Visioning and Backcasting for Transport in London (VibatLondon)

Halcrow Group Ltd
in association with
Oxford University, Transport Studies Unit (Professor David Banister)
Space Syntax and ZupaStudio
Greater London Authority
Transport for London

Stages 3 and 4 Report:
Policy Packaging and Appraisal

UrbanBuzz Building Sustainable Communities
http://www.vibat.org
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August 2009

Halcrow

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1 Introduction

1.1 Context

The VIBAT London study assesses the contribution of the transport sector in reducing CO_2 emissions in London. It considers the challenging targets of a 60% reduction in CO_2 emissions by 2025, and an 80% reduction in CO_2 emissions by 2050.

The objectives of stages 3 and 4 of the VIBAT London study are to develop workable policy packages, representing different policy standpoints, and appraise these against a transparent appraisal framework. The appraisal framework developed also allows for sensitivity testing with criteria given different weightings.

An optimum policy package and implementation pathway is developed. This analysis builds on and informs the policy approach as set out in the Mayor's Transport Strategy (TfL, 2006a), the London Plan (GLA, 2004) and Transport 2025 (TfL, 2006b).

The VIBAT project is funded through the UrbanBuzz programme. This is a 2 year programme that aims to develop new ways of delivering sustainable forms of development and community in London and the wider southeast region. It is a University College London (UCL)-led programme whose prime partner is the University of East London.

1.2 Study Team

The VIBAT London core study team is as outlined below:

- Dr Robin Hickman (Halcrow Group) - Project Coordinator and UrbanBuzz Research Fellow
- Professor David Banister (Transport Studies Unit, Oxford University Centre for the Environment) - Project Director and Urban Buzz Innovation Fellow
- Olu Ashiru (Takedo International and Halcrow Group)
- Sharad Saxena (Transport Studies Unit, Oxford University and intern at Halcrow Group)
- Dr Annabel Bradbury (Halcrow Group)
- Alain Chiaradia (Space Syntax)
- Chris Stutz (Space Syntax)
- Jorge Gil (Space Syntax)
- Jasia Ward (ZupaStudio/Space Syntax)
- Gavin Baily (ZupaStudio/Space Syntax)

Richard McGreevy (GLA Transport Team) and Catherine Jones (TfL) act as steering group members from the London authorities. Richard McGreevy is an UrbanBuzz Research Fellow.

The lead authors of this stage 3/4 report were Sharad Saxena, Robin Hickman and David Banister.

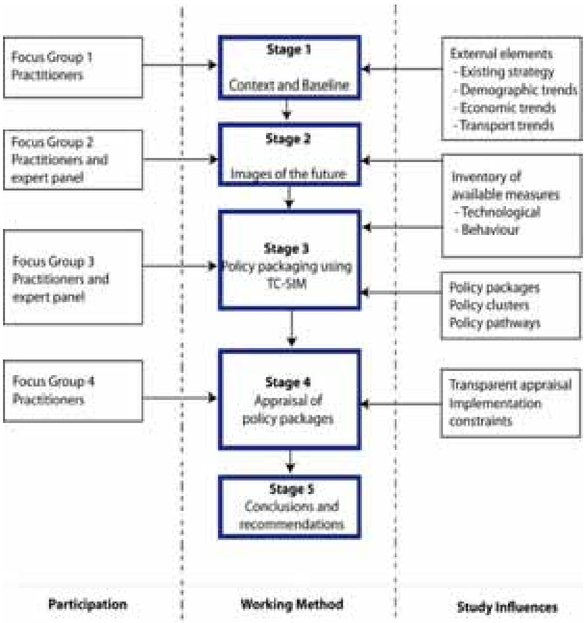
An academic expert panel plus formal peer review has been used to comment on study outputs throughout the VIBAT London study.

1.3 Structure of the Report

The remainder of this third stage study report has four main sections as follows:

- Section 2: Clustering the policy packages
- Section 3: The multi-criteria appraisal framework
- Section 4: Appraisal of policy package clusters
- Section 5: Conclusions.

Figure 1: The VIBAT London Research Framework



2 Clustering the Policy Packages

2.1 Policy Packaging

Policy measures and policy packages perform best in terms of CO_2 reduction (and indeed other objectives) when grouped together into complementary, integrated clusters of policy packages – i.e. a strategy. It is at this level that impacts can most easily be quantified and compared in relative terms.

A transport and carbon simulator (TC-SIM) has been developed in the VIBAT London study to help explore the packaging of policy options. TC-SIM is hosted on the project website (www.vibat.org). TC-SIM is a participation tool which includes a scenario building and policy discussion platform, with a spatial base for London, around which decisions concerning possible future scenarios. The playing screen for TC-SIM is shown in Figures 2 and 3.

The policy packages (PP) available include:

- PP1: Low emission vehicles;
- PP2: Alternative fuels;
- PP3: Pricing regimes;
- PP4: Public transport;
- PP5: Walking and cycling;
- PP6: Strategic and local urban planning;
- PP7: Information and communication technologies (ICT);
- PP8: Soft measures 'smarter choices';
- PP9: Ecological driving and slower speeds;
- PP10: Long distance travel substitution;
- PP11: Freight transport;
- PP12: International air travel.

Each policy package can be selected at a variety of levels of intensity of application – typically a 'low', 'medium' or 'high' level of application. The assumption in terms of background traffic growth is that traffic grows year on year as an extrapolation of recent trends (however, relative to the rest of the UK, London is different in that traffic growth has been limited in recent years. London appears to have reached the top of the "S" curve of traffic growth).

The BAU application is assumed to be the Reference Case (Scenario 1) in T2025 (TfL, 2006b). This broadly represents the current fully funded investment strategy for TfL and is thus the best representation of current BAU. It does however represent a significant amount of funding – approximately £2-7 billion per annum to 2025 (TfL, 2006a), hence is more akin to a 'reference case' as commonly used in transport planning.

TC-SIM draws on attitudinal theory (Shiftan et al, 2008; Anable, 2005) in acknowledging that there are different viewpoints and attitudinal cohorts in the travel market. A single policy response is unlikely to encourage changed behaviour in all users. The travel market is thus probably best simplified and understood by segmenting it into coherent groups. These share similar, archetypical characteristics. TC-SIM is therefore designed to be played under a 'free role' or in different user modes, for example as 'free riders', 'techno optimists', 'enviro-optimists', 'complacent car addicts' and other cohorts. The policy choices under each user role are restricted to represent the likely viewpoints for each cohort, e.g. a techno-optimist performs well on the technological options (low emission vehicles, alternative fuels, ICT) but poorly on the behavioural options. As well as user roles, the user modes can be viewed as [entrenched] policy standpoints, e.g. the techno-optimist position might replicate the King Review position (HM Treasury, 2007), and many would argue the current UK governmental position (CCC, 2008).

Game playing or scenario testing is then undertaken to illustrate particular views within certain cohorts or policy positions and their likely success in achieving objectives. Game theory (originally developed by Von Neumann and Morgenstern, 1944) has been applied to transport modelling and route choice (Bell, 2000; and others), but has seldom been used in transport futures studies and strategy development. It has much potential in exploring whether certain policy positions are likely to succeed in achieving certain objectives.

In previous applications, it has been the expert that has put the policy packages together in a set of mutually supporting clusters to meet the targets set. Here, the work can be used to represent the views of different types of users; their views give the key determinants of particular combinations of policy measures and packages. The two different approaches can be pursued independently but the rationale is similar. The latter approach may become much more important in future years. Engagement with stakeholders and the public will become critical if we are to achieve trend-break futures. They cannot be implemented in a top-down manner (certainly in the UK). Debate with the public, however, has hardly commenced.

The need to act across a wide range of policy areas is well appreciated in London. Achieving the ambitious targets that have been adopted in London may, in the main, require only a more *intensive* application of the policy measures already being considered. "Application", in this context, means strategic policy direction, scheme implementation (governmental) and take-up (the public). These are all inextricably linked. [In all likelihood there will also need to be some innovation in terms of the development of new policy measures and new ways of implementaation].

A number of user roles have been developed in discussion within the study team and with project partners at TfL and GLA. They represent stereotypical cohorts or policy positions within the travel market. The user roles are as follows:

- "Free rider";
- "Complacent car addict";
- "Techno optimist" – ambitious and realistic;
- "Enviro-optimist" – ambitious and realistic;
- "Concerned realist";
- "Optimised balance";

International air emissions are also considered, relative to concerned realist and optimised balance.

Figure 2: The TC-SIM Main Playing Screen

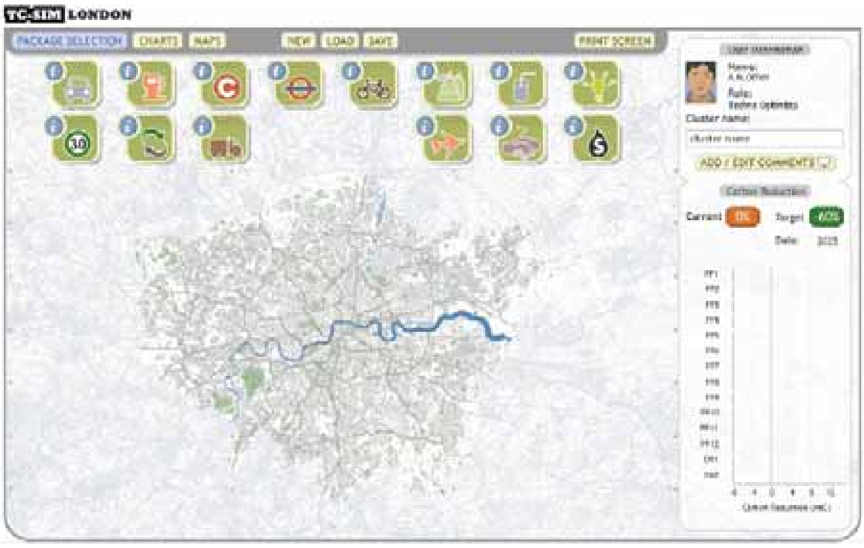
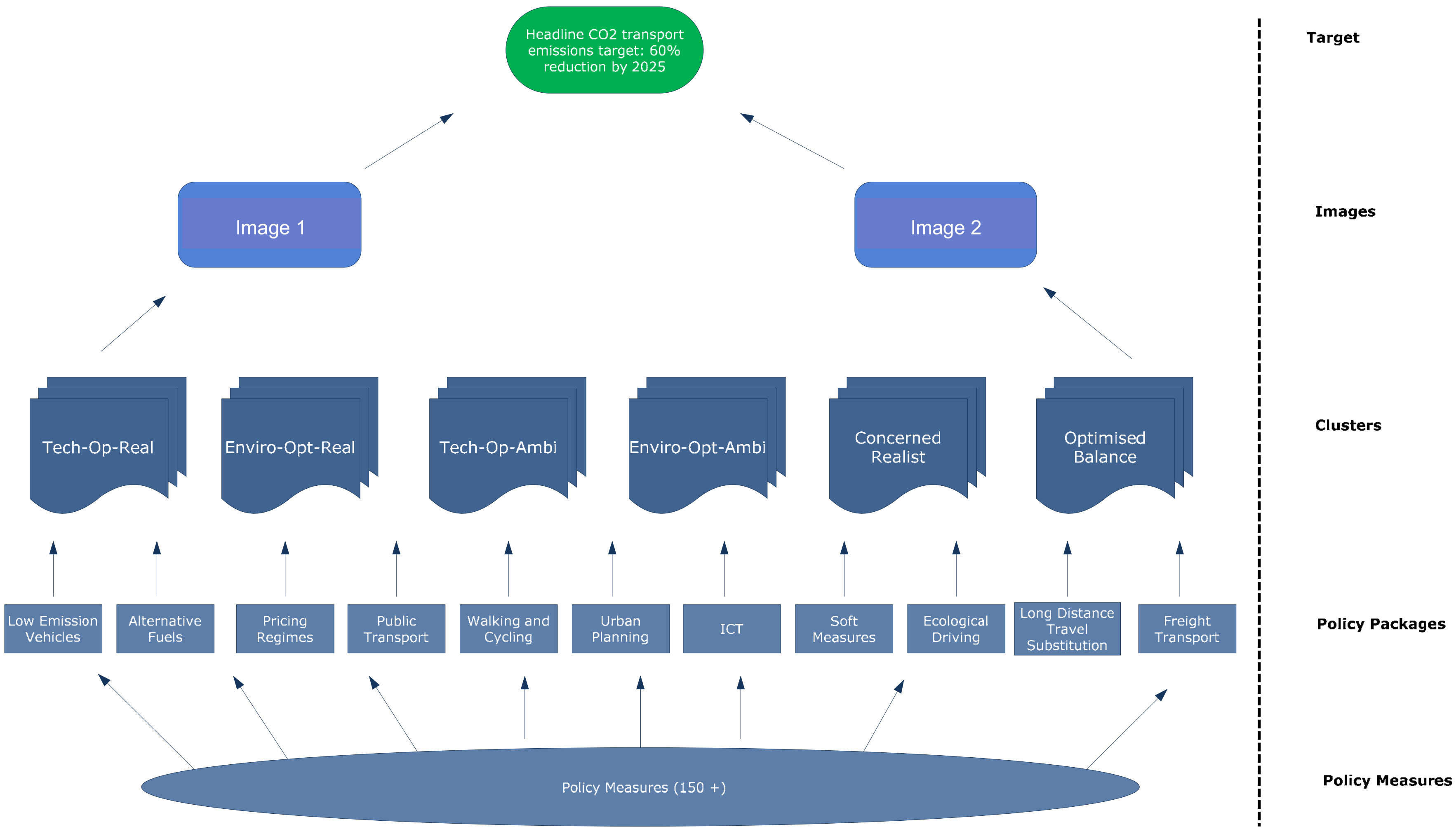


Figure 3: The TC-SIM User Roles

Figure 4: Clustering the Policy Packages



2.2 Free Riding

The free rider role illustrates the cohort of population, or policy position, believing that a reduction in CO_2 emissions will result if we achieve modest gains from technology and behavioural change.

Despite relatively high concern for the negative effects of car use, this cohort is reluctant to sacrifice current lifestyles for the sake of the environment. They need much more persuasion that reducing their car use will make much difference to CO_2 emissions, as they believe others will not reduce their car use (they have concerns with efficacy). They perceive many problems in using public transport, walking and cycling on a mass scale. They see a small increase in vehicle km (from present levels), with moderate gains from technology, as the best way to achieve CO_2 reduction targets.

Figure 5 shows the result when the free rider role is played. Progress towards the headline target is not made to any great degree – resulting in an aggregate 4.5% contribution to the VIBAT London target.

Figure 5: TC-SIM Free Rider Mode

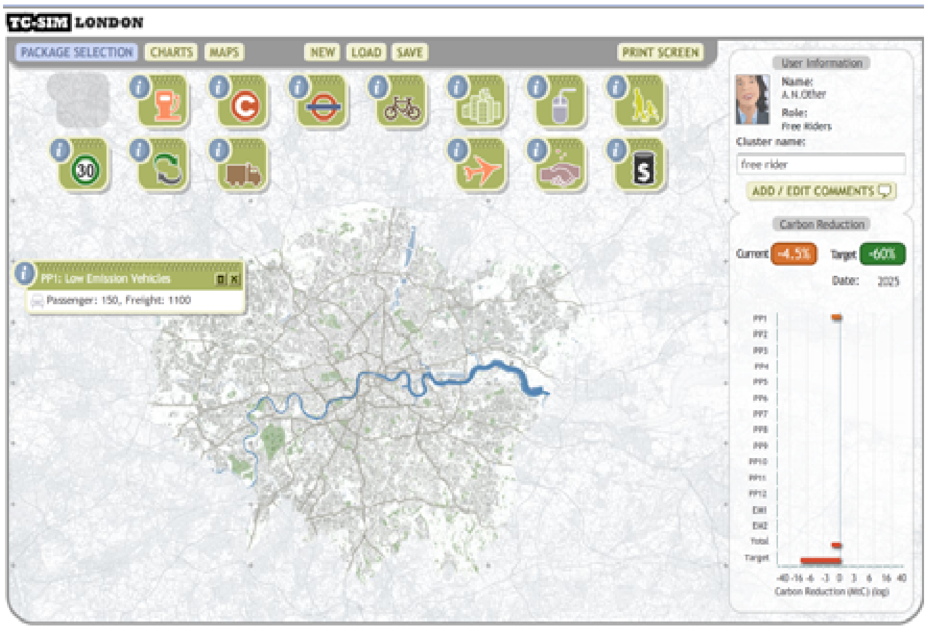


Table 1: Free Rider

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low intensity application: 150 gCO_2/km car fleet; 1,100 gCO_2/km heavy goods vehicles	4.5%
PP2 Alternative Fuels	BAU	0%
PP3 Pricing Regimes	BAU	0%
PP4 Public Transport	BAU	0%
PP5 Walking and Cycling	BAU	0%
PP6 Urban Planning	BAU	0%
PP7 ICT	BAU	0%
PP8 Soft Measures	BAU	0%
PP9 Slower Speeds and Ecological Driving	BAU	0%
PP10 Long Distance Travel Substitution	BAU	0%
PP11 Freight Transport	BAU	0%
Progress against VIBAT London Target (60% reduction in CO_2 emissions)		**4.5%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used. This includes a large amount of investment, yet is used as the “Reference Case” as this is [broadly] the current accepted investment strategy for transport in London.

2.3 Techno-Optimism

The techno-optimist role is used to illustrate the cohort of population that focuses on technological options to reduce CO_2 emissions. PP1 low emission vehicles, PP2 alternative fuels and PP7 ICT are the policy packages with most technological focus. It could be argued that this user role is broadly illustrative of policy development at the UK level. Only a narrow range of policy measures are being employed here; these include voluntary car emission agreements, some limited fiscal tinkering, a renewable fuels target and other 'low intensity' application of measures such as freight distribution and soft measures. Within the simulation, background mobility is allowed to grow; the assumption is that traffic grows year on year as an extrapolation of recent trends (relative to the rest of the UK, London is different in that traffic growth has been limited in recent years, even in outer London).

Figure 6 illustrates the techno-optimist role played to a very optimistic, high intensity level of application, and Figure 7 to a less ambitious, low level of application [potentially more realistic based on current trends]. The result for a low level application of this role is a contribution reduction in CO_2 of just 6% of the total target.

PP1 Low Emission Vehicles

Looking in more detail at the individual policy packages within the techno-optimist user role, it is evident that there are a number of potential policy pathways. The take up of low emission vehicles, based largely on hybrid technology, is likely to be very important in reducing CO_2 emissions. The types of vehicles currently on the market in the UK are shown in Annex 2. There is much variation in terms of CO_2 emissions (and specification and price). The current best generations of new vehicles have emissions levels of around 100 gCO_2/km (the VW Polo Diesel emits 99 gCO_2/km and Toyota Prius Hybrid emits 104 gCO_2/km). The intention with technological improvements is to push hard to reduce these levels even further. The current (2006) UK car fleet average emissions is 181 g/km (from 196 gCO_2/km in 1997), whilst the new 2006 car fleet average is 167 gCO_2/km (from 190 gCO_2/km in 1997) (SMMT, 2006). Light goods vehicles emit more CO_2, averaging 182 gCO_2/km in 2002.

An ambitious application of this policy package results in the introduction of a total car fleet averaging at least 100 gCO_2/km by 2025 (and hopefully less) and total heavy goods vehicles fleet (fully loaded) averaging around 800 gCO_2/km. To reach these levels requires massive investment by car manufacturers and consumer purchasing choices to change markedly in the next few years. There is an important role for Government in developing and applying a range of incentives to enable changes in fuel efficient vehicle penetration rates. This involves a serious application of incentives, beyond the current tinkering with financial mechanisms (an example being fuel duty, where there is currently little difference between Vehicle Emissions Duty (VED) for petrol or low emission vehicles).

Because of the difficulties in delivering low emission vehicles to the mass market, relying on this policy package may be high risk as there is no guarantee that low emission vehicles will penetrate the market to any great degree. The current consumer trend is for higher specification and heavier vehicles, which emit more carbon. The current [mainstream] business model for motor manufacturers to sell petrol or diesel cars. There are major issues concerning the costs and feasibility of converting the whole of the London [and wider] car fleet to hybrids.

Figure 6: TC-SIM Techno-Optimist Mode (Ambitious)

Table 2: Techno-Optimist (Ambitious)

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	High: 100 g/km car fleet; 800 g/km heavy goods vehicles	18.3%
PP2 Alternative Fuels	Medium	5.2%
PP3 Pricing Regimes	BAU	0%
PP4 Public Transport	BAU	0%
PP5 Walking and Cycling	BAU	0%
PP6 Urban Planning	BAU	0%
PP7 ICT	Medium	1%
PP8 Smarter Choice Soft Measures	BAU	0%
PP9 Slower Speeds and Ecological Driving	BAU	0%
PP10 Long Distance Travel Substitution	BAU	0%
PP11 Freight Transport	BAU	0%
Progress against VIBAT London Target (60% reduction in CO2 emissions)		**24.5%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

Figure 7: TC-SIM Techno-Optimist Mode (Realistic)

Table 3: Techno-Optimist (Realistic)

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low: 150 g/km car fleet; 1,000 g/km heavy good vehicles	5.7%
PP2 Alternative Fuels	Low	0.5%
PP3 Pricing Regimes	BAU	0%
PP4 Public Transport	BAU	0%
PP5 Walking and Cycling	BAU	0%
PP6 Urban Planning	BAU	0%
PP7 ICT	BAU/Low	0%
PP8 Smarter Choice Soft Measures	BAU	0%
PP9 Slower Speeds and Ecological Driving	BAU	0%
PP10 Long Distance Travel Substitution	BAU	0%
PP11 Freight Transport	BAU	0%
Progress against VIBAT London Target (60% reduction in CO_2 emissions)		**6.2%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

The current market share for fuel efficient vehicles in the UK is not impressive. Band A and B vehicles (<120 g/km) are currently at 4.7%, Band C (121-150 g/km) is the most popular at 31.9% and Band D (151-165 g/km) at 24.2%. Band G (>226 g/km) is at 7.5% (SMMT, 2006).

The G-Wiz had 298 new registrations in 2006; the Toyota Prius 5,015 new registrations – hence, despite the hype, low emission driving remains very much a niche activity. A large contributor to this is cost: the Toyota Prius retails at over £17,000. Note that if everyone buying a new car in 2006 opted for the most fuel efficient model in its class, CO_2 emissions from new cars would be reduced by 24% (Vehicle Certification Agency, 2007). Although this sounds optimistic, it is a little misleading. In making a choice on vehicle purchase, most individuals view CO_2 emissions as a long way down the list of important features. Model, specification, availability of a CD player and colour are more important for most. This illustrates the difficulty in moving low emission vehicles into the mass market. It requires concerted effort and change in terms of supply (the manufacturers) and demand (the public). The problem is that neither of these are altruistic; hence the role for government.

The current trends in terms of average vehicle fleet CO_2 emission reduction are not encouraging. The European Commission and the European Automobile Manufacturers Association (ACEA) signed a voluntary agreement in July 1998 that committed ACEA to reduce the CO_2 emissions from new passenger cars by over 25% to an average CO_2 emission figure of 140 gCO_2/km by 2008. Similar voluntary agreements have been reached with Japanese and Korean motor manufacturers (but with an end date of 2009). This has led to more fuel efficient vehicles being brought to the market, however the targets are not likely to be reached. Europe's car producers managed to cut the CO_2 output of new cars by 1% in 2006 - less than a quarter of the rate required to meet the EU target. Manufacturers tend to offset improvements in fuel efficiency by producing heavier cars (including air conditioning units and safety bars and other in-car gadgets) – creating and satisfying consumer demand for more powerful vehicles. This strategy typically raises profit margins on vehicles; higher profits are available for larger cars and 'add ons'.

Britain is not the 'worst' in the average fleet CO_2 emission league table (lying 6th in Europe). Sweden, where consumers 'prefer' large-engine brands such as Volvo and Saab, has the highest CO_2 output in the EU, almost 25% higher than the country with the lowest output, Italy. The average new car sold in Sweden produces 196 gCO_2/km; Italy averages 148 gCO_2/km (2006).

Bearing in mind these current trends, a less ambitious application of this policy package may be much more realistic. A low level of application of this policy package may therefore aim for a car fleet averaging at around 150 gCO_2/km by 2025 and heavy goods vehicles at around 1,100 gCO_2/km.

The results of different levels of application of this policy package are markedly different. The high intensity application of PP1 results in a reduction of CO_2 contributing to 20% of the total target; the low intensity application of PP1 results in a reduction of 5% of the total target. The latter would represent a huge missed opportunity.

PP1: Low Emission Vehicles Pathways

Assumption		% of Target by 2025
High intensity application	100 gCO_2/km car fleet 800gCO_2/km heavy goods vehicles	18%
Low intensity application	150 gCO_2/km car fleet 1,100 gCO_2/km heavy goods vehicles	6%

PP2 Alternative Fuels

Additional benefits can be obtained if alternative fuels are used in conjunction with petrol or diesel-electric hybrids. There are many possible alternative fuels on the market - including compressed natural gas, liquid petroleum gas, biofuels (methanol, ethanol, biodiesel) and hydrogen. Many alternative fuels can be used on their own; others can be blended with existing fuels and used in vehicles without any major modifications to the engines. There are a range of estimates as to the likely take up of biofuels. The International Energy Agency (2004) is very ambitious in suggesting that that, by 2030, some 20-40% of all fuels in transport could come from alternative sources. Recent estimates have been more sceptical about the potential for take up, particularly on a mass market scale (Di Lucia and Nilsson, 2007; Comyns, 2006; and others). There are a number of potential difficulties in moving beyond niche use:

- Battery electric vehicles: long considered as the most likely technology to break through; the battery, however, has remained as the weak point with little development in terms of battery life or power. There is some potential - the GM-Volt uses batteries with a range of 50 miles with recharging overnight. It also has an ICE which runs at a constant speed (efficient) to recharge batteries or to extend the range when the batteries run out. Progress is being made with battery technology and by 2020 the range will be 200 miles; sufficient for most car drivers. Off peak overnight electricity can be used to recharge the car (but the source of electricity should also be carbon neutral.

- Biofuels (also known as agrofuel or agrifuel): can, in theory, be generated from a range of feedstocks (or any biomass), and most commonly plants. Brazil, for example, uses biofuels in 40% of car fuel (from sugar cane-based ethanol). First generation biofuels are developed from sugar cane, sugar beet or starch (corn and maize), and then use yeast fermentation to produce ethanol (ethyl alcohol). Plants can also be used to naturally produce oils, such as oil palm or soybean. When these oils are heated their viscosity is reduced, and they can be burned directly in a diesel engine, or the oils can be chemically processed to produce fuels such as biodiesel. Wood and various by products can be converted into biofuels such as woodgas, methanol or ethanol fuel. Mass market implementation of biofuels is, however, proving very difficult. There is much controversy over lifecycle CO_2 emissions (the CO_2 emitted through the use of fertilisers, in the transport of fuels and in the emissions of nitrous oxides offsets the CO_2 reduction potential of the biofuel), and also the potential land take (mass market application would require vast amounts of land take, with potential knock on impacts for soil erosion, biodiversity, deforestation and food supply shortages). Second generation biofuels may prove more effective in the long run, these include non-food crops such as waste biomass, biomethanol, synthetic biofuels (from plastics) and shrubs (jatropha). Third generation biofuels include algae fuel, potentially generated using algaculture and algae farms. Again, moving beyond niche supply is likely to be difficult.

- Natural gas: includes liquid petroleum gas (LPG) and compressed natural gas (CNG). Both are derived from a finite resource and therefore are not a long term solution. Natural gas might, however, act as a niche bridging technology that leads onto other gaseous fuels such as hydrogen.

- Hydrogen: has the long term potential to be the cleanest fuel option. However, there are at least two major problems - production and storage. The fuel is highly flammable and requires large storage capsules. Hydrogen is not a fossil fuel and is not found in significant quantities in nature. It therefore needs to be manufactured. The most common methods are electrolysis of water, reforming natural gas, or partial oxidation and steam reforming other fossil fuels. The most economical form is from reforming natural gas. Significant investments are needed in infrastructure for delivery, storage and dispensing of hydrogen if it is to be used as a vehicle fuel. The combustion of hydrogen produces mainly water vapour and no direct CO_2 emissions. Indirect CO_2 emissions however depend on the nature of the energy source used to produce hydrogen. Hence, again, there are huge difficulties in turning the potential into anything more than a niche fuel option by 2025 or even 2050.

The Renewable Transport Fuel Obligation (RTFO) aims for the UK to achieve 5% of road vehicle fuels sold on forecourts by renewable sources by 2010. The EU biofuels directive as amended (EC, 2003; CEU, 2007) aims for 10% of biofuels by 2020. It appears that these targets will not be met due to the difficulties in applying fuel technologies to the mass market and the debate over whether energy crops should have precedence over food crops.

London is testing the use of zero emission fuel cells in the bus fleet. A trial was run through the CUTE project (Clean Urban Transport for Europe), and the follow up HyFLEET:CUTE project. This brought together a large number of organisations including bus manufacturers, operating companies, hydrogen suppliers, fuelling and storage facilities. This type of test pilot project is important in demonstrating that the technologies are workable in a large city. Fuel cells are still very expensive though and mass market roll out is still likely to be years away. The CUTE project demonstrated that the technology works well in large vehicles, but there are still problems in sourcing the hydrogen.

The theoretical levels of potential application for this policy package can again be conceptualised as high/medium/low. An optimistic assumption is that alternative fuels have a successful penetration of the fleets to the following proportions - passenger, freight and bus (13% reduction in CO_2 emissions). A less optimistic assumption is that alternative fuels are slow to enter the market, with penetration rates at passenger, freight and bus (1% reduction in CO_2 emissions). The recent scepticism concerning the likely role of biofuels and wider alternative fuels means that the low intensity application is likely to be most realistic.

PP2: Alternative Fuels Pathways

Assumption		% of Target by 2025
High intensity application	Passenger, freight and bus (35% reduction CO_2 emissions)	13%
Low intensity application	Passenger, freight and bus (7% reduction CO_2 emissions)	1%

PP7 Information and Communications Technology (ICT)

The final major technological policy lever within the techno-optimist role is in applying ICT to reduce emissions in transport and from transport. Measures in transport are targeted at personal and freight travel, and include advanced route and parking guidance, car sharing, public transport information systems, freight logistics and local traffic regulation. Teleactivities are encouraged to explore the potential for CO_2 reduction from travel.

The scope for CO_2 reduction however seem limited from this package. The likelihood is that levels of communication rise, with a complex adaptation of social interaction behaviours rather than a simple substitution. There may also be rebound effects as ICT encourages more, not less travel. If society changes markedly in the future – along the lines of the network society vision (Castells, 2000) – then there is a possibility that changes in travel behaviour will help to reduce CO_2 emissions, with a much larger proportion of activities carried out electronically. The techno-optimist role however assumes a medium intensity of application for PP7.

The result for a medium level application of PP7 is a contribution reduction in CO_2 of just 1% of the total target.

PP7: Information and Communication Technologies

Assumption		% of Target by 2025
Medium intensity application	Potential high ICT uptake, but low impact on travel substitution	1%

Wider Behavioural Measures

There are a range of wider policy packages available, however under the techno-optimist role, these are not used to their full potential. A BAU application is therefore assumed – essentially a 'limited effort' across the remaining packages. A BAU application is based on the Reference Case in T2025 (TfL, 2006a). It does, therefore, include the current congestion charging scheme and some major public transport investment.

2.4 Enviro-Optimism

The enviro-optimist role is used to illustrate the cohort of population, or policy standpoint, that focuses on behavioural options to reduce CO_2 emissions.

Figure 8: TC-SIM Enviro-Optimist Mode (Ambitious)

Table 4: Enviro-Optimist (Ambitious)

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	BAU	-
PP2 Alternative Fuels	BAU	-
PP3 Pricing Regimes	High	11.0%
PP4 Public Transport	Medium	5.1%
PP5 Walking and Cycling	Medium	1.1%
PP6 Urban Planning	Medium	1.8%
PP7 ICT	Medium	1.0%
PP8 Smarter Choice Soft Measures	High	2,6%
PP9 Slower Speeds and Ecological Driving	High	4.9%
PP10 Long Distance Travel Substitution	Medium	0.6%
PP11 Freight Transport	Medium	0.8%
Progress against VIBAT London Target (60% reduction in CO_2 emissions)		28.9%

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

Figure 9: TC-SIM Enviro-Optimist Mode (Realistic)

Table 5: Enviro-Optimist (Realistic)

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	BAU	-
PP2 Alternative Fuels	BAU	-
PP3 Pricing Regimes	Low	0.8%
PP4 Public Transport	Medium	4.1%
PP5 Walking and Cycling	Medium	1.1%
PP6 Urban Planning	BAU	-
PP7 ICT	BAU	-
PP8 Smarter Choice Soft Measures	Low	0.5%
PP9 Slower Speeds and Ecological Driving	Low	1.2%
PP10 Long Distance Travel Substitution	Medium	0.3%
PP11 Freight Transport	Low	0.3
Progress against VIBAT London Target (60% reduction in CO2 emissions)		**9.3%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

2.5 Complacent Car Addiction

This user cohort does not see any problems with car use, nor the point in reducing travel by car. They do not attempt to limit their annual growth in travel and show low participation in non-car means of travel. They exhibit the highest psychological levels of car dependency, feel strongly about an individual's right to use a car and show no interest in behavioural change or in technological change (Anable, 2005). Average car fleet emissions rise (to 220 gCO2/km) as people buy higher specification cars. The group believe a CO2 reduction target should, if at all, be achieved in the non-transport sectors. This user role results in a contribution reduction in CO2 of +11% of the total target, hence is moving in the opposite direction to that required.

Figure 10: TC-SIM Complacent Car Addiction Mode

Table 6: Complacent Car Addiction

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Car fleet average increases – 220 gCO_2/km car fleet; 1,200 gCO_2/km heavy goods vehicles	+11.1%
PP2 Alternative Fuels	BAU	0%
PP3 Pricing Regimes	BAU	0%
PP4 Public Transport	BAU	0%
PP5 Walking and Cycling	BAU	0%
PP6 Urban Planning	BAU	0%
PP7 ICT	BAU	0%
PP8 Smarter Choice Soft Measures	BAU	0%
PP9 Slower Speeds and Ecological Driving	BAU	0%
PP10 Long Distance Travel Substitution	BAU	0%
PP11 Freight Transport	BAU	0%
Progress against VIBAT London Target (60% reduction in CO_2 emissions)		**+11.1%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

2.6 Concerned Realism

The user role, or policy position, discussed here is to take a more pragmatic approach and use all policy levers available to the full potential. There is realism within the simulation, though, reflecting the view that implementation may not be as successful as expected. This limits the CO_2 reduction potential of this package. If there is a strong trend against a certain policy package take up, then the scenario assumptions reflect these difficulties.

The concerned realist user role envisages that a deep reduction in CO_2 emissions will only result if large gains are achieved from both technological and behavioural change. Users have high concern for the negative effects of car use, and believe that urban liveability and lifestyles will improve if public transport, walking and cycling are used to a much greater degree. They are concerned that we will not achieve the forecast gains in technology and behavioural change. They see holding vehicle km (at present levels), with large gains from technology, as the best way to achieve CO_2 reduction targets.

The end result of this scenario is a 25.4% reduction. The user role makes good progress towards the required 60% reduction target (against BAU), despite introducing some scepticism [realism] into expected CO_2 reduction impacts. Deeper reductions in CO_2 are however required to actually meet the target.

PP1 Low Emission Vehicles

As previous, a low intensity application of this policy package is envisaged as more realistic, bearing in mind current rates of technological penetration.

PP2 Alternative Fuels

As previous, a low intensity application of this policy package is envisaged as more realistic, bearing in mind the recent scepticism concerning the role of biofuels and wider alternative fuels.

PP3 Pricing Regimes

Congestion charging or area-wide road pricing could potentially make a substantial difference to CO_2 emissions on a London-wide scale. The BAU application assumes the current congestion charge scheme (with the western extension) is operated. There is more potential here. Road pricing could be operated for Greater London and the whole of the UK on an environmental basis (i.e. the charging relates to the carbon emissions profile of the vehicle and the number of passengers). This would give clear signals to consumers to switch to more efficient cars or to other modes of transport. There are political difficulties with implementing this package, hence the concerned realist package assumes a BAU application of the congestion charge (the current scheme) and a medium application of parking charging.

PP4: Public Transport

Public transport investment is critical in allowing consumers to choose carbon efficient means of travel. There is already an extensive public transport network in London, with massive investment plans in Transport 2025 (TfL, 2006a). The BAU application assumes that the Reference Case (Scenario 1) in T2025 is implemented. This is broadly all currently funded projects, but not including Crossrail. It therefore includes capacity and frequency upgrades on the Underground, National Rail and Docklands Light Railway. More investment could be considered, as represented in Scenario 4 in T2025, or even beyond. This might include Crossrail and other proposed schemes such as Crossrail 2 (a north-south pan-London link), additional tram routes and demand responsive public transport in the suburbs. The concerned realist package assumes a medium intensity investment in public transport (T2025 Scenario 4, Full Programme) and a medium level of fare reduction.

PP5 Walking and Cycling

Similarly, investment in walking and cycling facilities and in the streetscape and public realm makes carbon efficient means of travel more attractive, particularly for short journeys. There is already a fairly extensive walking and cycling network in London, yet aggregate walking and cycling mode shares remain low relative to the best examples in Europe. The BAU application assumes that the Reference Case (Scenario 1) in T2025 is implemented; again, broadly all funded walking and cycling projects. The concerned realist package assumes a medium intensity investment in walking and cycling (T2025 Scenario 4, Full Programme).

PP6 Urban Planning

This package focuses on using urban form to support sustainable transport, with efforts ant strategic and local scales. Strategically, urban structure is used to support public transport use - higher density development is clustered around an upgraded public transport system. More locally, urban areas are masterplanned to vastly improve their urban design quality, attractiveness for living and working. There is complementary heavy investment in walking and cycling facilities and streetscape design. The BAU application assumes that the Reference Case (Scenario 1) in T2025 is implemented. This represents the urban strategy of the London Plan (GLA, 2004) – some polycentric thickening of densities, with most effort made in central London, and some investment in improved streetscapes, again mostly in central London. The concerned realist package assumes a medium intensity application of urban planning to reduce travel CO_2 emissions (London Plan+).

PP7: ICT

As previous, the scope for CO_2 reduction from this package seems limited. A complex adaptation of social interaction is more likely than a simple substitution. The concerned realist package assumes a medium intensity application of ICT however the impacts are not great in terms of transport CO_2 reduction.

PP8 "Smarter Choices" Soft Measures

This option includes investment in workplace and school travel plans, personalised travel planning programmes and future changes in car ownership (including leasing and car clubs), car sharing and travel awareness initiatives. These are important supporting measures to other packages, but they also have an important impact on reducing CO_2 emissions in their own right. The BAU application assumes that the Reference Case (Scenario 1) in T2025 is implemented. This broadly represents all funded projects. There is more potential if funds were made available for a greater intensity of application of this package.

The concerned realist package assumes a medium intensity application of soft measures to reduce travel CO_2 emissions, reflecting that impacts are less than often forecast due to diminished returns when spread beyond the initial enthusiastic take up.

PP9 Slower Speeds and Ecological Driving

This option has the potential for substantial immediate and long term benefits if take up is high in terms of reduced speeds and changed driving styles. Slower speeds have the potential to provide extensive savings with some 15-20% reduction in CO_2 emissions if a maximum speed limit of 80 km/hr is introduced on motorways and trunk roads, with lower speeds on other roads such as residential roads. Effective compliance is a critical issue and is likely to impact on end CO_2 reduction impacts. Although the fuel use and speed value curves for new cars are flatter than those for older cars, there are still considerable fuel savings from lower speeds.

Lower speeds need to be combined with awareness programmes and better driving techniques to reduce fuel use. Ecological driving skills have been developed in the

Netherlands and include simple measures such as driving at moderate speeds, avoiding excessive acceleration and harsh braking, changing gears at low engine revolutions, driving in the highest comfortable gear at any given speed, avoiding unnecessary use of in-car equipment (especially air conditioning), keeping tyres inflated and reducing unnecessary loads. Again there are issues of take up and compliance here.

The BAU application assumes that speed limits remain the same and there is little funding of these types of driver skill projects. There is therefore more potential if funds were made available for a greater intensity of application of this package. The concerned realist package assumes a medium intensity application of this package to reduce travel CO_2 emissions; however the impacts are less than often expected due to enforcement difficulties.

PP10 Long Distance Travel Substitution

There is some limited potential for long distance travel substitution of air to rail (e.g. Eurostar) and the possibility of substituting local goods and services for those that are sourced from further away - 'Buy Local'. However the savings here are not likely to be substantial. Only travel within the London boundary is considered, hence the longer journey effects are not included. The BAU application assumes that only existing high speed train services operate. There would be more potential if a network of services was built. The concerned realist package assumes a medium intensity application of this package; however the CO_2 reduction impacts remain small.

PP11 Freight Transport

Freight transport is covered tangentially in several of the other policy packages, but this package concentrates on the freight sector as a whole with a series of measures targeted at reducing CO_2 emissions. Different applications of the policy package draw from changed handling factors (the number of links in the supply chain); reduced length of haul; improved mode share; reduced empty running; improved fuel efficiency and choice of fuel/power source. Subsidiarity (local production and knowledge transfer) and dematerialisation (miniaturisation, advanced logistics and distribution networks, load matching and material consumption) can also lead to savings, some substantial. The BAU application again assumes a limited effort in this area. There is much greater potential on offer if a concerted effort is made in this area.

The London Low Emission Zone (LEZ) scheme deters the most polluting vehicles from driving into the area. The vehicles affected by the LEZ are older diesel-engine lorries, buses, coaches, large vans, minibuses and other heavy vehicles. A stricter regime would get freight vehicles to reassess the pollution profiles of trucks. The consolidation of goods and a new distribution network using ICT could significantly reduce the carbon dioxide emissions.

The concerned realist package assumes a medium intensity application of the package; however the CO_2 reduction impacts remain small.

Figure 11: TC-SIM Concerned Realist Mode

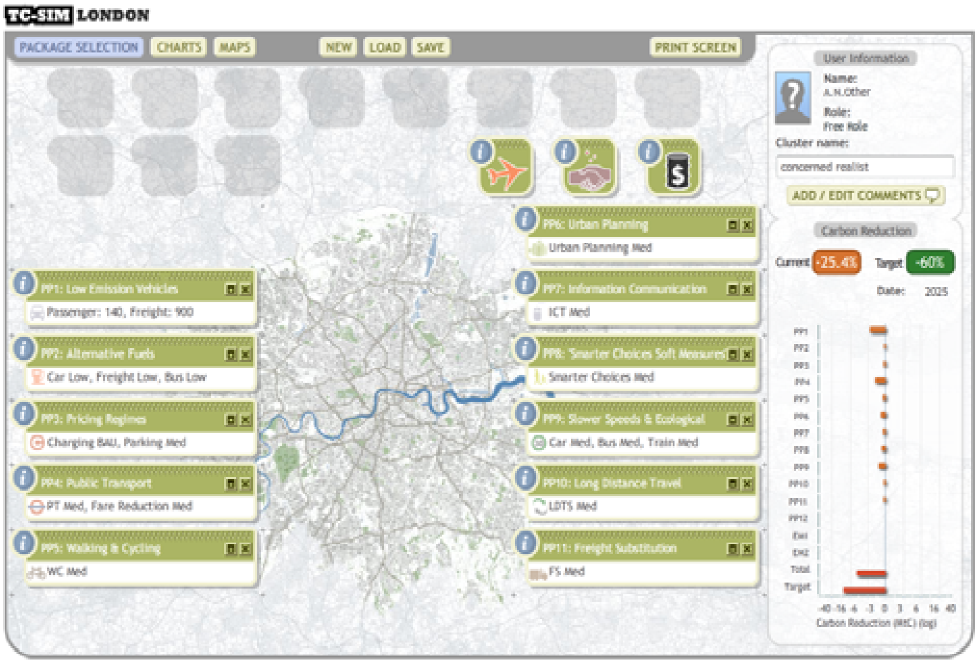
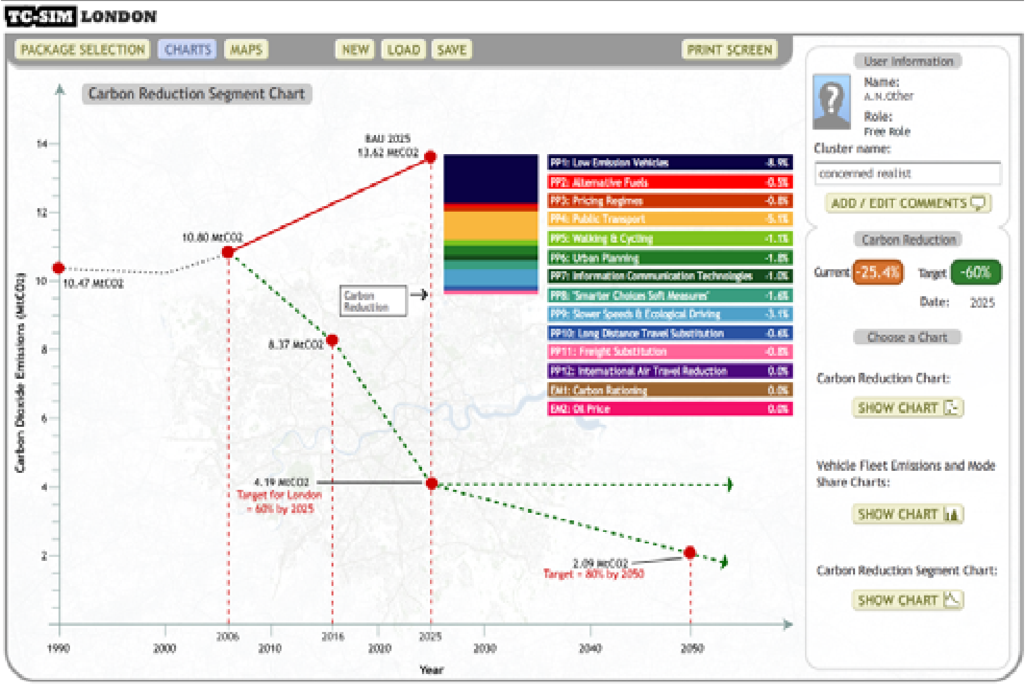


Table 7: User Role - Concerned Realist

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low: 140 g/km car fleet; 900 gCO_2/km heavy goods vehicles	8.9%
PP2 Alternative Fuels	Low	0.5%
PP3 Pricing Regimes	Low/medium – BAU congestion charging scheme; medium parking charging	0.8%
PP4 Public Transport	Medium – medium investment strategy; medium fare reduction	5.1%
PP5 Walking and Cycling	Medium	1.1%
PP6 Urban Planning	Medium	1.8%
PP7 ICT	Medium	1.0%
PP8 Smarter Choice Soft Measures	Medium	1.6%
PP9 Slower Speeds and Ecological Driving	Medium	3.1%
PP10 Long Distance Travel Substitution	Medium	0.6%
PP11 Freight Transport	Medium	0.8%
Progress against VIBAT London Target (60% reduction in CO_2 emissions)		**25.4%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

Figure 12: TC-SIM Concerned Realist Segment



Note. Baseline includes short haul international air emissions (London residents' share)

2.7 Optimised Balance

The user role discussed here is to take a more ambitious approach and uses all policy levers available to the full potential. The assumption within the simulation is that a very high degree of [successful] implementation is possible. This enhances the CO_2 reduction potential of this package and hence this is a potential policy package cluster that attains the target of 60% reduction in carbon emissions.

The optimised balance user role envisages that a deep reduction in CO_2 emissions will only result if large gains are achieved from both technological and behavioural change. Users have high concern for the negative effects of car use, and believe that urban liveability and lifestyles will improve if public transport, walking and cycling are used to a much greater degree. They are concerned that we will not achieve the forecast gains in technology and behavioural change. They see holding vehicle km (at present levels), with large gains from technology, as the best way to achieve CO_2 reduction targets. The user role achieves the required 60% reduction target but the inclusion of the vast majority of packages applied to a high level of application may be very unrealistic and ambitious (based on previous experience of application).

Figure 13: TC-SIM Optimised Balance Mode

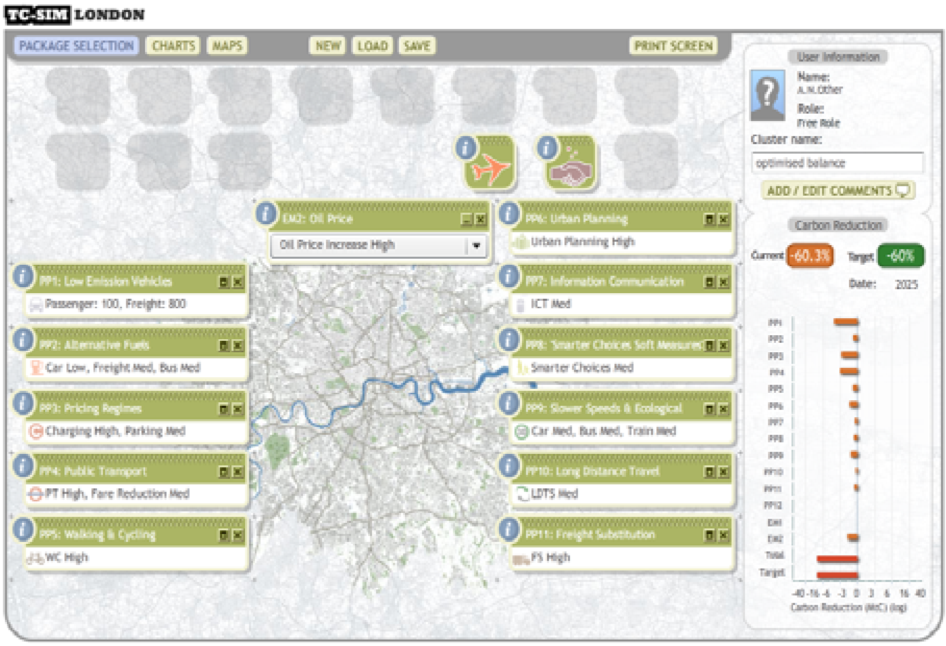
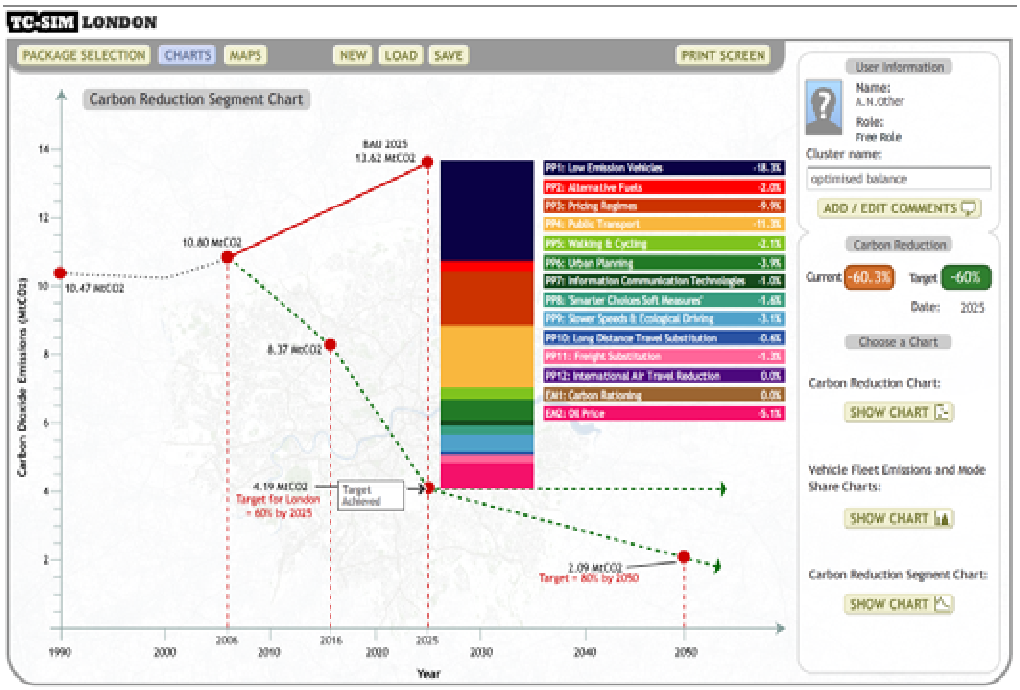


Table 8: Optimised Balance

Policy Package	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low: 100 gCO2/km car fleet; 800 gCO2/km heavy goods vehicles	18.3%
PP2 Alternative Fuels	Car Low, Freight medium, Bus medium	2.0%
PP3 Pricing Regimes	Emissions charging scheme - high; medium parking charging	9.9%
PP4 Public Transport	High investment strategy; medium fare reduction	11.3%
PP5 Walking and Cycling	High	2.1%
PP6 Urban Planning	High	3.9%
PP7 ICT	Medium	1.0%
PP8 Smarter Choice Soft Measures	Medium	1.6%
PP9 Slower Speeds and Ecological Driving	Medium	3.1%
PP10 Long Distance Travel Substitution	Medium	0.6%
PP11 Freight Transport	High	1.3%
EM2 Oil Price	High - $140 barrel	5.1%
Progress against VIBAT London Target (60% reduction in CO2 emissions)		60.3%

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

Figure 14: TC-SIM Optimised Balance Segment



Note. Baseline includes short haul international air emissions (London residents' share)

2.8 International Air Travel

There is an additional [huge] problem looming. Air travel is growing at an ever increasing rate, particularly short-haul travel, but also long-haul travel, and beginning to emit relatively high aggregate levels of CO_2. There is strong consumer demand for growth in air travel and a strong lobby to increase supply.

TC-SIM can also be used to illustrate the impacts of various issues: (1) including international air travel in the calculations in discussions over transport and CO_2 emissions (most studies concentrate on surface, domestic travel only, hence miss the international sector); and (2) consider likely options to reduce growth projections for international air travel. These include reducing the demand for particular types of journey (largely through awareness initiatives) and reducing supply (largely through restricting airport growth). [Note that long distance travel substitution, short haul air to HST, is covered in PP10].

Adding the CO_2 emissions associated with London's residents' international air travel to the baseline and target within TC-SIM means that an additional 35 $MtCO_2$ are added to the baseline BAU in 2025. The previous concerned realist package selection achieved a 25% reduction in transport CO_2 emissions; if international air emissions are considered this contribution reduces to a 6% reduction in transport CO_2 emissions.

A medium level intervention to reduce the growth in supply for air travel means that a greater reduction in CO_2 emissions is possible – up to a 9% reduction in transport CO_2 emissions in aggregate. There are, of course, huge implementation difficulties with this package. The concept of reducing the projected growth in air travel is not currently a mainstream political option.

There may need to be strong links to enabling mechanisms, such as carbon rationing, to significantly reduce CO_2 emissions in this area. Also, if international air travel is allowed to continue its upward growth, then the effort in reducing CO_2 emissions from ground transport needs to be much greater.

The two scenarios that follow include international air emissions relative to:

- Concerned Realist
- Optimised Balance

Figure 15: TC-SIM - The International Air Travel Problem

Table 9: - The International Air Travel Problem

Policy Package (Relative to Concerned Realist)	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low: 140 g/km car fleet; 900 gCO2/km heavy goods vehicles	8.9%
PP2 Alternative Fuels	Low	0.5%
PP3 Pricing Regimes	Low/medium – BAU congestion charging scheme; medium parking charging	0.8%
PP4 Public Transport	Medium – medium investment strategy; medium fare reduction	5.1%
PP5 Walking and Cycling	Medium	1.1%
PP6 Urban Planning	Medium	1.8%
PP7 ICT	Medium	1.0%
PP8 Smarter Choice Soft Measures	Medium	1.6%
PP9 Slower Speeds and Ecological Driving	Medium	3.1%
PP10 Long Distance Travel Substitution	Medium	0.6%
PP11 Freight Transport	Medium	0.8%
International Air Emissions (additional 35 MtCO2 added to baseline BAU emissions)		
Progress against VIBAT London Target Assuming no intervention in international air sector		6.2% (from 25.4%)
Progress against VIBAT London Target (60% reduction in CO2 emissions) Assuming medium level intervention in international air sector		**9.4%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

Figure 16: TC-SIM - The International Air Travel Problem

Table 10: - The International Air Travel Problem

Policy Package (Relative to Optimised Balance)	Comment	% of VIBAT London Target by 2025
PP1 Low Emission Vehicles	Low: 100 gCO_2/km car fleet; 800 gCO_2/km heavy goods vehicles	18.3%
PP2 Alternative Fuels	Car Low, Freight medium, Bus medium	2.0%
PP3 Pricing Regimes	Emissions charging scheme - high; medium parking charging	9.9%
PP4 Public Transport	High investment strategy; medium fare reduction	11.3%
PP5 Walking and Cycling	High	2.1%
PP6 Urban Planning	High	3.9%
PP7 ICT	Medium	1.0%
PP8 Soft Measures	Medium	1.6%
PP9 Slower Speeds and Ecological Driving	Medium	3.1%
PP10 Long Distance Travel Substitution	Medium	0.6%
PP11 Freight Transport	High	1.3%
EM2 Oil Price	High - $140 barrel	5.1%
International Air Emissions (additional 35 $MtCO_2$ added to baseline BAU emissions)		
Progress against VIBAT London Target Assuming no intervention in international air sector		15% (from 60%)
Progress against VIBAT London Target (60% reduction in CO_2 emissions) Assuming medium level intervention in international air sector		**22%**

Note. Within the BAU for London, the T2025 Reference Case (Scenario 1) is normally used.

2.9 Enabling Mechanisms

Further incentives or enabling mechanisms may be required to help achieve the headline CO_2 reduction targets being adopted. One of the possibilities is carbon rationing. There are a number of possible ways of implementing a rationing scheme in the transport sector. The most likely are through (1) car manufacturers; (2) fuel suppliers; or (3) individual carbon rations. Each would involve a set level of emissions, potentially reduced in volume over time. This enabling mechanism might help achieve high intensity application in the preceding packages. There are, however, very large implementation difficulties, particularly with Variant 3.

There is some precedence here. The EU Emissions Trading Scheme (EU ETS) is already running, where large businesses trade emission permits according to use. There is a high probability that the transport sector will be included in this scheme, potentially even including international air emissions. The idea is to set a cap on the aggregate level of emissions and trade within this level. Trading is likely to be at the business and/or national level.

Oil price rises also make a difference to travel. Price rises can themselves be seen as enabling mechanisms to help achieve greater gains in low emission technologies and behavioural change. Over the past thirty years there has been some stability in oil prices – at relatively low levels – but recently this has changed with much variability. Prices reached over US$150 a barrel in 2008, though have reduced since (currently below $50 a barrel..

There is much concern in the literature about the future supply of oil. Estimates for the peaking of oil supply range from “2007-08” to “after 2010” (World Energy Council) and “2025” (Shell). Oil peaking is likely to result in dramatically higher oil prices as suppliers and consumers react to perceived supply shortages. The consumer is shielded to a certain extent by the high tax component in the price of petrol and diesel. Nevertheless, if the current levels of tax are maintained (in 2008, 120p per litre of unleaded petrol incorporated around 66p of tax, including fuel tax and VAT, representing almost 55% of the total price) then a large increase in the cost of oil impacts markedly on the price of petrol and diesel. Large price increases are likely to dampen the demand for travel using oil and provide clear signals to industry and consumers to increase efficiencies. Large price increases may, therefore, help achieve high intensity application in the preceding packages. There are, however, very large difficulties in terms of acceptability of large price increases (public and business).

The analysis in this paper does not consider the enabling mechanism issues in any further detail. In the coming years, however, they are likely to be very important.

2.10 Conclusions: Towards Optimised Packaging

There are a range of pathway(s) towards carbon efficiency in the transport sector. All represent huge breaks in current trends and will therefore be very difficult to implement. A number of contextual issues have been raised:

1. The headline targets adopted in London are very ambitious, with a 60% reduction in cross-sectoral CO_2 emissions on a 1990 base by 2025. Sectoral targets would also be useful. Most commentators agree that targets will need to get more stringent – upto 80% reductions on a 1990 base by 2050.

2. A number of policy packages are available to help reduce CO_2 emissions. They include: PP1: Low emission vehicles, PP2: Alternative fuels, PP3: Pricing regimes, PP4: Public transport, PP5: Walking and cycling, PP6: Strategic and local urban planning, PP7: Information and communication technologies (ICT), PP8: Smarter choice

soft measures, PP9: Ecological driving and slower speeds, PP10: Long distance travel substitution, PP11: Freight transport; and PP12: International air travel. These should all be used to their full potential and developed as part of coordinated, integrated implementation packages, differing according to context.

3. Many previous estimates of CO_2 reduction potential tend to overstate impacts. For example, the take up of low emission vehicles is less than expected: gCO_2/km fleet averages are not reducing at the required rate to hit voluntary targets. The use of alternative fuels, particularly biofuels, is in question. There are serious concerns in terms of life cycle emissions and also in the potential for mass market take up (including land take and fuel supply issues). RTFO targets are not likely to be achieved. Behavioural measures potential may also be prone to overestimation – the likelihood being that initial impacts will reduce as the mass market is tackled. The assumption of successful implementation should also be questioned. The history of transport planning suggests this is not likely to happen, hence more realistic assumptions may prove more accurate. Getting people to reduce their cars less is notoriously difficult.

4. The scenarios tested in the VIBAT London study, using TC-SIM, illustrate that a range of entrenched policy positions are not likely to be successful in achieving the current CO_2 reduction targets for London:

    a. The free rider user role is only likely to achieve minimal CO_2 reduction gains – in the order of 5% CO_2 reduction relative to the BAU in 2025.

    b. The techno-optimist user role is only likely to achieve reductions of 6% in CO_2 reduction relative to the BAU in 2025. Much more potential however is available here – upto a 25% CO_2 reduction relative to the BAU in 2025. The 100 gCO_2/km total car fleet and 800 gCO_2/km total heavy goods vehicle fleet 9fully loaded) should be developed as a mandatory target for an agreed future year.

    c. The complacent car addict user role is now untenable, moving in the opposite direction to required CO_2 reduction targets.

    d. The concerned realist user role illustrates that we need to act across the full range of policy packages to achieve CO_2 reductions, however the "realism perspective" dampens likely impacts. The lesson here is that the focus needs to be on achieving high intensity application across all measures.

    e. The optimised balance user role achieves the 60% CO_2 emission reduction target, representing a very high application across the range of available policy interventions.

The current trends mean that the transport sector continues to perform poorly in contributing to cross-sectoral CO_2 reduction targets. The clear message is to work across the broader range of policy packages and at a higher intensity in application. Low emission vehicles and alternative fuel penetration are likely to remain the most important policy levers as they tackle carbon efficiency in the dominant means of travel (the private car). The main difficulty here is in achieving any level of success in penetration to the mass market. The motor industry and government need to develop mechanisms to achieve this; this should include mandatory targets.

There is also much potential in the behavioural measures, including pricing regimes, public transport, walking and cycling, ecological driving and slower speeds and freight transport. Urban planning and smarter choice soft measures, as well as acting in their own right, potentially perform very important roles as supporting measures to other policy packages, enabling higher levels of success in implementation.

5. If international air emissions are included in the debate, then target achievement becomes extremely difficult. The main perceived difficulty on the behavioural side is in political implementability. This leads us to a requirement to develop our means of knowledge dissemination, communication, participation in decision-making and marketing of policy options and futures. Tools such as TC-SIM, applied to different contexts, could become very powerful.

There is a need for some form of mechanism or framework that can help in assessing target achievement over time, with a clear linkage between technological penetration and behavioural change requirements.

Current progress in moving towards headline targets is far from satisfactory. Scenario testing and backcasting offer a way forward here. Much more thought is also required in developing potential synergetic packages of policy options and the incentives for change.

The final thought is to think beyond CO_2 reduction potential. Efforts should, of course, be made to improve quality of life and wider sustainability goals. Carbon efficient transport and lifestyles need to be consistent with these wider aspirations.

3 Developing a Multi-Criteria Appraisal Framework

3.1 Post Normality

An innovative element in the VIBAT London project is the development of an appraisal framework within which decisions can be assessed and sensitivities tested. Stage 1 of the project has shown that there are a range of policy measures available to help achieve the images of the future and move towards CO_2 emission reduction targets. Policy measures are also most likely to be effective when clustered together into policy packages, each of which consists of several policy measures. However, policy packages or clusters are unlikely to be selected only on the basis of their carbon emissions mitigation potential. There is a need to appraise the policy clusters against a wider set of criteria through a decision making framework that replicates, as far as is possible, the actual decision making process. In this section a multi-criteria appraisal framework is developed and then used to assess the relative merits of each policy package cluster.

Projects, policies and their impacts are part of a system of broader (national) objectives. If the impacts of projects and policies on these broader objectives can be valued economically, all such effects may be incorporated into the conventional decision-making framework of cost-benefit analysis (CBA). However, several social and environmental impacts cannot be easily quantified in monetary terms and multi-criteria analysis offers a complementary approach, which facilitates better decision making.

Participative Decision Making

The appraisal framework would need to go beyond the standard cost benefit analysis, as this tends to heavily weighted to the short term, with strong assumptions on discount rates and only a limited range of quantifiable measures used. The multi-criteria analysis, together with a strong input from a variety of stakeholders as part of a participatory process, could provide a more robust approach.

The participative multi criteria process stems from critical and reflective thought (post-normal science) in contrast to a precisely defined process (normal science). It accepts that technical and social incommensurability by moving away from substantive rationality towards procedural rationality (Functowicz and Ravetz, 1992).

3.2 Multi-Criteria Decision Analysis

Trade offs among conflicting objectives lie at the heart of transport planning. Some policies are better according to some criteria, whereas other alternatives will do better against differing criteria. Choosing one of the alternatives over the others means that the priorities must have been set in such a way that accomplishing some goals would sacrifice others. The need to account for economic, environmental, social, technical, political and factors makes transportation policy evaluation well suited to multi-criteria decision making.

Multi-Criteria Decision Analysis (MCDA) is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting objectives and multiple evaluation criteria measured in different units (Kersten, 1997). MCDA aims at highlighting these conflicts and deriving a method of compromise in a transparent manner. It moves the evaluation process away from a single indicator based on rates of return to looking at broader issues relevant to investment decisions. The advantage of MCA, over techniques such as extended cost-benefit analysis, is that it does not require that all criteria be reduced to one unit of measurement, but at the same time it provides a more structured framework within which to analyse different priorities and preferences than conventional qualitative approaches (Belton and Stewart, 2002).

3.3 MCDA Methodology

The methodological approach for the appraisal uses a stakeholder driven multi-criteria analysis framework. The perspectives of different stakeholders and their preferences can be included.

Gathering opinions and information from the interested stakeholders is an essential part of the policy package identification process, enhancing its transparency and ensuring that the packages are workable in practice and legitimate from the stakeholder's point of view.

An application of the multi-criteria analysis involves eight stages:

1. Establish the decision context. What is the main aim of the multi-criteria analysis?

2. Identify the options/alternatives;

3. Identify the criteria;

4. Weight the criteria – assign weights for each of the criteria to reflect their relative importance to the decision;

5. Score the options – assess the performance of each options against the criteria;

6. Combine the weights and scores for each of the options to drive an overall value;

7. Examine the results;

8. Conduct a sensitivity analysis of the results to changes in scores or weights.

Weighting Criteria

In this study, the key objective is to identify the policy packages that can help London achieve its challenging goal of a 60% reduction in CO_2 emissions by 2025. This is the overarching ambition to which the decision making process will contribute.

The criteria and sub-criteria are the measures of performance by which the options will be judged. A large proportion of the 'value added' by a formal multi-criteria process derives from establishing a soundly based set of criteria against which to judge the options. An exhaustive list of criteria needs to be created. Ideally the number of criteria should range from 8 to 15 and care should be taken to avoid any overlapping of criteria. With a large number of criteria, the importance of weights is reduced. In contrast a small number of criteria may lead to an oversimplification of the real world.

The criteria are selected to reflect four main aspects, namely environmental, economic, social and political. Some criteria or sub criteria can be quantifiable such as carbon mitigation potential. Others can be qualitative such as acceptability.

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation (Kirkwood, 1997).

Scoring of Options

The scoring of policy packages is used to help in the prioritisation of all the policy packages being considered. The total scores also help in assisting decision makers to decide upon the point of time in which they would like to implement the policy package. This could range from any of the following:

- Immediate implementation;
- Short term implementation;
- Medium term implementation;
- Long term implementation.

3.4 Proposed Approach

The results of the analysis can be surprising, and should not be taken as inviolate, the process is meant to be flexible and open ended, not deterministic. A thorough examination of the sensitivity of the overall assumptions made in the analysis, to uncertainties, and to weighting factors stemming from plurality of opinion is necessary to 'explore' the decision 'envelope' around the preferred options, and examine the robustness of the indications (Stirling, 1996). In many cases, iteration will be necessary to refine the alternatives, carry out more precise modelling or debate further the weights which should be used.

There are many multi-criteria appraisal methodologies, several of which have useful features that could justify their application. Some use pair-wise comparison to select the best or worse alternatives, whilst other approaches look at dominance (e.g. regime analysis) or qualitative scoring approaches (e.g. sign analysis). In all cases the intention is to use a wide range of criteria to determine the advantages of particular policy packages as compared with others.

For the purpose of this project, it was considered appropriate to select an approach that is broadly applicable across a range of policy options and one that fulfils the criteria of transparency, simplicity, robustness and accountability. Hence an approach based on the linear additive model is selected and it was decided to adopt the pair-wise comparison feature of the Analytical Hierarchic Process (AHP) for weighting and scoring. The strengths and weaknesses of the AHP have been the subject of substantial debate among various specialists. Most users find the pair-wise comparison form of data input straightforward and convenient and this feature is exploited in multi-criteria decision analysis by the MACBETH approach to scoring and weighting. For this project, a software tool HiView[1] that employs the MACBETH approach has been used for carrying out the multi-criteria decision analysis (details are found in Annex 5).

[1] HiView was used by Sharad Saxena (PhD student at Oxford Transport Studies Unit and intern at Halcrow) as part of his PhD studies. Some of the results are reported here.

4 Appraisal of the Integrated Policy Package Clusters

4.1 Introduction

This section gives an overview of initial results and outputs from the multi-criteria appraisal. Appraisal is carried out at the level of integrated policy package clusters.

The objective is to derive a score for each policy package concerning the degree of performance against each of the selected criteria and compile a record of the policy package scores for use in the prioritisation phase.

As mentioned previously, the existence of several different types of policy packages, as well as varying national and local priorities, favour the use of a multi-criteria appraisal methodology instead of a one based on a single criterion such as the CBA. Such a method allows available information to be taken into account, even at the very preliminary level of policy conception. At the same time, a variety of elements may be introduced against which the package can be appraised.

The policy package appraisal consists of the following key components:

- Definition of criteria;
- Weighting of criteria;
- Scoring various policy packages against different criteria;
- Derivation of total score per policy package.

Six of the main policy package clusters are appraised, as listed below:

- Techno-Optimist (Realistic);
- Enviro-Optimist (Realistic);
- Techno-Optimist (Ambitious);
- Enviro-Optimist (Ambitious);
- Concerned Realist;
- Optimised Balance.

4.2 Defining the Criteria

Criteria are used to differentiate between the decision options. By definition, criterion should be:

- Complete;
- Non-redundant;
- Clearly defined, so as to enable the expression of a preference value;
- Mutually preference independent;
- Accommodate preference over time.

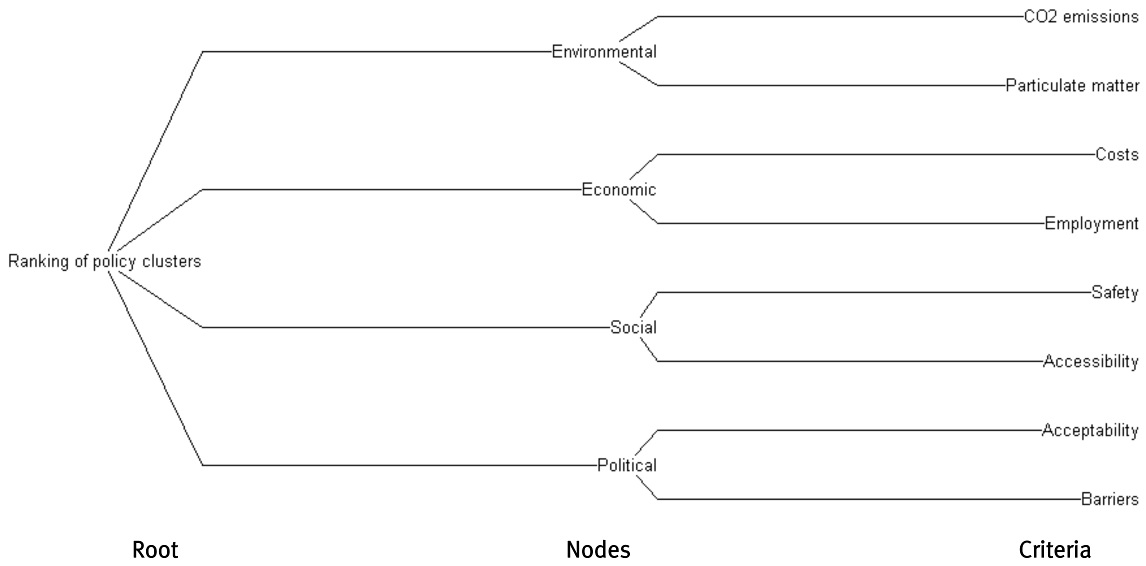
A total of 4 major criteria and 8 sub-criteria are defined. These criteria reflect the dominant issues which form the basis of transport policy decision making. The selection of criteria is partially based on the Appraisal Summary Sheet of the New Approach to Appraisal (NATA).

The design criteria and the sub criteria that were selected for use in the appraisal tool are shown below (Table 11).

Table 11: Appraisal Criteria

Main Criteria	Sub-Criteria
Environmental	Carbon emissions
	Particulates
Economic	Cost
	Employment
Social	Safety – accidents
	Accessibility
Political	Acceptability
	Barriers

Figure 17: Hierarchy of Criteria



Note: The criteria have been arranged in a hierarchical structure and considered in clusters. This helps in providing a holistic representation of the decision making process by enabling a structured visualization of the problem.

4.3 Scoring the Policy Clusters

After defining the criteria, each of the policy clusters was scored against each of the criteria. The score records the performance of each of the options against the criteria. Scores can include monetary, non-monetary, percentages, fractions and qualitative judgements.

Two types of scoring have been adopted:

- The first takes advantage of the available base data. A good example of this is the carbon mitigation potential. In the case of policy package clusters, the carbon mitigation potential has been modelled and the quantified data is available. This quantified data was directly entered into the multi criteria model as scores for each policy package cluster.

- The second type of scoring is based on subjective value judgements. This was used when no basis was available or when the criterion required qualitative assessment.

For the qualitative assessments, the multi-criteria assessment process generates numeric values from verbal judgements. The following steps were adopted during the qualitative scoring process:

- The first step to scoring is to rank the options in order of value by answering the question; "Which is the most preferred option for this criteria?"

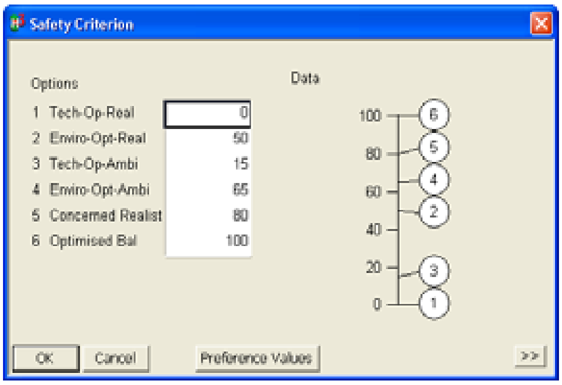
- The second step is to complete the judgements matrix with verbal judgements. Firstly, by considering the relative strengths or weaknesses, in relation to the criterion, of the most preferred option relative to the others. The question to answer is "How strong is the difference in value between my most preferred option and the alternative options for the relevant criterion?"

For the current appraisal of policy clusters, the approach of direct rating was adopted. This is normally adopted when a commonly agreed scale of measurement for the criterion in question does not exist or where there are limited time and resources available to undertake the measurement. Direct rating uses the judgement of an expert simply to associate a number in the 0-100 range with the value of each option on that criterion. 0 represents a least preferred option and 100 is associated with a most preferred option. All other options then fall between 0 and 100.

Figure 16 shows the adoption of global scaling. Additional policy clusters can easily be accommodated between these two extreme points.

The model also has a special function that facilitates qualitative judgements. This component is called 'Measuring Attractiveness by a Categorical Based Evaluation Technique' (MACBETH). This feature in the model generates numeric values from verbal judgements and also helps by ensuring the consistency of those judgements.

Figure 18: Scoring the Options



- The first step to scoring in MACBETH is to rank the options in order of value by answering the question; "Which is the most preferred option for this criteria?"

- With the most attractive option identified, other options can now be ranked. If it is not possible to agree a ranking of the options, it is possible to use an ordinal ranking process.

- The second step to scoring using MACBETH is to complete the judgements matrix with verbal judgements. The first step is to consider the relative strengths or weaknesses, in relation to the criterion, of the most preferred option to the others.

Hiview3 converts input scores into value scales, which are then weighted so that a unit of value on one scale equals a unit of value on the scales for all the other criteria. To facilitate this conversion, three types of scale are used:

- Relative Scale: this is the default scale and is the easiest to use. Input scores are converted to scales extending from 0 to 100 automatically. Hiview 3 assigns a value of 100 to the most preferred option and 0 to the least preferred. All other options are scaled 0-100 in proportion to their input scores, a direct linear conversion.

- Fixed Scale: the user defines what input values are to be associated with values of 0 and 100 before entering the scores for each option. This is most useful where the weighting of criteria is to be done first, as might be the case where not all of the input data are available.

- Identity Scale: used where the conversion of scores into values is not required. In this case, the weighting process applies directly to the input data. Identity scales are usually used for costs.

MCDA uses value functions; these allow comparisons of value to be made between criteria with different units. The first step is to normalise the scores that have been input. Value functions define how this normalisation is achieved.

A linear value function is the default in Hiview 3. The scores input for a criterion are normalised across the 0-100 scale proportionally to their values. This is the same as if the graph above was one straight line.

Piecewise or non-linear value functions are useful approximations for normalising continuous data. For example, it is well known that human reaction to changes in noise levels measured on a decibel scale is non-linear. After a certain decibel, the level may be perceived as unbearable. This may also be the case with CO_2 mitigation where higher levels of mitigation may be difficult to achieve and hence have a higher marginal value. Alternatively another case could be where the marginal increments have a diminishing value. For example, there are sometimes thresholds of achievement above which further increments are not greatly appreciated.

Figure 19: Linear Value Function

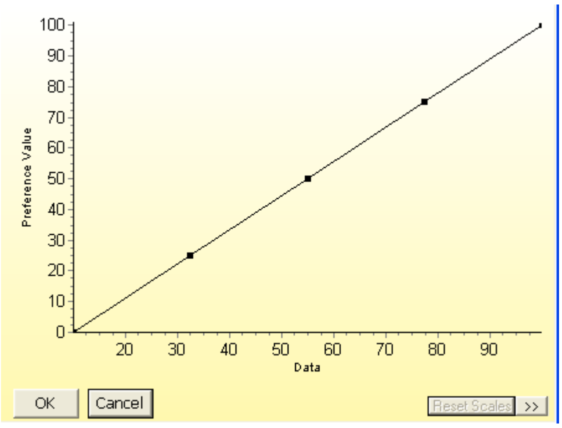
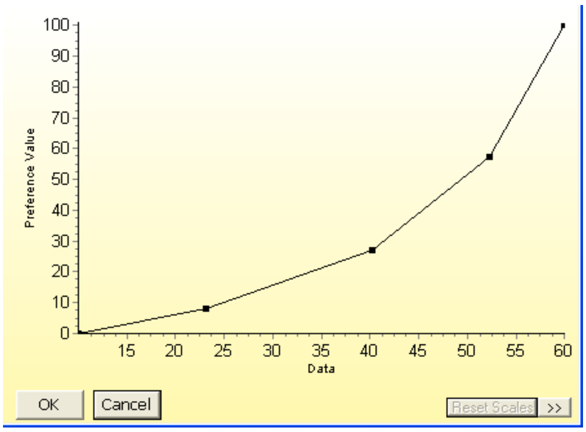


Figure 20: Non-Linear Value Function



4.4 Weighting

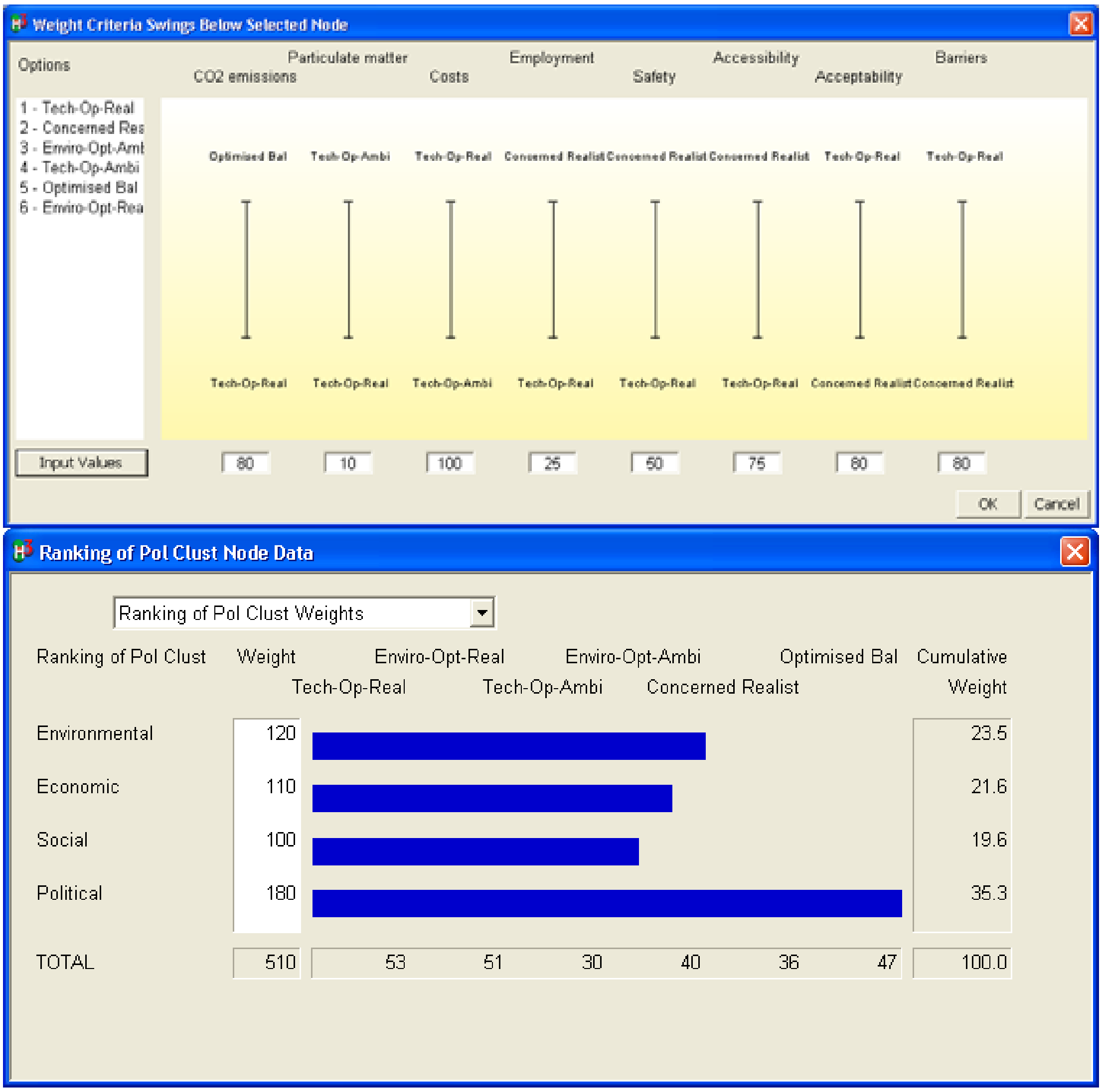
In this multi-criteria decision analysis, swing weighting has been used to derive weights for the model, i.e. weighting based on the difference between the lowest and highest scores.

As with many processes in MCDA, the key to correct weighting is to formulate the correct question for consideration. When weighting a group of criteria, the question for consideration should be "of all the swings within these criteria, which represents the biggest difference?" The criterion swing that is most important is weighted 100. The swing in value for the other criterion are then judged relatively against the most important criterion swing and assigned weights to 100.

To implement the weighting, it was decided to weight all the criteria at once. This is an important element and ensures that criteria swings are all judged relative to each other. It is essential to the integrity of MCDA that there is consistency in the judgement of swings. By viewing all criteria swings at once, consistency is ensured. The above weighting shows that the weight of the political criteria is approximately twice that of the environmental criteria. This does not mean that political criteria are twice as important as the environmental ones. It actually implies that the difference in scores against the political criteria for the options being considered would be judged as twice as important as the difference in environmental criteria for the options being considered.

The cumulative weights on the right hand side (Figure 19) show the discriminating power of the criteria. In this case, cost criteria came out at the top because the large difference in costs between the policy clusters matters a great deal, while the employment criteria and particulates are at the bottom because there is likely to be a limited impact on these two amongst the different policy option clusters.

Figure 21: Weighting of Options



4.5 Ranking the Policy Packages

The height of each bar (Figure 20) represents the total weighted score for that option. The bar is split into several coloured sections that show how the total weighted score is made up from contributions by major criterion. For instance, the Techno-Optimist (Realistic) cluster rating is mainly composed of the scores from the political and economic criteria. This is because this option is likely to have a low barrier to implementation and also offers a low cost solution. The social and environmental gains are however negligible. On the other hand, the Optimised Balance cluster is quite difficult to implement and also involves a high economic cost. Its scoring bar is therefore composed mainly from the environmental and social gains that are likely to made by implementing this policy cluster.

Figure 21 shows how the total weighted scores for each option are built up from individual criteria. This allows the decision maker to see how contributions to the total weighted score are made by different criteria. The Techno-Optimist (Realistic) approach scores well on the costs, public acceptability and barriers to implementation criteria but poorly on the others. Hence its low costs of ease of implementation give it an overall high score and make it the most preferred approach. The Optimised Balance approach scores well on the environmental and social criteria. It however scores poorly on the economic and political criteria as the costs of implementing all the policy packages are likely to be high and the barriers to implementation are also expected to be formidable. This type of analysis illustrates neatly the difficulties of implementing what might be seen as technically optimum strategies.

The ranking process shows how different approaches are built up of scores against different criteria. Subsequently in the sensitivity analysis we will explore how a change in the weighting of the different criteria can alter the preferred option and change the overall ranking of the different approaches.

Figure 22: Ranking of Options (Nodes)

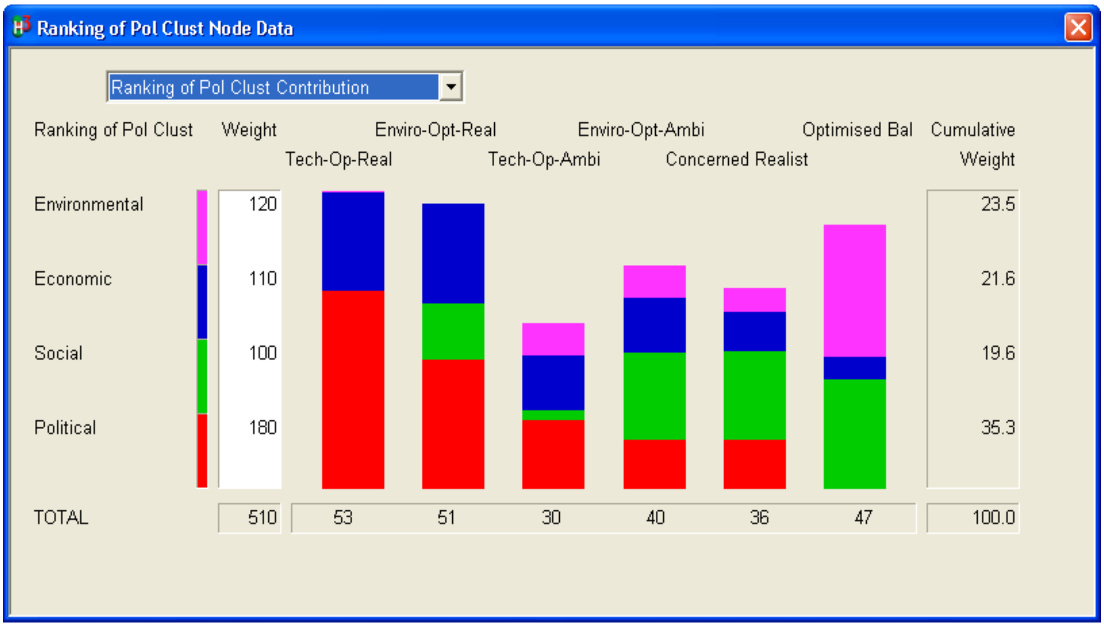
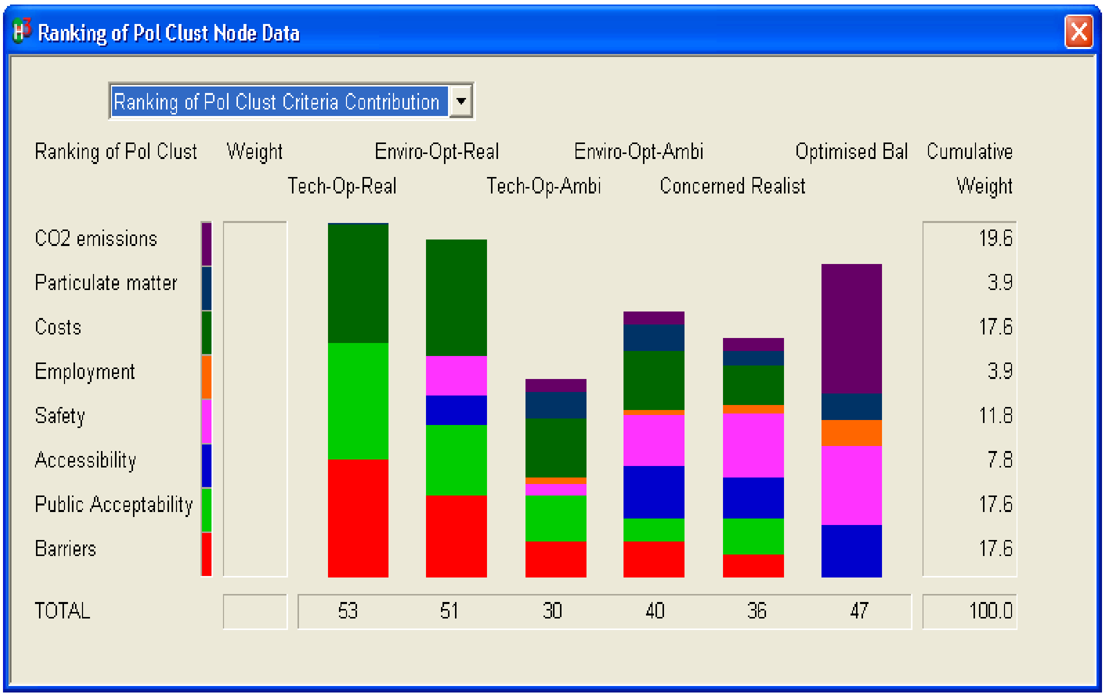


Figure 23: Ranking of Options (Criteria)



4.6 Sensitivity Analysis

Sensitivity analysis offers a valuable tool for characterising the uncertainty associated within the analysis. Areas in the model can be highlighted that have a large influence on outcomes and where only small changes in score or weight would change the most preferred option.

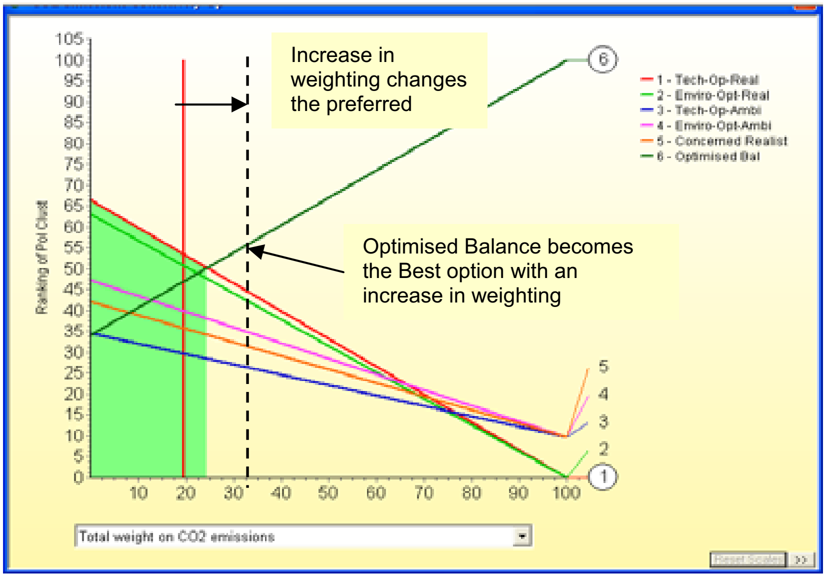
Sensitivity analysis is also useful to test quality assurance within the modelling. Inputs can be subject to many sources of uncertainty, including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on our confidence in the response or output of the model. For instance, the process of scoring and weighting can generate considerable debate in such a multi-criteria decision analysis. Hence, sensitivity analysis is essential and intrinsic for the multi-criteria analysis to be useful in public policy formulation. The different opinions can be properly analysed using a sensitivity analysis.

With the complete model in place, sensitivity analysis was carried out for various criteria to see the effect of changing weights. This helps explore whether the ranking of the policy clusters change significantly depending upon whether substantial changes are made in the order of magnitude of individuals' weight assessments. The process showed that the overall results are sensitive to the weights given to the objectives and criteria.

Figure 22 shows the effect on the overall ranking of policy package clusters (vertical axis) by varying the weight (horizontal axis) on the CO_2 criteria from 0 (no weight on the node) to 100 (all the weight on this objective). As the weight increases from zero, all other weights are reduced but kept in the same proportion to each other. The vertical line at about 19 percent shows the base-case cumulative weight for the CO_2 criterion. The vertical line intersects at the top of the figure with a sloping line that represents the overall preference score of the Techno-Optimist Realistic cluster. However as the weight of the CO_2 criterion is increased, the Techno-Optimist (Realistic) remains the overall most preferred option until the weight becomes 24 percent; then Option 6 which is Optimised Balance becomes the most preferred option.

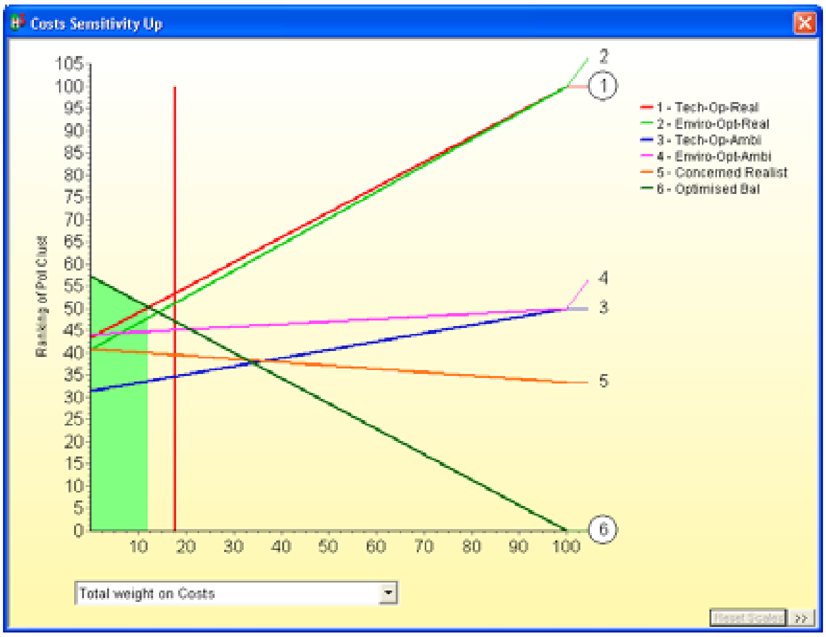
This clearly shows that in a scenario in which the CO_2 weight is increased, perhaps owing to the growing need to mitigate carbon emissions, then the increase in weight of the CO_2 criteria will also change the ranking of the policy packages. Hence increasing the weight of the CO_2 criterion will make 'Optimised Balance' the most preferred option.

Figure 24: Sensitivity Analysis (CO2)



A similar sensitivity analysis can be done with other criterion as well. Figure 23, for example, shows the results of the sensitivity analysis done by varying the weight on the costs criterion.

Figure 25: Sensitivity Analysis (Costs)



Similar to the previous example, it can be seen that changing the weight of the costs criterion can potentially change the ranking of the policy packages. If the weight of the costs criterion is reduced then 'Optimised Balance' becomes the preferred option instead of 'Tech-Op-Real'. This shows that in a given situation in which costs are relatively less important, and are hence given a reduced weighting, the multi-criteria decision making process would generate a different ranking of the policy package clusters.

4.7 Cost Effectiveness

Although CBA or its variants remain the preferred framework for assessing transport policy options in many countries, it perhaps is not the best choice for assessing qualitative contexts where the monetary equivalents may prove to be inadequate. The inadequacy of CBA in dealing with intangible factors and strategic concerns is its main weakness (Shang et al., 2004).

These difficulties were reinforced in the recent study carried out for CfIT (Anable and Bristow, 2007), where it was concluded that the emphasis on technological solutions, which are more amenable to quantification, underestimates the role that behavioural change can and should have in achieving targets. Also policies tend to be assessed in isolation rather than in combination or as integrated packages.

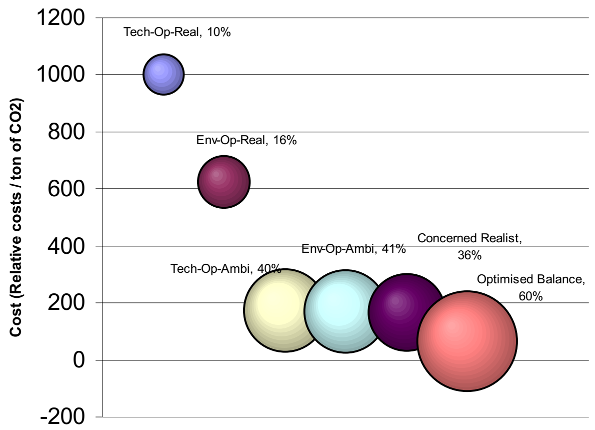
The trade-offs involved can be viewed graphically by plotting the scores for any node or criterion against others. The most common mapping is for Costs versus Benefits which shows, for any given costs, what benefits can be realised and which options provide them.

There are considerable advantages in making trade-offs explicitly within a transparent decision aiding framework. The process is structured and comprehensive, ensuring that all concerns are identified and addressed. The approach should retain sufficient flexibility for the robustness of trade-off decisions to be thoroughly explored, and it should be sufficiently transparent to ensure that the reasons behind a particular choice are made clear. The advantages of a structured approach are particularly apparent where there are many alternatives and numerous conflicting objectives. In such cases, a transparent framework can aid communication and debate, and potentially even the route towards consensus.

A cost effectiveness analysis could be adopted for estimating the costs of carbon reduction strategies in transport in London but there are substantial limitations regarding the data availability of the different policy approaches. This would be a substantial piece of work in its own right. Nevertheless, it is probably an important methodology for analysis provided that estimates can be obtained.

In this case, the relative costs of the different policy approaches have been taken based on the inputs of the multi-criteria appraisal. The graph essentially reflects the cost effectiveness of different approaches and shows that the Techno-Optimist package which has the least absolute costs is actually the least cost effective. The Optimized Balance works out to be the most cost effective as the large number of measures also result in substantial carbon dioxide mitigation.

Figure 26: Cost Effectiveness of Policy Approaches



Note: The size of each 'bubble' represents the quantum of CO_2 emissions reduction envisaged through that approach. The vertical axis represents the marginal abatement cost for the policy approach.

5 Conclusions

The VIBAT London project is innovative in developing and mapping a variety of possible scenarios for CO_2 emissions mitigation in the transport sector. It has been based on a thorough inventory of potential measures available. The work has been based on the London urban area, and has involved the use of a range of datasets sourced from GLA and TfL. TC-SIM has proved a very useful way of explaining the issues involved in lowering CO_2 emissions in the transport sector, and in exploring the potential trade-offs and scales of impact.

Each scenario, as tested, includes several policy measures and policy packages, applied to different levels of intensity, in order to achieve a certain level of CO_2 reduction consistent with strategic targets. Each scenario results in a different level of CO_2 mitigation level. There are clear difficulties with certain policy standpoints, for example in relying on a limited range of interventions.

An important point, however, is that the selection of a preferred approach would need to be decided based on several criteria. Hence the development of an developmental appraisal mechanism using a multi-criteria methodology, with the possibility of weighted criteria. Such an appraisal framework can be used as an effective decision-support tool as it enables decision makers to prioritise complex policy approaches by essentially providing a multi-dimensional ex-ante evaluation assessment. The framework does not rely on monetary evaluations. It forms a useful complement to those techniques which use monetary valuation, namely financial analysis, cost effectiveness analysis (CEA) and cost benefit analysis (CBA).

The appraisal framework developed as part of this project has several unique and useful features including the incorporation of a 'weighting system' that enables the prioritisation of the environmental and even social factors. Risk and uncertainty are equally important and the project includes a sensitivity analysis which allows the testing of the robustness of assumptions. Much further work can be carried out in developing and refining this type of appraisal framework.

The pessimistic conclusion is that the likelihood of deep CO_2 reductions in the transport sector is looking very unlikely, based on current patterns, although major efforts has been made in certain leading cities (such as London). The public needs to radically change their purchasing patterns and behaviour to be more carbon efficient. The means of knowledge dissemination, communication, participation in decision-making and marketing of policy options and futures all need to be considerably strengthened.

The backcasting approach offers a way forward to this extremely challenging future policy [and lifestyle] dilemma. Tools such as TC-SIM, applied to different contexts, could play an important role in testing different options with a range of different users. The debate and transformation to a low carbon transport society has hardly begun.

This background paper has been produced by the study authors as part of the VIBAT-London study under a contract with UrbanBuzz. The study has been carried out as a piece of independent research using data kindly supplied by TfL, GLA and others. The views expressed in the study are, of course, from the authors and do not necessarily reflect those of UrbanBuzz, TfL or the GLA. TfL has developed and uses its own transport and CO_2 models.

Annexes

Annex 1: Selected References

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Annex 2: Vehicle Types and CO_2 Emissions

Vehicle Manufacturer and Model	Emissions (g/km)	Annual Travel (Km)	Annual CO2 Emissions (kg)
Band A – Mini (up to 100 g/km)			
G-Wiz AC, Electric	0	15,000	0
Band B – Super Mini (101 g/km to 120 g/km)			
Toyota Prius, Petrol Electric Hybrid, 1.5l	104	15,000	1,560
Toyota Prius, 1.5l	*104*	*10,000*	1,040
Honda Civic, Petrol Electric Hybrid, 1.3l	109	15,000	1,635
Citroën C1, Petrol, 1l	109	15,000	1,635
Vauxhall Corsa, Diesel, 1.3 DTi	115	15,000	1,725
Band C – Lower Medium (121 g/km – 150 g/km)			
Renault Clio, Diesel, 1.5l	123	15,000	1,845
BMW 1-Series, Diesel, 2.0l	123	15,000	1,845
Mercedes Benz A-Class, Diesel, 2.0l	141	15,000	2,115
Band D - Upper Medium (151 g/km – 165 g/km)			
Volkswagen Golf, Diesel TDI, 2.0l	154	15,000	2,310
Volkswagen Golf, Diesel TDI, 2.0l	*154*	*6,500*	*1,001*
Ford Focus, Petrol, 1.6l	162	15,000	2,430
Band E – Executive (166 g/km – 185 g/km)			
Mini R52, Petrol, 1.6l	168	15,000	2,520
Volkswagen Golf, Petrol, 1.6l	171	15,000	2,565
Vauxhall Vectra, Petrol, 1.8i	175	15,000	2,625
Mercedes Benz C-Class Estate, Diesel, 2.1l	183	15,000	2,745
Band F - Luxury (186 g/km - 225 g/km)			
Ford Ka, 1.6i, Petrol	189	15,000	2,835
Lexus "Sustainable" Petrol Hybrid SUV, RX 400h	191	15,000	2,865
Lexus "Sustainable" Petrol Hybrid SUV, RX 400h	*191*	*5,225*	*998*
BMW 3-series, Petrol, 2.0l	196	15,000	2,940
Ford Mondeo, Petrol, 2.0l saloon	218	15,000	3,270
Band G - Sports (226 + g/km)			
Audi A6, Petrol, 2.4l	262	15,000	3,930
Renault Grand Espace, Petrol, 3.5l	289	15,000	4,335
Land Rover Discovery, Petrol, 4.4l	354	15,000	5,310
Hummer H6, Petrol, 3.7	365	15,000	5,475
Bentley Arnage R, Petrol, 6.5l	465	15,000	6,975
Ferrari Superamerica	499	15,000	7,485
Ferrari Superamerica	*499*	*2,000*	*998*

Annex 3: The Multi-Criteria Appraisal Framework

A number of multi-criteria methods have been developed and applied for different appraisal objectives in different contexts (Costa, 1990; Yoon and Hwang, 1995). There are 40 or more different approaches that are distinguishable in the literature, from the sophisticated through to simple rating systems (Nijkamp et al, 1990). Although most of these methods were designed to cover a wide variety of problems, in practice they can be applicable and provide effective solutions only in particular decision situations. The common rationale of these methods is to establish a broad framework for assessing the impact of making a choice, simplifying the decision into its constituent elements.

The multi-criteria assessment procedures are distinguished from each other principally in terms of how they process the basic information in the performance matrix. Different circumstances will be better suited to some MCA procedures than others.

Linear Additive Models

A widely used approach to the problem of determining a rank order of policy options is to assign weights to the various criteria, apply them to the impact assessments of each option and then sum the weighted assessments to arrive at a single score for each option. This approach is known as the Linear Additive Model of Multi-Criteria Analysis (MCA) (see Keeney and Raiffa, 1976).

The linear additive weighting method evaluates each alternative, Ai, by the following formula:

$$A_i = \sum w_j * x_{ij}$$

Where x_{ij} is the score of the i^{th} option with respect to the J^{th} criteria, w_j is the normalized weight.

Each option's score on a criterion is multiplied by the importance weight of the criterion. This is done for all the criteria and the products summed up in order to generate the overall preference score for that option. The process is repeated for all the remaining options. If the scores for the criteria are measured on different scales, they must be standardised to a common dimensionless unit.

The Linear Additive method is quite widely used owing to its simplicity and ease of use. The practical application of the linear additive model is a little difficult in its original form because it requires the availability of very rich information, concerning the decision maker's preferences, in order to produce mathematically significant results. There are however, several frameworks based on the linear additive model which overcome this limitation.

Outranking Methods

A rather different approach to the Linear Additive Model is based on the concept of outranking. This approach was developed in France and has been applied in several continental European countries. The methods that have evolved all use outranking to seek to eliminate alternatives that are, in a particular sense, 'dominated'.

These methods are also known as concordance methods. They provide an ordinal ranking and sometimes only a partial ordering of the alternatives which means that it can only express which alternative is preferred but cannot indicate how much.

The best known outranking method is the Elimination and Choice Translating Reality (ELECTRE I) and several modifications of this method have been suggested (ELECTRE II, III, IV, PROMETHEE I AND II) (Vincke, 1992).

The basic elements of this method are concordance measures which are the set of all criteria for which alternative i is not worse than the competing alternative j and disconcordance measures which are the set of all criteria for which alternative i is worse than the competing alternative j (Nijkamp and van Delft, 1977). These indicators are calculated for all pairs of alternatives and then the alternatives with the highest concordance value and with the lowest disconcordance value are found.

Some of the other well known outranking methods are as follows:

- Regime Analysis Method;
- ELECTRE;
- PROMETHEE.

Fuzzy Logic Methods
Fuzzy logic sets attempt to capture the idea that our natural language in discussing issues is not precise. Fuzzy arithmetic then tries to capture these qualified assessments using the idea of a membership function, through which an option would belong to the set of attractive options. The imprecision captured through fuzzy sets and the mathematical operations that can be carried out on them attempt to match the real fuzziness of perceptions that humans typically exhibit in relation to the components of decision problems (French, 1988). However, methods of this type are not yet widely applied.

Tsamboulas (2006) compares the most commonly applied multi-criteria methods for assessing transport projects using the criteria of transparency, simplicity, robustness and accountability. The evaluation concluded that there is no globally optimum method for transport assessment and that the selection of the method depended on the characteristics of the decision situation.

Our review of the multi-criteria methodologies led to the conclusion that the linear additive methodology is more appropriate for assessing policy packages and is best suited for providing robust and effective support to decision makers facing a range of policy packages and variety of different circumstances.

The Analytic Hierarchy Process (AHP) proposed by Saaty (1980, 1990) is also based on the linear additive model. It is perhaps the most commonly used method for the prioritisation of decision alternatives and has been applied in the selection of transportation alternatives by several authors (Saaty, 1995; Yedla and Shrestha, 2003; Vargas, 1990). The procedure for deriving the weights and scoring the alternatives is based on pairwise comparisons between criteria and between options. Thus, in assessing weights, the decision maker is asked a series of questions, each of which asks how important one particular criterion is relative to another for the decision being addressed.

Weighting Methodology
There are four different techniques when assigning the weights:

- Ranking;
- Rating;

- Trade off Analysis Methods;
- Pairwise Comparison.

Ranking Methods

This is the simplest method for evaluating the importance of weights. Every criterion under consideration is ranked in the order of the decision maker's preferences. Due to its simplicity, the method is very attractive. However, as the number of criteria used is increased, the method becomes less appropriate.

Rating Methods

The method requires the decision maker to estimate weights on the basis of a predetermined scale. One of the simplest rating methods is the point allocation approach. It is based on allocating points ranging from 0 to 100, where 0 indicates that the criterion can be ignored, and 100 represents the situation where only that criterion needs to be considered. Another method is ration estimation procedure which is a modification of the point allocation method. A score of 100 is assigned to the most important criterion and proportionally smaller weights are given to criteria lower in the order. The score assigned for the least important attribute is used to calculate the ratios.

Trade-Off Analysis Method

In this method, decision maker is required to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. Trade-off define unique set of weights that will allow all of the equally preferred alternatives in the trade-offs to get the same overall value/utility. There is an assumption in this method that the trade-offs the decision maker is willing to make between any two criteria do not depend on the levels of other criteria. The weakness of this method is the decision maker is presumed to obey the axioms and can make fine grained judgements.

Pairwise Comparison Method

The method involves pairwise comparisons to create a ratio matrix. It takes pairwise comparisons as input and produces relative weights as output. The pairwise comparison method of weighting is based on Saaty's analytical hierarchy process (AHP). The weights are provided by a panel of experts / stakeholders. In the first stage the panel of experts / stakeholders provide pairwise comparisons individually. By means of these comparisons it is possible to determine the relative position of one criterion in relation to all other criteria. Subsequently the results are synthesised and then circulated to the panel of experts for possible comments. Based on this the weighting for the different criteria is finalised.

The pairwise comparison can be carried out according to Saaty's 9-point scale (Table 12), where 1 implies that the base factor is equal in importance to the other factor and 9 implies that the base factor is extremely more important than the other factor (Saaty, 1980). The derivation of priorities is done by the eigenvector method and an example is presented in Annex 4.

Table 12: Semantic Scale

Value	Definition
1	Equal Importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Weights represent a particular value and preference set, and clearly they will change with the views of the decision maker, with corresponding alteration to the preferred outcomes. The effect may be explored with different weighting sets for different stakeholder groups.

The main advantage is that only two criteria have to be considered at a time. However if there are too many criteria, the number of pairwise comparisons becomes too large. The main criteria weights reflect the central priorities. The weights chosen are important in comparing alternative policy packages.

Annex 4: The Analytical Hierarchy Process

Introduction

At the core of the Analytic Hierarchy Process (AHP) lies a method for converting subjective assessments of relative importance to a set of overall scores or weights.

The fundamental input to the AHP is the decision maker's answers to a series of questions of the general form, ‘How important is criterion A relative to criterion B?’ These are termed pairwise comparisons. Questions of this type may be used to establish, within AHP, both weights for criteria and performance scores for options on the different criteria.

The primary reason for selecting the AHP methodology was that most people find the pairwise comparison procedure of AHP quite attractive and easy to use.

Derivation of Weights

For each pair of criteria, the decision-maker is required to respond to a pairwise comparison question asking the relative importance of the two. Responses are gathered in verbal form and subsequently codified on a nine-point intensity scale, as follows:

How Important is A Relative to B?	Preference Index
Equal Importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9
Intermediate values	2, 4, 6, 8

The decision maker is assumed to be consistent in making judgements about any one pair of criteria and since all criteria will always rank equally when compared to themselves, it is only ever necessary to make 1/2n(n - 1) comparisons to establish the full set of pairwise judgements for n criteria. Thus a typical matrix for establishing the relative importance of three criteria might look like:

1	5	9
1/5	1	3
1/9	1/3	1

The next step is to estimate the set of weights (three in the above example) that are most consistent with the relativities expressed in the matrix. Note that while there is complete consistency in the (reciprocal) judgements made about any one pair, consistency of judgements between pairs is not guaranteed. Thus the task is to search for the three wj that will provide the best fit to the 'observations' recorded in the pairwise comparison matrix. This may be done in a number of ways.

Saaty's basic method to identify the value of the weights depends on relatively advanced ideas in matrix algebra and calculates the weights as the elements in the eigenvector associated with the maximum eigenvalue of the matrix. For the above set of pairwise comparisons, the resulting weights are:

W1= 0.751 W2=0.178 W3=0.070

The weight estimation is done in three steps:

- Calculate the geometric mean of each row in the matrix;
- Total the geometric means;
- Normalise each of the geometric means by dividing by the total computed.

In the above example that would give:

Geometric Mean	Calculation		Weight
Criterion 1	$(1 \times 5 \times 9)^{1/3}$	3.5568	0.751
Criterion 2	$(1/5 \times 1 \times 3)^{1/3}$	0.8434	0.178
Criterion 3	$(1/9 \times 1/3 \times 1)^{1/3}$	0.3333	0.070
		4.7335	(=1.00)

Taken to further decimal points of accuracy, the weights estimated by the two different methods are not identical, but it is common for them to be very close.

In the literature, another multi-criteria method called REMBRANDT uses the concept of geometric means to identify estimated weights and scores from pair wise comparison matrices. However, when REMBRANDT was applied to the same problem as AHP, it was seen that REMBRANDT provided a similar result to AHP.

Scoring of Policy Packages

In addition to calculating weights for the criteria in this way, full implementation of the AHP also uses pairwise comparison to establish relative performance scores for each of the options on each criterion. In this case, the series of pairwise questions to be answered asks about the relative importance of the performances of pairs of alternatives in terms of their contribution towards fulfilling each criterion. Responses use the same set of nine index assessments as before. If there are m options and n criteria, then n separate m X m matrices must be created and processed.

With weights and scores all computed using the pairwise comparison approach just described, options are then evaluated overall using the simple linear additive model used for MCDA. All options will record a weighted score, Si, somewhere in the range zero to one. The largest is the preferred option, subject as always to sensitivity testing and other context-specific analysis of the ranking produced by the model.

Annex 5:Multi-criteria Decision Making Tool

HiView and MACBETH
(Measuring Attractiveness by a Categorical Based Evaluation Technique)

In developing the multi-criteria decision analysis model, software called HiView was used. This is an interactive software tool which uses pairwise comparison and requires only qualitative judgements about differences in attractiveness to help an individual decision maker or a decision-advising group quantify the relative value of options. It employs an initial, interactive, questioning procedure that compares two elements at a time, requesting only a qualitative preference judgement.

HiView 3 has a functionality that facilitates qualitative judgements. This component is called Measuring Attractiveness by a Categorical Based Evaluation Technique or MACBETH. This feature in HiView generates numeric values from verbal judgements. It also helps by ensuring the consistency of those judgements.

As judgements are entered into the software, it automatically verifies their consistency. A numerical scale is generated that is entirely consistent with all the qualitative judgements. Through a similar process weights are generated for criteria.

The HiView-MACBETH software provides tools to facilitate:

- Complete model structuring;
- Management of complex problems involving qualitative value scores and weights;
- Interactive sensitivity and robustness analyses.