that all new cars sold in Wellington from now to 2050 would need to be electric for this scenario to be achieved.

8.1.1 Other ways of travelling

The average occupancy of vehicles entering the Wellington CBD has been undeviating at around 1.38 persons (GWRC 2014). Increasing the number of people in each car could go some way towards reducing emissions if people could be persuaded to adopt car sharing.

In New Zealand up to 50% of the current car trips are less than 6 km (NZTA 2011). This short distance can be easily travelled by motorcycle, scooter or an e-bike or bicycle, the latter two with the added benefits of very low carbon emissions of 15 gm/km CO_2 (ECF 2011). Compared to a four wheel vehicle, two wheel vehicles cover less space on the road, they are easy to park and economical to buy and maintain. In Germany, recently, a stylish fully electric scooter named "Gogoro" was launched as a part of a scooter sharing program. This two wheeler electric scooter featured with digital dashboard and smart phone application can travel up to 96 kilometres at a speed of 45 km per hour. Customers of this scooter service are able to freely swap fresh batteries from kiosks stationed around the city. By this convenient service the maximum number of customers can be benefitted. In Taiwan a similar kind of service called "Rahne" launched last year with low battery power for targeted customers who want rides to last under 10 kilometres (O'Kane 2017).

This motorised mode could also work for Wellingtonians for those who do not choose to cycle or cannot walk as 30% of trips are less than 2 km and 50% of trip legs are less than 6 km as stated earlier (NZTA 2011). For a realistic approach it could be assumed that at least 10 – 20% of the Wellington region's daily commuting could be shifted to e-bikes which could shift by 1000 – 2000 km per annum the travel load of private vehicle travel onto two wheelers. The main incentive towards this mode shift would be that the existing parking space for cars will be made available for two wheelers and this can be complementary for bicycles and e-bikes only.

8.2 Light commercial vehicles vision 2050

Table 8.2 reveals the first part of the other mode of road transportation that is freight, with the light commercial vehicles vision by 2050. The estimated light commercial fleet growth is assumed to double from 36,000 in 2015 to 70,000 in 2050. Similar to the light passenger vehicles vision, three scenarios are proposed for the light commercial vehicles and if successfully implemented the estimated CO_2 emissions level generated from LCVs is 38,000 tonnes. In the first scenario the same controlled carbon emissions and controlled vehicle travel are suggested as were used for the LCVs. In the controlled carbon emissions approach

fuel efficient petrol and diesel commercial vehicles with permissible CO_2 emissions level of 140 gm/km are allowed to run on average 11 km per day.

Light Commercial Vehicles Vision 2050							
Scenarios	**Conditions**	**Fleet**	**VKT million (Projected)**	**Per year per vehicle travel (km)**	**CO_2 emissions per vehicle (gm/km) (Permissible)**	**CO_2 emissions generated tonnes 1000 (Expected)**	**Total CO_2 emissions from LCV tonnes 1000 (Targeted)**
1st scenario	Controlled Carbon Emissions	70,000	275	4000	140	38	38
	Controlled Vehicle Travelling	70,000	210	3000	200	38	
2nd scenario	25 % of Electric vehicles	17,500	140	8000	60	8	38 - 41
	75 % Conventional vehicles	52,500	236	4500	140	33	
3rd scenario	50 % of Electric Vehicles	35,000	490	14000	60	29	38 - 43
	50 % Conventional vehicles	35,000	105	3000	140	14	

Table 8.2: Light commercial vehicles vision by 2050

For a light commercial fleet of 70,000 vehicles with developed fuel efficient engines, the target carbon emissions level will be 140 gm/km and to stay within the target limit each vehicle is allowed per year travel also of 4000 km. The current distance travelled per light commercial vehicle is probably greater than the 11,251 km per year figure for the light fleet overall as light commercial vehicles generally travel a greater distance than light passenger vehicles (MoT, 2017). This means that even with the widespread deployment of more efficient engines the reduction in allowable travel is likely to be more than 60% of the current usage. This approach projects a limit of 275 million VKT to limit light commercial emissions to 38,000 tonnes CO_2. In the controlled vehicle travelling approach conventional commercial vehicles with higher emissions of 200 gm/km have to be controlled to only 3000 km per year per vehicle. This gives a projected VKT of 275 million and 210 million from the controlled carbon and controlled vehicle approaches respectively to control LCV CO_2 emissions to less than 40,000 tonnes.

The second scenario is based on moderate entering into the fleet of some proportion of electrified light commercial vehicles. The electrified commercial vehicles with assumed emissions of 60 gm/km CO_2 are allowed to run around 25 km per day which gives VKT of 140 million. The conventional petrol and diesel commercial vehicles will be limited to 12-13 km per day mileage to keep the total VKT to 236 million and total emissions within the range of 38 to 41 thousand tonnes.

The third scenario is with an increased percentage of electrified light commercial vehicles forming up to 50% of the fleet with liberty of more than 40 km per day and the remaining half being conventional commercial vehicles with around 10 km per day mileage covering 490 million and 105 million VKT respectively. It is possible that CO_2 emissions from electrified vehicles would be lower than assumed, particularly if they are powered by renewably generated energy sources in which case emissions could be reduced to a greater extent which can provide a cover to make up to some extent for conventional vehicles' emissions.

8.3 Heavy commercial vehicles vision 2050

The freight network of the Wellington region consists of roads, railways and sea port infrastructure, road and rail are the two primary freight modes in the region. Wellington's geographical location makes this region a freight hub within New Zealand by providing a bridge for the movement of land freight between the two islands. It is expected that Wellington's economy and population will continue growing in such a way that there will be increasing demand for the movement of freight to, from and within the region. This poses the need to seriously think about the challenge associated with transportation of increased demand with least possible CO_2 emissions. The year 2012 record shows that the region was origin of 0.9 and destination of 1.7 billion tonne-km of freight movement (NZTA 2014). For the estimated fleet of 14,000 trucks in 2050 from 7,700 trucks in 2015 in each of the heavy commercial vehicles scenarios the targeted level of CO_2 emissions is 50,000 tonnes. Table 8.3 shows the proposed scenarios to achieve this emissions target from this mode of transportation.

Heavy Commercial Vehicles Vision 2050							
Scenarios	**Conditions**	**Fleet**	**Billion tonnes km**	**Per year per vehicle travel (km)**	**CO_2 emissions per vehicle (gm/km) (Permissible)**	**CO_2 emissions generated tonnes 1000 (Expected)**	**Total CO_2 emissions from HV tonnes 1000 (Targeted)**
1st scenario	Controlled Carbon Emissions	14,000	4.3	18000	200	50	50
	Controlled Vehicle Travelling	14,000	4.3	8000	450	50	
2nd scenario	Moderate Controlled HV entering	10,000	4.3	17000	300	51	50
3rd scenario	Strict Controlled HV entering	8,000	4.3	16000	400	51	50

Table 8.3: Heavy commercial vehicle vision by 2050

As in Tables 8.1 and 8.2 the two approaches of the first scenario deal with carbon emissions and vehicle travel control for heavy commercial vehicles. In the controlled carbon emissions 14,000 fuel efficient trucks with 200 gm/km CO_2 emissions and 18,000 km annual travel per vehicle are allowed to run more than 50 km per day and travel 250 million VKT per year. In the controlled vehicle travelling approach conventional trucks with 450 gm/km are limited to 22-25 km per day to keep VKT up to 110 million km.

Different to the light passenger and light commercial vehicles, the second and third scenarios for heavy commercial vehicles are based on moderate and strict policies respectively regarding new heavy vehicles entering the fleet. In the moderate controlled HV scenario the regional fleet size is restricted to 10,000 trucks. In that situation, heavy vehicles with 300 gm/km of CO_2 emissions are allowed 17,000 km per year mileage to keep VKT up to 170 million km at around 48-50 km per day running. However if there is no significant improvement in fuel efficiency and no reduction in CO_2 emissions is observed from heavy vehicles then fleet size is further reduced to keep it to 8,000 trucks with per day running of around 45 km which gives an annual travelled distance of 128 million km. In each scenario the CO_2 emissions from heavy commercial vehicles are estimated to meet the limit of 50,000 tonnes. In each scenario it is expected that the Wellington region's freight tonnage is expected to increase to 4.3 billion tonne-km that will need to be transported with the likely

available fleet by 2050 in each of the three scenarios and without further increase in truck vehicle kilometres travelled.

8.4 Wellington region bus transportation Vision 2050

Regional public transportation as part of the total land transport system has been discussed in chapter 6. Wellington regional bus share of commuting travel is the highest in New Zealand in spite of higher fares than Auckland and Christchurch and a lower perceived customer services level. But still there is room to increase bus commuting from 24 million trips in 2015 to 42 million. Increase in bus boarding by 2050 is also likely due to the fact that short journey trips will be increased as private car owners will shift to bus riding as a result of necessary limits on private car use and increase in population and changes in the built environment will result in increased boarding.

Wellington Region Bus Transportation Vision 2050								**CO_2 emissions**
Year	Fleet	Bus Travel Per Capita (km/head)	Passenger Boarding (million)	Passenger km (million)				
2000	456	44	19	134				6972
2015	770	50	24	169				6964
2050	1000	64	42	288	CO_2 emissions per passenger km	CO_2 emissions (tCO_2)		
Bus fleet 1000 with 288 million passenger km					(Diesel 0.2kg CO_2/Passenger km)	57600	300 – 57,600	300
					(Electric Powered 0.03kg CO_2/Passenger km)	8640		
					(Renewable Electric Power 0kg CO_2/Passenger km)	300 (taking 0.001 kg/passenger km)		

Table 8.4: Wellington region bus transportation vision by 2050

Table 8.4 presents an overview of bus transportation by 2050 when the bus fleet will have increased from 770 in 2015 to 1000 in 2050. Per capita bus travel is not only assumed to increase from 50 km per head to 64 km per head, passenger km will rise from 169 million km to 288 million km in 2015 and in 2050 respectively. Further discussion on possible strategies to increase the bus passenger km and passenger boarding is given in chapter 9.

Chapter 6 briefly discusses the transition of GO Wellington's network of trolley bus routes from electric power to diesel buses. As stated by the Wellington Regional Council the replacement diesel buses are an interim arrangement to make the transition to a fleet of battery electric buses. It is presumed that these new electric buses, as it is planned, will be powered by renewable generated energy so that this will minimise the CO_2 emissions from buses to less than 300 tonnes. The strategy for this mode of transportation in terms of technical changes is relatively easy but substantial efforts are required to undertake to move the public from their private vehicles to buses and other public transport modes such as rail.

8.5 Wellington regional rail transportation vision 2050

In the rail mode of transportation efforts are required to increase passenger boarding to every possible extent rather than changes in technology and/or increase in fleet size as proposed in other modes of transportation. This is because the existing fleet of trains in Wellington is already fully electric and powered directly from overhead lines which is more efficient than charging and discharging batteries Table 8.5

Wellington Region Rail Transportation Vision 2050					
Year	Passenger Boarding (million)	Passenger km (million)	Average Per Capita Travelling (km/head)	Average Per Person Travelling (km)	CO_2 emissions
2000	10	242	23.1	24	12265
2015	12.8	305	26.7	24	10980
2050	20	468	30	20	8000

Table 8.5: Wellington region train transportation vision by 2050

Based on technological developments in train engine technology, it is assumed that future train engines will be more environmentally friendly and energy efficient. Substantial

changes/modifications in engine and bogies will significantly change the overall weight of the train resulting in lower CO_2 emissions in addition to effective signalling and rail tracks improvements (available at https://www.diva-portal.org/smash/get/diva2:943415/FULLTEXT01.pdf) (http://www.railway-energy.org/static/EnergyEfficiencyTech.pdf). For example by 2050 it would be possible to replace the diesel trains which operate currently on the Wairarapa line. All of these changes are assumed to make it possible to reduce rail-related CO_2 emissions from 10980 tonnes in 2015 to 8000 tonnes in 2050.

8.6 Consolidated overview "Wellington Transportation Vision 2050"

Table 8.6 presents a consolidated overview of the Wellington Transportation Vision for the year 2050 for each land transportation mode.

Consolidated Overview of Wellington Transportation Vision 2050			
Transportation Modes	CO_2 emissions/km (gm/km)	CO_2 emissions	Achievable Target CO_2
Light Passenger fleet of 530,000 vehicles	25 – 105	160,000	250,000
Light Commercial fleet of 70,000 vehicles	60 – 200	38,000 – 42,000	
Heavy Commercial fleet of 14,000 to 8,000 vehicles	200 – 450	50,000 – 52,000	
Bus fleet 1000 with 288 million passenger km	0 – 200 gm/Passenger km	300	
Rail average boarding 20 million	10 – 17 gm/Passenger km	8,000	

Table 8.6 Consolidated overview of transportation vision 2050

Table 8.6 shows each mode of transportation in terms of its CO_2 emissions permissible share and total level of 250,000 tonnes to be achieved by 2050. Table 8.6 also shows the range of emissions per km for a number of vehicle types. Technology will not be enough to maintain the existing level of transport provision. However, a combination of more walking and cycling (either pedal or electrically assisted), increased use of the existing public transport system and more car sharing would be sufficient to achieve the targeted 250,000 tonnes emissions from land transportation. Maximum car sharing in terms of full occupancy would make it easier to achieve the reduction target as would greater fuel efficiency and the introduction of EVs as well as converting the entire public transportation system to run on electric power supplied from renewably generated energy.

The main feature of the first scenario is that focus is given only to the likely possible improvements in the overall engine fuel efficiency of LPVs with conventional engines using oil. In the second scenario for LPVs the entering of EVs in the region is in stages of 2% of the fleet by 2020, 10% by 2030, 20% by 2040 and 30% by 2050 whereas in the third scenario this gradual entering is less conservative. It starts similarly, that is 2% by 2020 and then 10% by 2030 but then is assumed to reach 30% and 60% by each subsequent ten years period up to 2050. New Zealand electricity generation will move in the future from 85% which is already high by world standards, to 90% renewable, which makes EVs a much better option than conventional engine LPVs. In a country like New Zealand, life cycle CO_2 emissions per vehicle kilometre travelled (VKT) are claimed to be 86% lower for EVs compared with petrol vehicles (Underhill, 2014) that is 21 gm/km of CO_2. Energy supply analysis shows that, in New Zealand, per kWh electricity costs $0.17 and an EV costs $0.03 per km against petrol price of $2.10 per litre and average running cost of a conventional vehicle is more than 4.5 fold higher at $0.14 per km (Ross, 2014) which makes this an attractive option. Though not confirmed, EV maintenance is estimated to be 30% less than for a conventional LPV (McEwen, 2014). One of the arguments that has been given in the past is about EVs' mileage. Since 2014 due to increased battery capacity, driving range has increased from 100–200 km mileage range during 2011-16 to over 450 km which is near to the driving distance for conventional fuel vehicles.

Hence, the assumed 530,000 LPV fleet in 2050 consists of a mix of fuel efficient compact designed light weight fossil fuel cars plus EVs with a combined range of 25 to 105 gm/km of CO_2 emissions which gives 160,000 tonnes of CO_2 emissions.

The retail price of the entry model of some of EVs, for example the Hyundai Ioniq EV is around $60,000 ($66,000 for the "Elite" version) while a replacement battery costs NZ$9,000 and presumably this should continually decrease with increase of scale and advancement (EERE (undated)). EVs could be promoted financially if government were to provide incentives. For New Zealand, Norway with the highest EVs per capita in the world, is an exemplary country where Norwegians receive incentives from their government like tax exemption, free parking and access to transit lanes.

During the period of 2000 to 2015 the growth rate of light commercial vehicles was 1.9% per year which gives 70,000 light trucks and vans by 2050 keeping the same trend for vehicles

entering and leaving the fleet of the existing situation. The current distance travelled per light commercial vehicle is 11,250 km per year as obviously light commercial vehicles generally travel a greater distance than LPVs. This means that either a drastic reduction in travel is needed, likely to be more than 60% of the current usage, or widespread deployment of electrified light trucks is required. But preferably if fleet growth is controlled to half of the growth rate it has been shown in the past through the use of more efficient origin and destination management of trips and the development of light weight (10% reduction in vehicle weight can give 7% fuel saving (EEA 2006)) and fuel efficient vehicles and controlled vehicle travelling could make it possible for light commercial vehicles to be limited to 38,000 tonnes of CO_2 emissions. In an EU study (OECD/ITF 2017), it is projected that vehicle mass reduction can reduce CO_2 emissions by 18% and fuel efficiency can reduce emissions by 21% as part of moves towards the EU decarbonisation target and the same strategy should also be considered in the New Zealand perspective. Alternatively, the entering of battery electric light trucks would definitely be a good option if annual travel is not controlled. In this case, the entry of electrified commercial vehicles is in phases from 1%, 5%, 15% and 25% in the moderate second scenario and 2%, 10%, 30% and 50% in the third scenario by 2020, 2030, 2040 and 2050 respectively. A 50% share of battery electric light commercial vehicles will have the added advantage of more allowance of annual travel of 14,000 km which is more than the existing per year light commercial VKT with the additional benefit of reduced CO_2 emissions.

The permissible CO_2 emissions target level from heavy vehicles by 2050 of 50,000 tonnes is primarily based on the strategy “Less heavy vehicles less CO_2 emission”. The heavy vehicles travel record of New Zealand shows around 2000 km decrease from 24,253 km to 22,335 km from 2001 to 2010 and it is estimated that if this trend continues until 2050 it will give heavy vehicle travel of around 17,000 km per year. This per year travel is well suited to estimated fleet growth rate and the targeted CO_2 emissions level if per km emissions are limited to 300 – 400 gm/km. This would need to be associated with a policy framework of gradual shifting of freight cargo load from road traffic to the railway network under mandatory obligations. To give some idea of the benefits of rail transport, for European railways CO_2 emission from passenger rail is 41 gmCO_2/passenger km while for freight rail it is 21 gmCO_2/tonne-km (CER 2016). Given the continued improvement in truck technology it can be said that in the near future conventional heavy vehicles with CO_2 emissions of around 300 gm/km will be easily

available (21st Century Truck 2013) but this is still more than ten times the figure for rail freight transport.

The commonest form of public transport is the bus which offers a cheaper and "greener" way of meeting transport needs, is cooler on the environment and lighter on traffic flow. Maximizing the bus occupancy means lowering the emissions per passenger and also less private car travel. Public transport not only brings social and economic development but also consumes 3 to 4 times less energy per passenger per kilometre while large numbers of people commuting by bus use much less road space than if each person were in a private car. Especially in the existing case where Wellington Regional Council is committed to switching its bus network to fully electric buses powered by renewable sources, a combination of subsidised fares, free bus passes for employees, well connected network and more comfortable bus fleet and services could ensure boarding of 42 million passengers per year using a fleet of 1000 buses with assumed 300 tonnes of CO_2 emissions by 2050.

Between 2000 and 2015 there was a 2.8 million increase in train boarding whereas the annual decrease in train related CO_2 emissions over the same period is 1.7%. The figures for 2000 and 2015 show 50 gm/pass-km and 36 gm/pass-km respectively for Wellington's electric trains. The greatest train usage in Wellington is electric but diesel train services operate over the Wairarapa Line. Assuming an increase in line with the current trend and some additional attractiveness given to this component of public transport with increased services and routes, the passenger boarding is expected to increase to 20 million per year and 468 million passenger km. It is assumed that average per head travelling will be decreased from 24 km per head in 2015 to 20 km per head in 2050 because of passengers who will become commuters for a shorter distance instead of using a private vehicle. This increased train ridership will give a per head emissions contribution of 17 gm/pass-km.

Planning policies will need to encourage a built environment which actively promotes active transport. The cheapest, healthiest, most environmentally friendly and space efficient way to travel is walking whereas the fastest (for shorter distance), good exercise and least expensive way to travel by vehicle is cycling. The role of these two components of active transport has always been critical in a developed and healthy culture. By changes in the built environment and in human behaviour it would be possible potentially to shift about 50% of the current car traffic load given that currently almost half of the regions' car travel trips are under 6 km long

(NZTA 2011). Increase in VKT driven is greatly affected by changes in the built environment that shape travel attitudes in the form of requiring longer trips, for example, the move from local shops within walking distance to large retail centres on the edges of cities . Hence, the design of the built environment can make a difference to transport emissions, the move to large retail centres is no doubt driven by the profit motive but it certainly results in changes to the built environment.

Chapter 9 | Future prospects and recommendations

9.1 Wellington region's future prospects

"Where there is a will there is a way"

(Pauline Kael, American Critic and Author,

http://thinkexist.com/quotation/where_there_is_a_will-there_is_a_way-if_there_is/218347.html)

The aim of this research is to see what combination of transport technology and/or transport behaviour could be most effective in achieving more sustainable transport in the Wellington region to meet the requirements of the Paris climate agreement, to which the New Zealand government is a signatory. To achieve ecologically viable long-term existence of human society on the Earth, it must be clear that there is no single way or technique which provides the necessary control of emission reductions, nor one sole policy that can bring them about from the transportation sector. Achieving sustainable reductions of CO_2 emissions up to the magnitude required to meet the Paris Agreement demands a comprehensive short as well as long term strategy, strongly supported by the public as well as by politicians and strengthened where possible by rapid technological as well as social progress.

Sustainable transportation systems can make a great contribution to the healthy environment, social strength and economic prosperity of the communities they serve. The advantages of increased mobility need to be measured in comparison with the environmental, social and economic costs that the transport system poses for society. This is not always straightforward, for example, energy-environment-efficient vehicles may be environmentally friendly and cheaper to run but the ownership of such a vehicle may then tempt the owner to make more vehicle trips hence creating more volume of traffic on the roads and traffic congestion as well as resulting in less energy saving. In a similar way a vehicle may have lower operational emissions but higher manufacturing emissions, meaning that its use may not achieve the desired effect at the global scale. That is why both technical and behavioural aspects should be employed to mitigate the issue.

The situation is developing of how to measure and quantify the positive outcomes of future sustainable transport systems (OECD 1996). Various researchers have correlated the success of results using different models and methods with certain sustainability indicators, but no model seems completely able to encompass the parameters of sustainability (Geurs and Van Wee 2003). The effects of sustainability policies on sustainable transport indicators and outcomes may be compared by systematically examining the economic, social and environmental effects of various rational transport systems.

Economic parameters are those related to economic prosperity like GDP growth, increased per capita income, reduced unemployment rates and more equal income distribution. The latter links to social parameters, which generally are concerned with betterment in standard of life of each individual in terms of factors such as education, health and safety. Environmental parameters are CO_2 emissions and other gases which directly affect human health, noise and air pollution, resource wastage and related factors (OECD 2002).

Increased buying power, economic growth and rapid development of electronic communications do not, from the data studied for the Wellington region in earlier chapters, appear so far to have caused people to reduce their number of trips and or the length of those trips. Ways of integrating transport with other aspects of the community, for example effective strategies that provide compact environments that can be potentially helpful to reduce per capita vehicle emissions, energy consumption and greenhouse gases associated with VKT should be used in transport planning. Further shifting of the current passenger load from oil-based road to non-motorised or renewably powered road transport and to rail and water transport for freight will strengthen the efforts. To make all these technical measures feasible and workable will require policies and procedures at the macro level to be established encompassing matters as varied as land use planning, mass transit corridors, and regulation of fuel and vehicles and information technology for drivers' guidance.

9.2 Timeframe needed for changes

In scenarios 2 and 3 the strategy is based on the assumption of gradual entering of electrified light passenger and commercial vehicles onto the regional roads up to a maximum share of

60% EVs in the light passenger fleet and 50% of electrified light commercial vehicles. By 2020 it is planned that the regional EV share needs to be increased to 2% of the fleet which gives a total of 6,200 EVs out of the then total 310,000 light passenger fleet while the remainder consists of increasingly fuel efficient conventional cars. For the next ten years this percentage is increased to 10% of EVs and 90% of conventional vehicles. It is assumed that after 2020 public awareness would have been developed and the necessary generation capacity and other infrastructure would also have been set up in coordination with public and private partnership. By following the same trend of EVs entering for the next ten years, EVs' share in scenario 2 would be increased to 20% and 30% by 2040 and 2050. On average, per year the EVs growth will be 1% of that year's fleet size with normal increase per year following the trend that has been in the past.

New Zealanders on average take 18 years to replace their car (MoT 2013). The customer perception/feedback regarding EVs' performance and suitability to the regional environment would be helpful in deciding the acceleration rate of entering. This is why in scenario 3, the approach is extreme entering of EVs, which is around 60% of that time's fleet size and the remaining 40% of the fleet to be conventional but highly efficient vehicles by 2050. The entering rate of EVs is twice that of scenario 2 with more or less same per year per vehicle travel as it is now for conventional vehicles.

Similar to light private vehicles, the assumptions adopted in the first scenario for light commercial vehicles are that there will need to be a maximum reduction in vehicle travelling with fuel efficient light commercial vehicles. In the second and third scenarios a percentage of electrified commercial vehicles are assumed to replace the old light commercial vehicles. In the second scenario strategy the assumptions are electrified commercial vehicles entering starting with 1% by 2020 which is 400, 5% by 2030, 15% by 2040 and 25% by 2050 within 33 years whereas for the same duration, in the third scenario the entering percentage is twice that of the second scenario which is up to 50% of the fleet size by 2050 which permits per year per vehicle travel of 14,000 km which is twice the travel limit for conventional commercial vehicles.

9.3 How these proposals are different from the current transport system

Overall the focus of this research is to determine how to accommodate the increased demand for travel due to the Wellington region's increasing prosperity and population growth, while providing 80% reduction in transport generated greenhouse gas emissions by 2050 at the latest or before 2050 if possible and at the same time providing safe, affordable and easy access to home, work and amenities. The first scenario is based on the assumptions that the annual travel limit per vehicle in the light passenger vehicles vision 2050, under the "Controlled Carbon Emissions" condition is 4000 km with average fleet emissions of 75 gm CO_2/km, while under the "Controlled Vehicle Travelling" condition the limit is 3000 km with emissions of 105 gm CO_2/km, a fleet average representing the best vehicles that exist now with no infrastructure or powertrain changes. This scenario makes clear that to meet the Paris target with oil powered vehicles, even with technology better than the best currently available, would require a large reduction in expectations of travel. For the second and third scenarios the assumptions are the introduction of EVs, increasing allowable VKT with less CO_2 emissions. This depends on considerable energy and of course engine type changes. In the second and third scenarios the findings are that by taking a provision of 25 gm CO_2/km emission from EVs, the annual allowable travelling limit is approximately 9000 km and 14000 km for light private and light commercial vehicles respectively depending upon the percentage of electric vehicles entering the fleet. To achieve control over GHGs from regional transportation without changing the vehicle ownership rate as it is (for private vehicles and commercial vehicles), means the need either to limit VKT or improve the fuel efficiency and the type of fuel used and quite possibly to do both of these things. Both these strategies are entirely opposite to what currently exists in the region. Different from the assumptions for light private and commercial vehicles, instead of dependency on electrified heavy vehicles, in the second and third scenarios the assumptions for heavy vehicles are to adjust the estimated tonne-km either by shifting freight onto trains or using available fuel efficient trucks. For heavy vehicles there is the question of trucks entering the fleet at certain percentages and fleet size will decide their annual travelling limit. A fleet size of 8,000 trucks will be allowed each to do 16,000 km per year travelling and 14,000 fleet size will need to be restricted to 8000 per year km. In all the heavy commercial vehicles scenarios, an attempt is made to achieve the targeted CO_2 emissions without powertrain changes (possibly relying on a change

to biodiesel as fuel) and therefore fuel efficiency will play a key role in deciding the fleet size and corresponding travelling limit.

Although there is nothing particularly difficult about understanding the need for a shift to a new policy to avoid CO_2 emissions, as the scenarios demonstrate, the shift requires the will to adopt it, and this is likely to be more difficult because of the scale and nature of the changes that will be required. For example, the first scenario does not require any infrastructural or powertrain changes, hence no financial aspects are involved at the individual and wider scale levels although it assumes that manufacturers will improve the fuel economy of their vehicles to a considerable extent. This scenario offers increased savings at individual and national level in terms of less fuel consumption and subsequently less operational maintenance. However it also requires a very great change in individual travel behaviour to achieve the necessary reduction in VKT, and this is where the difficulties of implementation are likely to occur. Up to now the spoken or unspoken ideological focus of all political parties in New Zealand, as in most other countries, has been on growth, on having more, in terms of transport as in everything else, so to suggest having less travel represents a considerable change. The difficulty of bringing about such change is well expressed in a recent book (Lent, 2017) in the field of cognitive history, which suggests that societies may become patterned through their culture into particular patterns of values and the behaviour that results from these values may be very hard to change.

The necessary changes for Wellington require that the region's transport network should strengthen smart public transport and active transport that make it easy to get around. Because of Wellington's geographical condition if more cars are encouraged into the region's narrow streets, particularly in the centre of the city, that will tend to create more and more congestion. This congestion will slow down traffic and economic flow. The significance of this transport strategy is less dependency on private cars and also to create a springboard for a dynamic, prosperous future for the region as it faces global challenges. This research has also considered other ways to reduce transport-related emissions that are less based on transport-related solutions. Spreading the existing pattern of low density housing, for example, means further sprawl that causes loss of farmland and open space, increases long distance private vehicle driving, leading to more fuel consumption and more CO_2 emissions at the same time as less walking, cycling and public transport.

One of the significant findings of these three scenarios is that they make very clear that there is a need to introduce long term sustainability planning to recognise a changing world and start building Wellington into a world leader in sustainable urban living for our children and grandchildren by making key decisions in the short term about what should or should not be done going into the future. One thing is for sure that business will not be as usual in 2050 and burning of fossil fuels by the transportation system, if it continues, will put huge costs on the economy, the environment and the whole planet.

9.4 Traffic congestion in Wellington; what does it cost?

Low cost sustainable transportation strategies include strategies that reduce the need for travel, that shift trips to lower emission modes like buses and trains, and that provide overall improvement in the traffic system by reducing congestion and other inefficiencies (GCI 2017)http://hub.globalccsinstitute.com/publications/powering-future-mapping-our-low-carbon-path-2050/appendix-a1-transport-sector. A recent study by Greater Wellington Region Council based on the technique used by Wallis and Lupton 2013 found that traffic congestion is a burden on the regional economy.

The cost of congestion is defined as;

> *…the difference between the observed travel time and the travel time when the road is operating at capacity – plus schedule delay costs, reliability costs and other applicable social and environment costs.*
>
> (Wallis and Lupton 2013)

This cost includes the value of time wasted in delays due to longer travel time and the value of people having to reschedule their travel to avoid congestion periods, as well as increased vehicle operating costs and cost of additional GHG emissions due to increased travel time. Reducing congestion would reduce traffic related air pollution which would be a benefit for Wellingtonians. So far no formal estimation has been done to calculate the impact of congestion on traffic generated air pollution but the cost impact has been calculated. The cost of congestion in Wellington is estimated at $680,000 per day from road traffic, of which the car traffic share is 71%, 26% from buses and 3% from trucks. Analysis shows that 74% of the

cost is due to longer travel time, 17% of the cost is due to the need for people to reschedule their travel to avoid road congestion, and 9% of the cost is due to higher vehicle operation costs associated with increased travel time (Dave Grimmond 2017). The annual cost of congestion is around $133 million (195 weekdays a year are considered outside of school and public holidays) and Monte Carlo distribution analysis (a simulation technique that generates a probability distribution around the central estimate) suggests a standard deviation in the range of $98m and $168m. In a business as usual situation with no change in the existing Wellington traffic congestion the projected annual cost of road congestion over the next ten years will increase from $133m to $226m. In order to work out these costs, a figure of 159 gm per km CO_2 emissions was used for private vehicles and 322 gm per km for trucks and buses. The carbon price taken for calculation was $18 sourced from www.carbonmatch.co.nz. (Dave Grimmond 2017)

All day vehicle occupancy figures for the Wellington region are 1.54 passengers per car and 25 and 104 commuters per bus and train respectively. With this occupancy rate against ideally full capacity of 2 to 5 for a private car and 60 commuters for a bus and the high level economic cost of existing congestion the importance of non-technical measures such as increasing the usage of public transport, has increased manifold (WCC 2015). The figures show there is spare capacity in the existing public transport provision which could be employed if people could be persuaded to take it up, particularly for non-commuting trips.

9.5 Foreseeing the Region's Future

New Zealand infrastructure in recent years, rather than giving emphasis to a fast and interconnected rail network as seen in the European countries, China and Japan, has only concentrated on road transport with ongoing extensions to the existing network and the need for regular pavement maintenance (Susanne Becken 2001).

The key aspect of this study is to ensure that in spite of the pressing need to limit carbon dioxide emissions, Wellingtonians can still get around and get ahead. Wellington has been described by the Lonely Planet tourist guide as "the coolest little capital in the world" (New Zealand Herald, 2010). This description is because of its vibrant culture, full of life, its nightlife,

its environment and people friendly public places but certainly not because of its sustainable infrastructure and transport network. Though “Let’s Get Wellington Moving” and other similar projects (see the discussion below) have been introduced they do not seem to have any focus on the need to reduce the emissions from transport. This aspect itself is an issue that gives a gap in knowledge. What is needed is the knowledge of how to make this city not only the coolest but also the smartest (green, sustainable and vibrant) little capital in the world by creating space to accommodate the likely increase in population and traffic demand with much greater focus on low emission modes, which means public and active transportation modes. However, even if there were aspirations towards a low-emissions future, such aspirations have little meaning if robust policy plans are not provided.

9.6 Sustainability parameters

It has been argued that the key sustainability concepts of a transport system should significantly support the following principles (Pearce & Shepherd 2011).

∞ Principle of integration of economic, environmental and social factors: decision making for sustainable development should effectively integrate economic, environmental and social factors.

∞ Principle of futurity and equity: the present generation should ensure that it considers the needs of future generations when making decisions and conducting activities (inter-generational equity); the present generation should also ensure that the needs of all people are met fairly (intra-generational equity)

∞ Principles of protection of biological diversity and ecological integrity: the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.

∞ Precautionary principle: where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not postpone measures to prevent environmental degradation.

∞ Principle of participation and community capacity: all groups should be involved in decision making for sustainability and local communities should be actively engaged in deciding what future they want.

These principles are hard to disagree with, but given the results of democratic elections which frequently do not favour candidates who give priority to environmental goals, it is not entirely clear how participation may align with environmental sustainability. What happens if what needs to be done to reduce emissions does not find favour with the public? This is a problematic issue in all democratic countries, exacerbated by the changing policies which can result from the replacement of one government by another with opposing views. A good example of this in New Zealand is what happened to the "Rapid Rail" plan promoted by the Mayor of Auckland, Sir Dove-Meyer Robinson, as described below on the website of the company formed to build the Auckland City Rail Link (CRL Ltd, undated). In 1963, the Auckland Regional Authority (ARA) commissioned a report from De Leuw Cather & Co. a firm of transport engineers based in San Francisco. As well as promoting motorways the report recommended public transport using buses co-ordinated with an electrified rail network including a new tunnel under the city with new underground stations. At peak times the trains would run at 5 minute intervals. This system was seen as to be in operation by 1970.

"For the rail proposals, there was support from the Norman Kirk Labour government which even commissioned test borings but then came an election and a change of government. In 1975, the newly elected National government of Robert Muldoon killed off the plan. Sir Dove-Myer was voted out of office and his rail dream died. The part of the De Leuw Cather & Co. report adopted was for an expansion of the motorway system."

The City Rail Link now under construction in Auckland will be operating at least 50 years later than it would have been if the original plans had not been cancelled by the incoming National Party government.

9.7 Policies practice

After the establishment of key sustainability principles, one should review the suitability and applicability of those principles to transport planning. Robert Pearce and Ian Shepherd observed that:

"The concept of sustainable transport, as an application of sustainability to transport, originally grew out of concerns to minimise the harmful environmental effects associated with our increasing use of transport (particularly automobiles). However, the concept has evolved to require a more explicit link to the achievement of the triple bottom line, rather than purely addressing environmental concern, in the context of transport. In other words, the goal of sustainable transport needs to express how transport integrates, influences and affects broader social, economic and environmental outcomes. Another key theme in applying sustainability to transport is the need to recognise the explicit links between transport and land use planning. It has long been accepted that both transport and land use planning are inherently linked and that activities in one area can affect the other. So, for example, the planning of new and existing urban communities needs to take account of the transport infrastructure that supports it. Likewise, the planning of transport infrastructure needs to take account of the needs of the communities it serves. Accordingly, in applying the concept of sustainability to transport, the work of the (Transport Legislation) review proceeded on the basis of developing an overarching legislative framework based on integrated and sustainable transport" (Pearce & Shepherd 2011, Page 359).

Any policy guidelines framework that may be introduced to reduce transport emissions needs to apply to all transport authorities and other non-transport interface agencies whose work and activities may not apparently be related but are greatly concerned with the transport system. Hence the area of responsibility of the national transport authority/ Ministry of Transport is enhanced by including interface bodies such as Go Wellington Bus, NZ Bus, Metlink Greater Wellington Public Transport, the Regional Council, and the City Council. Each of the concerned authorities besides doing their primary business, also simultaneously needs to coordinate with the transport authority to achieve the core object. That is why these guideline principles need to be designed, among other aspects, to motivate people positively about the impacts of their behaviour on the global ecology through the transport system. The

system needs to be flexible enough to adjust to different conditions as there is not only interconnectivity within road transportation but also important links with water and air transportation systems. Accordingly the framework's areas of concern need to cover the following areas:

- Non-motorised modes including walking, cycling (and e-cycling)
- Roads and motorised vehicles including cars, taxis, buses, trucks, motorcycles.
- Rail system including passenger and freight trains and light rail
- Waterways transportation including freight ships and domestic vessels.
- International and domestic air transportation.

In order to encompass all these modes of transportation the policy framework components need to include not only direct aspects of the transport modes but also:

- Strategies and working plans
- Well decided and interconnected routes for each mode of transportation
- Timetables and schedules
- Fares and fees system
- Allied services
- Print and social media
- Job opportunities

An integrated sustainable transport system needs to perform at a multidimensional level to link private car transport, public road and light rail transport, freight and goods road and rail transport, passenger and freight ferries, cargo ship transport, passenger and cargo air transportation in a way that can meet the required emissions targets. A policy framework needs to be based on the concept that transport is a vital organ of an overall international policy of moving towards a sustainable environment both locally and globally, as demonstrated by the fact that all nations of the world have signed the Paris Climate Agreement (UNFCCC 2016) (UNFCCC 2017) (UNFCCC 2016b).

9.8 Policy framework

This research is based on the need to develop workable policies and meaningful practices in order to find solutions to the transport emissions problem which work effectively and actively develop coordination within the transport portfolio, that is between road (light passenger, light and heavy freight vehicles, light rail, bus, taxi, three and two wheel vehicles) railways, airways and waterways and their coordination with concerned land use and transport agencies at the national, regional, and local level collectively to meet the objectives of the sustainable transport journey towards a greener future. These proposed policies and practices need to be based on rational principles and logic. A rationally based system is different from principles based regulation in the sense that instead of providing procedural detail, it establishes an action plan in term of guidelines for citizens individually as well as collectively to achieve mutual objectives of the future sustainable transport journey by framing guidelines and assisting authorities to develop a systematic programme (Roseland M. 2000). The prime factor required for these guidelines is their flexibility to be moulded according to the country's prevailing situation.

The Ministry for the Environment, fulfilling the New Zealand Government's reporting requirements under the United Nations Framework Convention on Climate Change and the Kyoto Protocol is required to undertake the following actions;

i) Set emissions reduction targets for the first commitment period to mitigate GHG emissions to their 1990 levels.

ii) Submission of annual inventory of GHG emissions to the UNFCCC.

iii) Publications of regular updates of formulations and implementations of national and regional strategy that contain action plan to facilitate climate change mitigation.

iv) Cooperating with international and regional policies and measures and facilitate public access to information on climate change.

The question is, do any of the proposed behaviours or technologies in the field of land transport as discussed in chapters 5, 6 and 7, have the potential, either singly or in combination, to meet the required emissions reductions, which differ widely from the current

proposed reduction targets? The likelihood seems that technological improvements will not be enough to achieve reductions, as shown for example by the 50 by 50 Global Fuel Economy Initiative, a joint project of the FIA Foundation, the International Energy Agency, the International Transport Forum and the United Nations Environment Programme to reduce the fuel consumption of light duty vehicles (LDVs, i.e. cars, minivans and SUVs) by 50 percent by the year 2050 (FIA/IEA/ITF/UNEP 2009). The report outlining this project shows that the effect of this technological improvement will be the levelling off of the CO_2 emissions related to LDVs (FIA/IEA/ITF/UNEP (2009) Fig 3, p9). This is nowhere near what is needed to meet the Paris Climate Agreement, which requires not a levelling off but a reduction in emissions of at least 80%. Technological solutions were also analysed by Heywood (2008) who came to a similar conclusion. In both cases, increased emissions caused by increased demand for private vehicles and population growth are shown to be negating or overtaking technological improvements. The first scenario for Wellington in chapter 8 came to the same conclusion, even with the best technology internal combustion engine vehicles cannot achieve the required emission reductions while allowing the same amount of annual travel as currently provided by private vehicles.

It is likely that if the Wellington Region successfully achieves the reduction target by 2050 then those policies and action plans which have been used to achieve this can be used by other regions and cities of the developed and developing world for implementation, although what is required is parallel action rather than one country following another. One of the main reasons of possible failure of whatever measures are adopted is that they are only just seen as policy initiatives and often used in isolation. In order for its successful implementation a consolidated and coherent package of different instruments should be initiated (Amin 2008) including Regulatory Instruments (as directives), Economic Instruments (as financial incentives) and Persuasive Instruments (as ethical actions).

There is little hope of reducing emissions unless vehicles are changed, in particular this means giving up the use of petroleum-based fuels. The use of “environmentally friendlier” fuel like unleaded blended gasoline, compressed natural gas, and liquefied petroleum gas will do little or nothing to reduce CO_2 emissions. Using corn based ethanol instead of gasoline reduces CO_2e emissions by up to 48% depending on the source of energy used during ethanol production. Cellulosic ethanol provides a greater reduction of emissions by 115% again

depending on conversion processes (EERA 2017) but biofuels require land which may be needed for food crops so cannot represent a long term solution.

One way to move away from conventional fuels is for their price to rise. It is observed from various studies (Arnott R. and Small K. 1994) (Newman P. & Kenworthy J. 1998) (Litman 2013) (Noland and Hanson 2013) that when the fuel prices are reduced then the public started to use more private vehicles and their average travelling increased whenever fuel prices reduced within their purchasing power. However this would again raise the democratic problem since there are not likely to be many votes in increased petrol prices.

9.9 Proposed planning policies that may help to achieve the scenarios

Wellington could become a people centred, connected, dynamic eco city but a combination of strategic approaches and policy instruments is required for the formation of a "smart" transport sector which could support the policy of avoiding emissions through active transport. The main components of regional smart transport planning are discussed in the following section.

● Access: The main focus of the emissions reduction strategy needs to be to avoid private vehicle use, which is only possible when offices, shopping centres, recreational facilities and utilities services are accessible by walking, cycling and public transport. Regional authorities should give particular emphasis to nearer, cheaper and easier accessibility by non-motorists and by public transport in the preferred areas where such land uses are planned to develop. The development plan and the local transport plan should be closely linked. The Regional Council should also make this possible through traffic and travel demand management planned according to an overall strategy with a focus on transport emissions reduction. Over 24,000 cars, carrying 1.39 people on average, a total of 33,000 people, arrive in Wellington CBD during the morning peak and there are 1.15 million daily vehicle trips per day on the road network across the region. Over 15,000 and 11,000 people arrive in Wellington CBD on the train and by bus respectively during the morning peak (LGC 2015). These facts need to be changed by linking the pattern of Wellington CBD growth and development trends closely

with transport improvements to promote a much greater uptake of public transport use and a corresponding reduction in private car use.

● Mixed Use Design Consideration: Physical design of places should ensure that they can be used safely and securely by all in the community, for a wide range of business, commercial and social purposes and throughout the day and evening. In the design substantial consideration needs to be given to the safety of pedestrians, cyclists, and users of public transport through the design and layout of rights of way, pedestrian crossings, footpaths, cycleway, bus lanes and roads. Mixed use design can provide significant benefit by promoting walking and cycling as primary modes of travel leading to less car dependency. At the same time, mixed use of functions has the potential to reduce the need to travel, as part of balanced development.

● Balanced Development: Because of the Wellington region's geographical and topographical nature, it is necessary to produce broad balanced policies in all ways, both within urban areas and in rural communities, to minimise the need for long distance travelling. Each urban and rural centre needs to be facilitated by reasonable employment opportunities, and by shopping centres and services as well as residences near to a major public transport hub.

● Aged and Disabled services: For aged and disabled people private car use is currently often the only option. The Wellington region and transport authority need to make public transport use easily accessible and free for disabled people and make attractive dedicated walkways and pedestrian crossings that enable them to make use of it. A robust policy needs to be formulated that should work to meet the accessibility needs of disabled and aged people in all kind of developments taking into account their needs.

● Work near home: Central government, Regional and City Councils should work together to seek a comprehensive policy for public and private companies to give a certain chance/percentage of preference of recruitment to local residents.

● Enhanced use of Information and Communication Technology: Information and Communication technology use has been increased manifold in every walk of life. Its role to reduce daily commuting to work or flexibility in working time potentially affects regional daily vehicle trips. Work from home, online shopping and purchasing should be free from extra or hidden charges. Such measures could impact on the need to travel.

● Educational & Medical Institutes: School, colleges and hospitals are major generators of travel and should be centrally located where access by foot, cycling and public transport is possible. A detailed study needs to be carried out for the existing institutes that can possibly be redeveloped by using a similar approach or alternatively public transport routes and cycling facilities can be designed to increase the accessibility of such places.

● Renewable energy generation: Last but not least for any future transport planning and network development, it should be mandatory that energy is supplied from renewable generation.

9.10 The way forward

"Change is happening across the world"

Urban strategist Ludo Campbell-Reid

In this study the main emphasis is given to ways to avoid car use and increasingly to depend on walking and cycling and reduced VKT rather than hoping to rely on improved fuel efficiency. All these efforts require an understanding of the fact that it might be not far off being cheaper to buy a car than the fuel price. For example car financing, free service/maintenance for 3 or 5 years and company subsidized cars given to their employees as a package makes initial cost of the car cheaper than its monthly fuel bill. These kinds of schemes and "perks" and privileges should be banned immediately. A litre of fuel saving by reduced vehicle use, especially from a private car, in terms of sustainability is more beneficial than the same energy saving obtained by shifting to a fuel efficient or even an electrified private car. This is simply because of the fact that a kilometre of motorised travel reduction provides other economic, social and of course environment benefits like reduced traffic congestion, facility costs, road maintenance and accidents. On the other side possibly increased fuel efficiency may stimulate more car travelling, as it would be cheaper to travel, which may intensify associated transportation problems such as congestion, noise pollution, accidents and parking costs while possibly achieving one positive thing which is emissions reduction. If fuel efficiency increases travelling then the emissions reduction will be smaller than intended. This argument does not mean that vehicle fuel efficiency is not required or

that energy conservation is not beneficial. Simply not to use a precious resource today and save it for future generations is always good rather than to think of its maximum usage and then minimise unintended consequences in form of rebound effects from increased usage. Wellingtonians needs to be ready for reduced fossil fuel reserves and increasing fuel prices. Individuals' increased purchasing power as the economy grows over time will tend to worsen the situation, making it possibly more likely that people will wish to choose to buy more private vehicles. This could make it harder to meet these challenges unless people not only choose low-emission vehicles but also choose to do less travelling in them once they have bought them.

The control of CO_2e emissions through the introduction of new vehicles may be possibly effective in the long term, and the switch to EVs, as proposed in the second and third scenarios, does not need a large amount of new infrastructure to be set up although it will require charging widespread charging facilities. Strategies will be required to ensure the smooth entering of EVs as scheduled and to ensure energy for them is supplied from renewably generated power. EV registration in New Zealand has reached more than 4500 and it was planned that the registration should reach 5000 before the end of last year (Huffadine 2017). Though EVs are not new in New Zealand, how to manage their entering in phases and development of infrastructure required for charging their batteries are the key factors.

A report by Greater Wellington Regional Council claims that driving full EVs (i.e., not petrol-electric hybrids) could reduce by 80% the emissions from conventional fossil fuel vehicles. The initial cost of electric vehicles is generally higher but running expenses are less (Sigurd Magnusson 2016). This report states a different version about the LCA of EVs than those discussed in chapter 5. Including all factors including raw material extraction, EV manufacturing and shipping, and manufacturing of batteries used in BEVs, the Energy Efficiency and Conservation Authority (EECA) found that a BEV used in New Zealand emits 60% less greenhouse gases emissions than a conventional vehicle during the life cycle period (Sigurd Magnusson 2016 page 5). No significant difference is observed in the use of precious metal between EVs and other conventional vehicles. It is also assumed that if the country's entire fleet of light vehicles were to shift to electric tomorrow, the effect of this increased consumption of 10% can be easily met by already planned improved renewable energy generation.

In a country like New Zealand where more than 80% of electricity generation is from renewable sources, on average CO_2e emissions per vehicle kilometre travelled (VKT) are claimed to be 86% lower for EVs compared with petrol vehicles. In comparison to 152 gm/km of CO_2e emissions from petrol vehicles, EVs emit 21 gm/km (Mike Underhill 2014), but this will very much depend on which EV and which petrol vehicle, as discussed in chapter 5. The New Zealand Government has a target to boost the share of renewable energy to 90% from 80% by year 2025 meaning carbon emissions from EVs will be reduced further (MoEcoDev 2016). It seems that overall, in New Zealand life cycle greenhouse gas benefits of EVs are positive (Hawkins et al 2012).

A critical analysis shows that, in New Zealand, per kWh electricity costs $0.17 and an EV costs $0.03 per km whereas the petrol price is $2.10 per litre and per km average running cost of a conventional vehicle is $0.14 (Nathan Ross 2014). The Energy Efficiency and Conservation Authority (EECA) states that comparing a 2014 model Nissan Leaf EV with a 2014 Toyota Corolla 1.8 litre petrol car in urban driving, the fuel cost of the EV is equivalent to buying petrol at 30 cents a litre compared with $2.00 per litre for the Toyota (EECA, 2017). On the other hand EV battery replacement costs NZ$9,000 (it is assumed that this should continually decrease with increase of scale and advancement) (EERE (undated)). However, EV maintenance is 30% less than for conventional vehicles but this is yet to be confirmed in due course of time (Rob McEwen 2014) Rob McEwen (2014) “Electric Vehicles: Setting the Stage” Executive Director, Association for the Promotion of Electric Vehicles, APEV Ministerial Round Table Meeting, Wellington, 8 May 2014. EV Batteries after their useful life have 80% capacity that can be used for other environmentally friendly applications (Kelly Detwiler 2014). On the basis of those assumptions, it is calculated that net present value of an EV at 20,000 km per year mileage (average VKT per year is 12,000 km for men and 8,000 km for women), is less than for conventional vehicles. For the driving range from 12,000 km per year to 8,000 km per year, an EV costs $264 and $400 extra per annum respectively compared to a conventional car (Mike Underhill 2014).

9.11 The role of cities

As discussed in chapter 4 section 4.2 the IPCC notes that cities have a critical role to play to keep global temperature increase below 2^0C (GCEA 2014). The city level is more appropriate for policy implementation because of the fact that cities consume more energy and at the same time produce more waste. With 86% urban inhabitants out of a total population of 4,785,100 in June 2017 (Stats NZ, undated) spread over 268,000 km^2 land area makes New Zealand an urbanised country (The World Bank 2015). Though the climate change policies adopted by the New Zealand Government are now gaining priority in respect to economic goals and have seriously started a long term connection between prosperity and the environment (Wilson et al., 2011) (Boven et al 2012) the OECD report "Economic Survey of New Zealand (OECD 2015) among member countries shows below average performance.

Auckland and Wellington between them contributed about half of national domestic product and have an almost similar ratio in population of residents. Given the high ratio of urban population in New Zealand, the capital, Wellington, needs to be committed to reduce carbon emissions and at the same time keep performing its key role in the country's economy, possibly with higher standard of human life (although the UNDP index was already at 0.915 in year 2016 http://hdr.undp.org/en/countries/profiles/NZL). Wellington city has a moderate population density of 38 persons/hectare and the average economic growth of 1.6% per year during the period 2005 to 2015 (the country's average growth was 1.9% per year) is likely to continue to grow (Infometrics 2015) Wellington region's population growth trend is similar to the country and apparently will continue growing at the same pace (Statistics New Zealand 2016). In general, Greater Wellington Regional Council is mainly responsible for planning and strategic control of the transport network, and Wellington City Council deals with land use planning, local roads and walking and cycling facilities (Chapman et al 2017).

The two main travel corridors which come together in the Wellington CBD are the lifelines of the region's commercial and business activities and in combination with its public transport network of electric suburban rail and trolley buses (now decommissioned by the Regional Council) and diesel buses, have formed the backbone of this region. In recent years the private vehicle occupancy entering the Wellington CBD has been steady at around 1.38 persons and public transport trips share during peak hours has reduced slightly. Unsurprisingly, transport

generated carbon emissions increased by 2% (GWRC 2015). So far the Wellington City Council's transport and land use policies show a lack of strategy towards meeting emissions targets even though transport is the largest source of the city's carbon dioxide emissions (WCC 2016). A rough estimate shows by 2043 a 35% growth in number of new housing units especially in the CBD, which means more private, public and freight transport movement over the roads (Dodge 2017). It is rather ironic to read that the Greater Wellington Regional Council's chairman said on the occasion of a new climate change mitigation strategy that *"We have realised that, in the absence of meaningful commitment from the Government, it is up to councils to take the lead in reducing emissions"* (GWRC 2015) given that the GWRC has removed the city's electric trolley buses and replaced them with second-hand diesel buses. At the very least, removal of free parking facilities, increasing car parking prices, increasing the number, routes and bus stops of public transport are some of the options that could be carried out that could support and encourage the mode shift from private vehicles to public transport. The problem of course with these measures, as with all measures aimed at reducing emissions, is that they may not be politically possible to introduce in a capitalist democracy which has to be based on economic growth (which may not be sustainable) and individual preferences (which may not support reduced car travel).

9.11.1 Technical measures

The technical discussion reveals that worldwide development of alternative energy resources is still premature in terms of their widespread use and having many issues to resolve before their practicable use to meet energy demands at a large scale. To rely on a statement for developing a long term strategy related to a global issue which is uncertain at the moment is not supportive. So instead of going in a single direction without considering possibilities and chances of success, at the world wide scale it is crucial to attempt to find policy integration and workable implementation mechanisms which may be able to give a sustainable transport system based on mitigation of CO_2 emissions while still using to some extent non-renewable energy resources and which produces more socially equitable outcomes in the near future. The situation is clearer in New Zealand. Because the major source of New Zealand's electricity generation is renewable energy resources (currently 80%, and more than enough to meet

future demand), it provides an ideal opportunity to shift from conventional to electrified vehicles, to reduce New Zealand's greenhouse gas emissions (MoT 2016). These aspects have been discussed in detail in a previous chapter, but at the moment the NZ Government has to play a role in coordinating an efficient and smooth transition from fuel combustion to engine electrification.

9.11.2 Nontechnical measures

Keeping in view the Wellington region's particular situation, emission free sustainable transport will need to include thorough adaptation in the whole transport system, as well as a completely reengineered vehicle fleet and revised transport operation with a focus on avoiding and shifting traffic, spreading cycling, providing motivation for walking as a means of mobility and also reducing the need for trips by alternatives like teleshopping, phone banking, e-business, etc. High consideration must be given to pedestrian facilities while keeping standards for any road and street design. A consolidated package of Technical as well as Non-technical measures with workable tax levies and a clear policy framework will be essential to help to foster actions to achieve the target by 2050 and to keep to it in the years following.

9.11.3 Driverless cars

The chance to determine to what extent driverless cars will be successful and whether driverless cars create or kill jobs is still premature. If autonomous vehicles become more reliable that could be a threat to 100 million jobs globally that currently require a human behind the wheel. The autonomous vehicle (AV) option certainly might be favourable for young, elderly, and disabled people. A certain amount of emissions reduction by autonomous vehicles is possible as they would reduce congestion by making driving patterns more efficient and avoid accidents that can cause severe traffic jams but congestion benefits of autonomous vehicles are unlikely to occur in the short term. This technology could reduce fuel consumption in the transportation sector by efficient driving pattern and minimized braking. From the perspective of the prospective AV users, such potential fuel saving is dependent

upon a large proportion of AV penetrations on the road (CoAP 2018). This sounds optimistic however, as there is nothing specific to AVs that means they will use less energy or have lower emissions per passenger-km than EVs with drivers. Possible emissions reductions can only be small in scope and nowhere near the level needed to meet the Paris target.

9.12 How much can Wellingtonians save by taking public transport?

Wellington has the highest active and public transport use in the country (WCC 2016). It has been found that if an average Wellington commuter were to give up the car completely and start commuting by public transport they could save $9065 a year and if they refrained from car use during weekdays they could benefit by around $3039 by simply parking the car at home (Andrea O'Neil 2015).

As shown in chapter 6 on average Wellington with 72 trips has the highest number of public transport trips per person per year compared to other New Zealand's large cities 47 in Auckland and 20 in Christchurch but overall driving is still the most preferred method of getting to work with around 40,000 workers commuting by car every day to/from different cities of Wellington region (Andrea O'Neil 2015). But mostly people use cars for their own convenience to get where and when they want to go, going for shopping or pick up/drop off kids from school which is hard to do on public transport. But if it became as convenient as private vehicle or nearer to their home and or shopping centres then at least some trips can be shifted from private vehicles to public transport. Based on the Automobile Associations (AA) and KiwiRail data, average annual operational cost to own and run a car is $12,478 while using public transport the cost is 85% cheaper, an average $1892 per year. If a car owner brings the car to CBD/City centre there are fuel (petrol) and parking costs. From Waikanae to the city centre a rough cost is $7,456 for a small car and $11,406 for a large car. Whereas the same commute by public transport costs $3286 for 11 months' monthly passes that is less than 30% of car transportation expenses. From the near vicinity like Johnsonville the fuel plus parking costs to CBD is $1939 and $2513 for smaller and large car respectively, while for similar distance it costs $1197 by train and $2420 by bus with 11 monthly passes (Andrea O'Neil 2015).

The average trip length of public transport is 23 Km in Wellington which is 7 km higher trip length than in Auckland. In Wellington 55% of people live within 400 metres distance from a public transport stop (Auckland Transport 2014). This close access to public transport shows more room to bring Wellingtonians to public transport commuting. Wellington region's electric buses and trains which are modes of land transport performed well during this period with a decrease in emissions by 25% and 35% respectively. This reduction in emissions is due to energy supply from the electricity generated from renewable sources of energy generation (AECOM 2016 page 9). Though the Wellington regions' trains are new with upgraded platforms and rail tracks the record shows that patronage has declined from 11.9 million in year 2009 to 11 million in 2010 and this patronage has still not reached the 2009 level. In year 2012 the average rail fare in Wellington was $3.37, which was 15% higher than the rail fare $2.92 in Auckland. This gap was increased to 20%, $3.56 in Wellington and $2.96 in Auckland in year 2013. Unsurprisingly with these high rail fares the customer satisfaction in Wellington was lower 59% against 79% in Auckland in 2013.

9.13 Recent Case Studies reveal the lack of awareness of the need to reduce emissions

9.13.1 Case study 1 "Let's Get Wellington Moving"

A recent study "Let's Get Wellington Moving (LGWM)" was carried out jointly by Wellington Regional Council, Wellington City Council and the New Zealand Transport Authority to investigate the outcomes of investment made by government to improve the Wellington Region transport system and to identify a preferred approach to adopt as implementation plan (LGWM 2017). A package of four scenarios were studied with a focus on the area from Ngauranga passing through the city centre to the Wellington Airport. In all four scenarios A, B, C and D the amount of travel by vehicles would not change significantly across the Wellington Region. The analysis of key areas of the potential benefits and impacts of the scenarios, of which some have more than $2 billion costs, sets out the attributes of the transport system, but all four of the scenarios are stated to have "minor impact" overall on vehicle emissions, with the statement for all four being "No significant change to greenhouse

gas emission at a regional level." There will be fewer emissions from inner city traffic but probably that will be offset by congestion on other routes. A small degree of modal shift from private vehicles to public transport results in no significant change to greenhouse gas emissions and in average daily VKT (as a proxy for fuel use and greenhouse gas emissions) there is even a small increase of 1.5% across the Wellington Region. In general there will be no impact on emissions, rather some adverse impacts on built environment and infrastructure. This means that the Paris Agreement and the Kyoto Protocol so far have not formed any part of the strategic approach for future planning considered by the Wellington Regional Council, Wellington City Council and the New Zealand Transport Authority. This is a shocking situation.

9.13.2 Case study 2 "Wellington Trolley buses"

The advantage of trolley buses is that they do not directly cause air/carbon pollution and they operate with low noise. Their acceleration is comparatively better than diesel buses and energy consumption is economical (Goodwin et al., 2012 page 125). In addition they use electricity which in New Zealand means largely renewable energy and because they use power direct from overhead wires they are not subject to the energy losses resulting from charging/discharging batteries.

Recently, the Wellington Regional Council has replaced the electric trolley buses with diesel buses and stated this replacement as a transition to a newer, more flexible, more modern and comfortable bus fleet with hybrid electric and full battery electric buses in the very near future. In fact trolley buses are obviously environmental friendly (WCC 2018) (Paul Bruce 2018) (GWRC 2006). A large difference in CO_2 emissions is found between trolley and diesel buses. CO_2 emissions from a diesel urban bus is 0.25 kg CO_2/passenger-km whereas average NZ electricity powered trolley bus relevant figure is 0.03 kg CO_2/passenger-km and renewable electricity powered trolley bus figure is zero. [Carbon intensity of diesel is 0.24 kg per kWh available at https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html and a kWh is 3.6 MJ, so diesel intensity is 0.24/3.6 = 0.07 kg CO_2 per MJ. Average value for a city bus is 2.80 MJ/pass-km, so emission for a city bus per pass-km is 2.80 X 0.07 = 0.2 kg CO_2 per pass-km. For trolley bus average energy use is 0.87 MJ per pass-km. NZ electricity average

carbon intensity is 0.1 kg per kwh, so electricity intensity is 0.1/3.6 = 0.03 kg CO_2 per MJ available at www.branz.co.nz]. Though this transition is against the objective 9 and policy 9 of the Regional Policy Statement regarding the need to meet the regional energy needs in such a way to reduce greenhouse gas emissions from transportation, the argument given by the Regional Council for the move from trolley buses to diesel buses and then to fully battery electric buses is to avoid unnecessary complications involved in the transformation of the fleet to full electric. Nevertheless the Council should need to consider waste embodied energy by early discarding of these buses which have about 10-20 years of remaining service life. They also require a sufficient budget provision to install battery charging stations for the proposed battery buses and charging and discharging batteries results in a loss of efficiency compared with the directly powered trolley buses. Such kinds of policies should be prepared after careful consideration of all aspects directly or indirectly impact on climate change especially in a situation where domestic transport contribute near to half (47%) of all energy sector emissions (2015) (MBIE 2015).

9.14 Freight transport

Freight transport refers to the total movement of goods using inland transport on a given network. Data are expressed in million tonne kilometres, a unit which represents the transport of one tonne over one kilometre. New Zealand's freight transport increased by 77% from 13,138 million tonne-km in 2000 to 23,290 million tonne-km in 2015 (OECD 2016).

As shown in Table 4.6 commercial and heavy vehicles volume is 7.5% of the total Wellington region's traffic but it causes 20% of CO_2 emissions. This is a serious issue which needs immediate attention. It is observed that this mode of transportation has always been neglected and never been tackled as it should be. Lack of sufficient funding and no strategic way of dealing with rail and coastal shipping has resulted in more and more trucks coming onto New Zealand roads. It was estimated that during the period of 10 years from 2005 to 2015 there was a growth of 1.7 million truck trips on New Zealand's highways making roads more dangerous for pedestrians, cyclists and private vehicle drivers as well as boosting air and noise pollution (MoT 2014 freight). The situation is worsened since each year 55 people

are killed by road accidents involving trucks and more than 850 are seriously injured by trucks (MoT 2014). New Zealand's roads are the dominant mode for freight in terms of both tonnes and tonne kilometres, sharing 91% of tonnes moved and 70% of tonnes-kms (MoT 2014, fig 1 page 2). Another reason to stop further investment on road-based freight infrastructure is that the OECD has forecast a long term GDP decline for New Zealand from 2.7% annual growth in year 2017 declining to 1.8% in year 2042 (OECD 2013). For this year 2042 the total freight movement of Wellington region is estimated to be 16.09 million tonnes and 2.59 billion tonne-km per year (MoT 2014, table 7.32, page 276) with no significant changes in Wellington region's freight flows by origin and destination during the same period (MoT 2014, figure 7.20, page 278). The energy demand forecast from the Ministry of Business, Innovation, and Employment for transport is expecting a steady increase of around 0.5% a year (MBIE 2012).

So far successive New Zealand Governments have been focusing on highways and have left little choice for cargo movements but to opt for heavy road vehicles. A diesel electric train can pull 2000 tonnes of cargo for which 70 trucks are required for movement of an equal amount of freight (KiwiRail 2016). The Road Transport Forum, a body which promotes the trucking industry, states that "Trucks transport 91% of New Zealand's total freight by weight, with 7% going by rail and 2% on coastal shipping" (Road Transport Forum, undated). This high proportion of trucks used for freight is not only increasing carbon emissions, but also increasing road accidents, road maintenance budget and export import cost that ultimately increases unit costs that are borne by end buyers. By moving this heavy vehicle load from road to railways, New Zealand rail will start to return a profit and can stop receiving further subsidies, unlike road freight which is subsidised by the national road maintenance and repair budget. In this way the roads and environment will be safer and cleaner. This was done in the past. In 1936, legislation was introduced preventing trucks from carrying loads more than 30 miles (48 km). Goods travelling a greater distance had to go by rail. This restriction on road freight was extended to 40 miles in 1961 and again to 150 kilometres in 1977. The legislation was abolished in 1983 (KiwiRail, undated).

Surprisingly national planners have a long term goal to increase freight by road transportation by up to 70% by 2042, while it is forecast that freight volume will be increased by 32%, which means another 1.7 million truck trips on roads, within 10 years (MoT 2014 freight, figure 7.21, and page 287) (KiwiRail 2016) which will make New Zealand's roads more dangerous. This

increased number of trucks and freight travelling will definitely increase movement in cities (mostly because their origin and final destination are in large cities). Urban areas will be suffering from more congestion and environmental problems besides creating more risk for road users.

The solution is both potentially simple and realistic as well. A reliable rail system and an efficient shipping network will certainly reduce environmental pollution and freight goods cost. Already the cost involved for transportation of a standard container from Auckland to Christchurch is significantly less by rail and ship than by road (MoT 2008 page 10). Sea freight transportation is an environmentally friendly option as there are 85% less emissions from freight by ship than the same tonnes of freight by truck and 40% less emissions from rail transportation that is 13.9 CO_2 gm/tonne-km by sea, 92 CO_2 gm/tonne-km by road and 22.8 CO_2 gm/tonne-km by rail respectively (MoT 2008 page 10).

Though sea transportation is not encompassed within the scope of this thesis it is worthwhile to highlight its features. Currently rail transportation carries 16% of freight and sea transportation contributed 14% only (MoT 2014 table 6, page 9). It is also estimated that a proper strategic transport network plan in the form of a national logistics package based on port and rail infrastructure development could shift 50% of freight from road to rail and coastal shipping. This would reduce 15% of carbon emissions which be otherwise generated from freight transportation by the next ten years that is 2027. This saving is equivalent to shifting of 300,000 conventional internal combustion engine vehicles to electrified vehicles which comparatively requires more time and effort and also involves 300,000 private car owners to switch from petrol and diesel vehicles to EVs and definitely requires finance to meet this shift, both from individuals and from government to provide the infrastructure required for EVs (Carbon News 2016). Wellington region generated freight volume is 8.41 million tonnes which is surprisingly 3.5% only of the country's total freight and for this the traffic freight generated is 0.90 billion tonne-km. This is currently dominated by road transport and is mostly comprised of manufactured and retail goods that can be easily transported by rail (Deloitte 2016).

One feature of the freight sector is that it is owned and operated by different operators which encourages a competitive environment that pushes the sector towards overall efficiencies and means it can adopt new innovations. Detailed data is now accessible and that information

can be utilised to increase operation output, vehicles operation and maintenance management, fleet scheduling, freight stock management, and overall supply chain management. Traffic flow scheduling can be managed to shift freight during off peak season to save cost and also increase vehicle utilisation. However efficiency is focused on saving money rather than on reducing emissions.

As written in chapter 5 there are strong arguments that as soon as 2020 conventional new heavy goods vehicles are to be 15-17% more fuel efficient compared to what they were in 2014. Though these new HGVs are expected to run over highways by the next three to four years in spite of these improvements in HGVs, rail freight is still the much better option with emissions of 15.6 $gmCO_2$/tonne-km against 140 $gmCO_2$/tonne-km CO_2 emissions from freight heavy vehicles (CER 2016). Though Wellington Regional Council has no direct regulatory control over HGVs and freight movements they could propose to the national government for the formation of policy to make it mandatory for transporters either to go for long haul shipment with rail or coastal shipping.

9.15 The future of Wellington region's transport

The findings of this research are that to meet the requirements of the Paris Climate Agreement transport in Wellington needs to change dramatically. The focus for personal travel needs to move away from private vehicles and towards active transport and public transport. Any private vehicles need to be electrically powered. The focus for local freight movement needs to be towards electric delivery vehicles while longer distance freight needs to move away from trucking and towards rail and coastal shipping.

Chapter 10 |Conclusion

"There is no single solution for solving global climate change, but cities have the ability, capacity and will to lead."

C40 Cities Initiative (WCC 2015)

The purpose of this study is to shape a sustainable transport strategy for the Wellington region that achieves the 80% CO_2 emissions reduction target from the regional transportation sector. While it is possible to devise a strategy in theory, this strategic approach for transforming the current transport system into the desired one will only be possible when this strategy becomes the "moving culture" of the Wellington population.

A transport system that moves more people, goods and services reliably and economically, without more vehicles, created by shaping the patterns of transport infrastructure and built environment that influence density, design, and mix of land uses, can help to reduce the need for car journeys and reduce the length of journeys. This reduction in journeys will work as a cushion to help accommodate the travel trips and vehicles which will be generated by the next generation and following generations. The more demand can be reduced, the more trips can be provided with least congestion and pollution while achieving better access to development and facilities.

In addition several clean road transport fuels and technologies are readily available that can offer air quality and climate change benefits compared to conventional petrol and diesel drivetrains but a compatible approach with least car use and maximum active transport will tend to be the most effective way to reach a sustainable Wellington region in terms of transport. These concluding remarks serve as a link back to the section **1.1 Research Aim** where the "strong model" of sustainability is discussed. Overall this study is an attempt *to focus on future mobility without the compromise of environmental damage to ensure a sustainable Wellington.*

10.1 Answers to research questions

In the context of the need to restrict CO_2 emissions and reduce transport energy consumption, this research addresses the following key question:

If CO_2 emissions have to be restricted to meet CoP21 what will this mean for mobility in Wellington, a small city in the developed world?

Primary Question: Should restrictions on CO_2 emissions mean that Wellington regional transport demand has to be restricted?

Answer: Research to date has not explored what types of transport services might result from the need to cut CO_2 emissions and how these services could work in the existing fabric of the built environment. The research in this thesis has shown that in 2050, based on three scenarios, an assumed increased regional light passenger fleet of 530,000 emits 160,000 tonnes, a light commercial fleet of 70,000 emits 38,000 tonnes, heavy commercial fleet of 8,000 emits 50,000 tonnes, a bus fleet of 1000 buses emits 300 tonnes and rail with average boarding of 20 million emits 8,000 tonnes (this could be reduced if the entire public transport network were powered by electricity with all regional buses converted to electric buses and the diesel rail line to the Wairarapa converted to electric) Overall, land transport would emit a total of around 215,000 tonnes of CO_2 emissions which is slightly more than 80% reduction of the regional emission of 1,236,962 tonnes in 2000. This provides some likelihood that the reduced emissions can be maintained in spite of population increase beyond 2050. The whole strategy consists of a framework of transportation prioritised in the order of choice of walking, cycling, public transport and least possible car use achieved with the maximum use of possible technical changes combined with behavioural changes of avoiding travel where possible, choosing active travel where possible and shifting transport modes to those with the lowest emissions. This framework will need to become the “moving culture” of the residents of the Wellington region.

Secondary Question: Would a technical/technological change reduce CO_2 emissions sufficiently or would a behaviour change reduce CO_2 emissions or are both needed in order to achieve the necessary reduction in emissions?

Answer: Entry into the regional fleet of fuel efficient vehicles and electrified vehicles plus increased use of public transport, cycling and walking are the proposed components to meet the target on or before 2050. No restriction will be needed on Wellington regional transport demand if fuel efficient LPVs, EVs, electrified commercial vehicles, controlled entry of heavy commercial vehicles, high dependency on railways for freight moment, renewably powered battery electric buses and electric trains are the main aspects of future transport in the Wellington region. But for the Wellington region's sustainability the peoples' mode choices need a paradigm reversal with the priority being active transport, then public transport and finally very energy-efficient private vehicles if the other choices are not available. The best approach is this combination of both technical and behavioural changes. On other hand if conventional vehicles without significant fuel efficiency continue to comprise the majority of the fleet then car owners will definitely need to have considerable limitations imposed on their annual private car travel.

This is the kind of transport system that will be required in the Wellington region by 2050 to meet the Paris climate agreement. It is very different from the current transport in the region. The pressing need for future research is to try to determine politically, socially and economically acceptable ways to bring about the necessary changes within the time available.

The theme of this research is to reduce the transportation sector's dependency on fossil fuel consumption to control CO_2 emissions. Reducing transport generated carbon emissions by 80% by 2050 is an achievable goal though very difficult but to make it possible means the need to keep open to new ideas, sustainable technologies and green policies that strengthen the efforts of lowering emissions. Perhaps there is no single best solution to mitigate emissions from land, sea and air transport, certainly it needs a combination of new technologies, cutting–edge public policy and changing how, or even if, we choose to travel. These are not blue-sky schemes but to achieve the necessary emissions reductions true commitment and enthusiastic implementation will be required from government level to individual level.

A low carbon future by 2050 demands a fundamentally different transport system which could range from new technologies such as driverless EVs charging during running on electrified roads and low carbon aircraft designs, as well as radically advanced information and traffic management systems, or known solutions such as electrified railways using renewable electricity as well as greatly increased enthusiasm for, and uptake of, clean non-motorised forms of mobility such as walking and cycling. These efforts are crucial for decarbonised transportation by 2050. Though air and sea transportation are beyond the scope of this thesis the situation with aviation and shipping is unlikely to be decarbonised completely because of growing demand for air transportation and increasing load of TEUs (Twenty foot Equivalent Units – used as a measure of freight volume in terms of the number of 20 foot freight containers (Embassy Freight Services, undated) of freight carried by sea. There is considerable room for improvement in operational efficiency of these modes in the future.

Transport provides access to many aspects of a person's freedom of life; the freedom to live and work in different parts of a city, a country or even of the world, freedom to buy, use and enjoy different products and services, and freedom to trade, socialise, and establish family contacts. The problem at present is that the exercise of these freedoms is restricting the freedom of others to have a future. In terms of transport the insufficiency of urban transport to meet the requirements of sprawling urban development is the main challenge as this pattern of development has encouraged the uptake of individual transport modes and ultimately is causing congestion and environmental pollution in the form of GHG emissions (European Commission 2009).

10.2 The way forward

Sustainable transport supports our quality of life, health, and prosperity and for economic prospects we need to understand when, where and how to travel or to transport goods perhaps most importantly in a manner that is safer for transport users the public and the environment. If we want to successfully enter into the twenty second century then we need to get this right by 2050 as the effects of carbon reductions start to appear several years after their implementation (NAP 2011b). Existing actions have an effect but much more is needed

locally as well as globally. A strong move towards a green society based on sustainable transportation networks is critical to arrest the increasing transportation generated emissions and pollution at regional and international scales.

The bottom line is that this is a long run problem and now is the time to think of what (built environment, technological changes and transport behaviour changes) structure should be adopted by the earliest possible date since this structure will determine energy and fossil fuel intensities for many years to come. It is therefore essential that city planning, urban infrastructure and transport networks be adjusted based on a high and rising fuel price for all transport fuels, in proportion to the environmental damage they cause, locally as well as globally. The entire process of research towards this goal needs to be based on careful collection and critical analyses of data, the generation of hypotheses, the formation of models to establish the entire process and develop predictions, and then the use of observations and calculations to develop appropriate conclusions. Long-term planning for effective sustainable transport cannot be based on prejudices, preconceptions or theories.

In fact most levers that can accelerate action on climate change mitigation lie with central government. For example carbon tax, increase in renewable energy generation sources, policy framework to promote and take up the use of biofuels and how to support and subsidize the entering of electric vehicles into the fleet could all have an impact on carbon emissions and are all actions which lie within the scope of national government strategies over which the region has no control. To a certain extent the region could play a role in convincing central government to adopt such policies and advocating for initiatives and action plans which mitigate emissions across the region and the country as a whole. There is a very long way to go to bring about a move towards the region taking up such a role. At present there is no sign of this happening, indeed the reverse is happening, with the Regional Council recently making Wellington the only city in the modern world to replace electric buses with diesel buses.

At the national scale New Zealand's government is still in the very early stages of the process to transform to a proper Zero Carbon Act. Surprisingly New Zealand's ex-Prime Minster Bill English's declaration during the 2017 election campaign that he saw no immediate need for such an Act and his comment that *"voters do not get out of bed every morning worried about climate change"* reflects government attitude towards this dilemma. The present government

will start setting up an interim Climate Commission in March or April 2018 that would operate for the target of New Zealand being net carbon neutral by 2050 while the Government consulted widely to win cross party support for a Zero Carbon Act. The reason for the delay in setting up of the Independent Climate Commission is argued that prior to this fresh macroeconomic research needed to be done by the new government. The good thing is that the present government is committed to continue their ambition to move to 100% renewable electricity by 2035 and start plans to plant 1 billion trees (NZherald 2017). Business-As-Usual policies of central government are dulling the regional ambitions and weakening their efforts, if they are making any efforts, to adopt more sustainable policies. It is therefore logical to say that city carbon mitigation measures will not be successful until the central government's intellectual attitude changes. The premise is that aspirations have little meaning unless robust policy plans are also provided. The situation is further complicated by the lack of cross-party agreement on the need for policies, meaning that policies may be changed or even abandoned following a change in government. This is one of the problems of a democratic system.

10.3 Concluding remarks

Wellington region's total emissions GHG inventory of 3,562,489 tonnes CO_2 equivalent in year 2015 does not contain substantial agricultural and forestry components as contained in other regions (AECOM 2016). Wellington emits 5.32 tCO_2e per person, the lowest in Australasia (WCC 2016), so it starts from a strong base but needs to transform by investing in climate friendly infrastructure to further promote a compact, healthy and liveable city which must be ready to lead by example changing the way we move to strengthen the greening of Wellington's growth. This city, already enriched by its social, cultural and innovation history, is ready to make a meaningful contribution to the global effort on climate change. All these CO_2 emissions mitigation measures are not simply for climate change or to reduce adverse effects but to ensure a sustainable future by promoting green transport to strengthen the economy to support the growth of the region and overall wellbeing. A pollution free environment provides health and wellness benefits that come from active transit and are part of developing and maintaining a vibrant liveable city that is possible by a compact

development profile. These are all sound arguments to justify why we need mitigation policies to make this *Wellington - the most liveable city in the world.*

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