Dynamic Analysis of Policy Options for Decarbonisation of Road Passenger Transportation in the United Kingdom

By

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ABSTRACT

The transport sector is one of the major contributors to GHG emissions in the United Kingdom, contributing 24% of the UK's total emissions in 2020. In 2021, the united Kingdom's government released a document setting the target to decarbonize the transport sector by 2050. The document highlighted different strategies that are being considered to achieve the set target. The strategies highlighted in the document aligns with the avoid-shift-improve (A-S-I) framework for reducing GHG emissions from the transport sector. The objective of this study is to examine the effectiveness of the policies and strategies for decarbonizing passenger road transport in the United Kingdom by 2050 using the system dynamics method. We develop a cause loop diagram which provides basic understanding of the factors that affect GHG emissions and how they are inter-related. We build on this causal loop diagram to develop detailed stock and flow diagrams which is subdivided into 6 subsystems. We use 1991 to 2020 as our historical period and examine the potential changes in GHG emissions up to 2050. We examine the impact of different policies in line with the A-S-I framework. For the "Avoid" policy, we consider the reduction in the average number of trips per year and the average distance travelled per year. For the "Shift" policy, we consider a shift in the types of new vehicles acquired and registered from diesel and gasoline vehicles to low emissions vehicles (LEVs). For the "improve" policy, we consider improvements in vehicles efficiency (litres of fuel consumed per kilometre) for all the types of vehicles. We also consider the impact of the three policies combined. The results show substantial reduction in GHG emissions in 2050 compared to the base-case scenario. We conclude by noting that even with all the policies implemented, the UK government may not still achieve its decarbonisation target. Further, we note that the implementation of these policies also reduce the amount of government revenues from private transport activities which will also affect the gross domestic product (GDP) of the country.

ACKNOWLEDGMENT

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In the course of my study, I have interacted with several students and staff who have helped me to gain immense knowledge of system dynamics. I thank my supervisor, Prof. Saeed P. Langarudi, for his inputs and support throughout the course of writing this thesis. I thank Dr. Uduak Akpan who extended his knowledge of transport economics and transport sector decarbonisation to support the research and writing up of this thesis.

I have spent these two years away from my family. I thank them for their understanding and support. I thank other people who have made my stay in Bergen eventful.

Finally, I take full responsibility of any errors or omissions in this thesis.

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LIST OF ACRONYMS

Acronym	**Meaning**
BaU	Business as Usual
CLD	Causal loop diagram
CO2e	Carbon dioxide equivalent
GDP	Gross Domestic Product
GFDT	Global Facility to Decarbonize Transport
GHG	Greenhouse gas
IEA	International Energy Agency
LEV	Low Emission Vehicle
UKTCM	United Kingdom Transport Carbon Model
UK-TDP	United Kingdom Transport Decarbonisation Plan

CHAPTER ONE

1 INTRODUCTION

1.1 Background

In recent times, the possible impacts of anthropogenic climate change have become more evident in the form of heat waves, rising ocean levels, wild fires, flash floods, etc. (Trenberth, 2018; He & Silliman, 2019; Williams *et al*., 2019; Fowler *et al*., 2021). Countries are responding to this by developing policies and strategies to decarbonize sectors that contribute substantially to GHG emissions. One of such sectors is the transportation sector which is one of the largest contributors to GHG emissions in the world, accounting for about 20% of global GHG emissions in 2018, but dropped considerably in 2020 due to travel restrictions during the COVID19 lockdowns (Ourworldindata, 2020; IEA, 2022). The transport sector is a critical sector in any economy and contributes substantially to the social and economic development of a country. The transport sector is a complex sector which interacts with many other sectors and socioeconomic variables (especially income, age distribution, and population), and also operates on locked-in infrastructure such as roads and rails. The evolution of transport technologies also affects the sector. The transport sector relies primarily on fossil fuels from crude oil derivatives. Energy consumption in the transport sector is a function of the pattern, frequency, and intensity of transportation activities in any country, i.e. travel demand as well as the energy efficiency of vehicles and occupancy rate of vehicles. Transport demand is influenced by several factors such as the socio-economic activities of a country; demography; cultural factors; land use patterns; quality of infrastructure; the efficiency of available transport services; cost of transportation; lifestyles; etc. (VTPI, 2015). Energy consumption from road transportation is the highest among all the modes of transportation representing over 75% of transport energy consumption and about 67% of this may be attributed to road passenger transport (IRENA, 2018)

Decarbonizing the transport sector implies the reduction in the energy consumption and GHG emissions from the sector. This depends on achieving considerable success in changing the current structure of the dominant technologies used in the sector as well as changes in aggregate travel demand. Reports have noted that achieving considerable reduction in the energy demand and GHG emissions in the sector may be challenging due to the continuing growth in demand for motorized transportation, especially from developing countries due to increase in urbanization and improvement in transport infrastructure (Sims *et al*., 2014; World Bank, 2021). Several countries have proposed policies and programs to reduce GHG emissions in the transport sector. For example, there is the fleet renewal mandate and clean transport investment plan in France; domestic electric vehicle subsidy in Russia; installation of electric vehicle chargers in Canada; electrification of heavy transport in Sweden; among others (IEA, 2022). Developing countries also have policies targeted at decarbonizing the transport sector (Emodi *et al*., 2022). In 2021, the World Bank together with Luxemburg, the Netherlands, Germany, and the United Kingdom launched the Global Facility to Decarbonize Transport (GFDT).

The UK's government enacted the Climate Change Act in 2019 which commits government to achieving net zero emissions by 2050. In 2020, the Department for Transport of the United Kingdom published a report entitled "Decarbonising Transport: Setting the Challenge" (UK Department for Transport, 2020). This was followed by a Transport Decarbonisation Plan (UK-TDP) (UK Department for Transport, 2021) which highlights government's plans and proposed pathway to net zero emissions in the transport sector in the UK. Some of the strategies for decarbonizing the transports sector in the UK as stated in the UK-TDP include: stoppage of sales of new diesel and petrol cars by 2030 and ensuring that all new cars and vans will be fully zero emission at tailpipe by 2035; increasing the share of trips taken by public transportation, bicycles, and walking; promotion of new technologies such as hydrogen fuels; etc. The plan also proposes several strategies for decarbonizing the land-based freights as wells as air and water transportation. The decarbonisation of the transport sector is expected to have co-benefits in terms of improved air quality and reduced noise pollution on the road; improved health and wellbeing of citizens from improved air quality and use of bicycles and walking, more job opportunities; reduced congestions; etc. (UK Department for Transport, 2021). All these plans fit within the Avoid-Shift-Improve framework for decarbonizing the transport sector (World Bank, 2021).

1.2 Statement of Problem

The transport sector is one of the major contributors to GHG emissions in the United Kingdom, contributing 24% of the UK's total emissions in 2020[1],[2]. Road transportation is responsible for 91% of the transport sector emissions while other modes of transportation are responsible for the remaining 9% (UK Department for Transport). Cars and Taxis contributed about 58% of GHG emissions from road transport in 2020 as shown in Figure 1.1. The trend of GHG emissions from cars and taxis is presented in Figure 1.2. It is important to note that amount of GHG emissions from cars and taxis has remained stable over the years but dipped in 2020 due to COVID19.

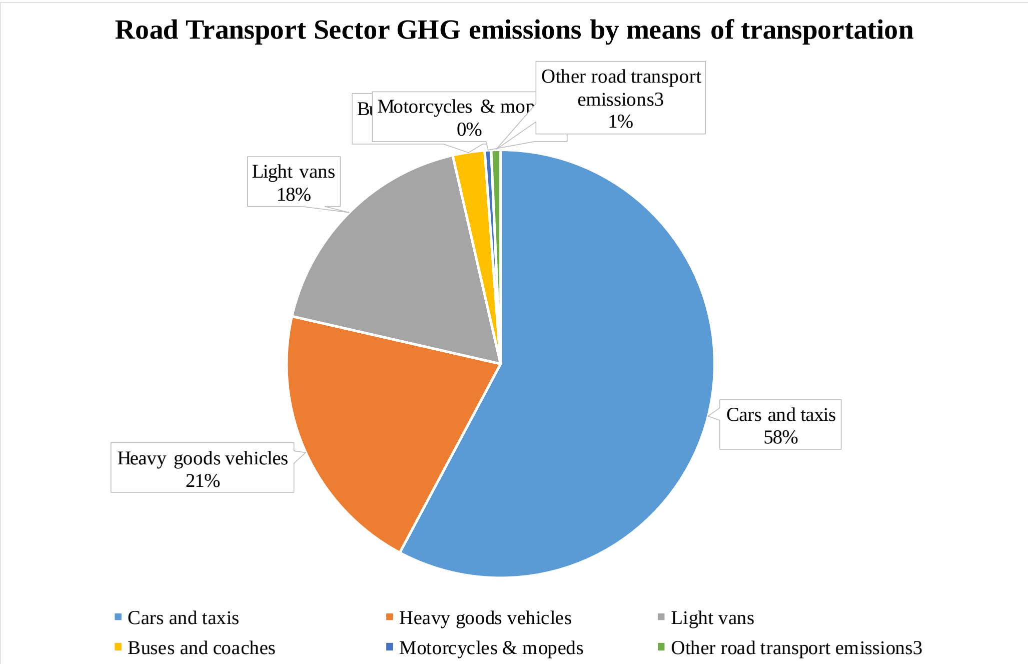

Figure 1.1: Road transport sector GHG emission by means of transportation (Percentage contributions in 2020)
Source: United Kingdom's Department for Transportation

[1] https://www.gov.uk/government/statistics/transport-and-environment-statistics-2022/transport-and-environment-statistics-2022#:~:text=domestic%20transport%20was%20responsible%20for,emissions%20in%202020%20(406%20MtCO2e%20)
[2] https://www.ons.gov.uk/economy/environmentalaccounts/articles/roadtransportandairemissions/2019-09-16

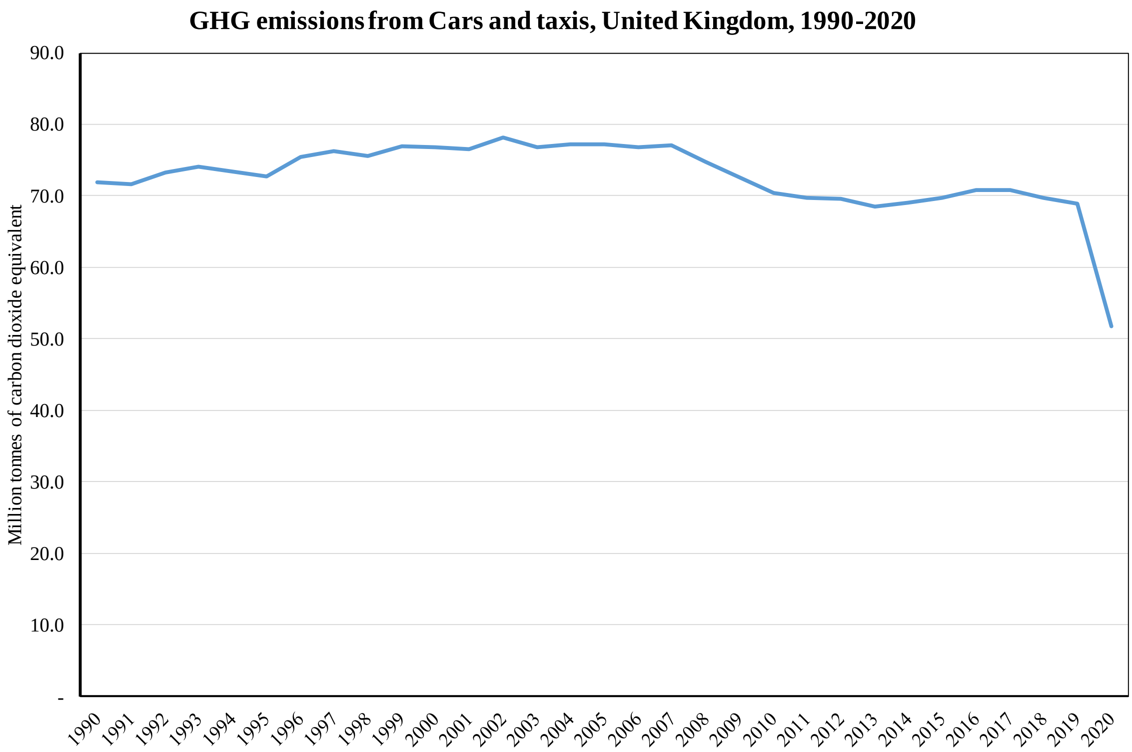

Figure 1.2: GHG emissions from Cars and taxis, United Kingdom, 1990-2020
Source: United Kingdom's Department for Transportation

The problem is that if the trajectory of road transport GHG emissions follow the same trend as seen in historical, the UK government will be unable to achieve its decarbonisation targets by 2050 (future projections are shown in Figure 3.4 in the section on Reference Modes). Consequently, it is important to examine the policy strategies for achieving net zero emissions from road transportation by 2050.

1.3 Objective of this study

The UK-TDP notes that the plans and strategies stated therein will be monitored and evaluated regularly, and updated or revise as need arises. This study will align with this mandate of regular appraisals of the road to net-zero transport emissions in the UK by 2050. The objective of this study is to examine the effectiveness of the policies and strategies for decarbonizing passenger road transport in the United Kingdom by 2050 based on the UK-TDP. Specifically, the following research questions fall within the remit of this study:

(i) How do different variables interact to contribute to road passenger transport energy consumption and GHG emissions?

(ii) Under what conditions (social, economic, technology) etc. will the decarbonisation of the road passenger transport by 2050 be possible)?

(iii) What will be the impact of decarbonisation on the economy in terms of fairness and equity with respect to the economy at the macro and micro level (fairness to people in different income bands, gender, locations, spatial dimension, etc.).

1.4 Significance of Study

This study is significant in many respects. First, it fully aligns with government's plans and strategies for decarbonizing the transport sector by 2050. The outcome of the study may be useful to different organizations involved in transport sector modelling and implementation of net zero policies. Second, given that the "open structure" nature of system dynamics with regards to making modifications on the input parameters and structure of the model, the use of system dynamics implies that changes in system elements can easily be captured alongside different feedbacks, time delays, and non-linearity of causal variables.

1.5 Organization of study

This study will be organized as follows: Chapter One is the introduction while Chapter Two will be the literature review. In Chapter Three, we will present our methodology and details of the model. In Chapter Four, we will valid and test the model and we will present and discuss our results in Chapter Five. Chapter Six will be the conclusion and recommendations

CHAPTER TWO

2 REVIEW OF RELATED LITERATURE

2.1 Review of literature on transport sector decarbonisation in the United Kingdom

Several studies have examined strategies and policy options for reducing energy consumption and GHG emissions from the transport sector in the United Kingdom. Bristow *et al*. (2008) examined pathways to low carbon personal transportation in the UK by 2050. The study tested different policy options including technological development, pricing, the use of public transport, and other soft measures. The study observed that the most effective measures for achieving low carbon transport is a switch from personal motorized transportation to public transport, and also the switch to low carbon personal transportation. The study concluded that it will be difficult to achieve low carbon transport targets even with most dramatic technological advancement unless there is a corresponding behavioural change in transport choices made by individuals. Churchman & Longhurst (2022) examined the social, technical, and political barriers to decarbonising road freights in the United Kingdom.

Brand *et al*. (2012) introduced a transport, energy, and environmental impacts model called the UK Transport Carbon Model (UKTCM) which captured several variables that affect GHG emissions from the transport sector in the UK, including socio-economic variables, lifestyle variables, political developments, etc. The model provides projections on how vehicle technologies evolve over time and how this will affect GHG emissions. Building on the UKTCM, Anable *et al*. (2012) examined how lifestyles and socio-cultural factors affect transport sector energy consumption and GHG emissions. Brand *et al*. (2013) examined the role of car purchase taxes and scrappage incentives in the transition to low-carbon transport system in the UK using the UKTCM. Another model that has been developed still for the purpose of modelling transport sector GHG emissions is the Transport Energy and Air Pollution Model for the UK (TEAM-UK) which builds on the UKTCM (Brand *et al*., 2012). TEAM-UK is a modelling tool which incorporates disaggregated, bottom-up modelling framework and incorporates different scenarios for socio-economic, socio-technical, and political evolution (Brand *et al*., 2012). TEAM has sub models targeted at different factors affecting road transport energy consumption and GHG emissions: travel demand model, household car ownership model, a model for simulating vehicle choice, a model for simulating the evolution of vehicle fleet, and a model for fuel emissions (Brand *et al*., 2012). Brand *et al*. (2019) applied TEAM to examine how lifestyle and socio-cultural changes will affect transport sector energy consumption in Scotland. Brand *et al*. (2020) uses TEAM to examine how transport sector decarbonisation target may be achieved through more ambitious plans. The study examined different scenarios regarding the bans on different categories of vehicles in the UK within the context of technology substation in vehicle fleet and concluded that careful policy designs as well as targeted investments in the development of battery technologies for vehicles will be crucial to reducing political and economic risks. Brand *et al*. (2017) also used the TEAM-UK model to examine the uptake of plug-in vehicles across different consumer segments.

Küfeoğlu & Hong (2020) examined the emission performance of electric and hybrid vehicles in the UK and observed that user behaviour may have a significant impact of emissions reduction from the use of electric vehicles. Hill *et al*. (2019) examined the role of electric vehicles in the GHG mitigation pathway of the of United Kingdom. The study observed that even under accelerated uptake, the impact of electric vehicles vis-à-vis GHG emissions mitigation will be low in 2030 but will steady increase as electric vehicles dominate the stock of vehicles. Berkeley *et al*. (2018) identified several barriers to adoption of electric vehicles in the UK. The implication of this study is that the adoption of low-emissions vehicles is still a matter of consumer choice and even the most aggressive government policies supporting LEVs will only yield result if there is a corresponding change in consumers' perception of the long term benefits of such vehicles. Logan *et al*. (2021) compared the results of scenario analysis for achieving net zero emissions in the transport sector from two methods: lifecycle analysis and TEAM-UK. Byers *et al*. (2015) developed a framework for examining multiple transport, energy use, and GHG emissions pathways in the United Kingdom. The approaches used by these studies differ significantly but usually involve making projections of the number of vehicles under consideration from a base year to an end year and examining the impact of changes in different factors that affect transport demand or energy consumption on GHG emissions.

Lam & Mercure (2021) examined the policy mixes that are best for decarbonizing passenger cars by 2050 in five countries: UK, US, Japan, China, and India. The policy options considered were taxes, subsidies, and different forms of regulations. Based on its findings, the study concluded that creating a system to promote zero-emission vehicles and a disincentive for the acquisition of gasoline and diesel vehicles are critical to achieving decarbonisation targets in these countries. Argyriou & Barry (2021) examined the role of government in promoting public road transportation to support low carbon transition.

2.2 Review of Literature on the application of system dynamics to transport sector GHG emissions

Given the complexity of the transport sector in terms of its interactions among several variables; the fact that the behaviour of some of these interactions are non-linear and create feedback loops; and the fact that some critical variables influencing energy consumption and GHG emissions cumulate over time thereby become stocks, some other studies have adopted methods that can reflect these complexities. One of such methods is System Dynamics (Benvenutti *et al*., 2019; Barisa & Rosa, 2018; Liu *et al*., 2015). Barisa & Rosa (2018) examined policy options for mitigating CO2 emissions from the road transport in Latvia. The study SD model developed by the study decomposed road transport CO2 emissions into 6 activities: transport activity modelling; mode split; vehicle demand forecast; technology distribution; energy demand modelling; and CO2 emission modelling. The transport activity modelling focused on factors that drive transport demand and used GDP and population to make projections on transport demand. The mode split represented the travel mode choices and identified different variables (cost of private cars, accessibility to transport infrastructure, travel time, etc.) as having an impact on travel mode choices. Energy demand modelling examine the fuel consumption of different vehicles types and at different vehicle ages. Akbari *et al*. (2020) examined energy consumption and CO2 emissions reduction strategies for urban transportation in Tehran, Iran. The study disaggregated the components of urban transport into four sub-systems: population, economic, transport, and energy consumption – CO2 emissions subsystems. An interesting feature of the population subsystem is the inclusion of "floating population" which constitute a substantial share of the daytime population in the study area.

Gupta *et al*. (2019) examined the effectiveness of carbon tax on road passenger transport in India. The study considered the time period of 2000 to 2050 for their analysis while using 2000 to 2011 as their reference period. The causal loop diagram developed by the study highlights different factors that affect road transport GHG emissions. Interestingly, there is no return loop from CO2 emissions to any other variable in the causal loop diagram. Han & Hayashi (2008) examine the potential for CO2 emissions mitigation from inter-city transport in China.

Liu *et al*. (2015) examined urban passenger transport energy consumption and CO2 emissions in Beijing, China. The model was also disaggregated into four sub-systems: population, economic, transport, and energy consumption – CO2 emissions subsystems. The study examined several policy scenarios and concluded that a combination of different policies which will include strategies on travel demand management will have the highest impact on energy consumption and CO2 emissions. In their study, (Wang, et al., 2008) identified some feedback loops involving variables such as economy growth, travel demand, number of registered vehicles, traffic congestion, GHG emissions, population, etc. Batur *et al*. (2019) examined the impact of supply-side management and travel demand management policies and strategies on energy consumption and CO2 emissions from urban transportation in Istanbul, Turkey. The feedback loops in the model were similar to those identified by (Wang *et al*., 2008). The study by (Fontoura, et al., 2019) identified 18 feedback loops even though the variables forming the loops are similar to those listed above.

We may observe from this brief review of literature that some studies are country-level studies (Barisa & Rosa, 2018; Gupta *et al*., 2019) while other studies are city-level studies (Batur *et al*., 2019; Liu *et al*., 2015; Han & Hayashi, 2008; Cheng *et al*., 2015; Wen & Bai, 2017; Fontoura *et al*., 2019). City level studies provide more detailed analysis of the specific spatial, demographic and transport-related factors influencing dynamics of urban transportation and often covers all the means of transportation available in a city as well as the population fluctuations that occur within a city on a daily or seasonal basis. City level studies are feasible for cities where data for model validation are available. In contrast, some data are often reported by some countries only at the national level which makes city-level studies not be feasible only when one is prepared to generate relevant data.

System dynamics has also been used for analysing other aspects of the transport sector (Ghisolfi *et al*., 2022; Astegiano *et al*., 2019; Setiafindari & Anggara, 2017; Shepherd *et al*., 2019). A review of some of the applications of system dynamics in the transport sector may be found in (Shepherd, 2014).

CHAPTER THREE
3 METHODOLOGY

3.1 Introduction

System dynamics will be used to develop the model to mimic the reference scenario which is the transport sector energy consumption and GHG emissions. The complex and dynamic interactions among variables that influence road transport energy consumption will be reflected in the model. The study will rely on secondary data for the development of the initial model and model validation and will incorporate several other variables to make the model a good reflection of actual road passenger transport GHG emissions. The modelling will be done using *Stella Architect*. We also use MS Excel to prepare some of the data and inputs used

3.2 The model

We followed the basic steps in system dynamics modelling as shown in Figure 3.1.

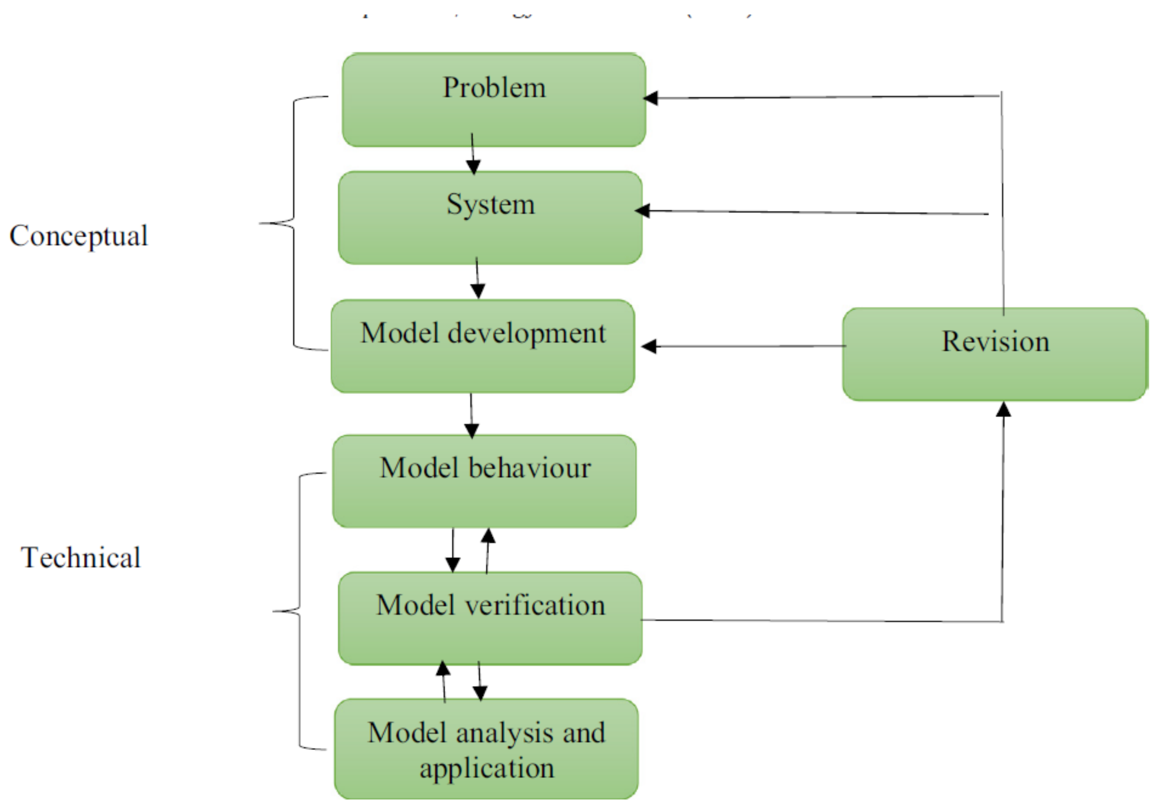

Figure 3.1: Basic steps in system dynamic modelling
Source: Adapted from (Sterman, 2000)

In developing our model, we drew insights from previous studies on modelling energy demand and CO2 emissions from road passenger transport (Barisa & Rosa, 2018; Liu *et al.*, 2015;

Gupta *et al*., 2019; Akbari *et al*., 2020). We disaggregate our model into three sub-systems: population- economic, transport activities, and energy consumption-CO2 emission sub-system

3.2.1 *Preliminary information*

3.2.1.1 Key variables

The key variables in this model are:

(i) the gross domestic product (GDP) which is a measurement of the economic output of the country. Data for the GDP are obtained from the World Bank and are expressed in constant local currencies (billions).

(ii) Population: data for population are obtained from the world bank and are expressed in millions.

(iii) passenger travel demand: passenger travel demand measures the total distance travelled by persons in a country in a year. This is expressed in passenger-kilometres. Data on passenger travel demand are obtained from the UK Department of transport

(iv) the number of registered vehicles by fuel types:

(v) GHG emissions from transport sector

3.2.1.2 Time horizon

To develop a good reference model in system dynamics, it is expected that the time horizon to be considered should go back in time sufficiently enough to understand how the problem emerged and should be projected into the future to capture the potential impact of delays in the system. For our study, the time horizon used for the reference mode is 1991 to 2020. We make our projections from 2021 to 2050 to align with the target date set the UK government to achieve its decarbonisation targets.

3.2.1.3 The reference mode

The aim of our model is to examine policy options for reducing GHG emissions from road passenger transportation. Our study focuses on only public transportation which is represented by "Buses and coaches" and private transport which is represented by "cars and taxis. We exclude motorcycles and non-motorized transportation. Heavy goods vehicles and light vans are categorized as road *freight* transport and not road *passenger* transport, therefore are also excluded. In this model, total road passenger transport GHG emissions is made up of **only** emissions from "buses and coaches" which we denote as public transport; and "cars and taxis" which we denote as private transport. The reference model describes how important variables evolve over time taking cognizance of historical trend and future (projected) trends with or without interventions. We present in Figure 3.2 the reference mode of GHG emissions from public (coaches and buses) and private (cars and taxis) road passenger transport. We may observe from Figure 3.2 that emissions from private travel constitute a very large share of the total road passenger transport emissions and the GHG emissions from public and private transport are reducing over time. The dip in 2020 is as a result of the restrictions of movements due to COVID19 lockdowns.

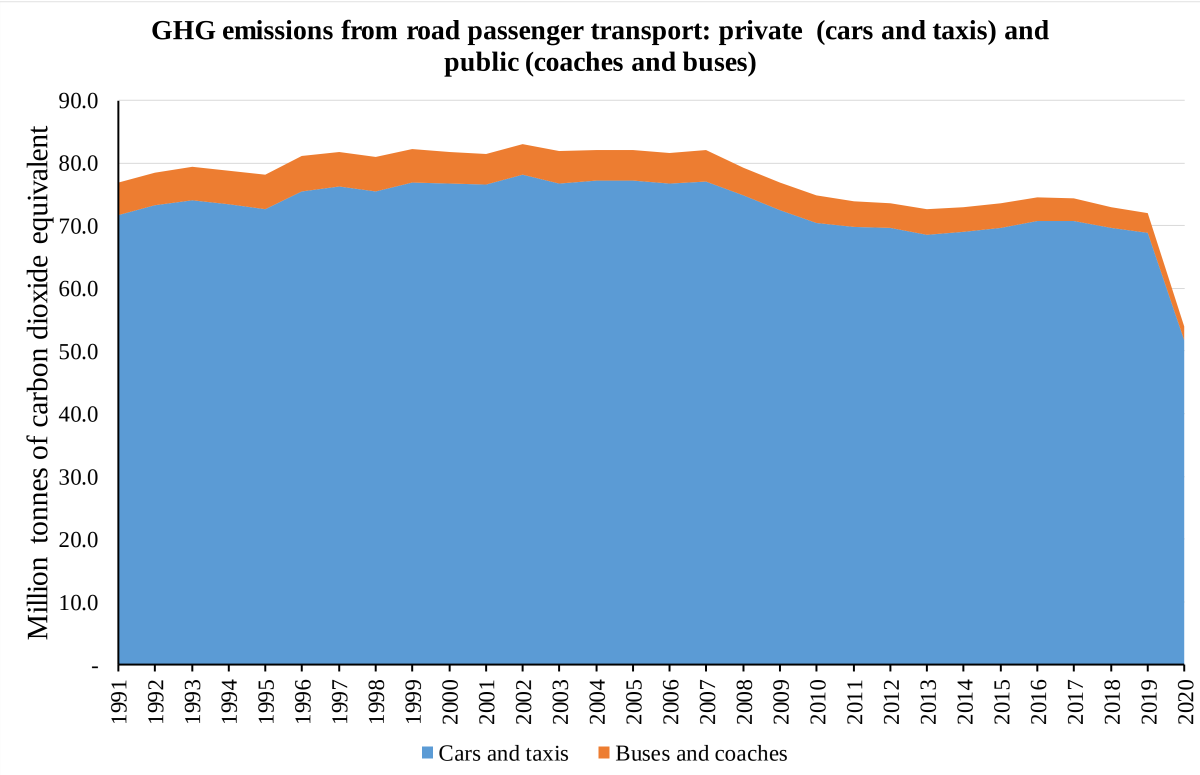

Figure 3.2: GHG emissions from road passenger transport: private (cars and taxis) and public (coaches and buses)
Source of data: United Kingdom Department for Transport

We present in Figure 3.3 and Figure 3.4 the reference mode for road passenger transport GHG emissions for public and private transport which are represented by “buses and coaches” and “cars and taxis” respectively. These disaggregated reference modes are presented to clearly show the trends of the GHG emissions from public and private transport

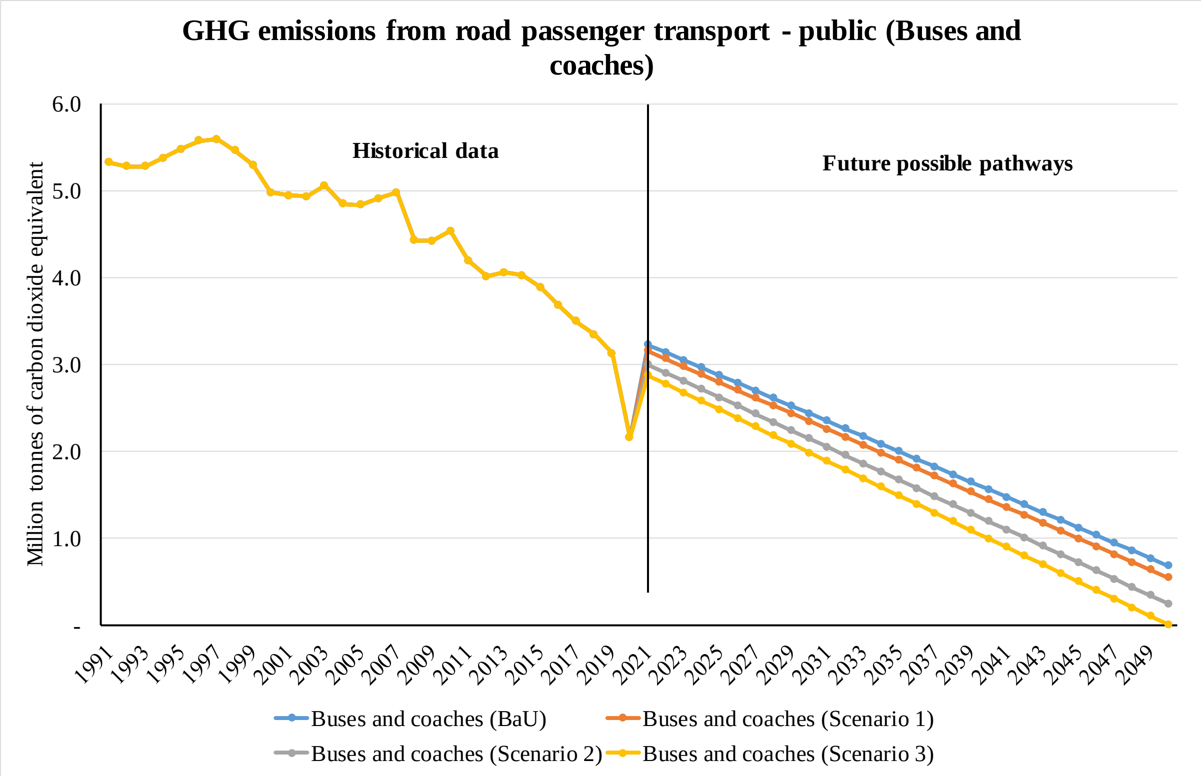

Figure 3.3: GHG emissions from road passenger transportation - public (buses and coaches)
Source of data: United Kingdom Department for Transport

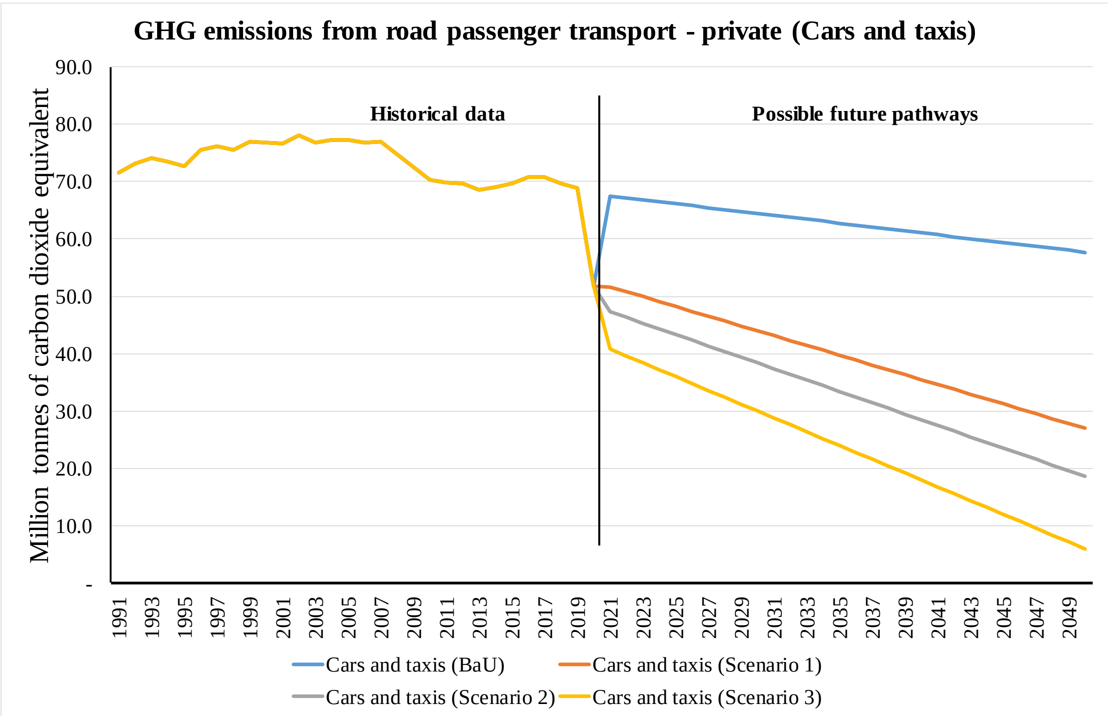

Figure 3.4: GHG emissions from road passenger transportation - private (cars and taxis)
Source of data: United Kingdom Department for Transport

We observe from Figure 3.3. that the GHG emissions from public transport has a downward slope and its slope is steeper than that of GHG emissions from private transport. The emissions plunged in 2019-2020 due to COVID-19 restrictions. If the trend of the slope continues as shown in the base-case scenario, emissions from public transport will not be zero by 2050. Similarly, we may observe from Figure 3.4. that GHG emissions from private vehicles (cars and taxis) are declining over time. However, if the rate of decline follows the trend from historical data, the target of decarbonizing road passenger transport by 2050 will not be achieved as may be seen from the business-as-usual scenario.

An important variable that influence road passenger transport GHG emissions is the road passenger travel demand. Data on road passenger travel demand are grouped into different means of transportation as follows: "cars, vans and taxis", "buses and coaches", "motorcycles", and "pedal cycles". In this study, we denote passenger travel demand in the category "cars, vans and taxis" as private demand while the category "buses and coaches" is demoted as public demand. We exclude "motorcycles", and "pedal cycles". Therefore, total road passenger travel demand in this study refers to the sum of "buses and coaches" and "cars, vans and taxis". We present in Figure 3.5 the total road passenger transport demand.

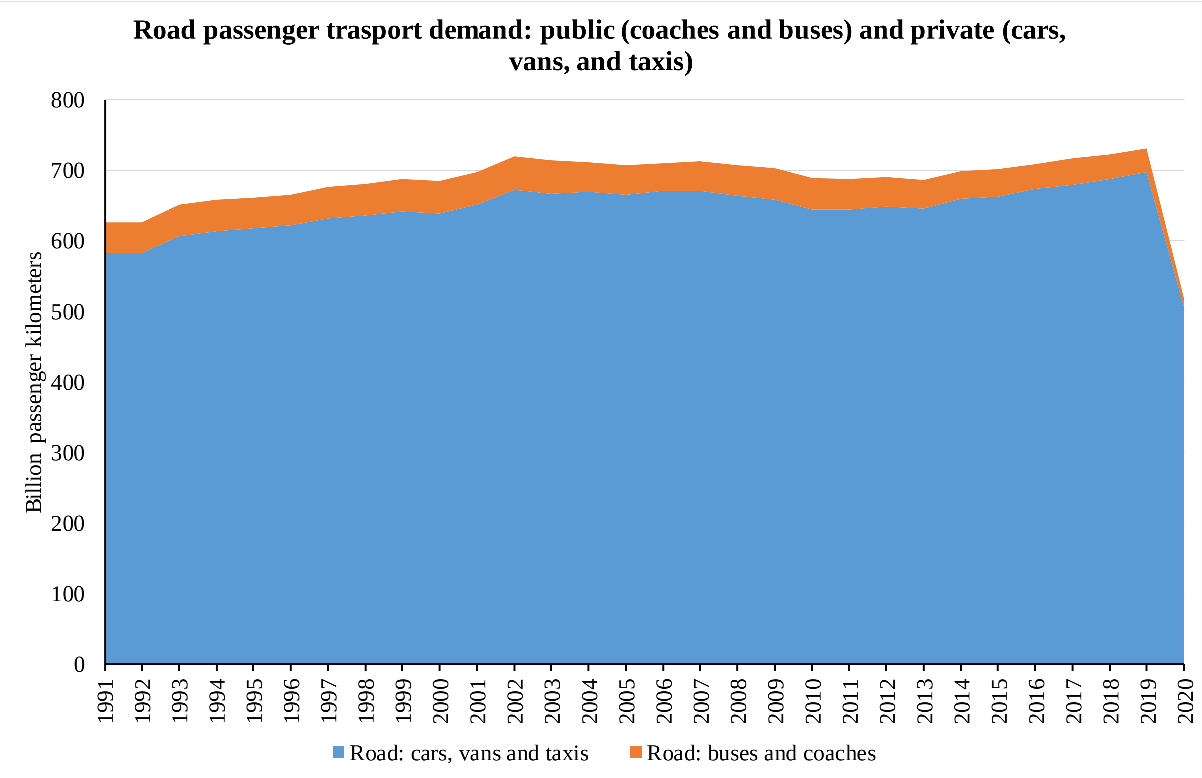

Figure 3.5: Road passenger transport demand: private (cars, vans, and taxis) and public (coaches and buses)
Source of data: United Kingdom Department for Transport

We observe that the trend of total road passenger demand is positive, albeit there was a dip in 2020 due to COVID19 pandemic. We also present the road passenger transport demand (public – coaches and buses) and private (cars, vans, and taxis) in Figure 3.6and Figure 3.7 respectively.

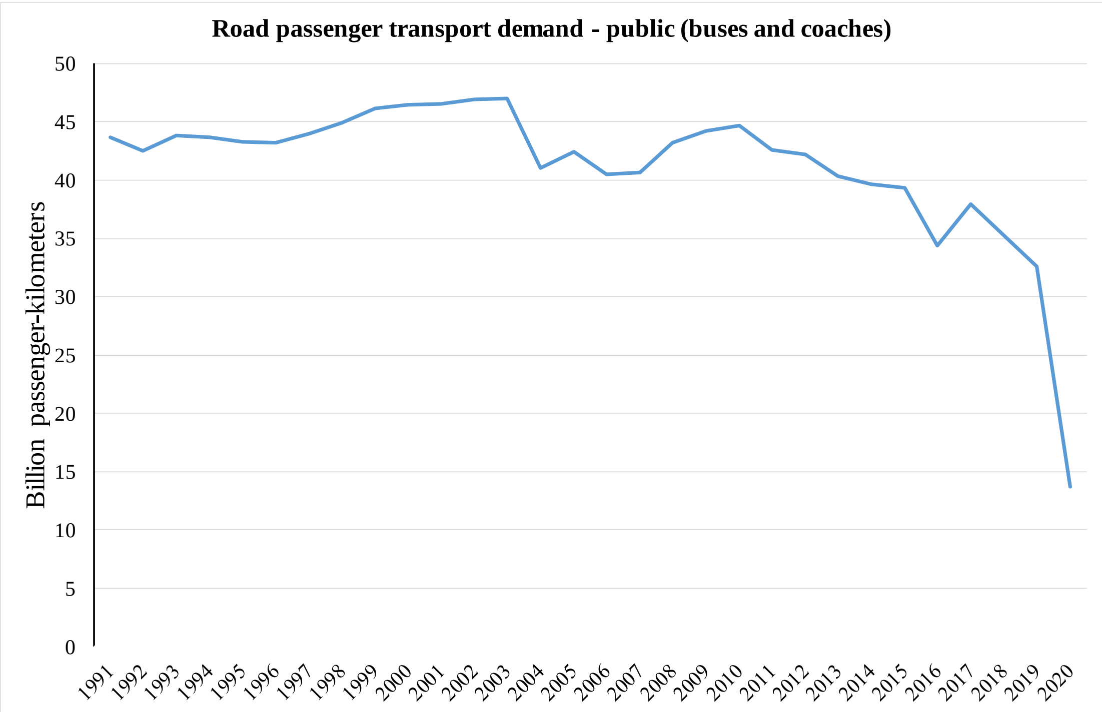

Figure 3.6: Road passenger transport demand - public (buses and coaches)
Source of data: United Kingdom Department for Transport

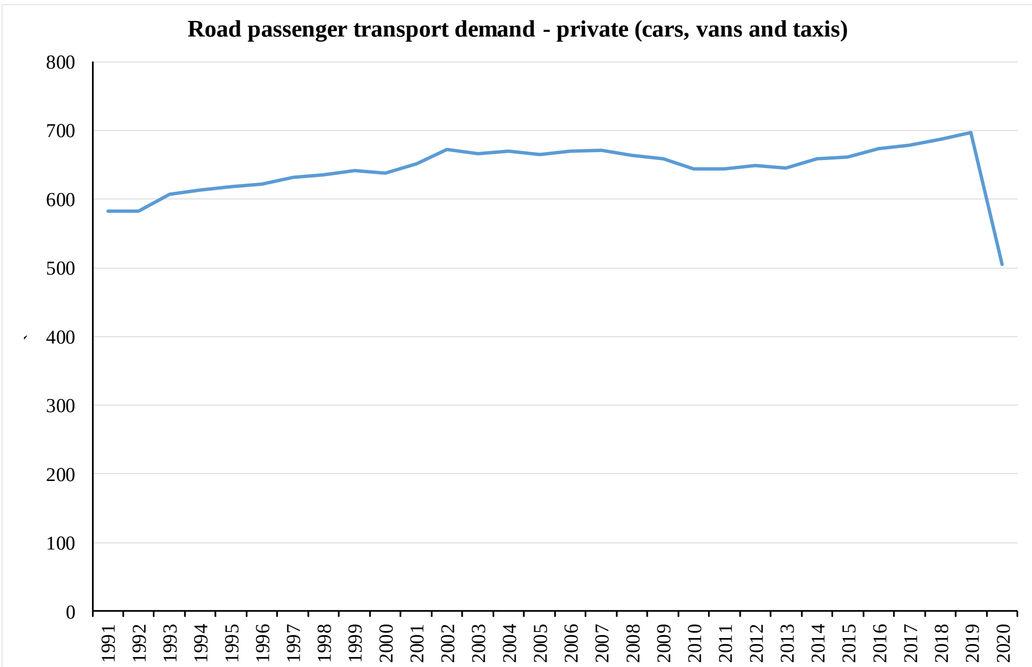

Figure 3.7: Road passenger transport demand – private (cars, vans and taxis)
Source of data: United Kingdom Department for Transport

We may observe from Figure 3.6 and Figure 3.7 that while road passenger transport demand (public) seems to be reducing, the reverse is the case for road passenger transport demand (private).

Another important variable that influence road passenger transport GHG emissions in the number of registered vehicles using different fuel types. We categorize vehicles using non-traditional fuels or hybrid fuels as "low emissions vehicles". We may observe from Figure 3.8. that the total number of registered vehicles in the United Kingdom is increasing albeit, slowly. The number of vehicles using petrol (gasoline) and diesel have remained fairly stable while the number of low emissions vehicles have increased exponentially.

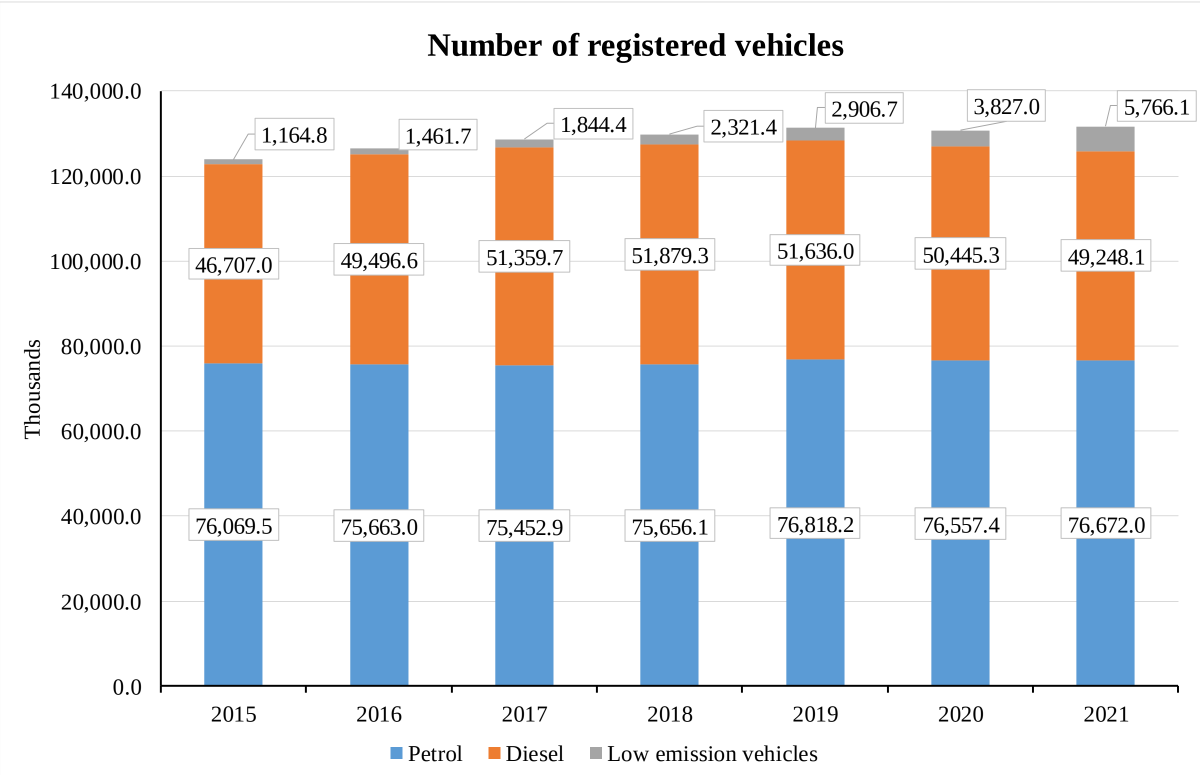

Figure 3.8: Number of registered vehicles in the United kingdom (2015 to 2021) disaggregated by fuel type
Source of data: United Kingdom Department for Transport

We aim to replicate the behaviours of road passenger transport GHG emissions over time with our model and thereafter to examine how different policies may alter the trajectories of the variables

3.2.1.4 *Dynamic hypothesis*

It is important to understand the drivers of road passenger transport GHG emissions in terms of the factors that are responsible for the trend. Road passenger transport GHG emissions are primarily from the combustion of petroleum products used in cars, taxis, buses, and coaches. As observed from Figure 3.2, private transport contributes over 90% of road passenger transport. This implies that reducing GHG emissions from private transport will substantially reduce emissions from road passenger transport. GHG emissions from road passenger transportation using private vehicles is driven by the travel activities, the number of vehicles using different fuel types (gasoline, diesel, low emission fuels), the average number of trips made by residents by private cars, the average distance of such trips, and the efficiency of the vehicles in terms of the volume of fuel consumption per km of travel. The acquisition of vehicles is dependent on travel demand, cost of acquisition, licensing, and fuel; household characteristics of residents such as family size, disposable income, etc.; other associated cost of using vehicles such as parking charges

3.2.2 Model building

We build a model to explain the historical trend of GHG emissions from road passenger transportation in the United Kingdom. We draw insights from previous studies as well as from our knowledge of transport economics. Our model is divided into for sub-systems as explained below.

3.2.2.1 *Population-Economy sub-system*

Transport demand is a derived demand – people do not travel just for the sake of traveling, but to meet a specific need. The larger the population of a country, the larger the transport demand. In the population sub-system, we denote the population as a stock. The stock is increased by a growth rate and depleted by a depletion rate. Similarly, the GDP of a country represents the value of economic activities in the country. The level of economic activities usually affects transport demand. We also represent the GDP as a stock which is increased by a GDP growth rate variable and depleted a GDP depletion rate variable. We assume that GDP and population are good predictors of total passenger travel demand in a country and we represent this relationship as a linear regression as shown in Eqn (1). This is reflected in the model documentation.

$$TotalPassengerTravelDemand = \beta_0 + \beta_1 * Population + \beta_2 GDP + \varepsilon \qquad \ldots(1)$$

3.2.2.2 Transport demand sub-system

Road passenger transport demand can be met using public transport, private transport, or non-motorized transport services. In this study, our focus is only on public and private transport. The decision to choose between these transport options follows the travel mode choice theory i.e. the choice of transport services used by a person depends on the personal circumstance of the person (or socio-economic attributes such as age, income, family size, etc.), the attribute of the different transport options (efficiency, speed, cost, regularity, etc.), and other exogenous variables in play at the time of making the decision to travel (e.g. public transport efficiency; probability of disruptions due to maintenance, strikes; etc.). We simplify this by initially focusing on public transport – specifically on the share of public transport demand in the total road passenger transport demand. The aforementioned variables affect the propensity of passengers to choose public transport over private transport, and by extension, the potential of the share of public transport to increase or decrease.

The income elasticity of public transport demand is the percentage change in the share of public transport demand due to a 1% change in disposable income of passengers (Balcombe *et al*., 2004; Dunkerley *et al*., 2014). Studies of suggested that income elasticity of public transport is usually negative (i.e. an increase in disposable income of passengers will likely make passengers to acquire personal vehicles which will increase private transport activities and decrease public transport demand). Therefore, if we have data on income elasticity of public transport demand and the percentage change in income in any year, we may estimate the percentage change in the share of public transportation. Similarly, own price elasticity of public transport is the percentage change in the share of public transport demand due to a 1% change in the cost of public transportation. Cross price elasticity of public transport demand is the percentage change in the share of public transportation due to a 1% change in the average cost of private transportation. Finally, we define public transport efficiency elasticity as the percentage change in the share of public transportation due to a 1% change in the efficiency of public transportation.

We model the share of public transport using historical data as follows:

Share of public transport (t) = f(share of public transport (t-1), impact of change in public transport efficiency on change share in public transport, impact of change in average disposable income on change in share of public transportation, impact of change in the cost of public transport on the share of public transport, and the impact of share in the cost of private transportation on the share in public transportation.

The share of private transport is then obtained by subtracting the share of public transport by 1.

$$Share\ of\ private\ transport = 1 - share\ of\ public\ transport$$

From the share of private transport and the estimate of total road passenger transport demand, we obtain estimate of total road passenger transport demand (private). The screenshot of this subsector is presented in Figure 3.9

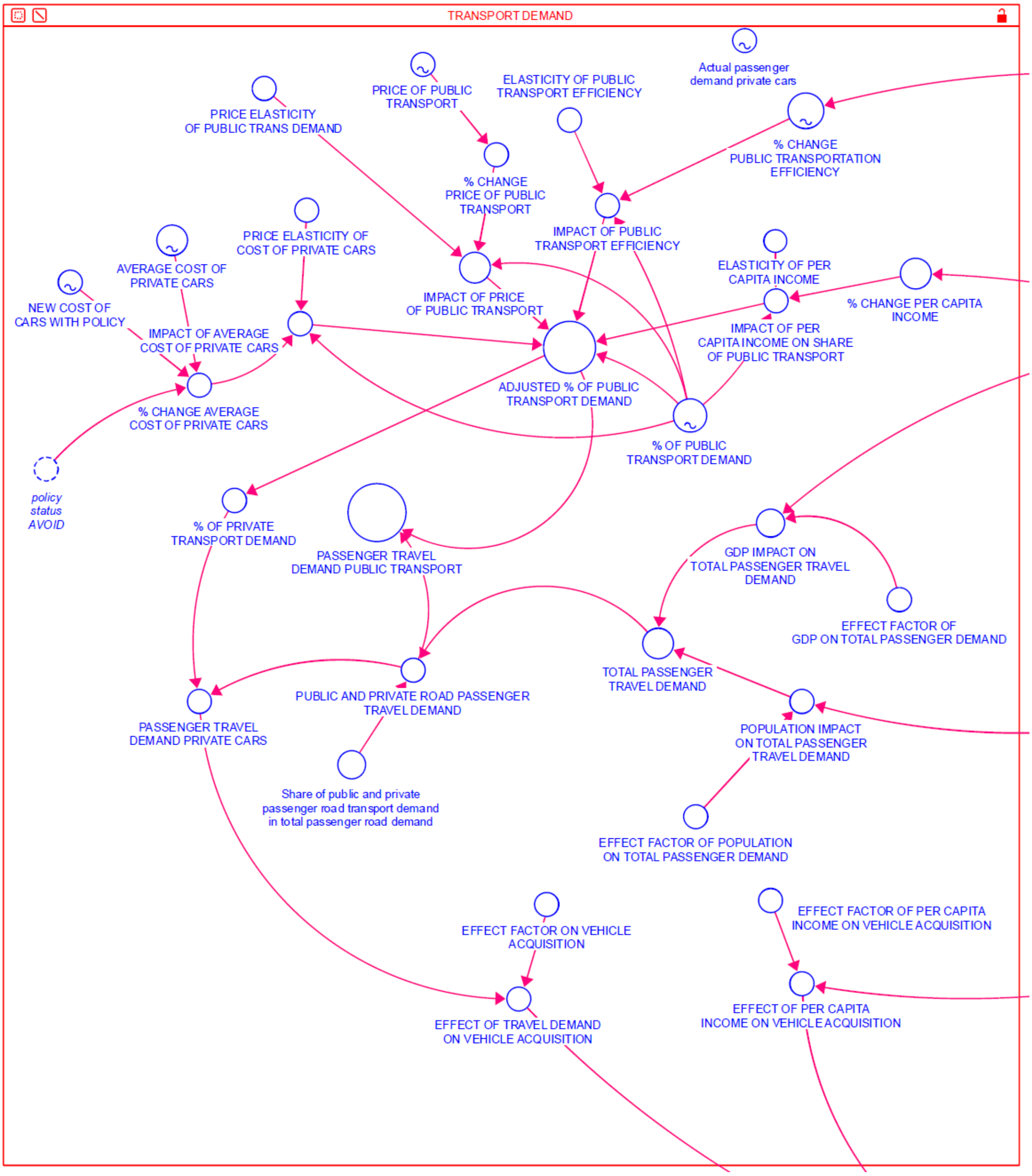

Figure 3.9: "Transport demand" subsector
Source: Author's model

3.2.2.3 ***Private vehicles subsystem***

This subsector focuses on the stock of private vehicles in the country. People purchase vehicles in response to a felt need to travel privately as subject to their disposable income. This makes the number of registered vehicle to be a function of the road passenger travel demand (private) and household income (we use GDP per capita as a proxy for income).

$$NumberOfRegisteredVehicles_t = \beta_0 + \beta_1 * RoadPassengerDemand(private)_{t-1} + \beta_2 GDP\_per\_capita_{t-1} +$$

Furthermore, for those who choose private transport, there is another choice to be made in terms the type of private cars to use: sedan or SUV; diesel, gasoline or electric. We focus on only the fuel type. Here, the choice of vehicles type is also dependent on the socio-economic attributes of people (age, income, family size) as well as the attributes of the vehicles (purchase price, average maintenance cost, fuel type, fuel efficiency, etc.). While it is possible to model the drivers of the choice of different vehicles, we elect to rely solely on historical trends. These different vehicles types will have different acquisition/licensing rates and will form different stocks. Each vehicle stock (i.e. by fuel types) will be increased by the rate of vehicle acquisition/registration and will be depleted by the rate of scrapping. We make an assumption that every vehicle in the stock will stay for 20 years before being scrapped. The rate of vehicle acquisition/registration is also influenced by the registration requirements. The licensing fees can contribute to government revenues and part of it may be re-invested to improve the efficiency of public transportation. The screenshot of this subsector is presented in Figure 3.10

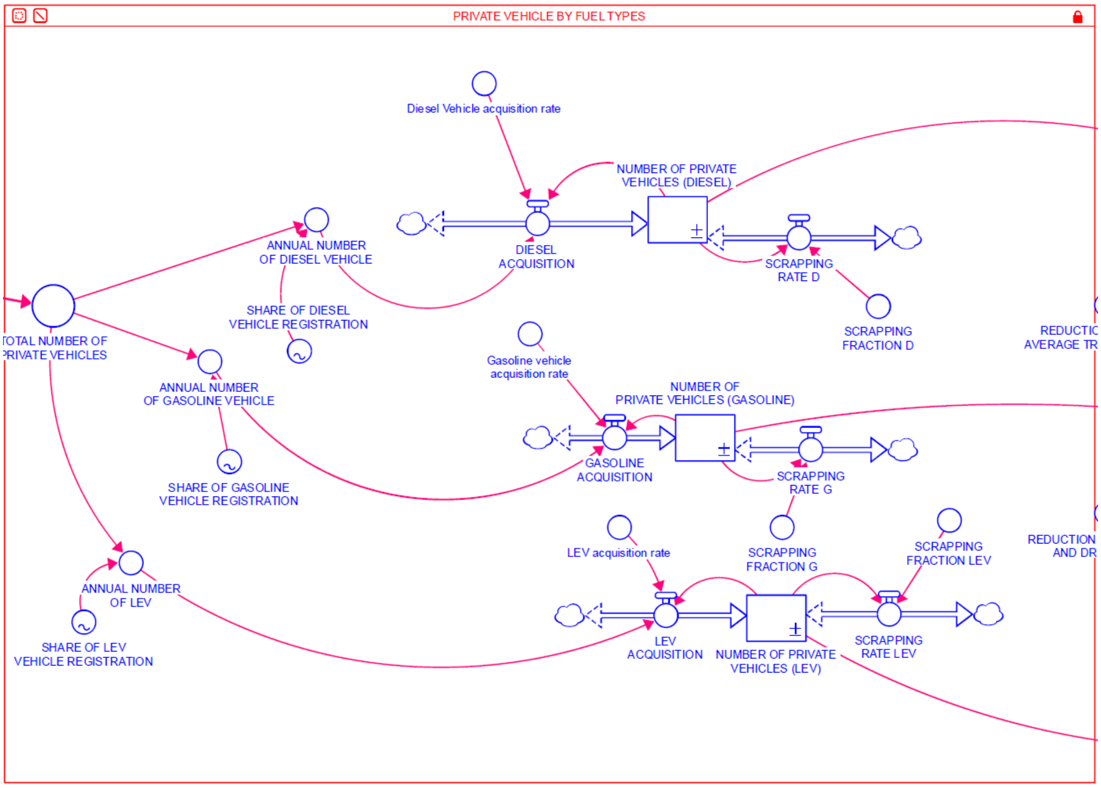

Figure 3.10:"Private Vehicles" subsector
Source: Author's model

3.2.2.4 Transport activities and Energy Consumption sub-system

Road passengers who prefer private transport will use their vehicles to commute or will commute with a taxi. The transport activity for the different vehicle types is a product of the number of registered vehicle in that category, the average number of trips per year, and the average length of trips per year. While the number of vehicles are disaggregated by fuels via their respective stocks, data on average number of trips per year and average length of trips per year are not. Therefore, we use the same data to get transport activities by vehicle type which are expressed in passenger-km. Data for average number of trips per year and average distance travelled are obtained from the UK Department for Transport

We compute energy consumption by vehicle type by multiplying the transport activities with the vehicle efficiencies of the different fuel types (expressed in liter/passenger-km). We note that different types of vehicles are grouped under LEVs and it is difficult to get a figure for vehicle efficiency that will be applicable to all the LEVs. Therefore, we assume that the vehicle efficiency for LEVs is five times that of diesel vehicles (this means that if vehicle efficiency of diesel vehicles is $x$liters/km, that of LEVs is $\frac{x}{5}$liters/km. Data for vehicle efficiency are obtained from the UK Department for Transport and expressed in liters/100km. Details of the subsystem are shown in Figure 3.11

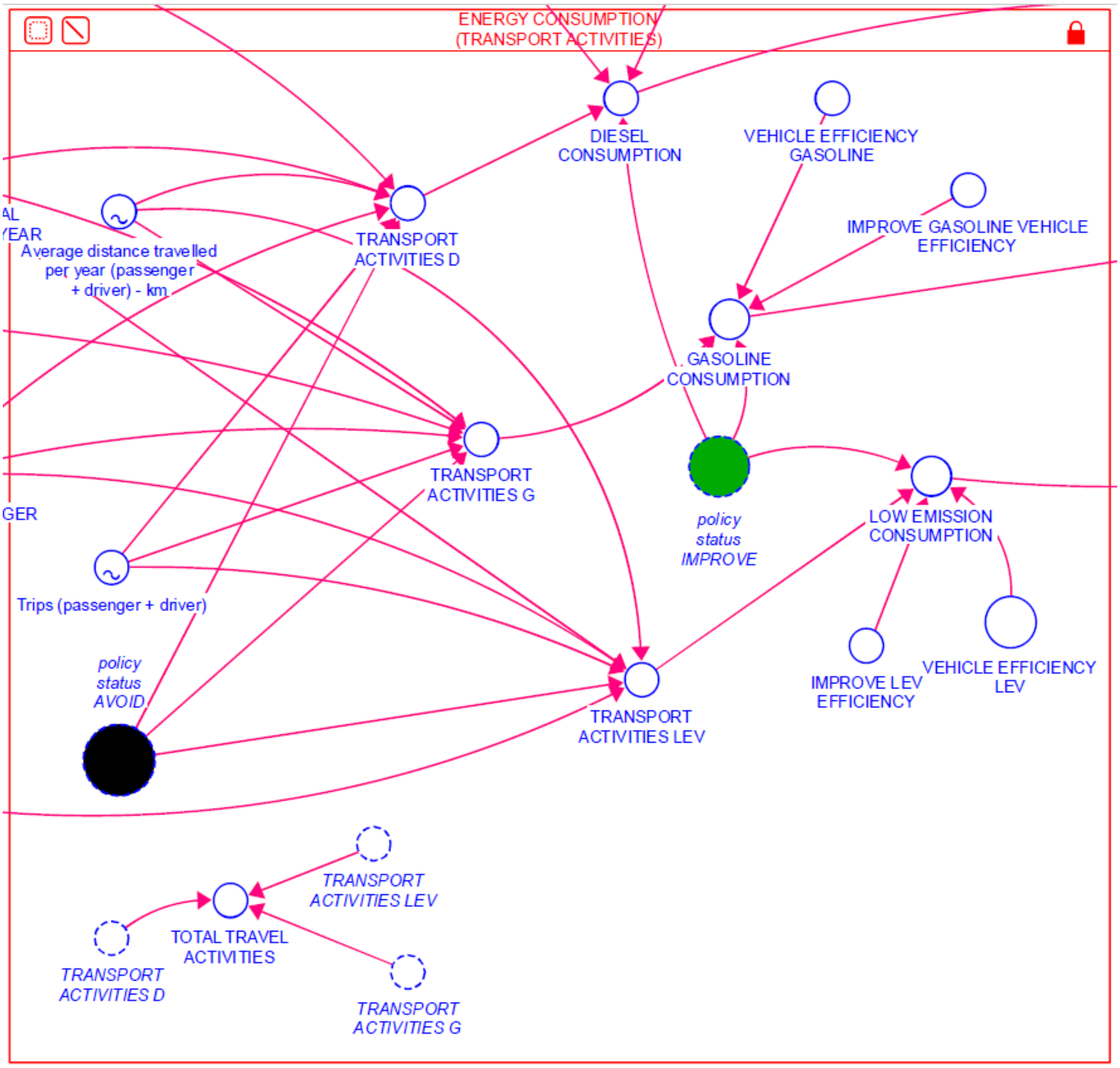

Figure 3.11:"Transport activities and energy consumption" subsector
Source: Author's model

3.2.2.5 GHG emissions subsystem

First, we consider GHG emissions from the use of private vehicles. Using the energy consumption by vehicle type obtained from the "Transport activities and energy consumption" subsystem, we note that different fuels have different CO2 emissions coefficients. We compute the CO2 emission from the different fuel types using data on energy consumption and CO2 emissions coefficient. We assume that the CO2 emission coefficient for LEVs is half of that of diesel.

Using actual data on: (i) CO2 emissions for buses and coaches; and (ii) Road passenger travel demand (public), we estimate CO2 emissions factor from public road transport. Thereafter, we use this CO2 emissions factor from public transport alongside the estimated values of road passenger travel demand (public) to estimate the stock of CO2 emissions from public sector. We present this subsystem in Figure 3.12.

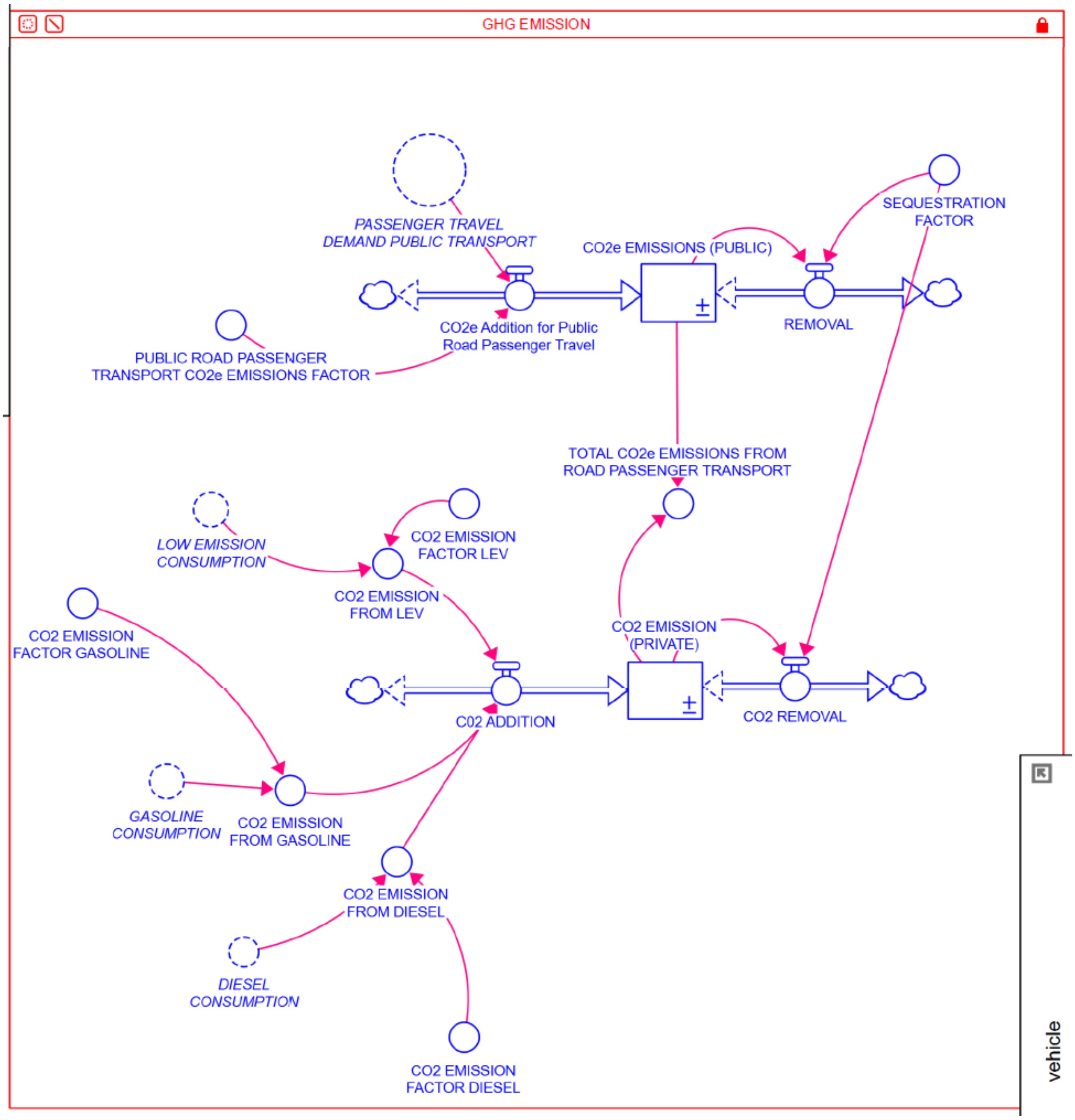

Figure 3.12:"GHG emissions" subsector
Source: Author's model

3.2.2.6 Revenue from private transport

Private transport is a source of revenue for government. In this study, we identify three types of revenues from private transport: (i) Tax component of the final retail price of gasoline and diesel; (ii) vehicle licensing cost; and (iii) vehicle tax. The total revenue from private transport contributes to the GDP of the country in subsequent years. Government can use a part of this revenue to invest in the transport sector to maintain existing infrastructure or build new ones.

The public sector will benefit from such investments in terms of improved efficiency of public transportation.

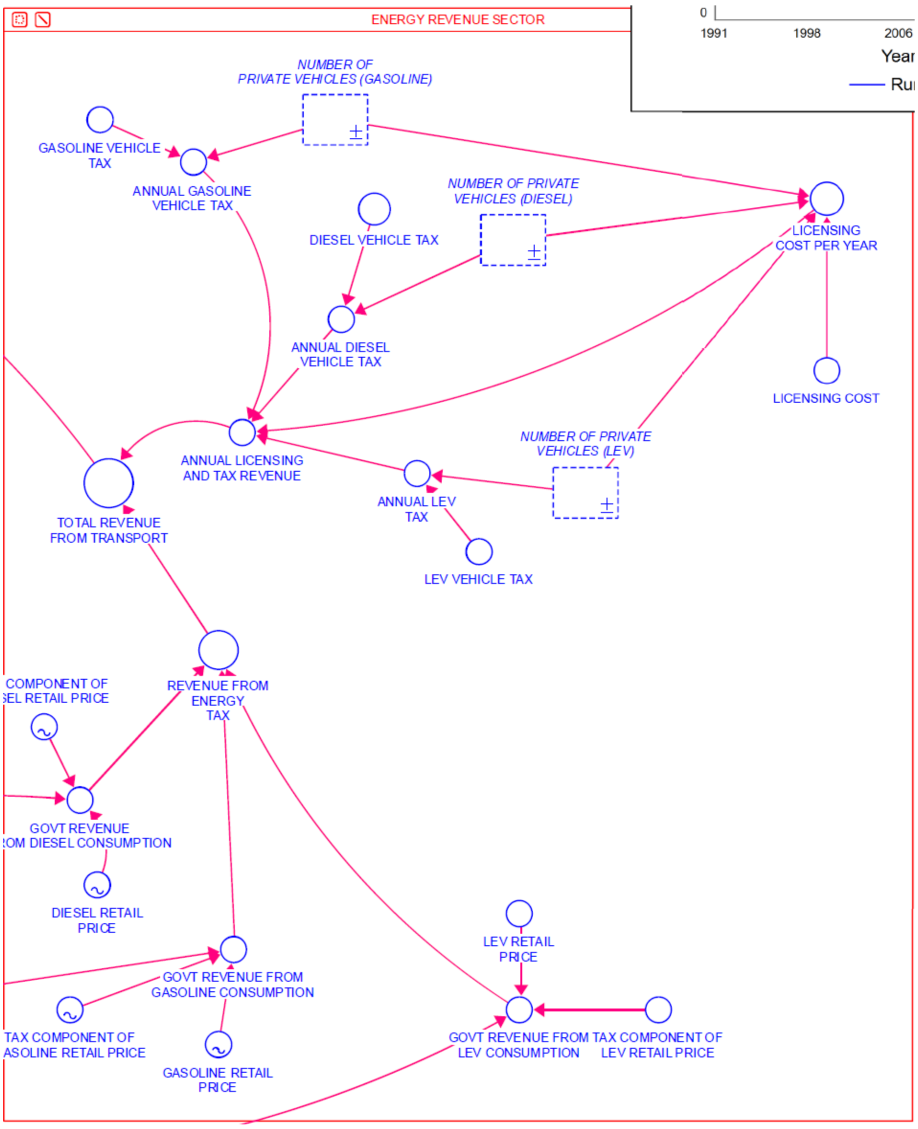

Figure 3.13: "Revenue from private transport" subsystem
Source: Author's model

3.3 Causal Loop Diagrams

In this study, we identify some causal loops similar to what was identified in the literature (Wang, et al., 2008), (Batur, et al., 2019), (Fontoura, et al., 2019) as may be seen in the causal loop diagram in Figure 3.14

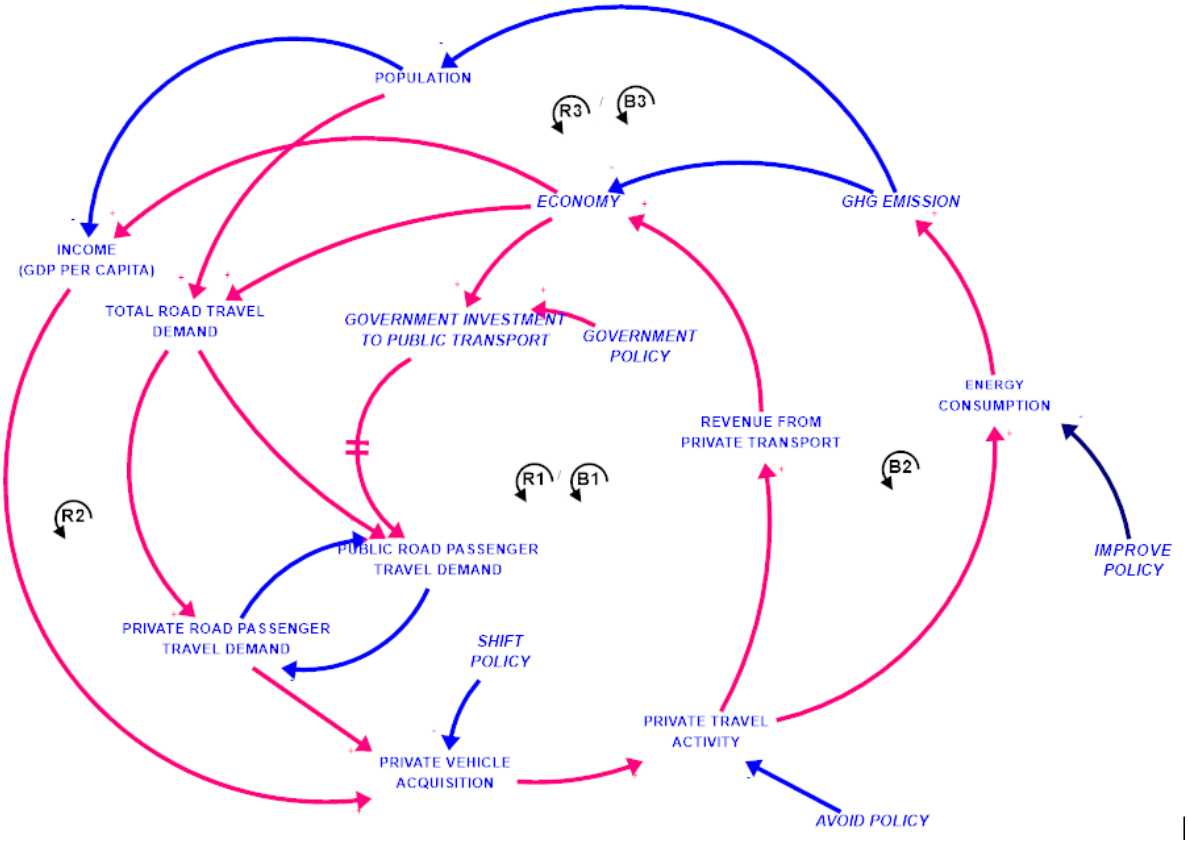

Figure 3.14: Causal loop diagram for road passenger transport GHG emission for private vehicles

The identified loops are:

(i) **R1**: Economy → total road travel demand → private road passenger travel demand → private vehicle acquisition→ private travel activity → revenue from private transport → Economy

(ii) **B1**: Economy → government investment to public transport → public road passenger travel demand → private road passenger travel demand → private vehicle acquisition → private travel activity → Revenue from private transport → economy

(iii) **R2**: Economy → income → private vehicle acquisition → private travel activity → revenue from private travel transport → economy

(iv) **B2:** Economy → total road travel demand → private road passenger travel demand → private vehicle acquisition→ private travel activity → energy consumption → GHG emission → Economy

(v) **R3**: Population → income → private vehicle acquisition → private travel activity → energy consumption → GHG emission → population

(vi) **B3**: Population → total road travel demand → private road passenger travel demand → private vehicle acquisition → private travel activity → energy consumption → GHG emission → population

CHAPTER FOUR

4 MODEL VALIDATION AND MODEL TESTING

We validate our model using different methods. Particularly, we carry out test for model structures and tests for model behaviours. First, we acknowledge that our model be used by third parties who are interested in the topic of road passenger transport GHG emissions in the United Kingdom or elsewhere. Therefore, we ensure that we have included adequate documentation (including the sources of data) in the model.

4.1 Tests for model structures

4.1.1 Structure Verification Test

The structure verification test seeks to compare the relationships in the model which what is obtainable in the real world.

4.1.2 Parameter Verification Test

We check and verify the different parameters used in the model. This includes the initial values of stocks; constant values used in converters; shape, slope, direction of table functions, etc. Given that we adopted data from different secondary sources, these checks are important to ensure that the data used are logical and reasonable.

4.1.3 Dimensional Consistency Test

Testing the consistency of the units used in the different converters, stocks or flows is an important aspect of modelling with System Dynamics. We ensured that data are in the appropriate units and all the units and dimensions and logical. We present in Table 4.1. a list of some of the unit adjustments that were made

Table 4.1: Procedure for converting units of variables used in the model

Variable	Initial unit	Correction	Final unit
GDP	Billion LCU (pounds)	We multiplied the values by 1 billion (i.e 1,000,000,000)	Pounds
Population	Millions	We multiplied by 1,000,000 (1 million)	Persons or passengers

Travel demand	Billion passenger-km	We multiplied by 1 billion (i.e 1,000,000,000)	Passenger-km
Vehicle efficiency	Litre/100km	We divided all figures by 100	Litre/km
GHG emissions	Billion tonnes of CO2 equivalent	We multiplied 1 billion to convert billion tonnes to tonnes, and then by 1000 to convert tonnes to kg	KgCO2e
Average distance travelled	Miles per person per year	We converted miles to kilometers	Km/passenger/year

We addressed most of the unit errors shown in our model. However, there were two errors that we were unable to address:

(i) The software suggested that the unit of population should be persons instead of passengers

(ii) The software suggested that the unit of a certain converter should be "kilometerpassenger/year" while we used "passengerkm/year"

4.1.4 Extreme Condition Test

The extreme condition test examines the performance of a model if some input variables are set to extreme values. In our model we set some input variables to zero to examine the whether there will be GHG emissions. Specifically, we set the emission factors (gasoline emissions factor, diesel emissions factor and LEV emissions factor) to zero and observe that the stock of GHG emissions deplete continuously as GHG emissions are not being added to the stock and the sequestration factor is removing from the stock. Similar, we set the sequestration factor to zero the examine the effects (see Figure 4.1)

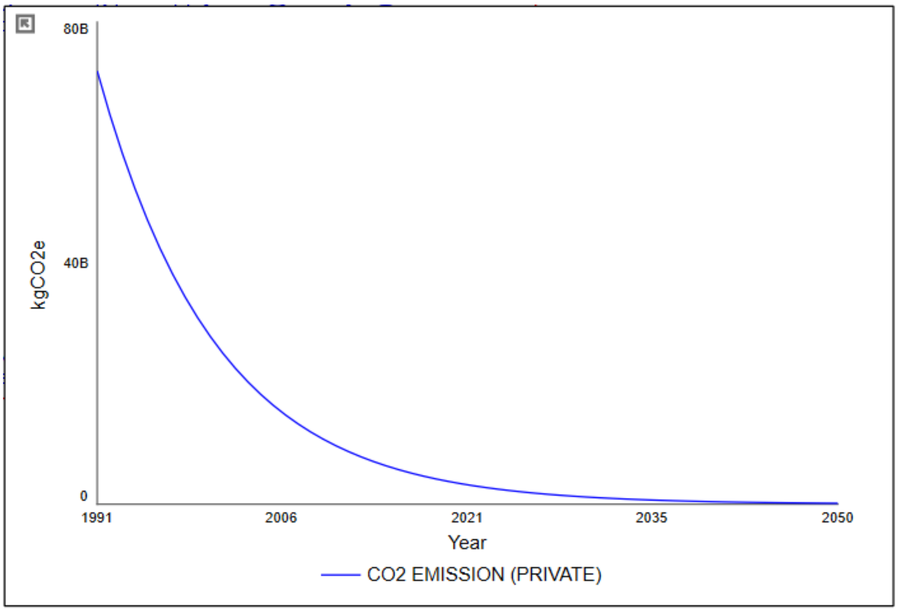

Figure 4.1: Extreme condition test: effect of setting emission factors of gasoline, diesel and LEV to zero

4.2 Tests for model behaviour

The objective of the tests for model behaviour is to examine whether the model can replicate real life.

4.2.1 Behaviour reproduction test (Historical behaviours)

An important aspect of model validation is to verify that the values of variables endogenously generated by the model align with historical (actual) values of such variables. We present the behaviours of key variables in the model used in the reference mode.

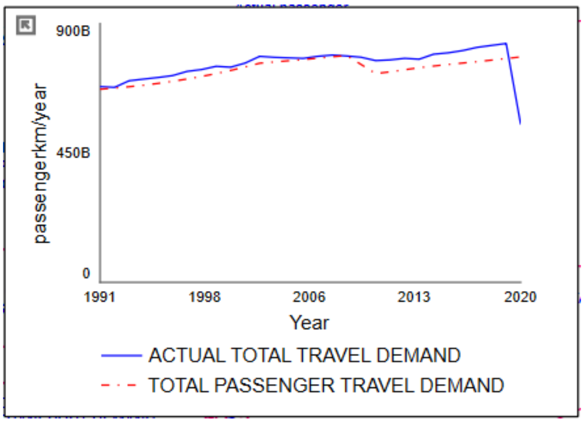

Figure 4.2: Historical behaviours: comparing actual total travel demand with modelled values

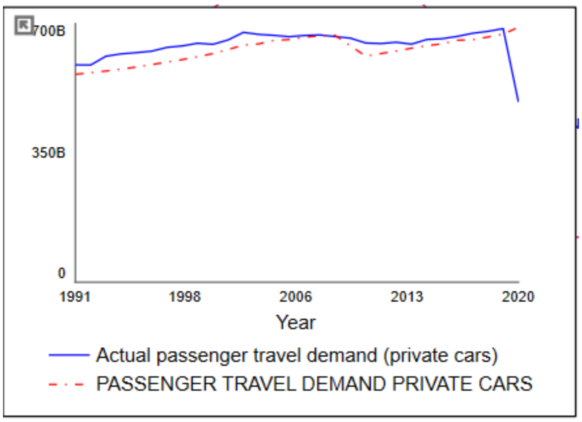

Figure 4.3: Historical behaviours: comparing actual road passenger travel demand (private cars) with modelled values

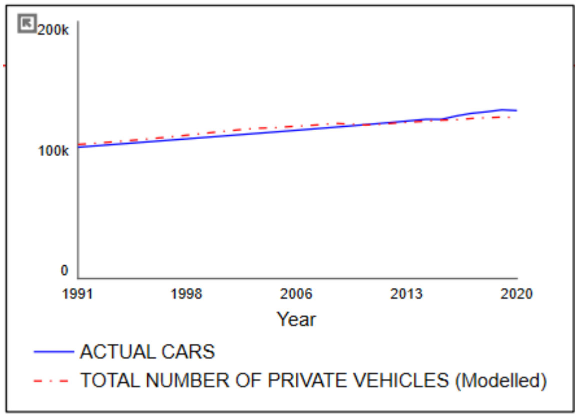

Figure 4.4: Historical behaviours: comparing actual number of registered vehicles with modelled values

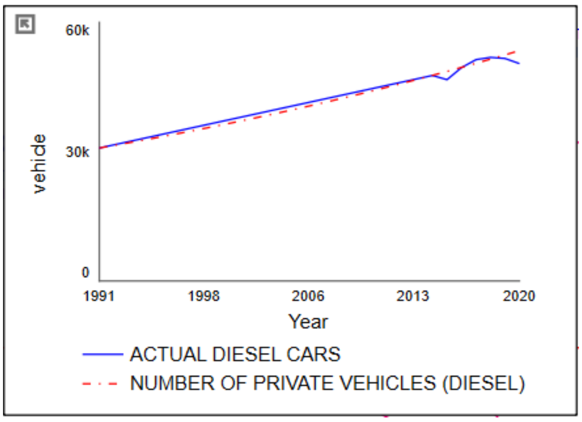

Figure 4.5: Historical behaviours: comparing actual number of private vehicles using diesel with modelled values

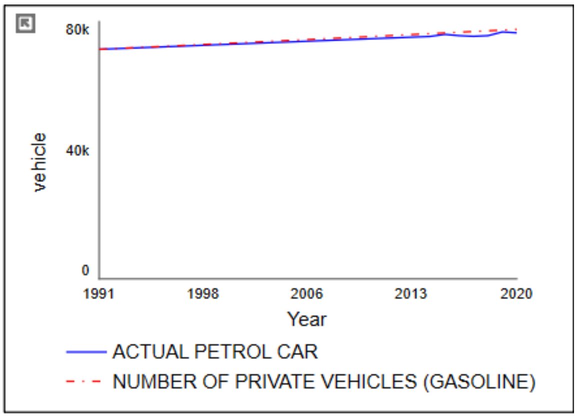

Figure 4.6: Historical behaviours: comparing actual number of private vehicles using gasoline with modelled values

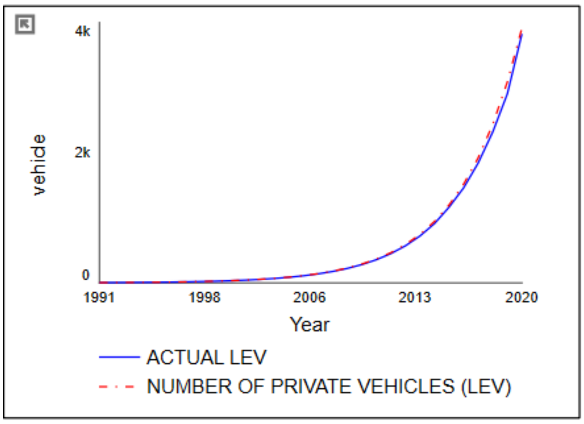

Figure 4.7: Historical behaviours: comparing actual number of private LEVs with modelled values

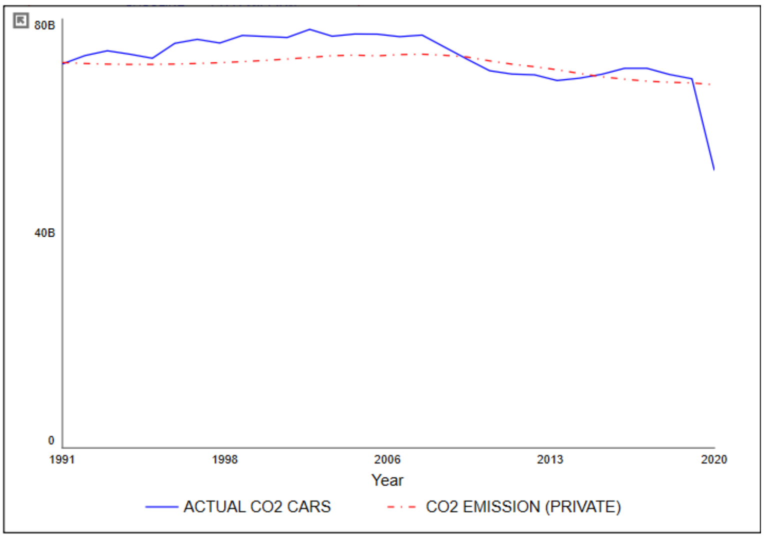

Figure 4.8: Historical behaviours: comparing actual GHG emissions (in CO2eq) from road passenger transportation (private cars) with modelled values

4.2.2 Behaviour sensitivity test (sensitivity analysis)

The sensitivity analysis seeks to examine how small changes in the values of selected variables in the model affect the entire outcome. Sensivity analysis can be performed any varaible, however, only variables that are constants may be used. We carry out sensitity analysis on the stock of GHG emissions using sequestion factor as shown in Figure 4.9.

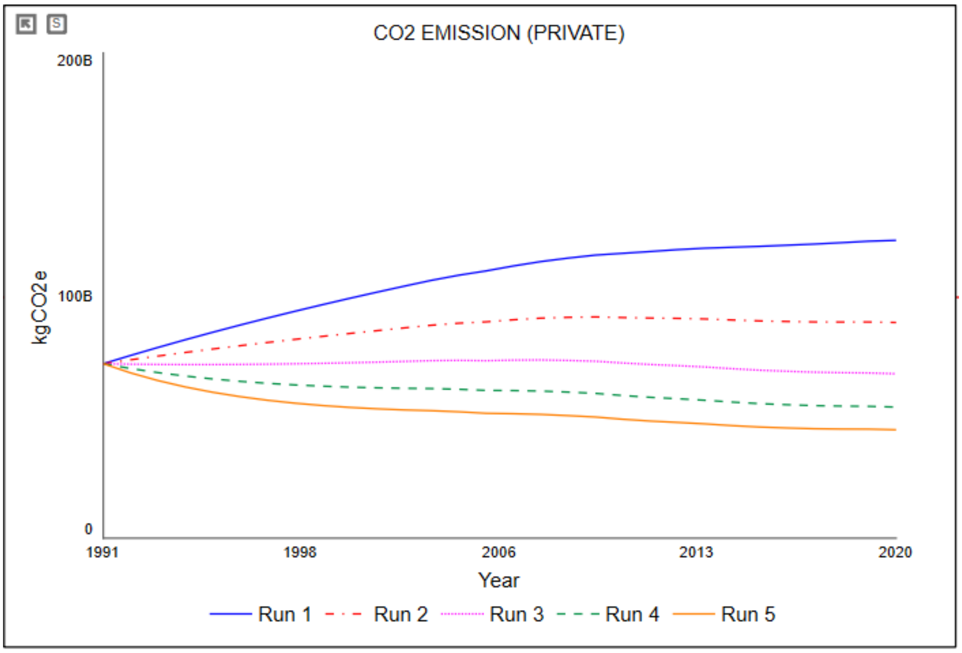

Figure 4.9:: Sensitivity analysis - effect of changes in sequestration factor on the stock of GHG emissions

4.2.3 Testing table functions

Table functions are used for mathematical mapping of one variable unto another which can be in form of effects. Table functions are particularly useful when such effects are non-linear. Our model makes use of one table function, i.e. the percentage change in public transport efficiency as a result of government investments. We use a S-shaped curve to demonstrate this relationship: we assume that there are thresholds below which investments will have neglegible impact, and above which the impact will also be negligible. The highest impacts can ob obtained when the investments fall within the set thresholds. In this section, we alter the shape of the table functions and examine whether the resulting impact will be logical and reasonable.

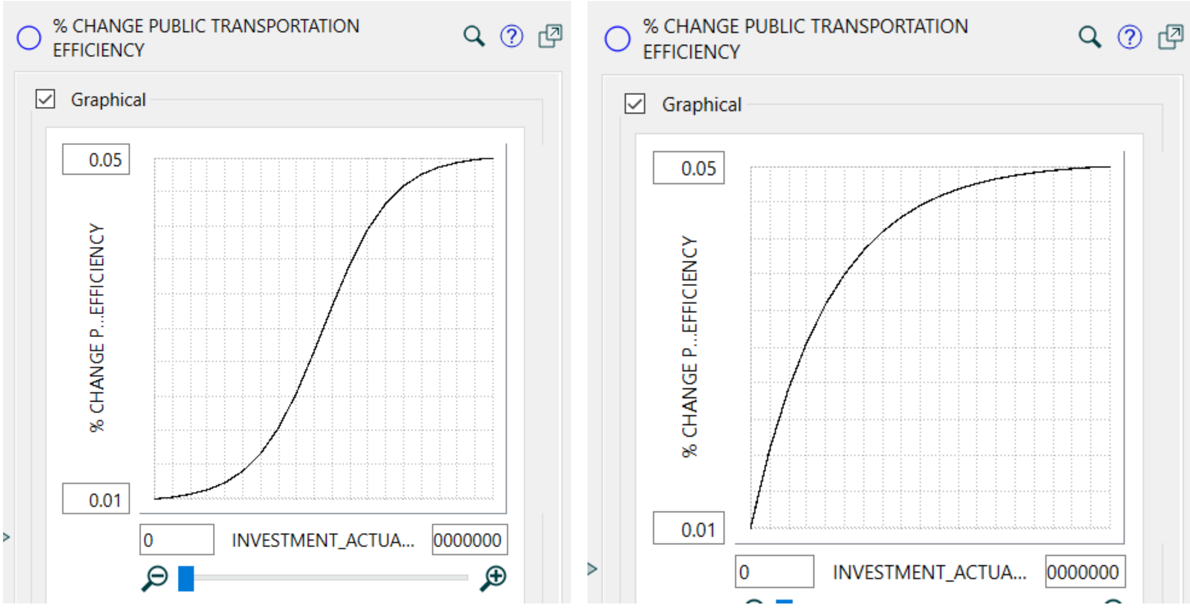

Figure 4.10: Table function test - testing the effect of changing the shape of the function generating the impact of public transport investment on public transport efficiency

CHAPTER FIVE

5 RESULTS: SCENARIOS AND POLICY ANALYSIS

5.1 Results (Base case scenario)

In the base-case scenario, we examine how road passenger transport GHG emissions from private vehicles will evolve till 2050. We note that future trend of GHG emissions is not expected to depart substantially from historical trend unless there are interventions, and the future trend of GHG emissions will be dependent on the future trends of the variables that contribute to GHG emissions. We present the future trends of GHG emissions from private road passenger transportation in Figure 5.1.

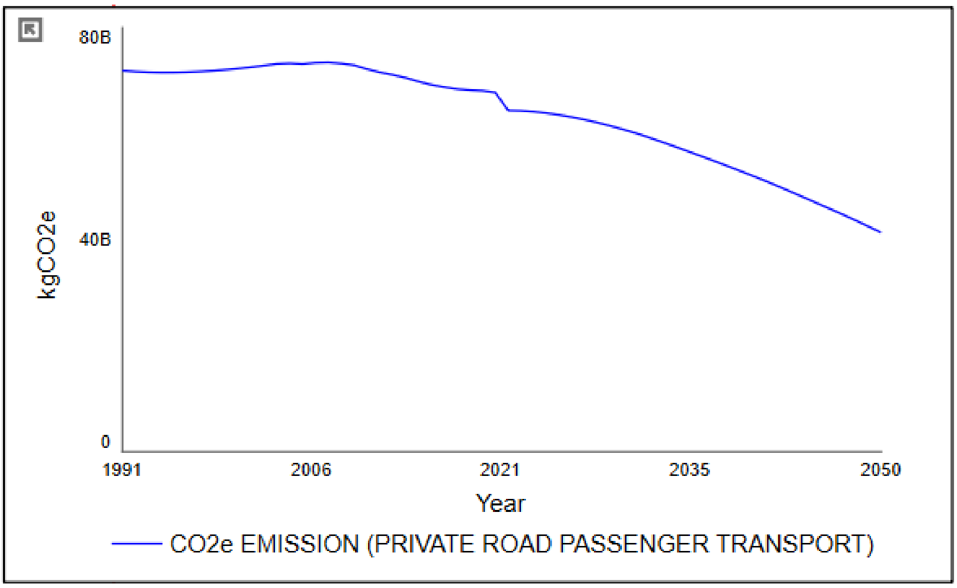

Figure 5.1: Trend of road passenger transport GHG emissions (private vehicles)
Source: Author's model

We observe that the historical trend of road passenger transport GHG emissions has been declining (as may be seen in Figure 3.2, Figure 3.4, and Figure 4.8). If this trend continues until 2050, GHG emissions will reduce from 67.8billion kg CO2e in 2020 to 41.4billion kgCO2e in 2050, and the UK government will be unable to meet its road transport sector decarbonisation target. It is insightful to also see the trend of the underlying factors. We present in the trends of the following variables: (i) average distance travelled per passenger; (ii) average number of trips per passenger; and (ii) number of registered vehicles by fuel type.

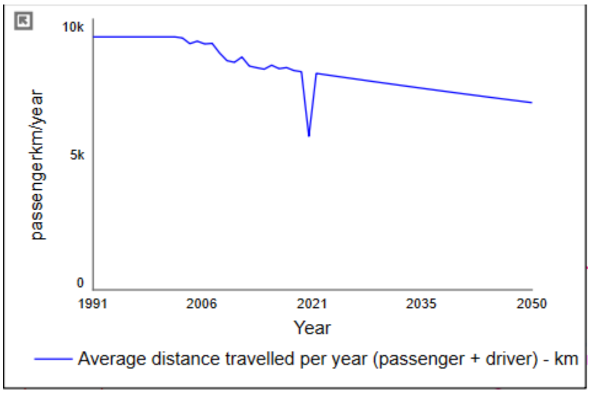

Figure 5.2: Trend of average distance travelled per year
Source: Author's model

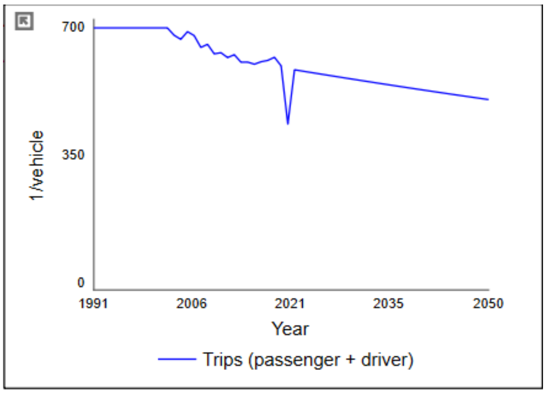

Figure 5.3: Trend of average number of trips per year
Source: Author's model

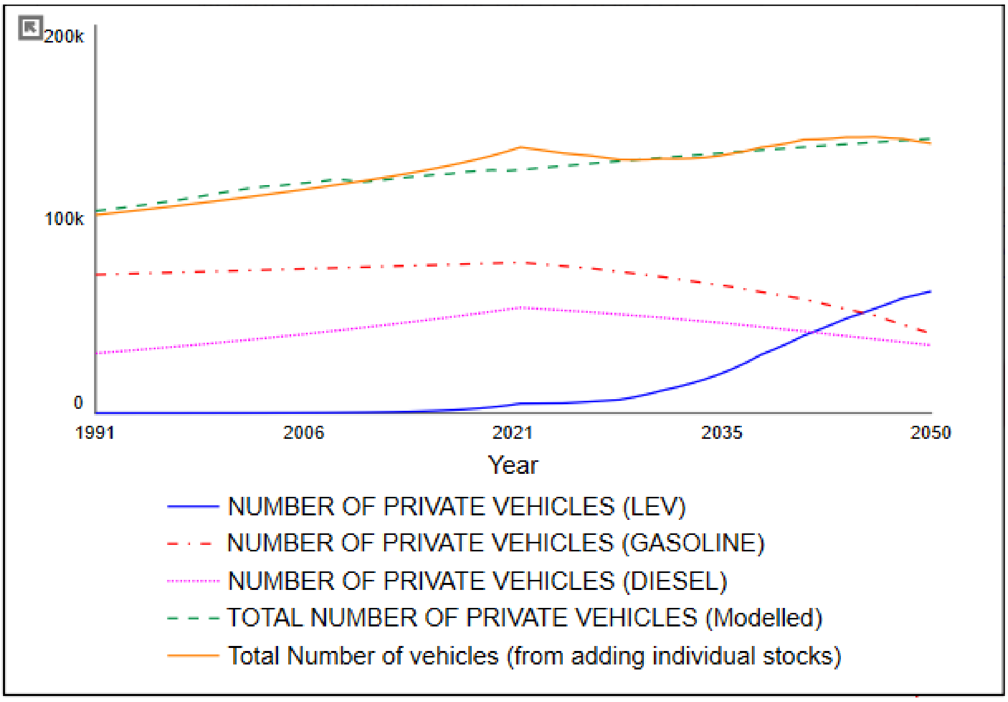

Figure 5.4: Trend of number of vehicles by fuel types in the base-case scenario
Source: Author's model

We observe from Figure 5.2 and Figure 5.3 that the trends of the average distance travelled per passenger and the average number of trip per passenger which has been declining will continue to decline until 2050. We also observe from Figure 5.4 that LEV continues to grow at a faster rate while gasoline vehicles and diesel vehicles will reduce. This response will be as a result of the current policies of the UK government to support LEVs.

As may be seen in the causal loop diagram as well as in Section 3.2.2.6, private transport activities are an important source of revenue for government. The revenues from three different sources: (a) tax components of retail prices of gasoline and diesel; (b) vehicle tax; and (c) licensing fees. We assume that LEVs do not use gasoline and diesel therefore government will not gain any revenue from gasoline and diesel retail prices when people switch to LEVs. Gasoline and diesel tax are £180/year (UK Department of Transport) while LEVs are tax free. The only revenue from LEVs is from licensing cost which is set at £55/vehicle per year. In the base-case scenario, the trajectory of revenue from private road passenger transport activities show that revenue will be declining till 2050.

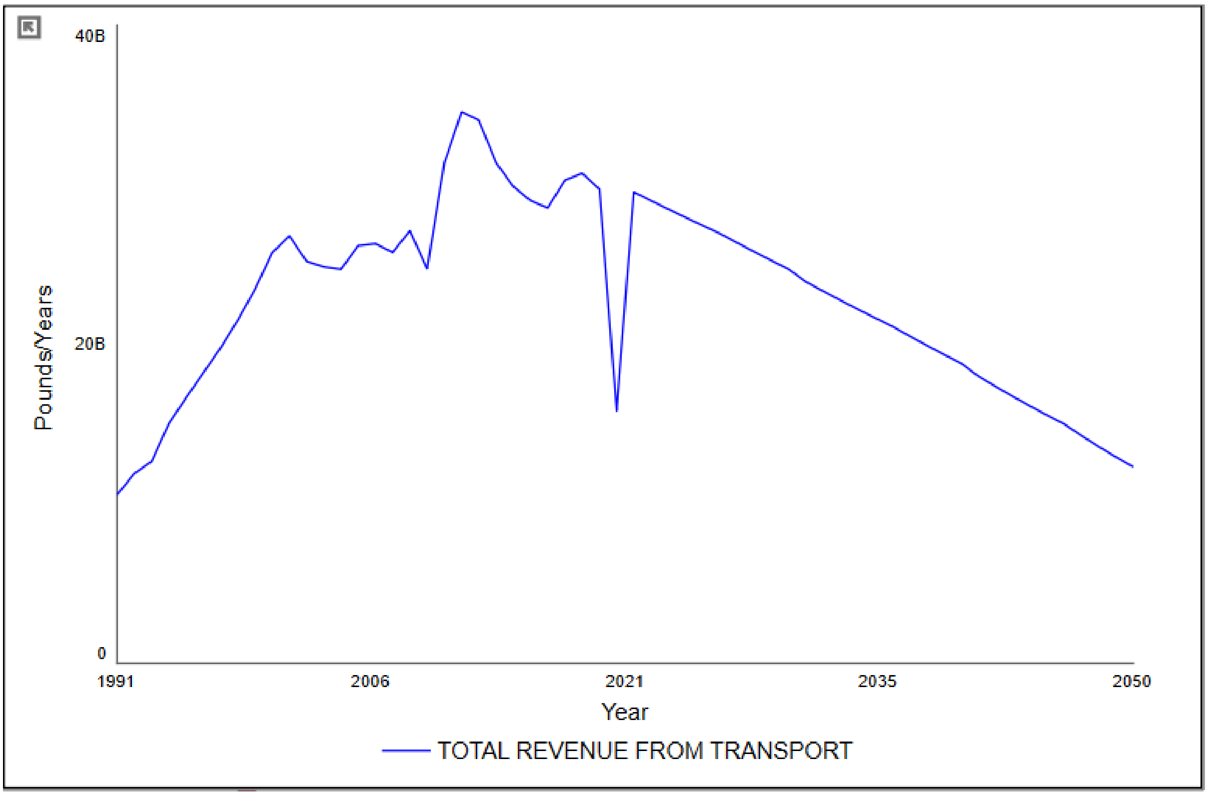

Figure 5.5: Total revenue for private road passenger transport activities in the base-case scenario
Source: Author's model

Beyond revenue, private transport activities create jobs for auto-technicians and these also contribute to the GDP in different ways. Most low emission vehicles require much less maintenance and repairs because they have fewer number of moving parts. This means that a shift from gasoline or diesel vehicles to LEVs will lead to job losses. However, we elected to exclude this area from the model due to modelling difficulties

5.2 Policy Analysis

The avoid-shift-improve (A-S-I) model has been used extensively to examine pathways for reducing energy consumption and GHG emissions in the transport sector (Solís & Sheinbaum, 2013; Bakker *et al*., 2017; Maduekwe *et al*., 2020). The "Avoid" focus on policies that can help commuters avoid some trips or reduce length or frequency of trips; the "Shift" focus on policies that facilitate modal shift from energy-intensive modes or means of transportation to other options that use less energy (e.g. from gasoline to electric vehicles); while the "Improve" focus on policies that will promote the vehicle efficiency so as to reduce the energy consumption per passenger-km. The A-S-I approach is very useful in the formulation of policies targeted at decarbonizing the transport sector (Sims *et al*., 2014; World Bank, 2021).

5.2.1 Avoid policies

Avoid policies seek to make passengers avoid certain trips. In recent times, the UK government has been promoting flexible working arrangements which enables workers to work off-site for works that can be done remotely. In terms of our model, "avoid" policies will aim to reduce the values of the variables: "average distance travelled per year" and "average number of trips per year". Given that transportation is connected with lifestyles and behaviours, we assume that the reduction in these variables will take time. We note that the values of these variables dipped in 2020 as a result of the COVID 19 pandemic and the 2021 values will follow the previous trend. Our policy assumption is that there will be a 2% annual reduction in the values average distance travelled per year from 2022 to 2050 and a 1.5% annual reduction in the number of trips from 2022 to 2050.

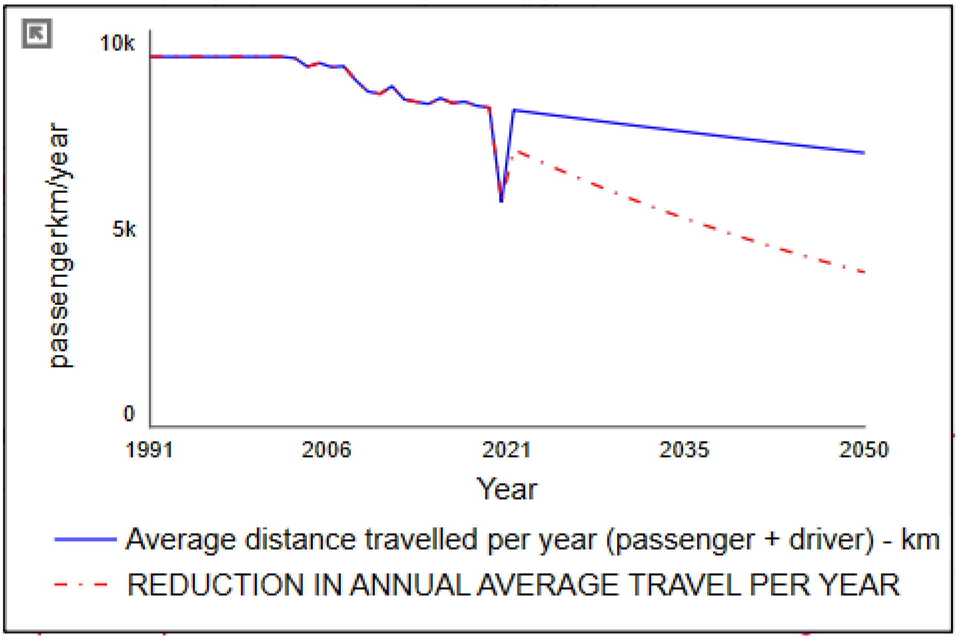

Figure 5.6: Reduction in the average distance travelled per year
Source: Author's model

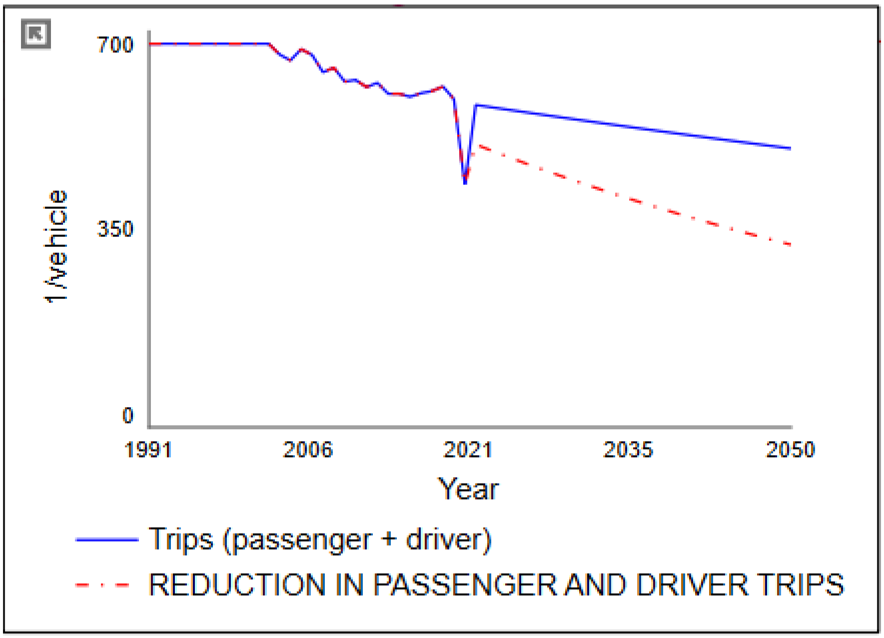

Figure 5.7: Reduction in the average number of trips per year
Source: Author's model

5.2.2 The shift policies

Shift policies focus on how passengers can shift from modes or means of transportation that emits more GHG emission to those that emit less. In terms of road passenger transportation, "shift" policies intend to shift passengers from private transportation to public transportation, or private transport passengers from using gasoline vehicles to using LEVs. For the first part of the shift policy, we assume that there will be a gradual shift in preference for public transport such that the share of public transportation will start increasing till 2050. This shift may be as a result of different factors such as increased route of public transport which will increase the efficiency of public transport, reduced cost of public transport, or a general societal change in the perception of public transportation.

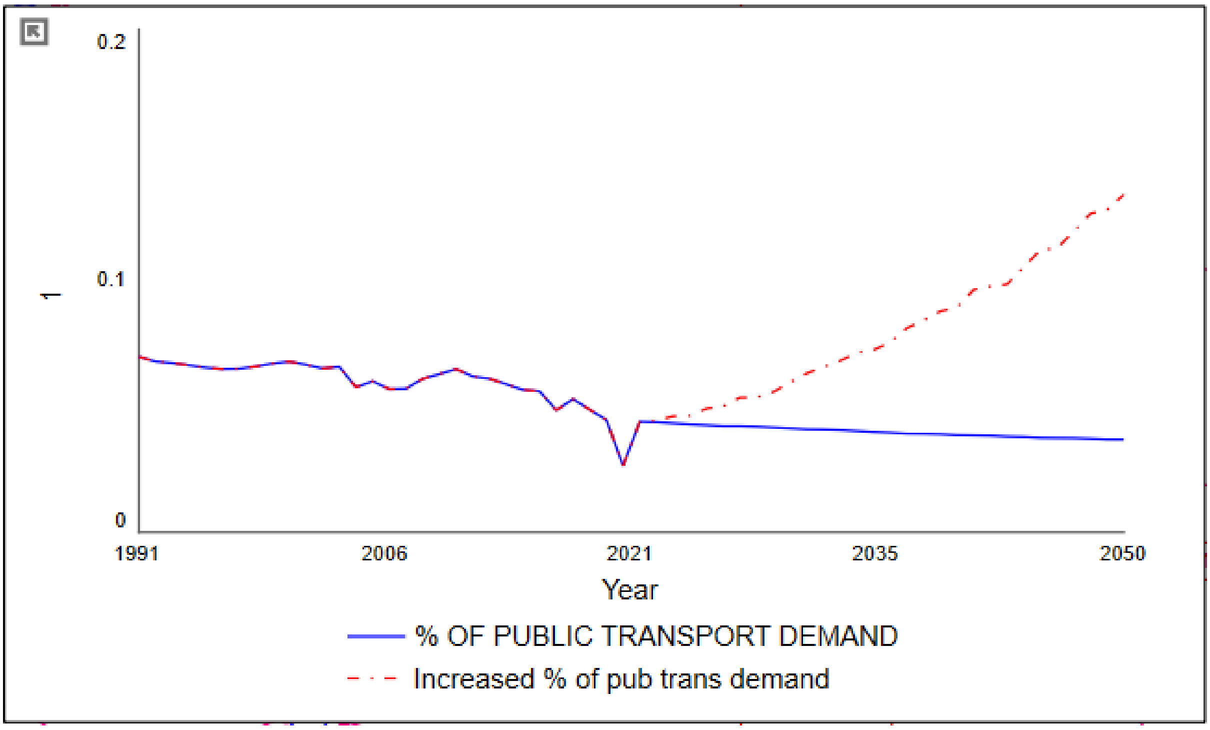

Figure 5.8: Possible changes in the percentage of public transport demand for road passenger transport
Source: Author's model

For the second part of the "shift" policy, i.e. shifting from gasoline or diesel to LEVs. In our base case scenario, we made an assumption that there will be a gradual transition from gasoline and diesel vehicles to LEVs and this transition will be a such a way that the total number registered vehicles do not deviate substantially from historical trend. The base-case scenario for the number of registered vehicles by vehicle type is shown in Figure 5.4. In the policy scenario, we assume that this transition will be faster due to government policies such as additional subsidies on LEVs (import duty waivers, low vehicle tax, low parking fees, low registration fees) and at the same time higher cost of using gasoline and diesel vehicles (higher registration fees, higher vehicle tax, higher VAT on diesel and gasoline which will increase their retail prices, etc.). In our model, this will lead to reduction in the "gasoline vehicle acquisition rate" and "diesel vehicle acquisition rate", and an increase in "LEV acquisition rate.

In the immediate years following the policy. These rates will gradually normalize in the future as shown in Figure 5.9

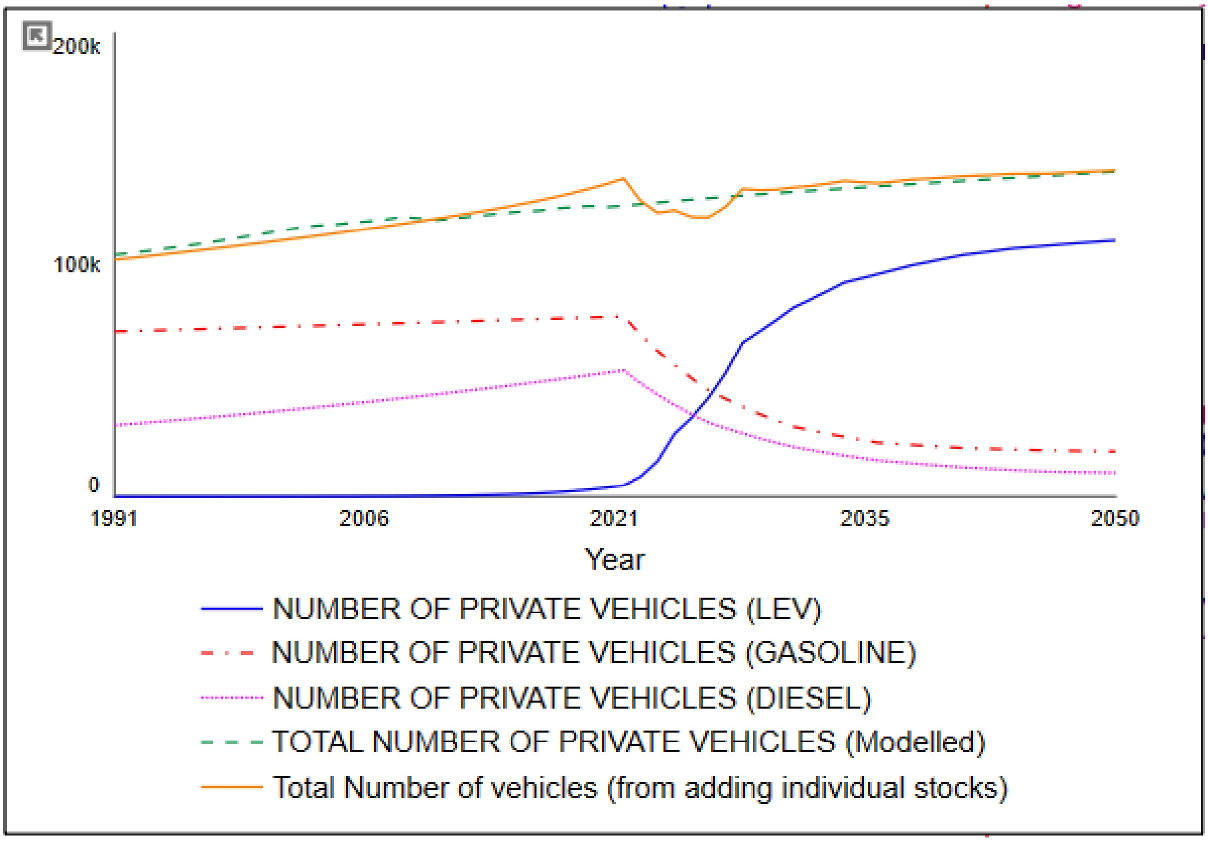

Figure 5.9: Changes in the trend of the number of registered vehicles by vehicle type due to implementation of "shift" policy.
Source: Author's model

5.2.3 Improve policies

The improve policies seek to improve different variables that contribute to GHG emissions such as vehicle efficiencies. Here governments may subsidize manufactures of vehicles to improve their efficiencies. This may be in terms of tax rebates or tax waivers for research activities carried out such manufacturers. In terms of our model, the improve policies will affect the vehicle efficiencies of all the vehicle types as shown in Figure 5.10, Figure 5.11, and Figure 5.12.

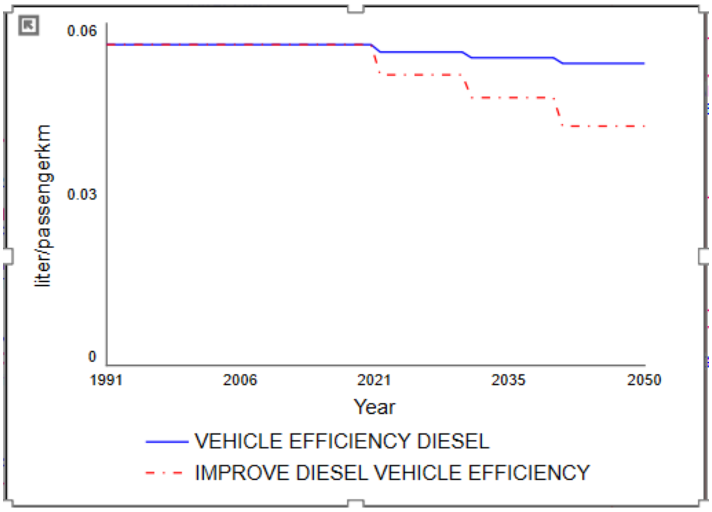

Figure 5.10: Changes in the trend of the vehicle efficiency of diesel vehicles due to implementation of "improve" policy.
Source: Author's model

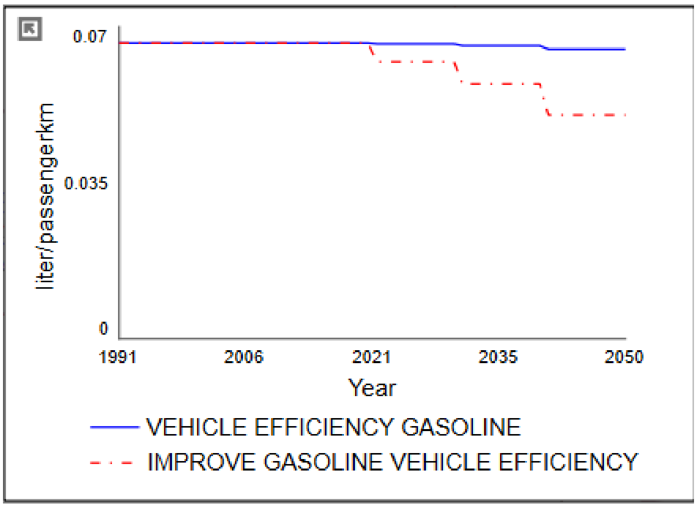

Figure 5.11: Changes in the trend of the vehicle efficiency of gasoline vehicles due to implementation of "improve" policy.
Source: Author's model

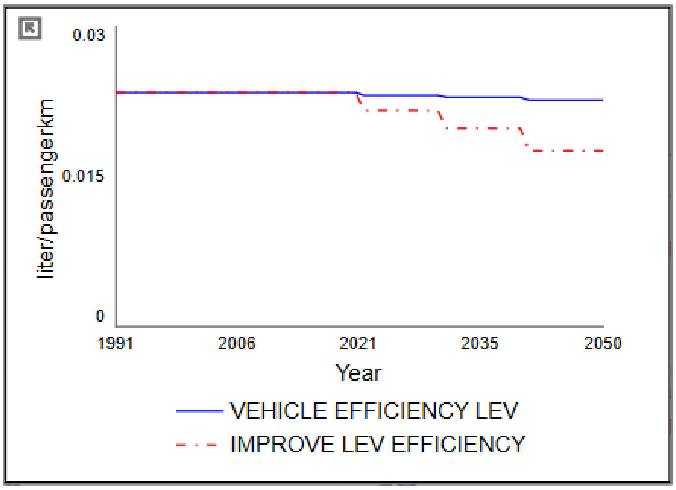

Figure 5.12: Changes in the trend of the vehicle efficiency of LEVs due to implementation of "improve" policy.
Source: Author's model

5.3 Results of Policy analysis

The policy interventions show that private road passenger transport GHG emissions in the United Kingdom will reduce further than the base-case scenario. In the "Avoid" scenario, GHG emissions will reduce from 67.8billion KgCO2e in 2020 to 21.6 billion kgCO2e in 2050. In the "Shift" scenario, GHG emissions will reduce from 67.8billion KgCO2e in 2020 to 23billion kgCO2e in 2050. In the "Improve" scenario, GHG emissions will reduce from 67.8billion KgCO2e in 2020 to 34.8billion kgCO2e in 2050. Combining the three policies, i.e. A-S-I scenario, GHG emissions will reduce from 67.8billion KgCO2e in 2020 to 11.4billion kgCO2e in 2050. It is important to state that here that the UK government's target of decarbonizing road passenger travel subsector by 2050 will not be achieved in any of the scenarios.

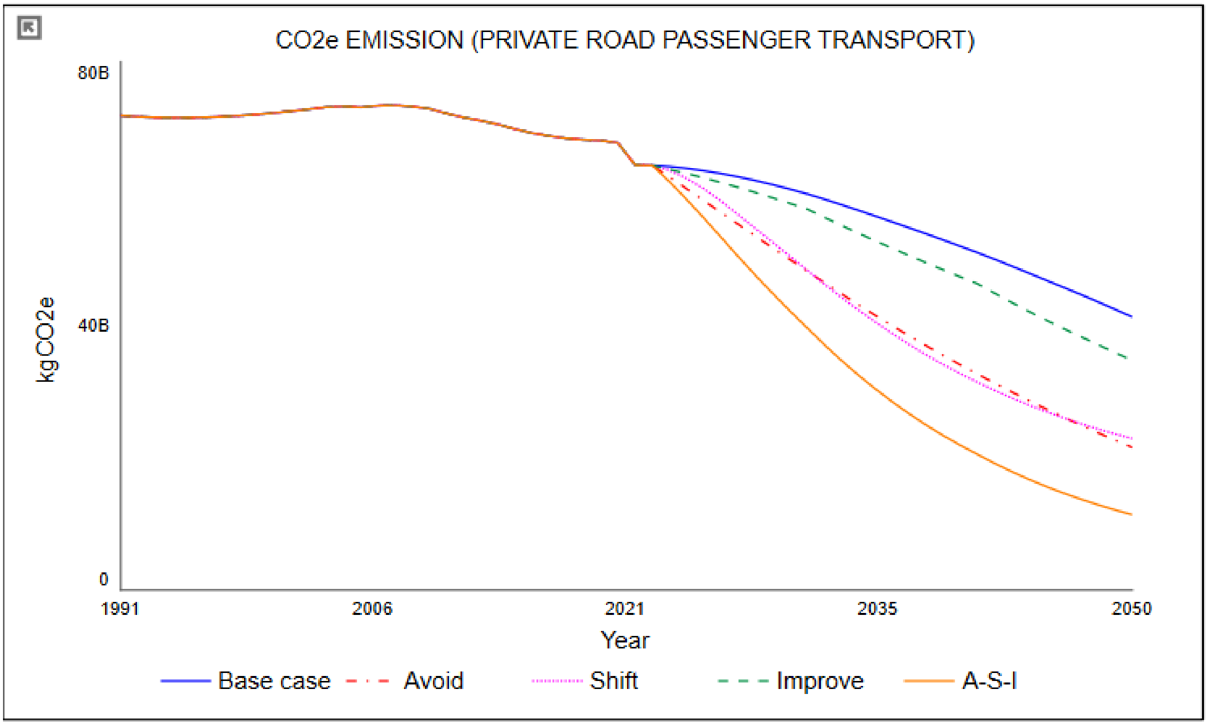

Figure 5.13: Result of policy analysis showing the trajectory of road passenger travel GHG emissions from private vehicles
Source: Author's model

In terms of loss of revenue, the implementation of the A-S-I policies will lead to a substantial loss of revenue from private road transport activities as shown in

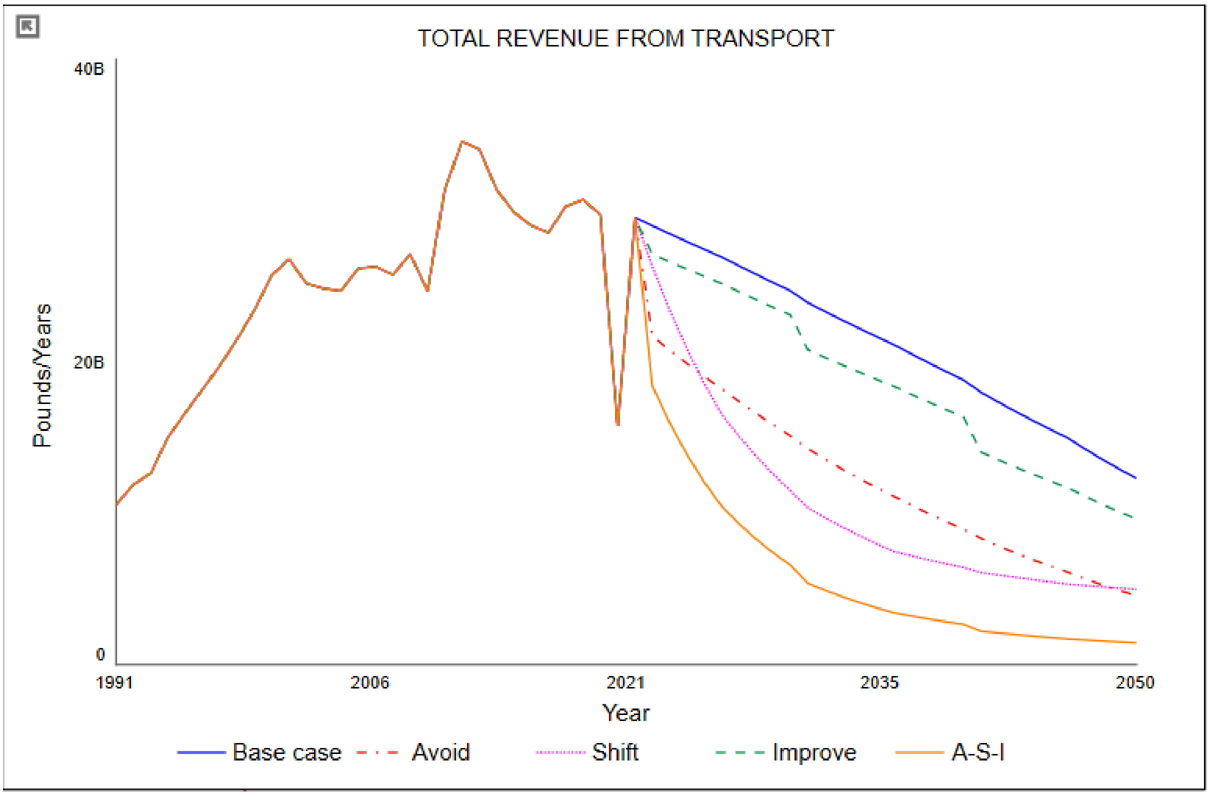

Figure 5.14: Total revenue from private road transport activities if A-S-I policies are implemented
Source: Author's model

CHAPTER SEVEN

6 CONCLUSION AND RECOMMENDATION

This study examines policy options from reducing private road passenger transport GHG emissions in the United Kingdom. The study relied on literature as well as on knowledge of transport economics to develop a system dynamics model for this purpose. The study adopted a time horizon of 1991 to 2050: 1991 to 2020 for historical data and 2021 to 2050 for projections. The end date of 2050 aligns with the target date set by the UK government to achieve its decarbonisation targets. We consider a base-case scenario as well as policy scenarios. The policy scenarios align with the avoid-shift-improve (A-S-I) framework for modelling low carbon futures in road transportation. The result of the base-case scenario shows that private road passenger transport GHG emissions will continue to decline gently following historical trend. However, by 2050, the GHG emissions will still be substantial in contrast to the decarbonisation targets. In the policy scenarios, the decline of GHG emissions will be more drastic, however, the decarbonisation targets will not be achieved in any scenario. It is important to state that the assumptions used in the policy scenarios are ambitious.

The result of this study aligns with findings from previous studies which analysed policy options for decarbonisation of the road transportation in the United Kingdom (Bristow, et al., 2008), (Brand, et al., 2013). The determinant of road passenger transport GHG emissions such as average number of trips, average length of trips, or vehicle ownership are themselves influenced by several other factors that are difficult to capture in a model. For example, several studies have shown that lifestyles play an important role in travel activities and vehicles ownership (Choo & Mokhtarian, 2004), (Axsen, et al., 2018), (Gallic & Aguilera, 2022). Therefore, changes in lifestyles can have some impacts on GHG emissions via changes in the travel frequency or changes in rate of car ownership. However, quantifying the extent of this impacts will require more detailed modelling and analyses. Furthermore, we had made assumptions on the vehicle efficiency for LEVs which was that LEV efficiency is one-fifth of diesel efficiency. This assumption was made because we categorized different types of vehicles into the LEV group and obtaining the energy consumption of these different types of vehicles in a comparable unit was difficult. For example, it is difficult to compare the energy consumption per 100km of plugged in vehicles, electric-diesel hybrid, and hydrogen vehicles. Our assumption may have an impact on the future trends of GHG emissions.

An important impact of reduction in the number of gasoline and diesel vehicles, and a corresponding increase in the number of LEVs is the reduction in the government revenues from private road passenger transport activities. We had assumed that the revenue structure from private road passenger transport activities will remain the same throughout the time horizon for this study. In reality, this is very unlikely: it is very likely that the UK government will introduce taxes of LEVs when LEVs become the dominant vehicle type in the UK. Notwithstanding, the task is that of balancing long terms environmental cost of GHG emissions with revenue losses that will arise from the pursuit of decarbonisation goals

This study can be improved in different ways:

(i) Shifting from private transport to public transport has an immense potential to reduce road passenger transport GHG emissions. However, we did not consider this form of "shift" policy which involves shifting from private road transport demand to public transport demand. Notwithstanding, we had highlighted several factors which influence the change in the share of public transport demand. A future study that incorporates detailed modelling of public road passenger transport demand as well as rail passenger transport demand will be a great improvement to this current study.

(ii) Our "shift" policy is based on assumptions of the trajectory of vehicle ownership for the different vehicle types. These assumptions were made solely based on historical trends. An improvement to this would be the adoption of a more objective approach based on empirical models to make just projections. For example, using empirical model to project future trends of LEV registration based on price, income, household sizes, and lifestyles. A future study may consider this.

(iii) We did not consider other contributions of private road passenger transport activities to the GDP. A future study may consider this.

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APPENDICES

Appendix 1: Model Equations

Model - for writing up Final.stmx

Total	Count	Including Array Elements
Variables	148	148
Modules	1	
Sectors	8	
Stocks	7	7
Flows	12	12
Converters	129	129
Constants	36	36
Equations	105	105
Graphicals	26	26
Macro Variables	11	

	Equation	Properties	Units	Documentation	Annotation
Top-Level Model:					
"CO2e_EMISSION_(PRIVATE_ROAD_PASSENGER_TRANSPORT)"(t)	"CO2e_EMISSION_(PRIVATE_ROAD_PASSENGER_TRANSPORT)"(t - dt) + (C02_ADDITION - CO2_REMOVAL) * dt	INIT "CO2e_EMISSION_(PRIVATE_ROAD_PASSENGER_TRANSPORT)" = 71908527986.53	kgCO2e		
"CO2e_EMISSIONS_(PUBLIC)"(t)	"CO2e_EMISSIONS_(PUBLIC)"(t - dt) + (CO2e_Addition_for_Public_Road_Passenger_Travel - REMOVAL) * dt	INIT "CO2e_EMISSIONS_(PUBLIC)" = 5198140343.41	kgCO2e		
GDP(t)	GDP(t - dt) + (GDP_RATE) * dt	INIT GDP = INITIAL_GDP	Pounds	GDP of the United Kingdom in local currency is used as an exogenous variable Source of data: World Bank	
"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"(t)	"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"(t - dt) + (DIESEL_ACQUISITION - SCRAPPING_RATE_D) * dt	INIT "NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)" =	vehicle	Stock of number of private vehicles (diesel)	

			INITIAL_NUMBER_OF_PRIVATE_DIESEL_VEHICLE			
	"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"(t)	"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"(t - dt) + (GASOLINE_ACQUISITION - SCRAPPING_RATE_G) * dt	INIT "NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)" = INITIAL_NUMBER_OF_PRIVATE_GASOLINE_VEHICLE	vehicle	Stock of number of private vehicles (gasoline)	
	"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"(t)	"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"(t - dt) + (LEV_ACQUISITION - SCRAPPING_RATE_LEV) * dt	INIT "NUMBER_OF_PRIVATE_VEHICLES_(LEV)" = INITIAL_NUMBER_OF_LEV	vehicle	Stock of number of private vehicles (LEVs)	
	POPULATION(t)	POPULATION(t - dt) + (GROWTH) * dt	INIT POPULATION = INITIAL_POPULATION	passenger	Population of the United Kingdom is used as an exogenous variable Source of data: World Bank	
	C02_ADDITION	CO2_EMISSION_FROM_GASOLINE+CO2_EMISSION_FROM_DIESEL+CO2_EMISSION_FROM_LEV		kgCO2e/Years		
	CO2_REMOVAL	"CO2e_EMISSION_(PRIVATE_ROAD_PASSENGER_TRANSPORT)"*SEQUESTRATION_FACTOR		kgCO2e/Years		
	CO2e_Addition_for_Public_Road_Passenger_Travel	PASSENGER_TRAVEL_DEMAND_PUBLIC_TRANSPORT*PUBLIC_ROAD_PASSENGER_TRANSPORT_CO2e_EMISSIONS_FACTOR		kgCO2e/Years		
	DIESEL_ACQUISITION	IF Policy_Switch:_SHIFT = 0 THEN Diesel_Vehicle_acquisition_rate*ANNUAL_NUMBER_OF_DIESEL_VEHICLE*"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"/ANNUAL_NUMBER_OF_DIESEL_VEHICLE ELSE Shift_policy:_Diesel_vehicle_acquisition_rate*ANNUAL_NUMBER_OF_DIESEL_VEHICLE*"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"/ANNUAL_NUMBER_OF_DIESEL_VEHICLE		vehicle/year		
	GASOLINE_ACQUISITION	IF Policy_Switch:_SHIFT = 0 THEN ANNUAL_NUMBER_OF_GASOLINE_VEHICLE*Gasoline_vehicle_acquisition_rate*"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"/ANNUAL_NUMBER_OF_GASOLINE_VEHICLE ELSE ANNUAL_NUMBER_OF_GASOLINE_VEHICLE*Shift_policy:_Gasoline_vehicle_acquisition_rate*"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"/ANNUAL_NUMBER_OF_GASOLINE_VEHICLE		vehicle/year		

	GDP_RATE	GDP*GDP_GROWTH+TOTAL_REVENUE_FROM_TRANSPORT		Pounds/Years		
	GROWTH	POPULATION*POP_GROWTH_FRACTION		passenger/Year		
	LEV_ACQUISITION	IF Policy_Switch:_SHIFT = 0 THEN ANNUAL_NUMBER_OF_LEV*LEV_acquisition_rate*"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"/ANNUAL_NUMBER_OF_LEV ELSE ANNUAL_NUMBER_OF_LEV*Shift_policy:_LEV_acquisition_rate*"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"/ANNUAL_NUMBER_OF_LEV		vehicle/year		
	REMOVAL	"CO2e_EMISSIONS_(PUBLIC)"*SEQUESTRATION_FACTOR		kgCO2e/Years		
	SCRAPPING_RATE_D	"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"*SCRAPPING_FRACTION_D		vehicle/year	We assume that all vehicles will be operational for 20 years from the year of first registration	
	SCRAPPING_RATE_G	"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"*SCRAPPING_FRACTION_G		vehicle/year	We assume that all vehicles will be operational for 20 years from the year of first registration	
	SCRAPPING_RATE_LEV	"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"*SCRAPPING_FRACTION_LEV		vehicle/year	We assume that all vehicles will be operational for 20 years from the year of first registration	
	"%_CHANGE_AVERAGE_COST_OF_PRIVATE_CARS"	(AVERAGE_COST_OF_PRIVATE_CARS - PREVIOUS(AVERAGE_COST_OF_PRIVATE_CARS, INIT(AVERAGE_COST_OF_PRIVATE_CARS))) /PREVIOUS(AVERAGE_COST_OF_PRIVATE_CARS, INIT(AVERAGE_COST_OF_PRIVATE_CARS))		1		
	"%_CHANGE_PER_CAPITA_INCOME"	((PER_CAPITA_INCOME-PREVIOUS(PER_CAPITA_INCOME, INIT(PER_CAPITA_INCOME)))/PREVIOUS(PER_CAPITA_INCOME, INIT(PER_CAPITA_INCOME)))		1	This is the percentage change in per capita income. It	

					is used to estimate the changes in the shares of public transport due to changes in per capita income through the elasticity	
	"%_CHANGE_PRICE_OF_PUBLIC_TRANSPORT"	((PRICE_OF_PUBLIC_TRANSPORT-PREVIOUS(PRICE_OF_PUBLIC_TRANSPORT, INIT(PRICE_OF_PUBLIC_TRANSPORT)))/PREVIOUS(PRICE_OF_PUBLIC_TRANSPORT, INIT(PRICE_OF_PUBLIC_TRANSPORT)))		1		
	"%_CHANGE_PUBLIC_TRANSPORTATION_EFFICIENCY"	GRAPH(INVESTMENT_ACTUALIZATION) Points: (0, 0.01), (2105263157.89, 0.01856), (4210526315.79, 0.02531), (6315789473.68, 0.03063), (8421052631.58, 0.03483), (10526315789.5, 0.03813), (12631578947.4, 0.04074), (14736842105.3, 0.04279), (16842105263.2, 0.04441), (18947368421.1, 0.04569), (21052631578.9, 0.04669), (23157894736.8, 0.04749), (25263157894.7, 0.04811), (27368421052.6, 0.04861), (29473684210.5, 0.04899), (31578947368.4, 0.0493), (33684210526.3, 0.04954), (35789473684.2, 0.04973), (37894736842.1, 0.04988), (4e+10, 0.05)		1	New investments in the transport sector are targeted at improving the efficiency of the sector which will affect the public and private sector. This converter focuses on how new investment will improve the	
	"%_OF_PRIVATE_TRANSPORT_DEMAND"	1-ADJUSTED_%_OF_PUBLIC_TRANSPORT_DEMAND		1	Road transport passengers interested in motorised means of transport have two options: public and private.	
	"%_OF_PUBLIC_TRANSPORT_DEMAND"	GRAPH(TIME) Points: (1991.00, 0.069818287), (1992.00, 0.067940813), (1993.00, 0.067291443), (1994.00, 0.066443667), (1995.00, 0.065486993), (1996.00, 0.064916967), (1997.00, 0.065053301), (1998.00, 0.065973381), (1999.00, 0.067123193), (2000.00, 0.067876665), (2001.00, 0.066682313), (2002.00, 0.065173334), (2003.00, 0.065851455), (2004.00, 0.057704354), (2005.00, 0.060055703), (2006.00, 0.056946349), (2007.00, 0.057144029),		1	share of road passenger travel demand (public - buses and coaches). These are	

		(2008.00, 0.061080335), (2009.00, 0.062909047), (2010.00, 0.064911883), (2011.00, 0.06198476), (2012.00, 0.061096616), (2013.00, 0.058900376), (2014.00, 0.056669689), (2015.00, 0.056136182), (2016.00, 0.048534268), (2017.00, 0.052971318), (2018.00, 0.048813338), (2019.00, 0.044686162), (2020.00, 0.026432819), (2021.00, 0.044), (2022.00, 0.04378), (2023.00, 0.0433422), (2024.00, 0.042908778), (2025.00, 0.042608417), (2026.00, 0.042224941), (2027.00, 0.042224941), (2028.00, 0.042013816), (2029.00, 0.041677706), (2030.00, 0.041344284), (2031.00, 0.040972185), (2032.00, 0.040890241), (2033.00, 0.04068579), (2034.00, 0.040278932), (2035.00, 0.039876143), (2036.00, 0.03959701), (2037.00, 0.039201039), (2038.00, 0.039161838), (2039.00, 0.039005191), (2040.00, 0.038654144), (2041.00, 0.038538182), (2042.00, 0.038422567), (2043.00, 0.038076764), (2044.00, 0.037924457), (2045.00, 0.037583137), (2046.00, 0.037507971), (2047.00, 0.037470463), (2048.00, 0.03724564), (2049.00, 0.036947675), (2050.00, 0.036910727)			the shares from actual data from the UK's Departmen t for Transporta tion	
	ACTUAL_CARS	GRAPH(TIME) Points: (1991.00, 102263.89), (1992.00, 103171.76), (1993.00, 104079.92), (1994.00, 104988.43), (1995.00, 105897.41), (1996.00, 106806.97), (1997.00, 107717.26), (1998.00, 108628.47), (1999.00, 109540.87), (2000.00, 110454.75), (2001.00, 111370.51), (2002.00, 112288.66), (2003.00, 113209.82), (2004.00, 114134.79), (2005.00, 115064.59), (2006.00, 116000.5), (2007.00, 116944.13), (2008.00, 117897.54), (2009.00, 118863.33), (2010.00, 119844.78), (2011.00, 120846.04), (2012.00, 121872.37), (2013.00, 122930.44), (2014.00, 124028.65), (2015.00, 123941.28), (2016.00, 126621.29), (2017.00, 128657.04), (2018.00, 129856.72), (2019.00, 131360.89), (2020.00, 130829.74)		vehicle	Actual data on number of registered vehicles in the United Kingdom (1991 - 2020) Source: UK's Departmen t for Transporta tion	
	ACTUAL_CO2_BU S	GRAPH(TIME) Points: (1991.00, 5324758898.0), (1991.49152542, 5276772584.0), (1991.98305085, 5279461431.0), (1992.47457627, 5377673477.0), (1992.96610169, 5478921724.0), (1993.45762712, 5571898059.0), (1993.94915254, 5594156822.0), (1994.44067797, 5459842580.0), (1994.93220339, 5295857507.0), (1995.42372881, 4980873476.0), (1995.91525424, 4944735471.0), (1996.40677966, 4933632310.0), (1996.89830508, 5059686590.0), (1997.38983051, 4846114746.0), (1997.88135593, 4835292777.0), (1998.37288136, 4910655855.0), (1998.86440678, 4979517534.0), (1999.3559322, 4426971518.0), (1999.84745763, 4420229234.0), (2000.33898305, 4538173886.0), (2000.83050847, 4192715530.0), (2001.3220339, 4014817205.0), (2001.81355932, 4059382732.0), (2002.30508475, 4024911836.0), (2002.79661017, 3885993207.0), (2003.28813559, 3682374088.0), (2003.77966102, 3496189226.0), (2004.27118644, 3341780488.0), (2004.76271186, 3128229406.0), (2005.25423729, 2155437296.0), (2005.74576271, 3153700000.0), (2006.23728814, 3063700000.0), (2006.72881356, 2973700000.0), (2007.22033898, 2883700000.0), (2007.71186441, 2793700000.0), (2008.20338983, 2703700000.0), (2008.69491525, 2613700000.0), (2009.18644068, 2523700000.0), (2009.6779661, 2433700000.0), (2010.16949153, 2343700000.0),		vehicle		

		(2010.66101695, 2253700000.0), (2011.15254237, 2163700000.0), (2011.6440678, 2073700000.0), (2012.13559322, 1983700000.0), (2012.62711864, 1893700000.0), (2013.11864407, 1803700000.0), (2013.61016949, 1713700000.0), (2014.10169492, 1623700000.0), (2014.59322034, 1533700000.0), (2015.08474576, 1443700000.0), (2015.57627119, 1353700000.0), (2016.06779661, 1263700000.0), (2016.55932203, 1173700000.0), (2017.05084746, 1083700000.0), (2017.54237288, 993700000.0), (2018.03389831, 903700000.0), (2018.52542373, 813700000.0), (2019.01694915, 723700000.0), (2019.50847458, 633700000.0), (2020.00, 543700000.0)				
	ACTUAL_CO2_EMISSIONS_PRIVATE	GRAPH(TIME) Points: (1991.00, 71643654436.0), (1992.00, 73197201033.0), (1993.00, 74101019707.0), (1994.00, 73459425880.0), (1995.00, 72702954528.0), (1996.00, 75493246832.0), (1997.00, 76233867299.0), (1998.00, 75546485625.0), (1999.00, 76958588932.0), (2000.00, 76764611405.0), (2001.00, 76577540855.0), (2002.00, 78093825852.0), (2003.00, 76811322203.0), (2004.00, 77225103999.0), (2005.00, 77201012708.0), (2006.00, 76729618796.0), (2007.00, 77026042016.0), (2008.00, 74780083060.0), (2009.00, 72538143576.0), (2010.00, 70377765318.0), (2011.00, 69749589401.0), (2012.00, 69610993390.0), (2013.00, 68553031844.0), (2014.00, 68985330233.0), (2015.00, 69721899010.0), (2016.00, 70826729905.0), (2017.00, 70828866534.0), (2018.00, 69676113064.0), (2019.00, 68876903188.0), (2020.00, 51766587834.0), (2021.00, 57827000000.0), (2022.00, 57177000000.0), (2023.00, 56527000000.0), (2024.00, 55877000000.0), (2025.00, 55227000000.0), (2026.00, 54577000000.0), (2027.00, 53927000000.0), (2028.00, 53277000000.0), (2029.00, 52627000000.0), (2030.00, 51977000000.0), (2031.00, 51327000000.0), (2032.00, 50677000000.0), (2033.00, 50027000000.0), (2034.00, 49377000000.0), (2035.00, 48727000000.0), (2036.00, 48077000000.0), (2037.00, 47427000000.0), (2038.00, 46777000000.0), (2039.00, 46127000000.0), (2040.00, 45477000000.0), (2041.00, 44827000000.0), (2042.00, 44177000000.0), (2043.00, 43527000000.0), (2044.00, 42877000000.0), (2045.00, 42227000000.0), (2046.00, 41577000000.0), (2047.00, 40927000000.0), (2048.00, 40277000000.0), (2049.00, 39627000000.0), (2050.00, 38977000000.0)		kgCO2e		
	ACTUAL_DIESEL_CARS	GRAPH(TIME) Points: (1991.00, 30849.02), (1992.00, 31581.28), (1993.00, 32313.54), (1994.00, 33045.8), (1995.00, 33778.06), (1996.00, 34510.32), (1997.00, 35242.58), (1998.00, 35974.84), (1999.00, 36707.1), (2000.00, 37439.36), (2001.00, 38171.62), (2002.00, 38903.88), (2003.00, 39636.14), (2004.00, 40368.4), (2005.00, 41100.66), (2006.00, 41832.92), (2007.00, 42565.18), (2008.00, 43297.44), (2009.00, 44029.7), (2010.00,		vehicle	Actual data on number of registered diesel vehicles in the United Kingdom (1991 - 2020)	

		44761.96), (2011.00, 45494.22), (2012.00, 46226.48), (2013.00, 46958.74), (2014.00, 47691), (2015.00, 46707.024), (2016.00, 49496.609), (2017.00, 51359.71), (2018.00, 51879.253), (2019.00, 51635.969), (2020.00, 50445.348)			Source: UK's Departmen t for Transporta tion	
	Actual_GDP	GRAPH(TIME) Points: (1991.00, 1171914517000.0), (1992.00, 1176614855000.0), (1993.00, 1205910576000.0), (1994.00, 1252290008000.0), (1995.00, 1283993858000.0), (1996.00, 1308489984000.0), (1997.00, 1365626260000.0), (1998.00, 1408743005000.0), (1999.00, 1451203512000.0), (2000.00, 1510596243000.0), (2001.00, 1543186272000.0), (2002.00, 1570512479000.0), (2003.00, 1619560421000.0), (2004.00, 1657538651000.0), (2005.00, 1701767379000.0), (2006.00, 1738532452000.0), (2007.00, 1783099044000.0), (2008.00, 1780346932000.0), (2009.00, 1700044640000.0), (2010.00, 1741356964000.0), (2011.00, 1759947881000.0), (2012.00, 1785439965000.0), (2013.00, 1817932533000.0), (2014.00, 1876100968000.0), (2015.00, 1920998000000.0), (2016.00, 1962591568000.0), (2017.00, 2010548876000.0), (2018.00, 2044829157000.0), (2019.00, 2077634528000.0), (2020.00, 1848453604000.0)		Pounds		
	ACTUAL_LEV	GRAPH(TIME) Points: (1991.00, 4.063938005), (1992.00, 5.142567434), (1993.00, 6.507481113), (1994.00, 8.234663129), (1995.00, 10.42026487), (1996.00, 13.18595774), (1997.00, 16.68570651), (1998.00, 21.11434053), (1999.00, 26.7183997), (2000.00, 33.80985931), (2001.00, 42.78349749), (2002.00, 54.13887235), (2003.00, 68.50813213), (2004.00, 86.69120661), (2005.00, 109.7003388), (2006.00, 138.8164359), (2007.00, 175.6603771), (2008.00, 222.2832469), (2009.00, 281.2805178), (2010.00, 355.9365396), (2011.00, 450.407377), (2012.00, 569.952176), (2013.00, 721.2259378), (2014.00, 912.65), (2015.00, 1164.785), (2016.00, 1461.694), (2017.00, 1844.435), (2018.00, 2321.37), (2019.00, 2906.677), (2020.00, 3826.97)		vehicle	Actual data on number of registered LEVs in the United Kingdom (1991 - 2020) Source: UK's Departmen t for Transporta tion	
	Actual_passenger_de mand_private_cars	GRAPH(TIME) Points: (1991.00, 588301446300), (1992.00, 587957403449), (1993.00, 611789392553.0), (1994.00, 618180801171), (1995.00, 621470496783), (1996.00, 625479669466), (1997.00, 635727513522), (1998.00, 639683682790.6), (1999.00, 646929622167), (2000.00, 643902529341), (2001.00, 655999329630), (2002.00, 676379717193), (2003.00, 670841862129), (2004.00, 668260376285), (2005.00, 664591341174), (2006.00, 667973933036), (2007.00, 669406052243), (2008.00, 664914497420.6), (2009.00, 660670595181.1), (2010.00, 647587323446), (2011.00, 646076445263.4), (2012.00, 649612645673), (2013.00, 644395094936), (2014.00, 657095156624), (2015.00, 659137163391), (2016.00, 665496722323), (2017.00, 673889426529), (2018.00, 679082656251), (2019.00, 686513954231), (2020.00, 487793860413)		passen gerkm/ year	This is the actual values for road passenger travel demand (private - cars and taxis). We use this to compare with the estimated values Source of data: UK Departmen t for Transport	

	"Actual_passenger_travel_demand_(private_cars)"	GRAPH(TIME) Points: (1991.00, 588301446300), (1992.00, 587957403449), (1993.00, 611789392553.0), (1994.00, 618180801171), (1995.00, 621470496783), (1996.00, 625479669466), (1997.00, 635727513522), (1998.00, 639683682790.6), (1999.00, 646929622167), (2000.00, 643902529341), (2001.00, 655999329630), (2002.00, 676379717193), (2003.00, 670841862129), (2004.00, 668260376285), (2005.00, 664591341174), (2006.00, 667973933036), (2007.00, 669406052243), (2008.00, 664914497420.6), (2009.00, 660670595181.1), (2010.00, 647587323446), (2011.00, 646076445263.4), (2012.00, 649612645673), (2013.00, 644395094936), (2014.00, 657095156624), (2015.00, 659137163391), (2016.00, 665496722323), (2017.00, 673889426529), (2018.00, 679082656251), (2019.00, 686513954231), (2020.00, 487793860413)		passengerkm/year		
	ACTUAL_PETROL_CAR	GRAPH(TIME) Points: (1991.00, 71410.81), (1992.00, 71585.34), (1993.00, 71759.87), (1994.00, 71934.4), (1995.00, 72108.93), (1996.00, 72283.46), (1997.00, 72457.99), (1998.00, 72632.52), (1999.00, 72807.05), (2000.00, 72981.58), (2001.00, 73156.11), (2002.00, 73330.64), (2003.00, 73505.17), (2004.00, 73679.7), (2005.00, 73854.23), (2006.00, 74028.76), (2007.00, 74203.29), (2008.00, 74377.82), (2009.00, 74552.35), (2010.00, 74726.88), (2011.00, 74901.41), (2012.00, 75075.94), (2013.00, 75250.47), (2014.00, 75425), (2015.00, 76069.473), (2016.00, 75662.988), (2017.00, 75452.895), (2018.00, 75656.094), (2019.00, 76818.24), (2020.00, 76557.418)		vehicle	Actual data on number of registered gasoline vehicles in the United Kingdom (1991 - 2020) Source: UK's Department for Transportation	
	ACTUAL_TOTAL_TRAVEL_DEMAND	GRAPH(TIME) Points: (1991.00, 680799311130), (1992.00, 678163974231), (1993.00, 701010000000.0), (1994.00, 706890438000.0), (1995.00, 712440000000.0), (1996.00, 719117471960), (1997.00, 733692877455), (1998.00, 740110487586), (1999.00, 751303200976.2), (2000.00, 748251065665), (2001.00, 762509092615), (2002.00, 785975261752.1), (2003.00, 782589857218), (2004.00, 780869168560), (2005.00, 778972705241), (2006.00, 786045004504), (2007.00, 790434258944), (2008.00, 787268900538), (2009.00, 782864721034), (2010.00, 771207308796), (2011.00, 773682549308), (2012.00, 779115771944), (2013.00, 776024875167), (2014.00, 793565027722), (2015.00, 798180751252), (2016.00, 806096602212), (2017.00, 817319968008), (2018.00, 824152623076), (2019.00, 830658353345), (2020.00, 549019392957)		passengerkm/year	Trend of total travel demand (1991 - 2020). Source: UK Department for Transport We used this value to compare with the estimated values from the regression: Total passenger travel demand = constant + GDP*Coefficient_of_GDP + Population	

					*Coefficient_of_population	
	ACTUALIZATION_TIME	3		year	This is the time that will be taken for the investment to be completed	
	ADJUSTED_%_OF_PUBLIC_TRANSPORT_DEMAND	"%_OF_PUBLIC_TRANSPORT_DEMAND" * (1+ IMPACT_OF_PUBLIC_TRANSPORT_EFFICIENCY+ IMPACT_OF_PER_CAPITA_INCOME_ON_SHARE_OF_PUBLIC_TRANSPORT + IMPACT_OF_AVERAGE_COST_OF_PRIVATE_CARS + IMPACT_OF_PRICE_OF_PUBLIC_TRANSPORT)		1	This is the adjusted shares. The reason for this variable is to represent the fact that the shares of public transport are influenced by diverse factors such as efficiency of public transport, price of public transport, cost of private transport, and household income (represented by GDP per capita). This approach is a better representation of the factors that drive public transport use.	
	ANNUAL_DIESEL_VEHICLE_TAX	DIESEL_VEHICLE_TAX*"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"		Pounds/Years	Annual vehicle tax from all diesel vehicles	
	ANNUAL_GASOLINE_VEHICLE_TAX	"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"*GASOLINE_VEHICLE_TAX		Pounds/Years	Annual vehicle tax from all gasoline vehicles	

	ANNUAL_LEV_TAX	LEV_VEHICLE_TAX*"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"		Pounds/Years		
	ANNUAL_LICENSING_AND_TAX_REVENUE	ANNUAL_DIESEL_VEHICLE_TAX+ANNUAL_LEV_TAX+ANNUAL_GASOLINE_VEHICLE_TAX+LICENSING_COST_PER_YEAR		Pounds/Years	This is the total revenue from licensing and vehicle tax	
	ANNUAL_NUMBER_OF_DIESEL_VEHICLE	"TOTAL_NUMBER_OF_PRIVATE_VEHICLES_(Modelled)"*SHARE_OF_DIESEL_VEHICLE_REGISTRATION		vehicle/year	Annual number of registered diesel vehicles based on actual shares of diesel vehicles and estimated total number of vehicles	
	ANNUAL_NUMBER_OF_GASOLINE_VEHICLE	"TOTAL_NUMBER_OF_PRIVATE_VEHICLES_(Modelled)"*SHARE_OF_GASOLINE_VEHICLE_REGISTRATION		vehicle/year	Annual number of registered gasoline vehicles based on actual shares of gasoline and estimated total number of vehicles	
	ANNUAL_NUMBER_OF_LEV	"TOTAL_NUMBER_OF_PRIVATE_VEHICLES_(Modelled)"*SHARE_OF_LEV_VEHICLE_REGISTRATION		vehicle/year	Annual number of registered LEVs based on actual shares of LEVs and estimated total number of vehicles	
	AVERAGE_COST_OF_PRIVATE_CARS	GRAPH(TIME) Points: (1991.00, 10972), (1992.00, 11197), (1993.00, 11227), (1994.00, 10991), (1995.00, 11025), (1996.00, 10992), (1997.00, 11210), (1998.00, 11095), (1999.00, 11111), (2000.00, 11211), (2001.00, 10912), (2002.00, 10818), (2003.00, 11117), (2004.00, 11213), (2005.00, 10908), (2006.00, 11034), (2007.00, 11188), (2008.00, 10874), (2009.00, 11194), (2010.00, 11172), (2011.00, 10943), (2012.00, 10836), (2013.00, 10948), (2014.00, 11196), (2015.00, 11199), (2016.00, 10904), (2017.00, 11098), (2018.00, 11139), (2019.00, 11081), (2020.00, 11092)		Pounds		GF DISCRETE

	"Average_distance_travelled_per_year_(passenger_+_driver)_-_km"	GRAPH(TIME) Points: (1991.00, 9348.135744), (1992.00, 9348.135744), (1993.00, 9348.135744), (1994.00, 9348.135744), (1995.00, 9348.135744), (1996.00, 9348.135744), (1997.00, 9348.135744), (1998.00, 9348.135744), (1999.00, 9348.135744), (2000.00, 9348.135744), (2001.00, 9348.135744), (2002.00, 9348.135744), (2003.00, 9309.515539), (2004.00, 9098.569154), (2005.00, 9190.499144), (2006.00, 9087.597679), (2007.00, 9109.795276), (2008.00, 8753.861278), (2009.00, 8470.417983), (2010.00, 8408.516878), (2011.00, 8604.630674), (2012.00, 8269.577708), (2013.00, 8208.456671), (2014.00, 8154.823903), (2015.00, 8302.860447), (2016.00, 8173.932243), (2017.00, 8213.678514), (2018.00, 8104.813737), (2019.00, 8061.95853), (2020.00, 5668.448317), (2021.00, 8000.0), (2022.00, 7960.0), (2023.00, 7920.2), (2024.00, 7880.599), (2025.00, 7841.196005), (2026.00, 7801.990025), (2027.00, 7762.980075), (2028.00, 7724.165174), (2029.00, 7685.544349), (2030.00, 7647.116627), (2031.00, 7608.881044), (2032.00, 7570.836639), (2033.00, 7532.982455), (2034.00, 7495.317543), (2035.00, 7457.840955), (2036.00, 7420.551751), (2037.00, 7383.448992), (2038.00, 7346.531747), (2039.00, 7309.799088), (2040.00, 7273.250093), (2041.00, 7236.883842), (2042.00, 7200.699423), (2043.00, 7164.695926), (2044.00, 7128.872446), (2045.00, 7093.228084), (2046.00, 7057.761944), (2047.00, 7022.473134), (2048.00, 6987.360768), (2049.00, 6952.423964), (2050.00, 6917.661845)		passengerkm/year	Average distance travelled by passengers and drivers per year	
	CO2_EMISSION_FACTOR_DIESEL	0.17082		kgCO2e/liters	This is the CO2 emissions factor per liter of diesel consumption.	
	CO2_EMISSION_FACTOR_GASOLINE	0.17048		kgCO2e/liter	This is the CO2 emissions factor per liter of gasoline consumption.	
	CO2_EMISSION_FACTOR_LEV	0.0684		kgCO2e/liters	This is the CO2 emissions factor per liter of fuel consumption from LEVs	
	CO2_EMISSION_FROM_DIESEL	DIESEL_CONSUMPTION*CO2_EMISSION_FACTOR_DIESEL		kgCO2e/Years	This is the total CO2 emissions from diesel vehicles per year	

	CO2_EMISSION_FROM_GASOLINE	GASOLINE_CONSUMPTION*CO2_EMISSION_FACTOR_GASOLINE		kgCO2e/Years	This is the total CO2 emissions from gasoline vehicles per year	
	CO2_EMISSION_FROM_LEV	LOW_EMISSION_CONSUMPTION*CO2_EMISSION_FACTOR_LEV		kgCO2e/Years	This is the total CO2 emissions from LEVs per year	
	DIESEL_CONSUMPTION	TRANSPORT_ACTIVITIES_D*VEHICLE_EFFICIENCY_DIESEL*(1-policy_status_IMPROVE)+IMPROVE_DIESEL_VEHICLE_EFFICIENCY*TRANSPORT_ACTIVITIES_D*policy_status_IMPROVE		Liters/Years	This represented the number of liters of fuel consumed by diesel vehicles. It is obtained by multiplying transport activities for diesel with vehicle efficiency of diesel	
	DIESEL_RETAIL_PRICE	GRAPH(TIME) Points: (1991.00, 0.433), (1992.00, 0.432), (1993.00, 0.471), (1994.00, 0.517), (1995.00, 0.541), (1996.00, 0.574), (1997.00, 0.620), (1998.00, 0.633), (1999.00, 0.640), (2000.00, 0.778), (2001.00, 0.816), (2002.00, 0.747), (2003.00, 0.764), (2004.00, 0.779), (2005.00, 0.842), (2006.00, 0.931), (2007.00, 0.914), (2008.00, 1.087), (2009.00, 0.987), (2010.00, 1.210), (2011.00, 1.411), (2012.00, 1.478), (2013.00, 1.413), (2014.00, 1.381), (2015.00, 1.158), (2016.00, 1.025), (2017.00, 1.220), (2018.00, 1.246), (2019.00, 1.293), (2020.00, 1.326)		Pounds/liter	This is the retail price of diesel	
	Diesel_Vehicle_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.02 ELSE IF TIME > 2020 AND TIME < 2026 THEN -0.008 ELSE IF TIME > 2025 AND TIME < 2031 THEN -0.010 ELSE IF TIME > 2030 AND TIME < 2036 THEN -0.013 ELSE IF TIME > 2035 AND TIME < 2041 THEN -0.016 ELSE IF TIME > 2040 AND TIME < 2046 THEN -0.019 ELSE -0.020		1/year		
	DIESEL_VEHICLE_TAX	180		Pounds/vehicle/year	This is the vehicle tax for diesel vehicles Source of Data: UK's Department of transport	
	EFFECT_FACTOR_OF_GDP_ON_TOT	0.413073230208122		passengerkm/	This is the coefficient of GDP	

	AL_PASSENGER_DEMAND			year/pounds	from the multiple linear regression: Total passenger travel demand = constant + GDP*Coefficient_of_GDP + Population*Coefficient_of_population	
	EFFECT_FACTOR_OF_PER_CAPITA_INCOME_ON_VEHICLE_ACQUISITION	3.019350422319		passenger*vehicle/(pounds*year)	The coefficient of GDP per capita from the regression: Number of registered vehicles = constant + GDP_per_capita*Coefficient_of_GDP_per_capita + Population*Road passenger travel demand (private)*Coeff_of_road_passenger_travel_demand	
	EFFECT_FACTOR_OF_POPULATION_ON_TOTAL_PASSENGER_DEMAND	-26644.6093775713		km/year	This is the coefficient_of_population from the multiple linear regression: Total passenger travel demand = constant + GDP*Coefficient_of_GDP + Population*Coefficient_of_population	

	EFFECT_FACTOR_ON_VEHICLE_ACQUISITION	-0.000000083913467957		vehicle/passengerkm	The coefficient of road passenger travel demand (private) from the regression: Number of registered vehicles = constant + GDP_per_capita*Coefficient_of_GDP_per_capita + Population*Road passenger travel demand (private)*Coeff_of_road_passenger_travel_demand	
	EFFECT_OF_PER_CAPITA_INCOME_ON_VEHICLE_ACQUISITION	PER_CAPITA_INCOME*EFFECT_FACTOR_OF_PER_CAPITA_INCOME_ON_VEHICLE_ACQUISITION		vehicle/year	The impact of per capita income on total number of private vehicles estimated on total number of private vehicles estimated using the multiple linear regression. Number of registered vehicles = constant + GDP_per_capita*Coefficient_of_GDP_per_capita + Population*Road passenger travel demand (private)*Coeff_of_road_passenger_travel	

					_demand The impact is the coefficient ofGDP_per_capita x GDP_Per_capita	
	EFFECT_OF_TRAVEL_DEMAND_ON_VEHICLE_ACQUISITION	PASSENGER_TRAVEL_DEMAND_PRIVATE_CARS*EFFECT_FACTOR_ON_VEHICLE_ACQUISITION		vehicle/year	The impact of changes in road passenger travel demand (private) on total number of private vehicles estimated using the multiple linear regression. The impact is the coefficient of road passenger travel demand (private) x road passenger travel demand Number of registered vehicles = constant + GDP_per_capita*Coefficient_of_GDP_per_capita + Population*Road passenger travel demand (private)*Coeff_of_road_passenger_travel_demand	
	ELASTICITY_OF_PER_CAPITA_INCOME	-0.1		1	Elasticity is the percentage change in the shares	

					of public transportation as a result of 1 percentage change in per capita income	
	ELASTICITY_OF_PUBLIC_TRANSPORT_EFFICIENCY	0.01		1	Elasticity is the percentage change in the shares of public transportation as a result of 1 percentage change in the efficiency of public transportation	
	GASOLINE_CONSUMPTION	TRANSPORT_ACTIVITIES_G*VEHICLE_EFFICIENCY_GASOLINE*(1-policy_status_IMPROVE)+IMPROVE_GASOLINE_VEHICLE_EFFICIENCY*TRANSPORT_ACTIVITIES_G*policy_status_IMPROVE		Liters/Years	This represented the number of liters of fuel consumed by gasoline vehicles. It is obtained by multiplying transport activities for diesel with vehicle efficiency of gasoline	
	GASOLINE_RETAIL_PRICE	GRAPH(TIME) Points: (1991.00, 0.421), (1992.00, 0.434), (1993.00, 0.471), (1994.00, 0.508), (1995.00, 0.534), (1996.00, 0.559), (1997.00, 0.611), (1998.00, 0.631), (1999.00, 0.629), (2000.00, 0.754), (2001.00, 0.769), (2002.00, 0.699), (2003.00, 0.750), (2004.00, 0.762), (2005.00, 0.790), (2006.00, 0.888), (2007.00, 0.869), (2008.00, 1.037), (2009.00, 0.863), (2010.00, 1.198), (2011.00, 1.347), (2012.00, 1.417), (2013.00, 1.368), (2014.00, 1.302), (2015.00, 1.084), (2016.00, 1.017), (2017.00, 1.187), (2018.00, 1.212), (2019.00, 1.195), (2020.00, 1.271)		Pounds/liter	This is the retail price of gasoline	
	Gasoline_vehicle_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.003 ELSE IF TIME > 2020 AND TIME < 2026 THEN -0.008 ELSE IF TIME > 2025 AND TIME < 2031 THEN -0.012 ELSE IF TIME > 2030 AND TIME < 2036 THEN -0.015 ELSE IF TIME > 2035 AND TIME < 2041 THEN -0.020 ELSE IF TIME > 2040 AND TIME < 2046 THEN -0.030 ELSE -0.050		1/year		

	GASOLINE_VEHICLE_TAX	180		Pounds/vehicle/year	Vehicle tax for gasoline vehicles (per vehicle) Source of Data: UK's Department of transport	
	GDP_GROWTH	IF TIME > 1990 AND TIME < 2002 THEN 0.016267807 ELSE IF TIME > 2001 AND TIME < 2008 THEN 0.004 ELSE IF TIME > 2007 AND TIME < 2010 THEN -0.045 ELSE IF TIME > 2009 AND TIME < 2021 THEN 0.003 ELSE 0.008		1/year		
	GDP_IMPACT_ON_TOTAL_PASSENGER_TRAVEL_DEMAND	GDP*EFFECT_FACTOR_OF_GDP_ON_TOTAL_PASSENGER_DEMAND		passengerkm/year	The impact of changes in GDP on total passenger travel demand as estimated using the multiple linear regression This is the coefficient_of_GDP*GDP from the multiple linear regression: Total passenger travel demand = constant + GDP*Coefficient_of_GDP + Population*Coefficient_of_population	
	GOVT_REVENUE_FROM_DIESEL_CONSUMPTION	DIESEL_CONSUMPTION*TAX_COMPONENT_OF_DIESEL_RETAIL_PRICE*DIESEL_RETAIL_PRICE		Pounds/Years	This is the total government revenue per year from the use of fuels by diesel vehicles	
	GOVT_REVENUE_FROM_GASOLINE_CONSUMPTION	GASOLINE_CONSUMPTION*TAX_COMPONENT_OF_GASOLINE_RETAIL_PRICE*GASOLINE_RETAIL_PRICE		Pounds/Years	This is the total government revenue per year	

					from the use of fuels by gasoline vehicles	
	GOVT_REVENUE_FROM_LEV_CONSUMPTION	TAX_COMPONENT_OF_LEV_RETAIL_PRICE*LEV_RETAIL_PRICE*LOW_EMISSION_CONSUMPTION		Pounds/Years	This is the total government revenue per year from the use of fuels by LEVs	
	IMPACT_OF_AVERAGE_COST_OF_PRIVATE_CARS	PREVIOUS("%_OF_PUBLIC_TRANSPORT_DEMAND", INIT("%_OF_PUBLIC_TRANSPORT_DEMAND"))*(1+"%_CHANGE_AVERAGE_COST_OF_PRIVATE_CARS"*PRICE_ELASTICITY_OF_COST_OF_PRIVATE_CARS)		1	This variable shows how the shares of public road passenger transport will change as a result of changes in the average cost of private cars. This is influenced by the previous share of public road passenger transportation, the price elasticity of cost of private cars on public road passenger transport, and the change in the average cost of private cars. The unit is dimensionless.	
	IMPACT_OF_PER_CAPITA_INCOME_ON_SHARE_OF_PUBLIC_TRANSPORT	PREVIOUS("%_OF_PUBLIC_TRANSPORT_DEMAND", INIT("%_OF_PUBLIC_TRANSPORT_DEMAND"))*(1+"%_CHANGE_PER_CAPITA_INCOME"*ELASTICITY_OF_PER_CAPITA_INCOME)		1	This variable shows how the shares of public road	

					passenger transport will change as a result of changes in household income. Per capita income is used as a proxy for household income. This is influenced by the previous share of public road passenger transportation, the elasticity of income on public road passenger transport, and the change in per capita income. The unit is dimensionless.	
	IMPACT_OF_PRICE_OF_PUBLIC_TRANSPORT	PREVIOUS("%_OF_PUBLIC_TRANSPORT_DEMAND", INIT("%_OF_PUBLIC_TRANSPORT_DEMAND"))*(1+PRICE_ELASTICITY_OF_PUBLIC_TRANS_DEMAND*"%_CHANGE_PRICE_OF_PUBLIC_TRANSPORT")		1	This variable shows how the shares of public road passenger transport will change as a result of changes in the price of public transport. This is influenced by the previous share of public road passenger transportation, the price elasticity of public transport on public road	

					passenger transport, and the change in the price of public transport. The unit is dimensionless.	
	IMPACT_OF_PUBLIC_TRANSPORT_EFFICIENCY	PREVIOUS("%_OF_PUBLIC_TRANSPORT_DEMAND", INIT("%_OF_PUBLIC_TRANSPORT_DEMAND"))*(1+ELASTICITY_OF_PUBLIC_TRANSPORT_EFFICIENCY*"%_CHANGE_PUBLIC_TRANSPORTATION_EFFICIENCY")		1	This variable shows how the shares of public road passenger transport will change as a result of changes in the efficiency of public transport. This is influenced by the previous share of public road passenger transportation, the elasticity of efficiency of public transport on public road passenger transport, and the change in the efficiency of public transport. The unit is dimensionless.	
	IMPROVE_DIESEL_VEHICLE_EFFICIENCY	IF TIME > 1990 AND TIME < 2021 THEN 5.63/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 5.1/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 4.70/100 ELSE 4.2/100		liter/passengerkm	This is a policy variable showing improvement in the efficiency of diesel vehicles	

	IMPROVE_GASOLINE_VEHICLE_EFFICIENCY	IF TIME > 1990 AND TIME < 2021 THEN 6.64/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 6.22/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 5.72/100 ELSE 5.02/100		liter/passengerkm	This is a policy variable showing improvement in the efficiency of gasoline vehicles	
	IMPROVE_LEV_EFFICIENCY	IF TIME > 1990 AND TIME < 2021 THEN 2.34/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 2.160/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 1.980/100 ELSE 1.760/100		liter/passengerkm	This is a policy variable showing improvement in the efficiency of LEVs	
	INITIAL_GDP	1171914517000		Pounds	Inital GDP (i.e. for 1991) Source: World Bank	
	INITIAL_NUMBER_OF_LEV	4.063938005		vehicle	Initial number of LEVs (actual) - 1991 Source: Department for Transport	
	INITIAL_NUMBER_OF_PRIVATE_DIESEL_VEHICLE	30849.02		vehicle	Initial number of private vehicles (diesel) - 1991 Source: Department for Transport	
	INITIAL_NUMBER_OF_PRIVATE_GASOLINE_VEHICLE	71410.81		vehicle	Initial number of gasoline vehicles (i.e. for 1991) Source: Department for Transport	
	INITIAL_POPULATION	57420000		person	Initial population (i.e. for 1991)	
	INVESTMENT_ACTUALIZATION	DELAYN(TRANSPORT_INVESTMENT/ACTUALIZATION_TIME, 3, 3)		Pounds/Years	This is the amount of annual investments based on the	DELAYCO

					actualization time	NVERTER
	LEV_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.28 ELSE IF TIME > 2020 AND TIME < 2024 THEN 0.05 ELSE IF TIME > 2023 AND TIME < 2028 THEN 0.10 ELSE IF TIME > 2027 AND TIME < 2031 THEN 0.20 ELSE IF TIME > 2030 AND TIME < 2034 THEN 0.15 ELSE IF TIME > 2033 AND TIME < 2038 THEN 0.15 ELSE IF TIME > 2037 AND TIME < 2041 THEN 0.10 ELSE IF TIME > 2040 AND TIME < 2044 THEN 0.07 ELSE IF TIME > 2043 AND TIME < 2048 THEN 0.05 ELSE 0.03		1/year		
	LEV_RETAIL_PRICE	0		Pounds/liter	We assume that LEVs do not use fuels and we fit the retail price at 0	
	LEV_VEHICLE_TAX	0		Pounds/vehicle/year	This is the vehicle tax for LEVs Source of Data: UK's Department of transport	
	LICENSING_COST	55		Pounds/vehicle/year	This is the licensing cost per vehicle per year	
	LICENSING_COST_PER_YEAR	LICENSING_COST*("NUMBER_OF_PRIVATE_VEHICLES_(LEV)"+"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"+"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)")		Pounds/Years	This is the total licensing cost per year	
	LOW_EMISSION_CONSUMPTION	TRANSPORT_ACTIVITIES_LEV*VEHICLE_EFFICIENCY_LEV*(1-policy_status_IMPROVE)+IMPROVE_LEV_EFFICIENCY*TRANSPORT_ACTIVITIES_LEV*policy_status_IMPROVE		Liters/Years	This represented the number of liters of fuel consumed by LEVs. It is obtained by multiplying transport activities for diesel with vehicle efficiency of LEVs	

	PASSENGER_TRAVEL_DEMAND_PRIVATE_CARS	PUBLIC_AND_PRIVATE_ROAD_PASSENGER_TRAVEL_DEMAND*"%_OF_PRIVATE_TRANSPORT_DEMAND"		passengerkm/year	This is an estimate of road passenger travel demand (private)	
	PASSENGER_TRAVEL_DEMAND_PUBLIC_TRANSPORT	PUBLIC_AND_PRIVATE_ROAD_PASSENGER_TRAVEL_DEMAND*ADJUSTED_%_OF_PUBLIC_TRANSPORT_DEMAND		passengerkm/Year	This represents an estimate of the road passenger travel demand (public transport-coaches and buses). This is obtained by multiplying the adjusted shares by the road passenger travel demand (public+private)	
	PER_CAPITA_INCOME	GDP/POPULATION		Pounds/passenger	Per capita income is used as a macroeconomic variable as well as a proxy for household income	
	policy_adj_time_AVOID	policy_time_period_AVOID*0 + (policy_time_period_AVOID/3)*0 + (policy_deadline_AVOID-TIME)*1		Years		
	policy_adj_time_IMPROVE	policy_time_period_IMPROVE*0 + (policy_time_period_IMPROVE/3)*0 + (policy_deadline_IMPROVE-TIME)*1		Years		
	policy_deadline_AVOID	2050		years		
	policy_deadline_IMPROVE	2050		years		
	policy_start_time_AVOID	2021		Years		
	policy_start_time_IMPROVE	2021		Years		
	policy_status_AVOID	IF(policy_switch_AVOID=1)AND(policy_start_time_AVOID<TIME)THEN 1 ELSE 0		1		
	policy_status_IMPROVE	IF(policy_switch_IMPROVE=1)AND(policy_start_time_IMPROVE<TIME)THEN 1 ELSE 0		1		

	policy_switch_AVOID	0		Dimensionless		
	policy_switch_IMPROVE	0		Dimensionless		
	Policy_Switch:_SHIFT	0		1		
	policy_time_period_AVOID	policy_deadline_AVOID-policy_start_time_AVOID		Years		
	policy_time_period_IMPROVE	policy_deadline_IMPROVE-policy_start_time_IMPROVE		Years		
	POP_GROWTH_FRACTION	IF TIME > 1990 AND TIME < 2006 THEN 0.005375965 ELSE IF TIME > 2005 AND TIME < 2021 THEN 0.005375965 ELSE 0.005375965		1/year		
	POPULATION_IMPACT_ON_TOTAL_PASSENGER_TRAVEL_DEMAND	POPULATION*EFFECT_FACTOR_OF_POPULATION_ON_TOTAL_PASSENGER_DEMAND		passengerkm/year	The impact of changes in population on total passenger travel demand as estimated using the multiple linear regression This is the coefficient_of_population*Population from the multiple linear regression: Total passenger travel demand = constant + GDP*Coefficient_of_GDP + Population*Coefficient_of_population	
	PRICE_ELASTICITY_OF_COST_OF_PRIVATE_CARS	0.001		1	Elasticity is the percentage change in the shares of public transportation as a result of 1 percentage change in the	

					average cost of private vehicles	
	PRICE_ELASTICITY_OF_PUBLIC_TRANS_DEMAND	-0.56		1	Elasticity is the percentage change in the shares of public transportation as a result of 1 percentage change in the price of public transportation	
	PRICE_OF_PUBLIC_TRANSPORT	GRAPH(TIME) Points: (1991.00, 164.30), (1992.00, 162.90), (1993.00, 165.30), (1994.00, 159.20), (1995.00, 160.20), (1996.00, 160.00), (1997.00, 160.80), (1998.00, 159.50), (1999.00, 160.90), (2000.00, 161.60), (2001.00, 164.10), (2002.00, 163.50), (2003.00, 160.50), (2004.00, 162.40), (2005.00, 161.90), (2006.00, 160.60), (2007.00, 158.40), (2008.00, 161.20), (2009.00, 161.40), (2010.00, 156.10), (2011.00, 164.50), (2012.00, 156.20), (2013.00, 163.00), (2014.00, 159.20), (2015.00, 165.20), (2016.00, 161.80), (2017.00, 156.20), (2018.00, 159.30), (2019.00, 160.10), (2020.00, 161.30)		Pounds		
	PUBLIC_AND_PRIVATE_ROAD_PASSENGER_TRAVEL_DEMAND	Share_of_public_and_private_passenger_road_transport_demand_in_total_passenger_road_demand*TOTAL_PASSENGER_TRAVEL_DEMAND		passengerkm/year	Data on total passenger travel demand considers all modes of transportation (air, rail, road, water). This study considers only road passenger transport and we use the shares of road in total passenger transport to derive this.	
	PUBLIC_ROAD_PASSENGER_TRANSPORT_CO2e_EMISSIONS_FACTOR	0.131773969		kgCO2e/passengerkm		

	REDUCTION_IN_ANNUAL_AVERAGE_TRAVEL_PER_YEAR	GRAPH(TIME) Points: (1991.00, 9348.135744), (1992.00, 9348.135744), (1993.00, 9348.135744), (1994.00, 9348.135744), (1995.00, 9348.135744), (1996.00, 9348.135744), (1997.00, 9348.135744), (1998.00, 9348.135744), (1999.00, 9348.135744), (2000.00, 9348.135744), (2001.00, 9348.135744), (2002.00, 9348.135744), (2003.00, 9309.515539), (2004.00, 9098.569154), (2005.00, 9190.499144), (2006.00, 9087.597679), (2007.00, 9109.795276), (2008.00, 8753.861278), (2009.00, 8470.417983), (2010.00, 8408.516878), (2011.00, 8604.630674), (2012.00, 8269.577708), (2013.00, 8208.456671), (2014.00, 8154.823903), (2015.00, 8302.860447), (2016.00, 8173.932243), (2017.00, 8213.678514), (2018.00, 8104.813737), (2019.00, 8061.95853), (2020.00, 5668.448317), (2021.00, 7000.0), (2022.00, 6860.0), (2023.00, 6722.8), (2024.00, 6588.344), (2025.00, 6456.57712), (2026.00, 6327.445578), (2027.00, 6200.896666), (2028.00, 6076.878733), (2029.00, 5955.341158), (2030.00, 5836.234335), (2031.00, 5719.509648), (2032.00, 5605.119455), (2033.00, 5493.017066), (2034.00, 5383.156725), (2035.00, 5275.49359), (2036.00, 5169.983719), (2037.00, 5066.584044), (2038.00, 4965.252363), (2039.00, 4865.947316), (2040.00, 4768.62837), (2041.00, 4673.255802), (2042.00, 4579.790686), (2043.00, 4488.194873), (2044.00, 4398.430975), (2045.00, 4310.462356), (2046.00, 4224.253108), (2047.00, 4139.768046), (2048.00, 4056.972685), (2049.00, 3975.833232), (2050.00, 3896.316567)		passengerkm/year	This is a policy variable to show the reduction in the number of trips per year	
	REDUCTION_IN_PASSENGER_AND_DRIVER_TRIPS	GRAPH(TIME) Points: (1991.00, 678.3494165), (1992.00, 678.3494165), (1993.00, 678.3494165), (1994.00, 678.3494165), (1995.00, 678.3494165), (1996.00, 678.3494165), (1997.00, 678.3494165), (1998.00, 678.3494165), (1999.00, 678.3494165), (2000.00, 678.3494165), (2001.00, 678.3494165), (2002.00, 678.3494165), (2003.00, 659.4115765), (2004.00, 648.8549426), (2005.00, 668.6813532), (2006.00, 658.5211738), (2007.00, 627.8842152), (2008.00, 635.947903), (2009.00, 611.2399999), (2010.00, 614.2513936), (2011.00, 601.5765863), (2012.00, 609.0622238), (2013.00, 589.6710369), (2014.00, 589.8771046), (2015.00, 584.3881807), (2016.00, 590.8035735), (2017.00, 594.2682016), (2018.00, 602.4137779), (2019.00, 580.1028648), (2020.00, 429.3696434), (2021.00, 500.0), (2022.00, 492.5), (2023.00, 485.1125), (2024.00, 477.8358125), (2025.00, 470.6682753), (2026.00, 463.6082512), (2027.00, 456.6541274), (2028.00, 449.8043155), (2029.00, 443.0572508), (2030.00, 436.411392), (2031.00, 429.8652211), (2032.00, 423.4172428), (2033.00, 417.0659842), (2034.00, 410.8099944), (2035.00, 404.6478445), (2036.00, 398.5781268), (2037.00, 392.5994549), (2038.00, 386.7104631), (2039.00, 380.9098062), (2040.00, 375.1961591), (2041.00, 369.5682167), (2042.00, 364.0246934), (2043.00, 358.564323), (2044.00, 353.1858582), (2045.00, 347.8880703), (2046.00, 342.6697492), (2047.00, 337.529703), (2048.00, 332.4667575), (2049.00, 327.4797561), (2050.00, 322.5675598)		1/vehicle	This is a policy variable to show the reduction in the number of passenger and driver trips per year	
	REVENUE_FROM_ENERGY_TAX	GOVT_REVENUE_FROM_DIESEL_CONSUMPTION+GOVT_REVENUE_FROM_GASOLINE_		Pounds/Years	This is the total revenues	

		CONSUMPTION+GOVT_REVENUE_FROM_LEV_CONSUMPTION			from fuel tax	
	SCRAPPING_FRACTION_D	0.0172/20		1/year		
	SCRAPPING_FRACTION_G	0.0024/20		1/year		
	SCRAPPING_FRACTION_LEV	IF TIME > 1990 AND TIME < 2021 THEN 0.253/20 ELSE IF TIME > 2020 AND TIME < 2024 THEN 0.7/20 ELSE IF TIME > 2023 AND TIME < 2028 THEN 0.5/20 ELSE IF TIME > 2027 AND TIME < 2031 THEN 0.2/20 ELSE IF TIME > 2030 AND TIME < 2034 THEN 0.15/20 ELSE IF TIME > 2033 AND TIME < 2038 THEN 0.05/20 ELSE IF TIME > 2037 AND TIME < 2041 THEN 0.03/20 ELSE IF TIME > 2040 AND TIME < 2044 THEN 0.02/20 ELSE IF TIME > 2043 AND TIME < 2048 THEN 0.01/20 ELSE 0.005/20		1/year		
	SEQUESTRATION_FACTOR	0.1		1/year		
	SHARE_OF_DIESEL_VEHICLE_REGISTRATION	GRAPH(TIME) Points: (1991.00, 0.301660917), (1992.00, 0.306103911), (1993.00, 0.31046854), (1994.00, 0.314756574), (1995.00, 0.318969651), (1996.00, 0.323109262), (1997.00, 0.327176735), (1998.00, 0.331173205), (1999.00, 0.335099589), (2000.00, 0.338956541), (2001.00, 0.342744402), (2002.00, 0.346463128), (2003.00, 0.350112213), (2004.00, 0.353690576), (2005.00, 0.357196422), (2006.00, 0.360627077), (2007.00, 0.363978764), (2008.00, 0.367246329), (2009.00, 0.370422903), (2010.00, 0.373499466), (2011.00, 0.376464309), (2012.00, 0.379302373), (2013.00, 0.381994415), (2014.00, 0.384515997), (2015.00, 0.376847998), (2016.00, 0.390902735), (2017.00, 0.399198598), (2018.00, 0.399511509), (2019.00, 0.393084811), (2020.00, 0.385580141)		1	shares of diesel vehicles in the total number registered vehicles from 1991 to 2020 based on actual data from the UK's Department for Transportation	
	SHARE_OF_GASOLINE_VEHICLE_REGISTRATION	GRAPH(TIME) Points: (1991.00, 0.698299343), (1992.00, 0.693846245), (1993.00, 0.689468936), (1994.00, 0.685164992), (1995.00, 0.680931949), (1996.00, 0.676767282), (1997.00, 0.672668362), (1998.00, 0.668632423), (1999.00, 0.664656498), (2000.00, 0.660737362), (2001.00, 0.656871444), (2002.00, 0.653054732), (2003.00, 0.649282644), (2004.00, 0.645549873), (2005.00, 0.641850197), (2006.00, 0.638176234), (2007.00, 0.634519148), (2008.00, 0.630868277), (2009.00, 0.627210677), (2010.00, 0.623530555), (2011.00, 0.619808573), (2012.00, 0.616020995), (2013.00, 0.612138641), (2014.00, 0.608125623), (2015.00, 0.613754124), (2016.00, 0.59755344), (2017.00, 0.586465342), (2018.00, 0.582612095), (2019.00, 0.584787773), (2020.00, 0.585168329)		1	shares of gasoline vehicles in the total number registered vehicles from 1991 to 2020 based on actual data from the UK's Department for Transportation	
	SHARE_OF_LEV_VEHICLE_REGISTRATION	GRAPH(TIME) Points: (1991.00, 0.0000397397), (1992.00, 0.0000498447), (1993.00, 0.0000625239), (1994.00, 0.000078434), (1995.00, 0.0000983996), (1996.00, 0.000123456), (1997.00, 0.000154903), (1998.00, 0.000194372), (1999.00, 0.000243913), (2000.00, 0.000306097), (2001.00, 0.000384155), (2002.00, 0.00048214), (2003.00, 0.000605143), (2004.00, 0.000759551), (2005.00, 0.000953381), (2006.00, 0.001196688), (2007.00,		1	shares of low emission vehicles (LEVs) in the total number registered vehicles	

		0.001502088), (2008.00, 0.001885393), (2009.00, 0.00236642), (2010.00, 0.00296998), (2011.00, 0.003727117), (2012.00, 0.004676632), (2013.00, 0.005866944), (2014.00, 0.007358381), (2015.00, 0.009397878), (2016.00, 0.011543825), (2017.00, 0.01433606), (2018.00, 0.017876395), (2019.00, 0.022127416), (2020.00, 0.02925153)			from 1991 to 2020 based on actual data from the UK's Departmen t for Transporta tion. LEVs include electric vehicles, hydrogen, hybrid, etc. We had to group all of them together for ease of analysis.	
	Share_of_public_and_private_passenger_road_transport_demand_in_total_passenger_road_demand	0.9053		1	Share of public and private passenger road transport. This is gotten by using the average of the shares of public and private across the year under consideration	
	SHARE_OF_ROAD_TRAN_INVESTMENT_IN_GDP	0.05		1	This is the average share of road transport investment in GDP (expressed as a fraction)	
	Shift_policy:_Diesel_vehicle_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.02 ELSE IF TIME > 2020 AND TIME < 2026 THEN -0.1 ELSE IF TIME > 2025 AND TIME < 2031 THEN -0.075 ELSE IF TIME > 2030 AND TIME < 2036 THEN -0.060 ELSE IF TIME > 2035 AND TIME < 2041 THEN -0.040 ELSE IF TIME > 2040 AND TIME < 2046 THEN -0.030 ELSE -0.01		1/year		
	Shift_policy:_Gasoline_vehicle_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.003 ELSE IF TIME > 2020 AND TIME < 2026 THEN -0.1 ELSE IF TIME > 2025 AND TIME < 2031 THEN -0.08 ELSE IF TIME > 2030 AND TIME < 2036 THEN -0.05 ELSE IF TIME > 2035 AND TIME < 2041 THEN -0.02 ELSE IF TIME > 2040 AND TIME < 2046 THEN -0.01 ELSE -0.005		1/year		

	Shift_policy:_LEV_acquisition_rate	IF TIME > 1990 AND TIME < 2021 THEN 0.28 ELSE IF TIME > 2020 AND TIME < 2024 THEN 0.8 ELSE IF TIME > 2023 AND TIME < 2028 THEN 0.275 ELSE IF TIME > 2027 AND TIME < 2031 THEN 0.08 ELSE IF TIME > 2030 AND TIME < 2034 THEN 0.05 ELSE IF TIME > 2033 AND TIME < 2038 THEN 0.022 ELSE IF TIME > 2037 AND TIME < 2041 THEN 0.016 ELSE IF TIME > 2040 AND TIME < 2044 THEN 0.01 ELSE IF TIME > 2043 AND TIME < 2048 THEN 0.006 ELSE 0.005		1/year		
	TAX_COMPONENT_OF_DIESEL_RETAIL_PRICE	GRAPH(TIME) Points: (1991.00, 0.635), (1992.00, 0.655), (1993.00, 0.635), (1994.00, 0.684), (1995.00, 0.728), (1996.00, 0.746), (1997.00, 0.743), (1998.00, 0.785), (1999.00, 0.852), (2000.00, 0.756), (2001.00, 0.747), (2002.00, 0.763), (2003.00, 0.749), (2004.00, 0.753), (2005.00, 0.709), (2006.00, 0.655), (2007.00, 0.678), (2008.00, 0.612), (2009.00, 0.661), (2010.00, 0.667), (2011.00, 0.638), (2012.00, 0.595), (2013.00, 0.588), (2014.00, 0.586), (2015.00, 0.667), (2016.00, 0.732), (2017.00, 0.642), (2018.00, 0.632), (2019.00, 0.615), (2020.00, 0.604)		1	This is the tax component of the retail price of diesel	
	TAX_COMPONENT_OF_GASOLINE_RETAIL_PRICE	GRAPH(TIME) Points: (1991.00, 0.593), (1992.00, 0.665), (1993.00, 0.646), (1994.00, 0.706), (1995.00, 0.735), (1996.00, 0.762), (1997.00, 0.752), (1998.00, 0.787), (1999.00, 0.849), (2000.00, 0.775), (2001.00, 0.784), (2002.00, 0.804), (2003.00, 0.760), (2004.00, 0.767), (2005.00, 0.745), (2006.00, 0.679), (2007.00, 0.705), (2008.00, 0.634), (2009.00, 0.737), (2010.00, 0.677), (2011.00, 0.649), (2012.00, 0.628), (2013.00, 0.621), (2014.00, 0.612), (2015.00, 0.701), (2016.00, 0.736), (2017.00, 0.655), (2018.00, 0.645), (2019.00, 0.652), (2020.00, 0.622)		1	This is the tax component of the retail price of gasoline	
	TAX_COMPONENT_OF_LEV_RETAIL_PRICE	0		1	The retail price of fuels for LEVs are fixed at 0. Therefore this tax component is also 0	
	TOTAL_CO2e_EMISSIONS_FROM_ROAD_PASSENGER_TRANSPORT	"CO2e_EMISSIONS_(PUBLIC)"+"CO2e_EMISSION_(PRIVATE_ROAD_PASSENGER_TRANSPORT)"		kgCO2e		
	"TOTAL_NUMBER_OF_PRIVATE_VEHICLES_(Modelled)"	89978.1423946863+EFFECT_OF_PER_CAPITA_INCOME_ON_VEHICLE_ACQUISITION+EFFECT_OF_TRAVEL_DEMAND_ON_VEHICLE_ACQUISITION		vehicle/year	Total number of private vehicles is estimated using multiple linear regressions as follows: total number of	

					private vehicles = f(per capita income, road passenger travel demand - private - cars and taxis). We used the actual values for the total number of private vehicles in the regressions and the estimates here are gotten from the values of the coefficients and the constant	
	"Total_Number_of_vehicles_(from_adding_individual_stocks)"	"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"+"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"+"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"		vehicle		
	TOTAL_PASSENGER_TRAVEL_DEMAND	1717464247079.39+POPULATION_IMPACT_ON_TOTAL_PASSENGER_TRAVEL_DEMAND+GDP_IMPACT_ON_TOTAL_PASSENGER_TRAVEL_DEMAND		passengerkm/year	Actual data for total passenger travel demand is obtained from the UK's Department for Transport. This is an estimate of the actual data. We use multiple linear regression for this estimate as follows: Total passenger travel demand = constant +	

					GDP*Coefficient_of_GDP + Population*Coefficient_of_population We elected to use this estimate because it reflects how GDP and Population affects travel activities	
	TOTAL_POPULATION	GRAPH(TIME) Points: (1991.00, 57424897.00), (1992.00, 57580402.00), (1993.00, 57718614.00), (1994.00, 57865745.00), (1995.00, 58019030.00), (1996.00, 58166950.00), (1997.00, 58316954.00), (1998.00, 58487141.00), (1999.00, 58682466.00), (2000.00, 58892514.00), (2001.00, 59119673.00), (2002.00, 59370479.00), (2003.00, 59647577.00), (2004.00, 59987905.00), (2005.00, 60401206.00), (2006.00, 60846820.00), (2007.00, 61322463.00), (2008.00, 61806995.00), (2009.00, 62276270.00), (2010.00, 62766365.00), (2011.00, 63258810.00), (2012.00, 63700215.00), (2013.00, 64128273.00), (2014.00, 64602298.00), (2015.00, 65116219.00), (2016.00, 65611593.00), (2017.00, 66058859.00), (2018.00, 66460344.00), (2019.00, 66836327.00), (2020.00, 67081000.00)		person	Trend of population (1991-2020) Source: World Bank	
	TOTAL_REVENUE_FROM_TRANSPORT	REVENUE_FROM_ENERGY_TAX+ANNUAL_LICENSING_AND_TAX_REVENUE		Pounds/Years	This is the total revenues from different taxes due to the use of private means of transportation. This contributes to government revenues	
	TOTAL_TRAVEL_ACTIVITIES	TRANSPORT_ACTIVITIES_D+TRANSPORT_ACTIVITIES_LEV+TRANSPORT_ACTIVITIES_G		passengerkm/year	This is the sum of the vehicle activities by vehicles using different fuel types	
	TRANSPORT_ACTIVITIES_D	"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"*"Trips_(passenger_+_driver)"*"Average_distance_travelled_per_year_(passenger_+_driver)_-_km"*(1-policy_status_AVOID)+"NUMBER_OF_PRIVATE_VEHICLES_(DIESEL)"*REDUCTION_IN_AN		passengerkm/year	Transport activity for diesel is obtained by considerin	

		NUAL_AVERAGE_TRAVEL_PER_YEAR*REDUCTION_IN_PASSENGER_AND_DRIVER_TRIPS*policy_status_AVOID			g the number of registered diesel vehicles, average number of trips, and average length of trips. Data for average number of trips and average length of trips are obtained from the UK's Department of Transport. The data are not dis-aggregated by fuel types therefore we use the same values for the different types of vehicles	
	TRANSPORT_ACTIVITIES_G	"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"*"Trips_(passenger_+_driver)"*"Average_distance_travelled_per_year_(passenger_+_driver)_-_km"*(1-policy_status_AVOID)+"NUMBER_OF_PRIVATE_VEHICLES_(GASOLINE)"*REDUCTION_IN_ANNUAL_AVERAGE_TRAVEL_PER_YEAR*REDUCTION_IN_PASSENGER_AND_DRIVER_TRIPS*policy_status_AVOID		passengerkm/year	Transport activity for gasoline vehicles is obtained by considering the number of registered gasoline vehicles, average number of trips, and average length of trips. Data for average number of trips and average length of trips are obtained from the UK's Department of Transport.	

					The data are not dis-aggregated by fuel types therefore we use the same values for the different types of vehicles	
	TRANSPORT_ACTIVITIES_LEV	"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"*"Trips_(passenger_+_driver)"*"Average_distance_travelled_per_year_(passenger_+_driver)_-_km"*(1-policy_status_AVOID)+"NUMBER_OF_PRIVATE_VEHICLES_(LEV)"*REDUCTION_IN_ANNUAL_AVERAGE_TRAVEL_PER_YEAR*REDUCTION_IN_PASSENGER_AND_DRIVER_TRIPS*policy_status_AVOID		passengerkm/year	Transport activity for LEV is obtained by considering the number of registered LEVs, average number of trips, and average length of trips. Data for average number of trips and average length of trips are obtained from the UK's Department of Transport. The data are not dis-aggregated by fuel types therefore we use the same values for the different types of vehicles	
	TRANSPORT_INVESTMENT	SHARE_OF_ROAD_TRAN_INVESTMENT_IN_GDP*GDP		Pounds	Total amount of new road transport investments in the UK based on the and the average share of	

					investments	
	"Trips_(passenger_+_driver)"	GRAPH(TIME) Points: (1991.00, 678.3494165), (1992.00, 678.3494165), (1993.00, 678.3494165), (1994.00, 678.3494165), (1995.00, 678.3494165), (1996.00, 678.3494165), (1997.00, 678.3494165), (1998.00, 678.3494165), (1999.00, 678.3494165), (2000.00, 678.3494165), (2001.00, 678.3494165), (2002.00, 678.3494165), (2003.00, 659.4115765), (2004.00, 648.8549426), (2005.00, 668.6813532), (2006.00, 658.5211738), (2007.00, 627.8842152), (2008.00, 635.947903), (2009.00, 611.2399999), (2010.00, 614.2513936), (2011.00, 601.5765863), (2012.00, 609.0622238), (2013.00, 589.6710369), (2014.00, 589.8771046), (2015.00, 584.3881807), (2016.00, 590.8035735), (2017.00, 594.2682016), (2018.00, 602.4137779), (2019.00, 580.1028648), (2020.00, 429.3696434), (2021.00, 570.0), (2022.00, 567.15), (2023.00, 564.31425), (2024.00, 561.4926788), (2025.00, 558.6852154), (2026.00, 555.8917893), (2027.00, 553.1123303), (2028.00, 550.3467687), (2029.00, 547.5950348), (2030.00, 544.8570597), (2031.00, 542.1327744), (2032.00, 539.4221105), (2033.00, 536.7249999), (2034.00, 534.0413749), (2035.00, 531.3711681), (2036.00, 528.7143122), (2037.00, 526.0707407), (2038.00, 523.440387), (2039.00, 520.823185), (2040.00, 518.2190691), (2041.00, 515.6279738), (2042.00, 513.0498339), (2043.00, 510.4845847), (2044.00, 507.9321618), (2045.00, 505.392501), (2046.00, 502.8655385), (2047.00, 500.3512108), (2048.00, 497.8494547), (2049.00, 495.3602075), (2050.00, 492.8834064)		1/vehicle	Average number of trips per year Source of data: UK's Department for Transportation	
	VEHICLE_EFFICIENCY_DIESEL	IF TIME > 1990 AND TIME < 2021 THEN 5.63/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 5.5/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 5.40/100 ELSE 5.3/100		liter/passengerkm	Vehicle efficiency is the volume over fuel consumed by a vehicle to cover 1km distance. Source of data: UK Department for Transportation	
	VEHICLE_EFFICIENCY_GASOLINE	IF TIME > 1990 AND TIME < 2021 THEN 6.64/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 6.62/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 6.58/100 ELSE 6.50/100		liter/passengerkm	Vehicle efficiency is the volume over fuel consumed by a vehicle to cover 1km distance. Source of data: UK Department for	

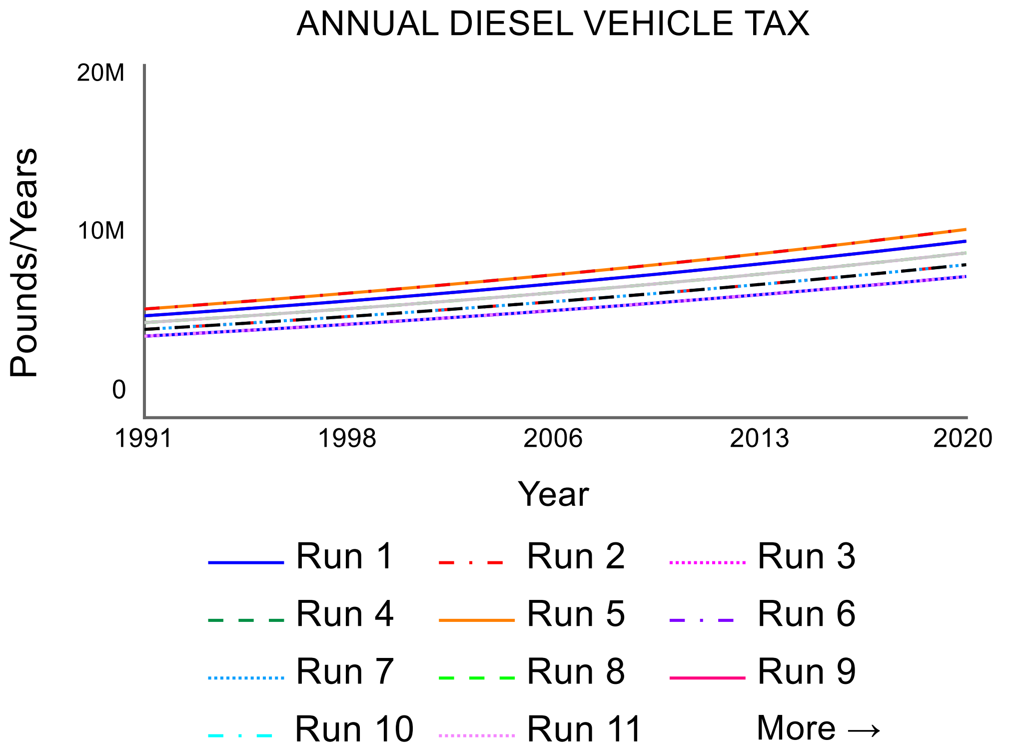
					Transportation	
	VEHICLE_EFFICIENCY_LEV	IF TIME > 1990 AND TIME < 2021 THEN 2.34/100 ELSE IF TIME > 2020 AND TIME < 2031 THEN 2.31/100 ELSE IF TIME > 2030 AND TIME < 2041 THEN 2.29/100 ELSE 2.26/100		liter/passengerkm	Vehicle efficiency is the volume over fuel consumed by a vehicle to cover 1km distance. We assume the vehicle efficiency for LEVs to be one-third of that of diesel. This is because different types of vehicles are grouped to form LEVs and we could not get data for vehicle efficiency of each vehicle type. Moreover, some vehicles in this category are electricity vehicles and vehicle efficiency will not apply to this types of vehicles Source of data: UK Department for Transportation	
	AVOID_TRIP:					

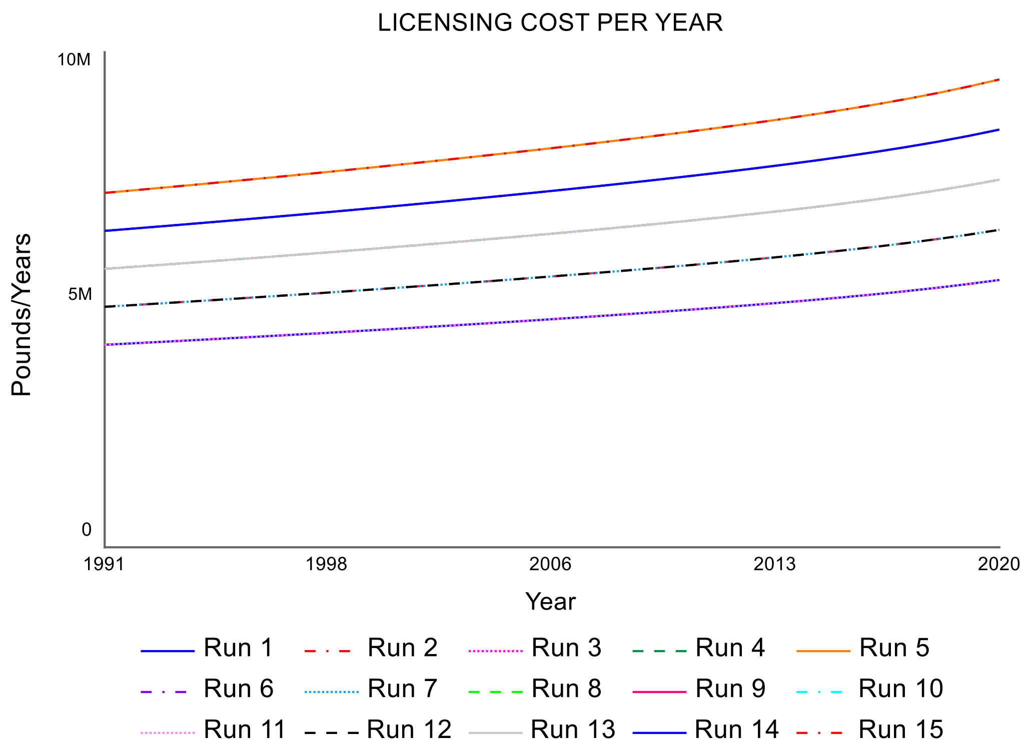
Run Specs	
Start Time	1991

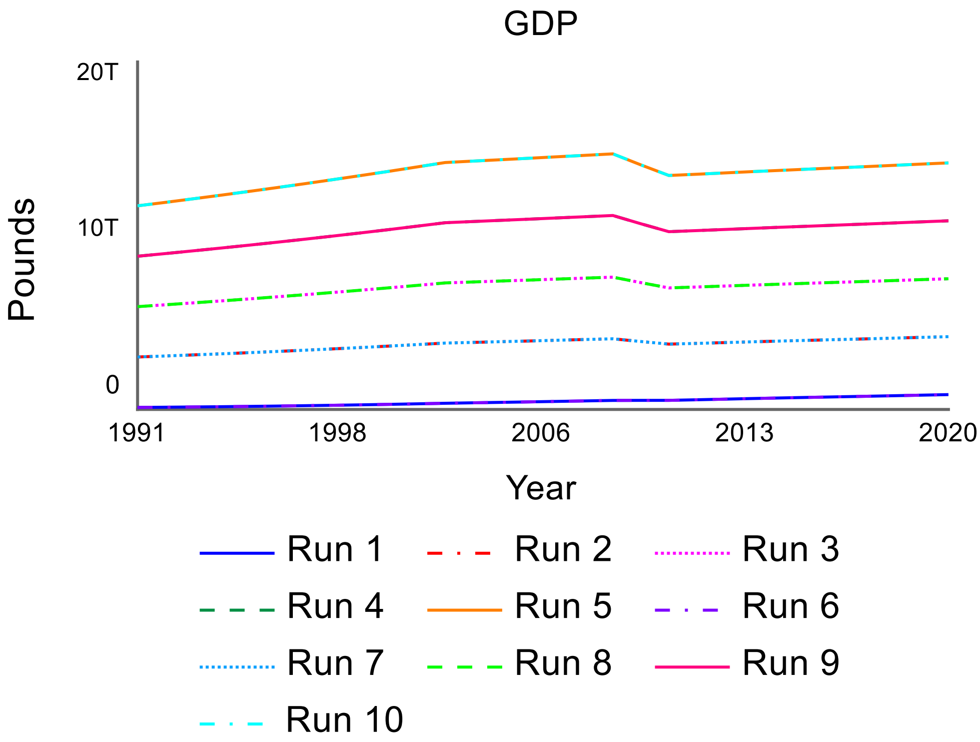
Stop Time	2050
DT	1/1
Fractional DT	True
Save Interval	1
Sim Duration	1.5
Time Units	Year
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

Custom Unit	Aliases	Equation
euros per year per person		EUR/(person-year)
lane kilometers	lkm	lane-km
people per lane kilometer		people/lkm

Appendix 2: Additional results of sensitivity analyses






GDP
20T
10T
0
Pounds
1991
1998
2006
2013
2020
Year
Run 1
Run 2
Run 3
Run 4
Run 5
Run 6
Run 7
Run 8
Run 9
Run 10