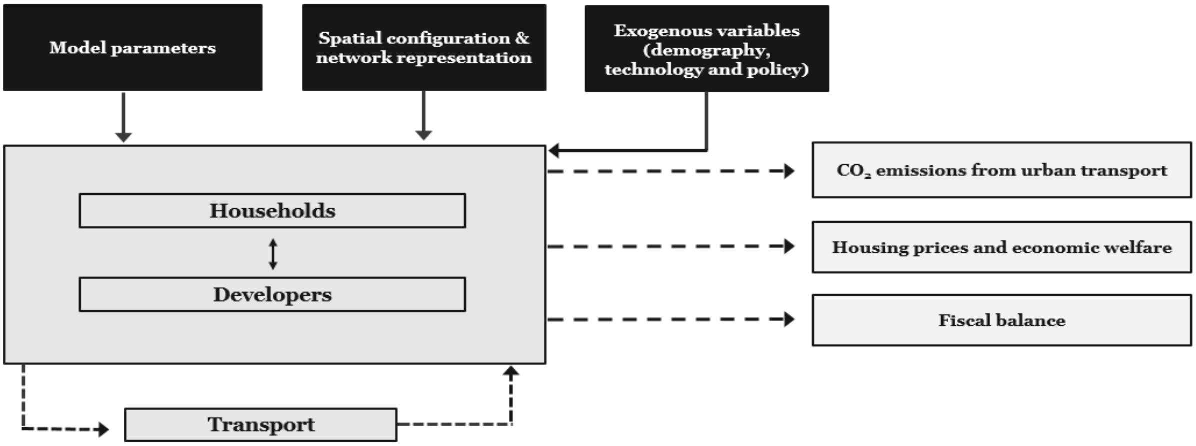
Chapter 3. Modelling transport and land use in Auckland

This chapter provides a non-technical description of the Multi-Objective Local Environmental Simulator (MOLES), i.e. the urban computable general equilibrium (CGE) model OECD has developed to evaluate the environmental and economic impact of land use and transport policies. The chapter focuses on the version of the model which has been tailored to Auckland. It details the behaviour of households and real-estate developers and elaborates on the way housing and land markets function in the model. It also describes the various outcomes of the modelling exercise, which include transport, emission, welfare, housing and fiscal indicators.

3.1. Overview of MOLES

The Multi-Objective Local Environmental Simulator (MOLES) is a multi-period urban Computable General Equilibrium (CGE) model developed by the OECD (Tikoudis and Oueslati, 2017[1]) to evaluate policy responses to scenarios in the spirit of those outlined in Chapter 2. It adopts features from traditional CGE models developed for national and international economies (*e.g.* clearing of multiple markets, atomistic behaviour of firms and households) and adjusts them to the scale of the urban economy, in which the markets for land, housing and transport play a key role. At the same time, MOLES imports a series of elements from microsimulation models in order to account for detailed behavioural mechanisms that cannot be represented in an aggregate model. In an urban environment, such mechanisms include, but are not limited to, the choice of the commuting route, the frequency of shopping and leisure trips and the decision to make a shopping detour during the course of a commuting trip.

Figure 3.1. The version of MOLES used in the current study



Note: Solid unidirectional arrows represent model inputs; bidirectional arrows represent model interactions; short-dashed arrows represent feedback effects; long-dashed arrows represent model outputs.
Source: Visualisation generated by the authors; for full model documentation please see Tikoudis and Oueslati (2017[2]).

The general structure of the model is presented in Figure 3.1. The core of MOLES contains a series of behavioural equations that determine the aggregate housing supply and demand for each residential type available in each zone considered in the model. In turn, these aggregate variables are computed using an iterative technique. That is, MOLES considers every feasible combination of a residential location, a job location, a vehicle type and a commuting mode (hereafter, alternative). For each such combination, it computes how individuals that commit to that choice split their expenditure between housing and other types of consumption and how they allocate their time. The associated calculations respect budget and time constraints that are formed using expected travel times and costs. The supply side of housing is driven by a profit-maximising construction sector which, in the context of the present study, is heavily regulated. That is, aggregate housing supply is determined completely by the background regulatory mechanisms that dictate building height and the percentage of the developable land that can be occupied by residential constructs. The core model equilibrates the housing markets by calculating the housing price that would eliminate excess demand or supply for any housing type in any model zone.

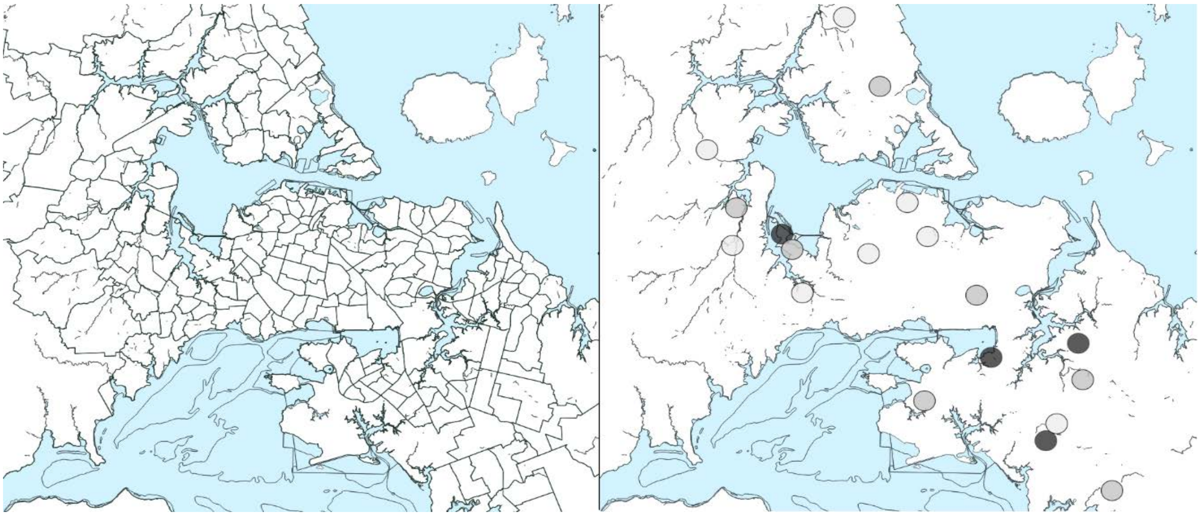
The *transport module* uses the resulting distribution of the population across residential zones and job hubs to predict its mobility pattern. The module uses statistical techniques designed to generate trips during the on-peak and off-peak period of weekdays, as well as during weekends. It then uses these techniques to compute the resulting traffic from those commuting, shopping and leisure trips. Subsequently, the module assigns the resulting traffic volumes in the various parts of the transport networks and updates the travel speeds in them. Finally, the updated speeds are used to provide new estimates for the annual expected travel time and cost associated with any joint choice of residential location, job location and vehicle type. These updates are then passed as feedback from the transport module to the model's core. That is solved again in order to provide a new distribution of the population across residential zones and employment hubs and to update the prices that clear all housing markets. MOLES keeps on iterating between its core and its transport module until the feedback from the latter induces only negligible changes in the output of the former. When this occurs, MOLES has converged.

Figure 3.1 suggests, the outcome of the simulation exercise depends partly on the exogenous model inputs. These include the values of model parameters that remain fixed throughout all time periods; the values of exogenous and policy variables, which may change across time periods but remain fixed within a given period; and the spatial configuration, which is retrieved from GIS data.

3.2. Model inputs

In order for MOLES to be initialised, the exogenous variables and the policy parameters have to be inserted in the model. As explained in Chapter 2, these inputs constitute a scenario, which can be in the form of a reference scenario or a counterfactual scenario. Furthermore, MOLES requires sufficient information about the spatial configuration of the examined urban area and its transport networks. These inputs, which are described in detail in Chapter 4, include: a representation of the highway, urban road and public transport networks; a partition of the urban area in zones; and a representation of the key loci of economic activity, such as employment areas, major shopping hubs and leisure locations. Finally, the model parameters need to be given numerical values. These parameters govern households' responses to changes in prices and the non-pecuniary elements that affect their budget and time constraints, choices and, ultimately, their well-being. That is, the model parameters determine how households adjust: their overall consumption; the size, type and location of their residence, therefore their housing expenditure; the choice of owning a private vehicle or not; and their mobility patterns. The *mobility patterns* encompass the mode and route households choose for their commuting, leisure and shopping trips, as well as the chosen frequency of all non-commuting trips. Due to the important role parametric specification plays in determining these values, the calibration of the model (*i.e.* the selection of model parameters so that the model predictions fit the data) is discussed separately in Chapter 4.

Figure 3.2. Residential zones and employment hubs in the study



Note: Left panel: residential zones; right panel: employment hubs. For more information about the construction of model residential zones and employment hubs the reader is referred to Chapter 4 of this study.
Source: Visualisation generated by the authors.

3.3. Core model: individual behaviour

The core module of MOLES is a mathematical representation of the market interactions taking place between households and real-estate developers. These interactions determine housing and land prices, as well as the allocation of population across the different zones of the city.

Individuals have some *initial expectations* regarding their annual transport expenditure, as well as the time they will have to spend on the road for any locational choice they make. Based on these expectations, households decide in which zone they are going to reside and to which employment hub they are going to supply labour. This choice is displayed in Figure 3.2, which shows the candidate residential zones (left panel) and employment locations (right panel) in the case study presented in this report. Simultaneously, households choose the type and size of their residence, as well as their consumption expenditure. They also decide whether they are going to own a private vehicle and, if yes, whether that vehicle is going to be a conventional ICE vehicle or an EV.

These *primary choices*, which are summarised in Table 3.1, have to be consistent with the households' budget and time constraint. Accounting for a valid budget constraint means that MOLES considers only options (alternatives) guaranteeing that a household's annual spending in consumption, housing and transport equals its annual income. The model allows all realistic substitution patterns to emerge during that choice. This means that households can control their housing expenditure by choosing to live in a less accessible area, in which land prices are typically lower. Alternatively, they may respond to house price raises by adjusting the size of their residence or by lowering their consumption.

Table 3.1. Primary choices made by households in MOLES

Variable	Description and options
Residential location	In which residential zone to reside (195 zones)
Residential type [a]	In which housing type to live (single family detached, single family attached, multifamily apartment building)
Employment location	In which employment hub to work (22 hubs)
Vehicle ownership	Whether to own a vehicle or not
Vehicle type [b]	Internal combustion engine (ICE) or electric vehicle (EV)
Residential size	Residential floor space (m^2)
Consumption	Annual spending excluding housing goods and transport

Note: [a] Further detail follows; [b] applicable only if the vehicle ownership decision is positive.

Furthermore, MOLES explicitly models the time constraint, in the sense that the sum of the working day duration, daily leisure and the average time spent on the various types of trips per day cannot exceed the 24-hour daily time endowment. As it is the case with the budget constraint, MOLES allows substitution patterns to emerge also through the time constraint. This means that households can choose to live at relatively more accessible locations if their valuation of leisure time is high, thereby substituting monetary resources for leisure time. If the valuation of leisure time is low, the reverse could happen. However, every such trade-off can only take place if it obeys the *budgetary* and *time constraints* of households.

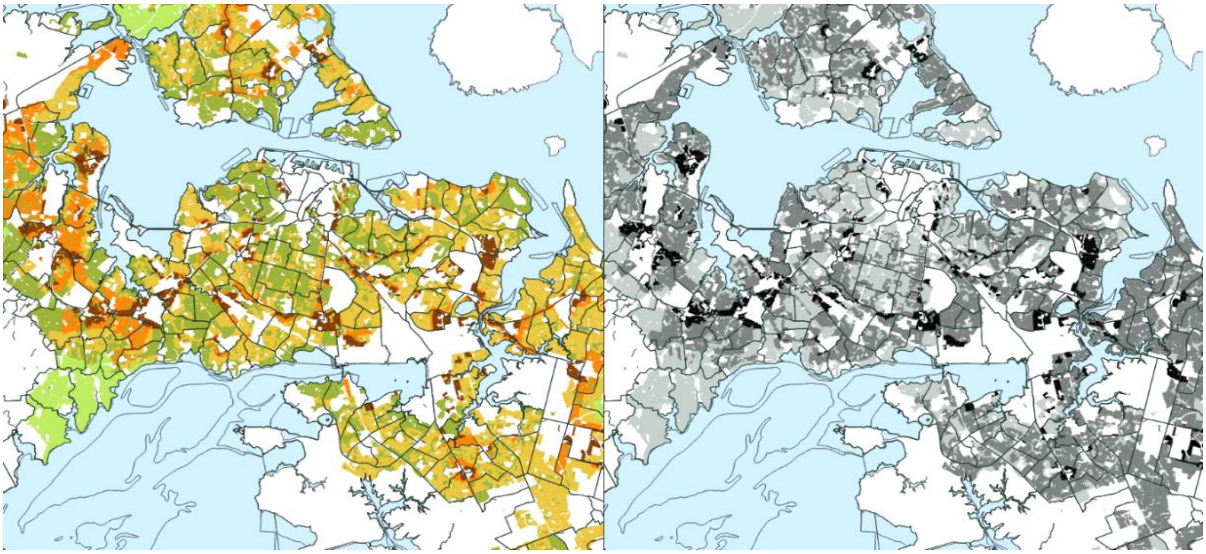
The primary choices of Table 3.1 contain the car ownership and vehicle type decisions. These decisions, together with the level of vehicle utilisation, bear a significant environmental importance: they determine whether the annual number of kilometres is going to be traversed with a relatively clean or polluting mode of transport.

By choosing residential size, type and location, households form the aggregate housing demand across urban space. That demand is the total number of m^2 of floor space from each residential type demanded in each zone of the model. The next section discusses the supply side of the housing market.

3.4. Core model: real estate developers

The *supply side* of housing is represented by the housing development sector, which operates under the constraints set out by land-use regulations. This sector can re-develop existing land and convert land to the various housing types the model considers. These housing types differ with respect to: (i) their *structural density*, which is the average number of m^2 of residential space the housing type yields for every m^2 of its building footprint; (ii) the *coverage coefficient*, which is the average percentage of the land plot occupied by the footprint of the building; (iii) whether they are attached or detached. The left panel of Figure 3.3 shows the residential development pattern in Auckland, which comprises five predominant residential types. The right panel of the same figure displays how these types are represented in the model by three aggregate residential types: attached single-family housing, detached single-family housing and multi-family appartment buildings.

Figure 3.3. Residential types and their representation in MOLES



Note: Left panel: the footprint of the five predominant residential housing types in Auckland; right panel: model representation of the residential development pattern. Light grey: detached single family housing; dark grey: attached single family housing; black: multi-family apartment buildings.
Source: Visualisation generated by the authors.

That conversion takes place according to a profit maximization plan and complies with the regulatory framework that applies in every residential zone. The former postulate implies that, in any given land plot, developers erect the housing type that provides the maximum profit. The latter postulate implies that, if land-use and housing development regulations are strict, the overall development pattern in a city is predetermined (at least to a large extent) by that regulatory framework. The latter is embodied in the scenario the model is provided with.

Table 3.2. Housing types in the reference and widespread densification policy packages.

	Reference		Widespread densification policy package	
Residential type	**Average FAR [a] ratio**	**Coverage [b] coefficient**	**Average FAR [a] ratio**	**Coverage [b] coefficient**
Detached single family	1.50	0.30	2.25	0.450
Attached single family	2.25	0.35	3.38	0.525
Apartment	5.00	0.50	7.5	0.750

Note: [a] Shorthand notation for floor-to-area ratio, i.e. the number of m^2 of residential floor space corresponding to one m^2 of built footprint; [b] the share of land plot's surface occupied by the building footprint.

Table 3.3. Housing types in the targeted densification policy packages.

Residential type	Average FAR [a] ratio	Coverage [b] coefficient
Dense type 1	4.00	0.55
Dense type 2	6.50	0.65
Dense type 3	8.00	0.75

Note: [a] Shorthand notation for floor-to-area ratio, i.e. the number of m^2 of residential floor space corresponding to one m^2 of built footprint; [b] the share of land plot's surface occupied by the building footprint.

3.5. Core model: market clearing in land and housing markets

MOLES solves for the housing prices that equalize the aggregate housing demand, i.e. the sum of demand for residential floor space, with the aggregate housing supply, i.e. the supply of residential floor space by real estate developers.[1] At the same time, MOLES solves for the land prices that equalize aggregate land demand with aggregate land supply.

The housing and land market clearing imply that every locational advantage a zone possesses will result in higher housing and land prices. Thus, housing in urban zones characterised by higher accessibility, lower levels of air pollution and noise, as well as proximity to environmental amenities (e.g. sea view, short distance from recreational areas) will be relatively more expensive and *vice versa*. For more information regarding the fit of relative housing prices predicted by MOLES to the actual relative prices of housing in Auckland, the reader is referred to the calibration of the model in Chapter 4. Taking consideration of the land market clearing implies that the flow of land value that remains within the local economy, i.e. the land revenue that returns to local property owners, fits the corresponding number observed in data.

The core part of MOLES depicted in Figure 3.1 is solved for assumed travel times and costs that deviate from the resulting ones. If the anticipated times and costs are too low, they will generate more travel demand than initially expected. Thus, the resulting traffic volumes will be larger, implying that the resulting travel times and costs will be larger than the anticipated ones. A similar logic holds *vice versa*. The peripheral *transport* module, which is connected with dashed arrows with the core of the model in Figure 3.1, corrects these expectations. The next section provides a non-technical summary of its function.

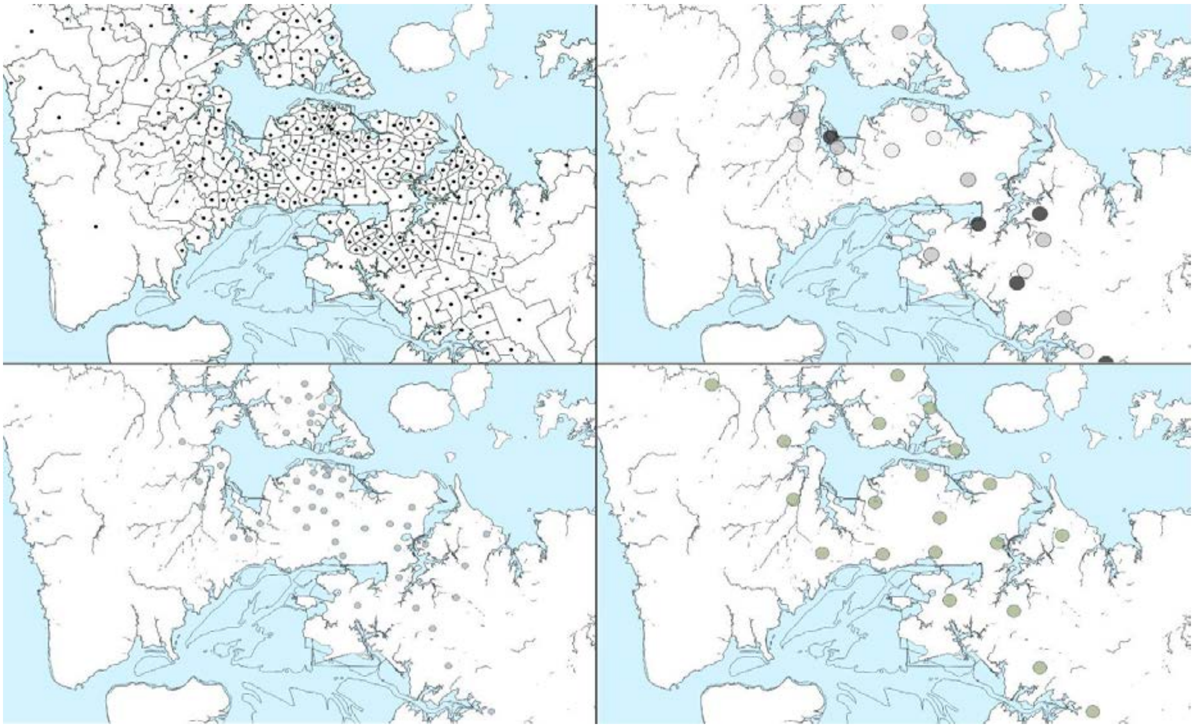
3.6. Transport module: route choice, traffic assignment and update of travel times and costs

The core solution of MOLES determines the population density in each urban zone and the employment level in each employment hub, but does not model explicitly the mobility pattern of households in the examined urban area. Stated differently, it determines the long-run location decisions of households (e.g. where to live, where to work) for any beliefs they may have regarding the travel times and transport costs associated with any such decision. These beliefs may be incorrect in the short run (e.g. due to imperfect information, change of habits). However, MOLES assumes that in the long-run households are able to make informed decisions based on the actual average travel time and cost they will face for every long-run decision they make.

The centroids of residential model zones, displayed in the upper left panel of Figure 3.4, are used as starting points to simulate commuting trips, home-based shopping trips and leisure trips. Similarly, the employment and leisure hubs, represented by the dots in the upper and lower right panels of Figure 3.4, are used as destination points in commuting and leisure trips, respectively. Finally, the shopping hubs, shown in the lower left panel of Figure 3.4 serve as destinations of home-based shopping trips or as interim stops in shopping detours embodied in commuting trips. Table 3.4 summarizes the four types of trips the model considers. Summary statistics and further detail on the various data sources used in the study are presented in Chapter 4.

Schooling trips were omitted due to computation constraints and as they contribute much less to carbon emissions than commuting, shopping and leisure trips. This is expanded on in Chapter 4.

Figure 3.4. Origins and destinations of commuting, shopping and leisure trips in MOLES



Note: Upper left panel: residential zone centroids functioning as origins of commuting trips (equivalently, destinations of home returning trips); Upper right panel: employment hubs, functioning as destinations of commuting trips (origins of home returning trips); Lower left panel: shopping hubs, functioning as destinations of shopping trips or detour stops during commuting trips; Lower right panel: representation of leisure locations, functioning as destinations of leisure trips.
Source: Visualisation generated by the authors.

Table 3.4. Types of trips in the MOLES application for Auckland

Commuting trip	A trip starting from the centroid of a residential location, ending in one of the employment nodes, and *vice versa*, without an interim stop.
Commuting trip with a shopping detour	A trip starting from the centroid of a residential location and stopping to an interim shopping location before reaching an employment node (and *vice versa*).
Home-based shopping trip	A trip starting from the centroid of a residential location, ending in one of the shopping locations, and *vice versa*.
Leisure-trip	A trip starting from the centroid of a residential location, ending in one of the leisure locations, and *vice versa*.

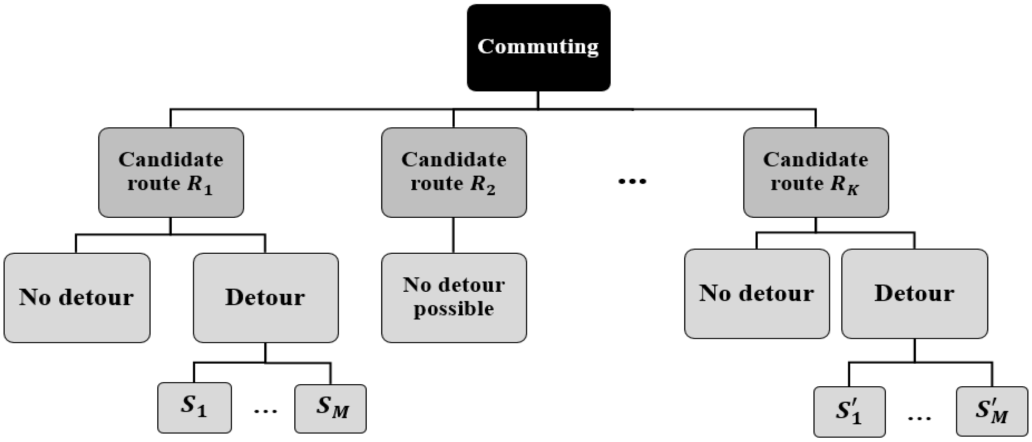
Figure 3.5. Transport network representation in MOLES

Note: Upper left panel: urban road network; Upper right panel: urban road network with a grid; Lower left panel: highway network; Lower right panel: public transport network.
Source: Visualisation generated by the authors.

In order to simulate any of the trips displayed in Table 3.4, MOLES uses three types of network representations: (i) a simplified version of the actual network of urban roads of low or medium capacity, consisting of 266 artificial nodes and 402 artificial links; (ii) a simplified version of the actual highway network (117 nodes, 127 links); and (iii) a representation of the public transport system (445 nodes, 685 links). These representations are shown in Figure 3.5. Then, MOLES simulates routes using the urban and the highway network, i.e. it generates routes for urban driving, highway driving, as well as hybrid routes in which the two types of driving are combined. All urban, highway and hybrid routes are available to those that own a private vehicle. Furthermore, MOLES uses the representation of the public transport system to simulate routes making use of public transport modes.

Subsequently, MOLES considers three separate statistical models for the choice of routes in daily trips. The first one, represented by Figure 3.6, regards the choice of a commuting route (urban, highway, hybrid or public transport) from a set of candidates. Some of these candidate routes are not compatible with a shopping detour. In that case, none of the shopping hubs shown in lower left panel of Figure 3.4 can be reached without a major deviation from the commuting route. An example is the candidate route R_2 in Figure 3.6, which serves as a pure commuting route. The rest of candidate commuting routes are compatible with shopping detours, i.e. one or more shopping locations lies at striking distance from some point within them. If the commuter decides to combine the candidate route with a shopping detour to a compatible shopping hub, the generalised cost of the trip increases accordingly. That accounts for the additional pecuniary and time costs the detour implies. However, the econometric model for the choice of commuting route accounts also for the additional utility derived from shopping detours. That additional utility correlates with the relative attractiveness of each shopping hub. The model yields choice probabilities for the most attractive routes that lead from any residential location (origin) to any employment location (destination).

Figure 3.6. Commuting route choice in MOLES



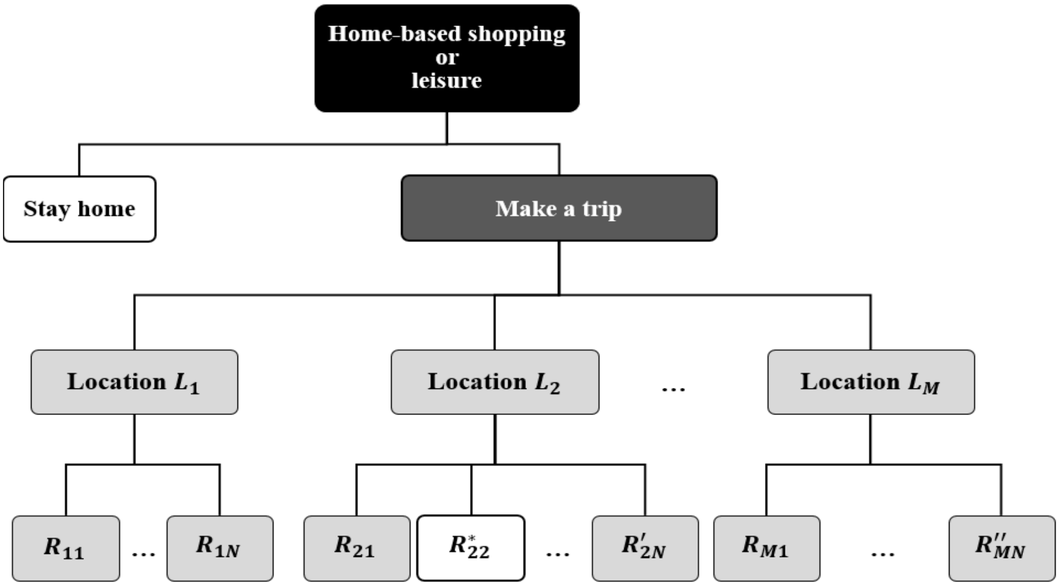
Note: Candidate route R2 is not compatible with a commuting detour, as no shopping hub can be accessed without a major deviation from it.
Source: Visualisation generated by the authors.

The two econometric models that are used to simulate, respectively, the households' behaviour in home-based shopping and leisure trips are similar and therefore represented schematically with a single graph in Figure 3.7. At any period considered in the analysis (see below), an individual makes a choice between staying at home and engaging in a shopping (respectively, leisure) trip. If the choice is the latter one, the individual chooses one of the shopping (leisure) hubs shown in the lower left (lower right) panel of Figure 3.4. Different hubs yield different levels of utility. That allows the statistical model to approximate the relative attractiveness of each shopping or leisure hub, which is empirically observed.

The last step in the choice process involves the selection of route from home to the location of the shopping (leisure) hub selected in the previous stage. In most of the cases, the available routes, displayed at the bottom level of Figure 3.7, are served by public transport or have to be traversed with a private vehicle. However, in some cases the trip's destination, i.e. the shopping (leisure) hub, lies at the vicinity of household's location. In these cases, soft-mobility options are added to the choice set associated to that origin-destination pair.

An example of such a soft-mobility option is the alternative coded as R_{22}^{*}, whose presence in Figure 3.7 reflects the proximity of location L_2 to the home location of the individual taking the trip. Once a route is chosen, utility adjusts to account for its pecuniary cost and time. The choice of route implies the choice of the underlying transport mode, thus utility adjusts also to account for mode characteristics. A final look to Figure 3.7 shows that the underlying statistical model explains, jointly, the trip frequency, the choice of destination and the route used to access that destination. In that sense, individuals are more likely to engage in a shopping (leisure) trip the larger the accessibility, i.e. the smaller the generalised costs of accessing the most desirable locations from their home's location.

Figure 3.7. Home-based shopping and leisure trips in MOLES



Source: Visualisation generated by the authors.

The total number of road users for each such origin-destination pair is known, i.e. it is the output of the MOLES core module. Thus, the average level of commuting traffic in each urban, highway and public transport route of Figure 3.5 can be computed by knowing the associated trip and route choice probabilities. MOLES generates a temporal variation in traffic by decomposing a period of one week into a two-day interval (weekend) and a sequence of on-peak and off-peak intervals, which succeed each other during the days between Monday and Friday. In that sense, route choice probabilities vary across the three representative periods composing a week, as shown in Table 3.5.

Table 3.5. Time periods in MOLES application for Auckland

On-peak period	All weekdays from 07:00 to 10:00 and from 16:30 to 20:00.
Off-peak period	All weekdays from 20:00 to 07:00 and from 10:00 to 16:30.
Weekends	Any time of the day during weekends.

Using these probabilities, highway traffic is allocated across the highway links shown in the lower left panel of Figure 3.5. Similarly, the traffic generated in urban and public transport routes is allocated across the rectangular cells (1.8 km × 1.8km) of the grid displayed in the upper right panel of Figure 3.5. Each of those cells can be viewed as a homogeneous area, in which the total traffic volume is the total number of passenger kilometres generated by public transport and privately owned vehicles. The total road capacity in the area is approximated by the percentage of land surface allocated to road infrastructure. The technical details of computing the level of traffic in links and grid cells from the traffic levels in routes are presented in Tikoudis and Oueslati (2017[1]).

3.7. Model outputs

Upon convergence of the core model and the transport module, the total fuel and electricity consumption and the fiscal and welfare implications of each of the scenarios are computed.

3.7.1. Transport sector outcomes and emissions

The *total fuel consumption* of ICE vehicles is computed using the number of kilometres they travel, on the highways and within the urban network. These kilometres are multiplied by the fuel consumption per kilometre. Equivalently, they are divided by the fuel economy, which is the inverse of fuel consumption. That is:

$$\begin{aligned}&\text{Fuel Consumption (ICE)}\\&\qquad=\frac{\text{ICE vehicle km urban}}{\text{Fuel Economy Urban (ICE)}}+\frac{\text{ICE vehicle km highway}}{\text{Fuel Economy Highway (ICE)}}\end{aligned}$$

The *total CO_2e emissions* from ICE vehicle use is the product of total litres of fuel consumption and the carbon content per litre of fuel[2]:

$$\text{CO}_2\text{e (ICE)} = \text{Fuel Consumption (ICE)} \times \frac{\text{kg CO}_2\text{e}}{\text{lt}}$$

The *total electricity consumption of EVs* is computed using the number of kilometres they travel in the two networks (highways, urban roads). These kilometres are multiplied by the EV electricity consumption per km (kWh/km) in the two types of driving (highway, urban). That is:

$$\begin{aligned}&\text{Electricity Consumption (EV)}\\&\qquad=\text{EV km Urban}\times\left(\frac{\text{kWh}}{\text{km}}\right)_{\text{U}}+\text{EV km Highway}\times\left(\frac{\text{kWh}}{\text{km}}\right)_{\text{H}}\end{aligned}$$

where the subscripts U, H stand for urban and highway, respectively.

The *total CO_2e emissions of EV use* is the product of electricity consumption and the carbon content embodied in each unit of energy, i.e. the *carbon intensity of the electricity generation sector*. That is:

$$\mathrm{CO_2e(EV) = Electricity\ Consumption\ (EV)} \times \frac{\mathrm{kg\ CO_2e}}{\mathrm{kWh}}$$

The total *CO_2e emissions from the use of public transport modes* is calculated directly from the number of passenger kilometres (pkm) using rail and bus. These are multiplied by the carbon content of a passenger kilometre in rail and bus, respectively. That is:

$$\mathrm{CO_2e(PT) = Bus\ pkm} \times \left(\frac{\mathrm{kg\ CO_2e}}{\mathrm{pkm}}\right)_{\mathrm{B}} + \mathrm{Rail\ pkm} \times \left(\frac{\mathrm{kg\ CO_2e}}{\mathrm{pkm}}\right)_{\mathrm{R}}$$

where PT stands for public transport, pkm stands for passenger kilometres and the subscripts B and R stand for bus and rail, respectively.

The emissions from ICE vehicles, EVs and public transport modes change across different periods of the study. In the context of this study, this means that the above outcomes differ between 2018, 2030 and 2050. This happens because of three reasons. First, total transport activity changes across these time points, as population increases and individuals may make different transport-related choices. That affects the total kilometres travelled by ICE vehicles, EVs, as well as the passenger kilometres travelled using bus and rail. The second reason is that the energy efficiency of private vehicles and the carbon intensity of public transport change over time. ICE vehicles become more fuel efficient, i.e. they require less fuel and thus emit less carbon per kilometre. EVs become also more energy efficient, i.e. consume less electricity and thus have a smaller carbon footprint per kilometre. Public transport is gradually electrified over the course of the study period (2018-2050). Furthermore, the electricity use of an electric bus per kilometre falls as buses become more energy efficient. Finally, the CO_2e emissions from transport-related electricity consumption depend on the carbon intensity of the electricity-generation sector. The emissions per kilometre of ICE vehicles and EVs are presented in Chapter 2.

An important transport-related outcome is travel time. If a policy reduces congestion, travel times decrease, leaving households with more leisure time. This increases their well-being insofar they value leisure time. In reality, but also in the modelling exercise, individuals value leisure time higher on working days than on days off. This is because spare time is, in general, scarcer during weekdays. Therefore, reduced commuting times can significantly increase welfare.

3.7.2. Social value of carbon reduction

The primary motivation of the policies this report explores is the reduction of greenhouse gas emissions. Therefore, the social benefit of carbon reduction is taken into explicit account. This is calculated as the product of the total emission reductions a policy yields (relative to emissions in the reference scenario) and the estimated marginal damage of carbon dioxide emissions, i.e. the social cost of carbon (SCC). The associated welfare change from the reduction of carbon emissions, induced by a policy, is:

$$\Delta \mathrm{W_{CO2}} = \Delta \mathrm{E_{CO2}} \times \mathrm{SCC}$$

The social cost of carbon evolves over time. This study assumes a SCC that is a weighted average of two values proposed by the US EPA (2017[3]): a value produced with a 2.5% annual discount rate (US$ 73 per ton in 2030, US$ 95 per ton in 2050) and a value produced with 3% discount rate, but under the assumption that extreme events have a high impact (US$ 152 per ton in 2030, US$ 212 per ton in 2050). Weighting the two proposals equally yields a SCC of US$ 112.5 per ton in 2030 and US$ 153.5 in 2050.

3.7.3. Impacts through housing prices

The land-use and transport policies examined in the report cause changes in the urban form, alter the distribution of population across space and affect housing prices. Also, the densification policies analysed in the study affect the proportion at which residential floor space and backyard open space will be consumed in each type of residential development.

Direct welfare impact of a policy

The direct welfare change of a policy is the difference in well-being (utility) expressed in monetary terms. It can be (roughly) expressed as:

$$\Delta \mathrm{W}_{\mathrm{Direct}} = \frac{\mathrm{W}\left(\mathrm{P}_{\mathrm{H}}^{1}, \mathrm{TT}^{1}, \mathrm{TC}^{1}, \mathrm{RB}^{1}\right) - \mathrm{W}\left(\mathrm{P}_{\mathrm{H}}^{0}, \mathrm{TT}^{0}, \mathrm{TC}^{0}, \mathrm{RB}^{0}\right)}{\mathrm{MUI}}$$

where W is the level of well-being captured by the model. That depends on housing prices (P_{H}), travel times and costs (TT, TC) and the proportion at which residential and backyard spaces can be consumed. Since policies may change any, or all, of the above, they directly affect well-being. Well-being (utility) is expressed in non-monetary terms (utils), thus the direct welfare change is not monetized. It is converted to monetary units by dividing the change in utility (numerator) by the marginal utility of money (utils/NZD).[3]

3.7.4. Implicit fiscal effects

The fiscal policy instruments examined in the study, such as the fuel taxes, have tax bases that are directly affected by changes in the values of these instruments. For instance, two of the policy packages examined in the study (see "Promote public transport" and "Promote EVs") largely affect the tax base of the fuel tax.

In reality, the policy instruments included in the study affect also a series of tax bases that are not modelled explicitly. For example, the labour income tax base may be negatively affected by the increase of the kilometre tax, the fuel tax or from the adjustment of any instrument that increases the cost of a commuting trip. The distortionary impact of any such change on economic efficiency has been examined in relevant literature (Parry and Bento, 2001[4]; Parry and Bento, 2002[5]; Tikoudis, Verhoef and van Ommeren, 2015[6]; Tikoudis, 2019[7]). Other tax bases that may be affected form the adjustment of transport-related taxes, include the property tax base, although the negative impact is expected to be much smaller (Tikoudis, Verhoef and van Ommeren, 2018[8]).

The distortionary impact of negative tax interactions is not modelled explicitly. Instead, this is accounted for through an explicit weighting of the tax revenue using the *marginal cost of public funds* (MCF). The value of MCF used in the study is 1.10. This imposes an additional cost of 10% beyond the simple transfer of funds, when raising revenue from households to government. The study weights any change in the total tax revenue with the reciprocal of MCF in order to account for the negative tax interactions. The monetized welfare impact from the fiscal adjustments is:

$$\Delta \mathrm{W}_{\mathrm{Fiscal}} = \frac{(\Delta \mathrm{R}_{\mathrm{tax}} + \Delta \mathrm{R}_{\mathrm{fares}})}{\mathrm{MCF}}$$

where $\Delta \mathrm{R}_{\mathrm{tax}}$ is the change in total tax revenue and $\Delta \mathrm{R}_{\mathrm{fares}}$ the change in total revenue from public transport fares.

3.7.5. Total welfare impact

The total welfare impact of a policy is composed of its direct welfare impact, its implicit fiscal effect and its social value of carbon reduction. The numbers reported in the study follow the convention:

$$\Delta \mathrm{W}_{\mathrm{Total}} = \Delta \mathrm{W}_{\mathrm{Direct}} + \Delta \mathrm{W}_{\mathrm{Fiscal}} + \Delta \mathrm{W}_{\mathrm{CO2}}$$

3.7.6. Non-modelled wider benefits

There are also other, broader benefits of the low-carbon transition which are not explicitly considered in the analysis. For example, a shift towards low-carbon transport improves air quality and reduces noise which has implications for welfare. These benefits are not included in the welfare calculations. Additionally, the health benefits of a shift towards active modes of travel such as biking or walking are not considered.

Notes

[1] Like every Computable General Equilibrium (CGE) model, MOLES assumes an instant adjustment of markets to exogenous shocks that affect the demand or the supply side. In that sense, housing markets clear instantly when regulations that affect housing supply change. This could be considered as a somewhat unrealistic assumption. Usually, property takes time to develop, e.g. 3 to 5 years to complete a development, and to sell. However, the multi-period version of MOLES used in this report assumes two large adjustment periods (see Chapter 5): the mid-term (2018-2030) and the long-run (2030-2050). These periods are long enough for all the relevant price adjustment mechanisms to be manifested.

[2] As explained in Chapter 2 data on diesel cars were not of sufficient quality to be included in the econometric analysis. Instead, the evolution of the fuel economy of diesel cars is assumed to follow the trajectory as gasoline and hybrid cars do.

[3] For the full technical documentation, see Tikoudis and Oueslati (2017[1]).

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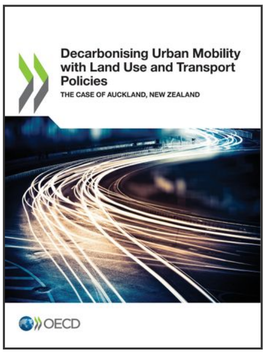

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