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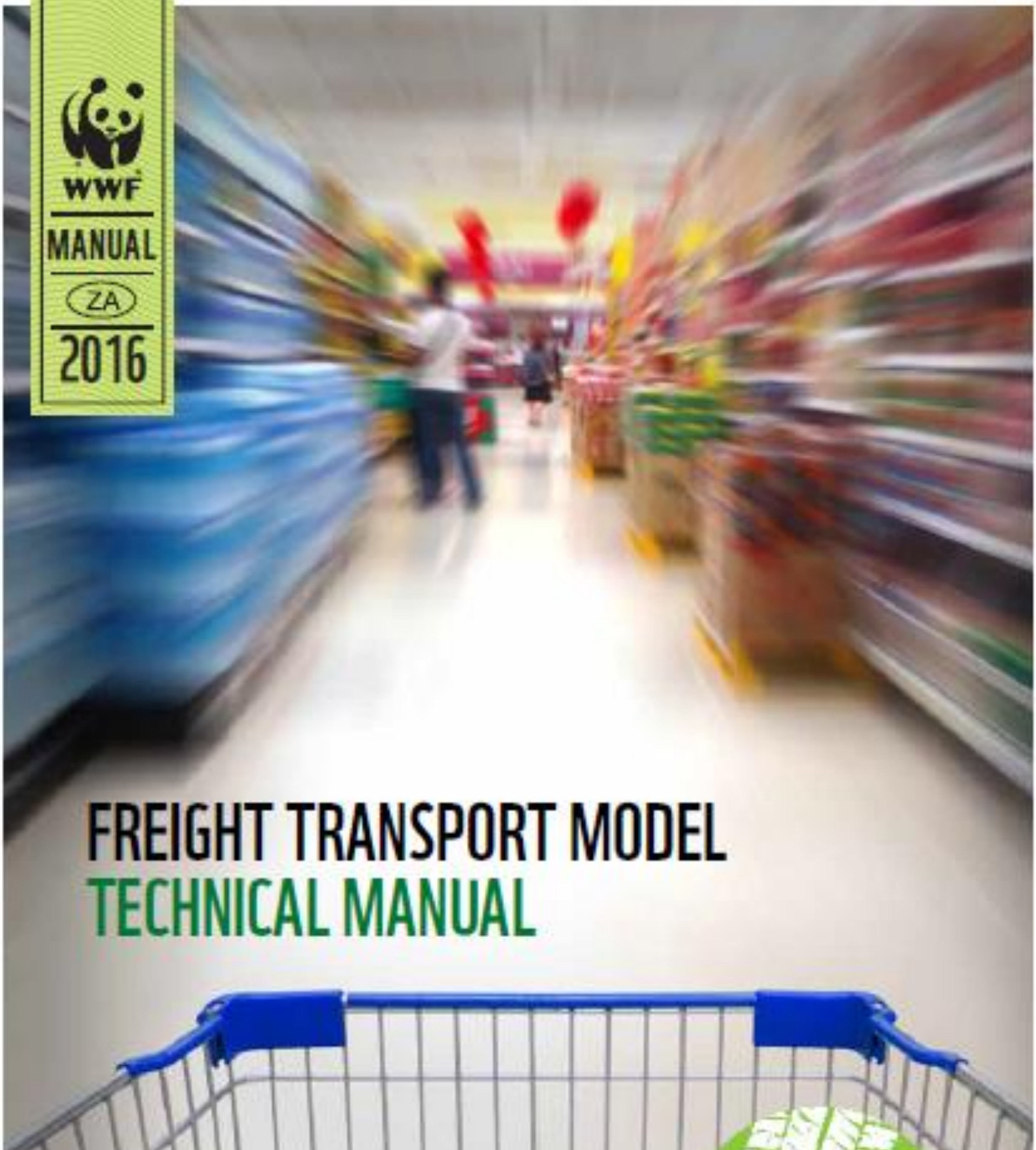

FREIGHT TRANSPORT MODEL
TECHNICAL MANUAL

Developed by:

THE GREEN HOUSE

Commissioned by:

WWF NEDBANK GREEN TRUST
WWF

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Technical specifications of a systems dynamics model constructed to investigate freight owners' decisions about road or rail transport modal choice and explore the operation of various options for greenhouse gas mitigation strategies

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THE GREEN HOUSE

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Authors: AB van der Merwe and Dr Brett Cohen of The Green House, and Louise Naudé of WWF South Africa
Reviewed by: Dr Yvonne Lewis of The Green House

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WWF is one of the largest and most respected independent environmental organisations, with almost 6 million supporters and a global network active in more than 100 countries.

Our mission is to stop the degradation of the earth's natural environment and to build a future in which we all live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful production and consumption. In South Africa, we focus on sustainable development, including work in the areas of marine, freshwater, land, species, agriculture, food, energy and transport.

For more information: • Saliem Fakir, Head: Policy and Futures Unit • telephone +27-21-6576600 • e-mail sfakir@wwf.org.za • www.wwf.org.za

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The Green House is a technical sustainability consulting firm based in Cape Town, with experience working on a wide range of energy, carbon and sustainability-related projects including strategic energy planning, carbon footprinting, and life cycle assessment. The Green House has significant experience in energy, transport, urban systems, bioenergy, biofuels, industry, commerce, agriculture, municipal waste management, mining and minerals.

For more information: • telephone +27-21-6712161 • e-mail info@tgh.co.za • www.tgh.co.za

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1 INTRODUCTION

1.1 Modelling framework

This manual provides the technical details of a model that was constructed to explore greenhouse gas mitigation strategies in the freight transport sector in an integrated fashion, and understand what the impact of these strategies on the wider economy and environment will be. It forms part of a larger study commissioned by WWF South Africa on low carbon frameworks for transport, and builds on previous work conducted by the authors for WWF on low carbon planning (WWF, 2011) in which a quantitative modelling framework to support national low carbon planning was proposed.

This framework had at its core a **system dynamics model** developed through a stakeholder engagement process known as “**mediated modelling**”. System dynamics allows for the exploration of the evolution of a complex system over time, through consideration of the feedback loops and dynamic behaviour of the system. This approach is useful in that it overcomes some of the problems inherent in linear thinking, and compartmentalised and non-participatory decision making. Similar international transport system dynamics modelling was conducted by the French Ministry of Transport (Salini & Karsky, 2003) and for the EU15 countries via the Assessment of Transport Strategies (ASTRA) model (IWW, 2000).

The manual details the **methodology** used in the development of the model, the **model structure**, all the **data inputs** and **assumptions**, and results from a **sensitivity analysis** on the model.

1.2 Online open access interface

The manual is complemented by an interface that is web-hosted (see https://forio.com/simulate/ab755188/13013-freight-sd-model-v-100) and enables the user to explore the impact on system performance of changing a number of variables, and three briefing papers that aim to highlight specific outcomes to stakeholders in government, private business sector and labour.

1.3 The context

WWF South Africa explores the shift to a low-carbon economy, seeking solutions for emitting fewer greenhouse gas emissions and enabling a flourishing South Africa, which delivers developmental outcomes and social equity. The transport sector is key: it is a commonplace that transport is an economic enabler, and at the same time it is highly emissions intensive.

While the causes are global, acting on climate change mitigation in South Africa matters. In 2011, South Africa's total greenhouse gas emissions were 18th highest out of 185 countries. While this is only about 1% of the world's emissions, South Africa's economy is 48th in carbon intensity (emissions per GDP) and 53rd in per capita emissions, high compared to other major emerging economies.[1]

Electricity generation contributes over 60% of South Africa's emissions (as at 2010). The next biggest contributor is transport. Direct emissions from the combustion of fossil fuels in road, rail and domestic aviation transport account for over 13% of South Africa's total emissions, and have grown by between 18% and 30% since 2000. (This excludes lifecycle emissions from fuel manufacture.) The greatest share comes from road transport, for both freight and passengers.[2] The most significant opportunity to reduce the emissions associated with freight transport is recognised to be the shift of freight from road to rail (IPCC, 2014), and this applies in South Africa too.

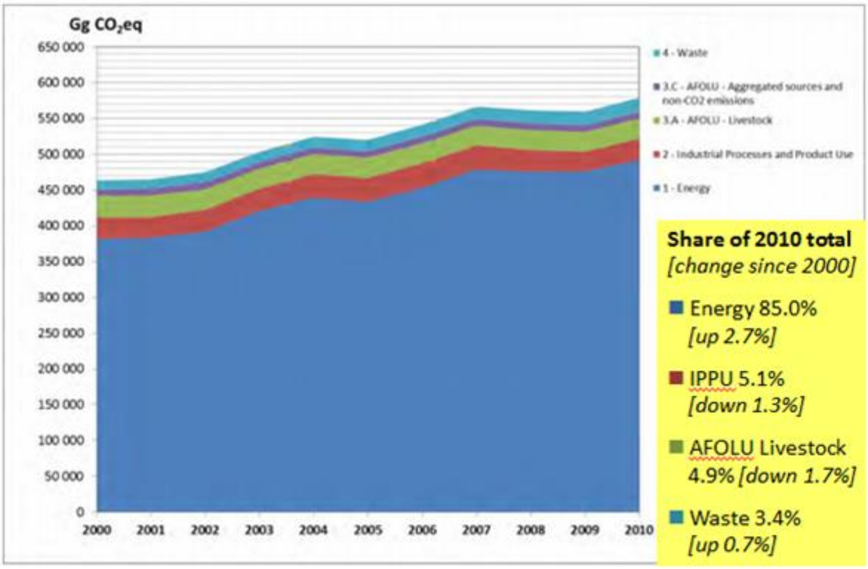

FIGURE 1: SOUTH AFRICA'S EMISSIONS OVER 2000-2010 (EXCLUDING THE LAND SUB-SECTOR)

Source: *GHG National Inventory Report South Africa 2000–2010* (November 2014), Department of Environmental Affairs

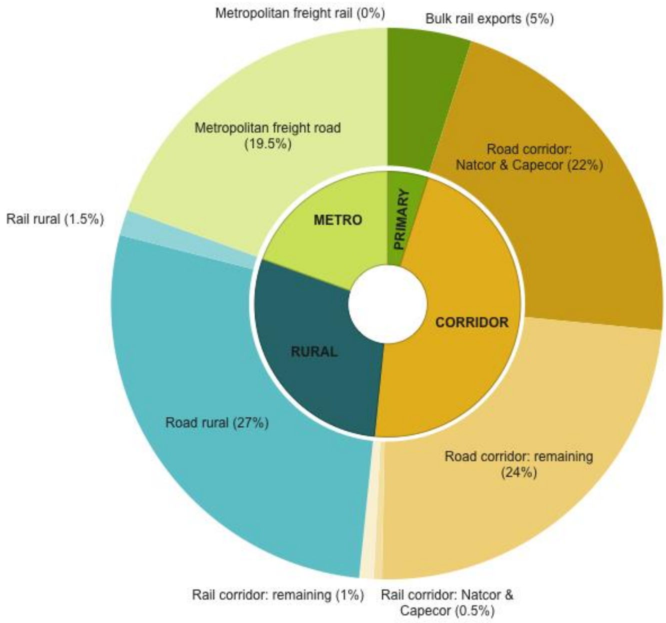

FIGURE 2: BREAKDOWN OF SOUTH AFRICA'S FREIGHT GHG EMISSIONS BY TYPOLOGY AND MODE IN 2012

Source: *Unpacking Freight Emissions and Mitigation Opportunities in the South African Context* (2014), commissioned by WWF from The Green House, available at www.wwf.org.za/freight_mitigation_opportunities

[1] Calculated from data at cait.wri.org (accessed 22/6/2015).
[2] *Briefing Note on Transport Emissions in South Africa*, commissioned by WWF from The Green House, available at www.wwf.org.za/transport_emissions (accessed 4/5/2016).

2 MODELLING OBJECTIVES AND APPROACH

As stated, the most significant opportunity to reduce the emissions associated with freight transport in South Africa is the shift of freight from road to rail. Most mitigation modelling efforts tend to assume a linear (or other simple) transition to a desired future modal split, with limited consideration being given to how this can be achieved in practice. The overarching aim of this work was to develop a model that could provide a deeper understanding of the complexities of the freight transport system, and in particular mode shift decisions.

- To achieve this aim, the model was specifically designed to:
- Explore the implications of strategies for reducing greenhouse gas emissions in freight transport, and the impacts of these strategies on the wider economy and environment, through:
    - Identifying the most effective mitigation actions and to what extent it should be implemented (tipping points may exist for unintended negative consequences of the actions)
    - Exploring the impacts of mitigation measures on direct emissions, other lifecycle emissions, water usage, job creation and the economy
- Determine the most significant barriers to change, with a specific focus on the switch from road to rail
- Recommend appropriate measures that could ensure developments towards improving sustainability in transportation planning
- Identify possible opportunities for further research and innovation.

2.1 Stakeholder engagement and expert consultation

The purpose of the stakeholder engagement and expert consultation process was three-fold: to elicit information and gather data on the freight transport system, the key players and their decision making behaviour in South Africa; to reality-test the model and preliminary outputs; and to increase the understanding of a wide group of stakeholders on the complex problem underpinning this project. To this end, three groups of stakeholders were identified: government, business and labour. WWF reached out to its pre-existing contacts and cultivated new ones; in terms of business we specifically included those in a scoping of top (by market share) users and providers of commercial transport in South Africa, previously commissioned by WWF (Frost & Sullivan, 2012).

The following workshops were held with these stakeholder groups:

- Government – 10 April 2013
- Business – 4 July 2012 and 26 March 2014
- Labour (SA Transport and Allied Workers Union) – April to June 2013 in Mpumalanga, Eastern Cape, North-West and KwaZulu-Natal/Free State.

In order to obtain stakeholder inputs and share learnings, intermediate findings from the study were presented at:

- Transport Forum (businesses in the transport sector) - 5 December 2013 and 6 November 2014
- Southern African Transport Conference – 8 July 2014
- Steering committee for study on socio-economic impact of road to rail shift of freight[3] – 27 August 2014
- Gauteng Department of Roads and Transport Technical working group forum – 31 October 2014
- National Climate Change Response Dialogue – 13 November 2014
- Southern African Transport Conference – 6 July 2015.

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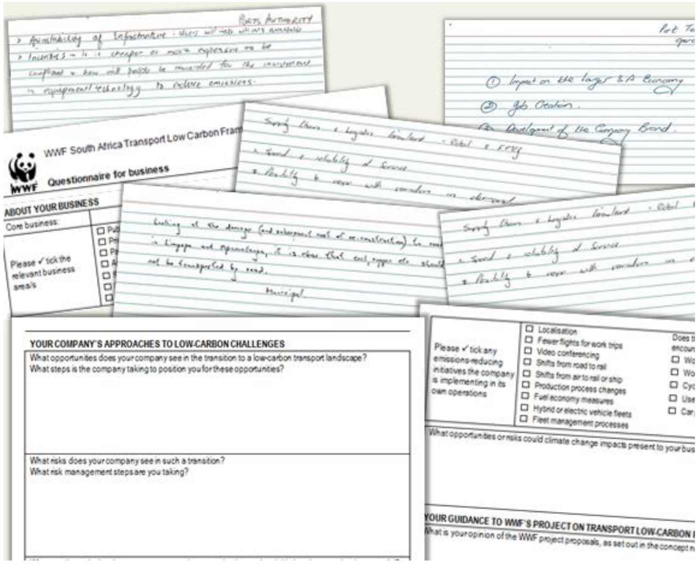
[3] *Socio-economic Impact of a Modal Shift of Freight from Road To Rail to Achieve Maximum Greenhouse Gas Mitigation in the Transport Sector*, commissioned by the Department of Environmental Affairs from consultants PDG, available at https://www.environment.gov.za/sites/default/files/docs/publications/freightshift_roadtorail.pdf (accessed 9/8/2016).

Business (above): Workshops with business, presentations to business forums, meetings with business associations and companies



Business (above): Various other methods were used to gather business views

Labour (below): Provincial workshops with SATAWU on causes of and solutions for greenhouse gas emissions in the transport sector

Government and Transnet (below): Workshops, meetings, presentations

FIGURE 3: STAKEHOLDER ENGAGEMENTS

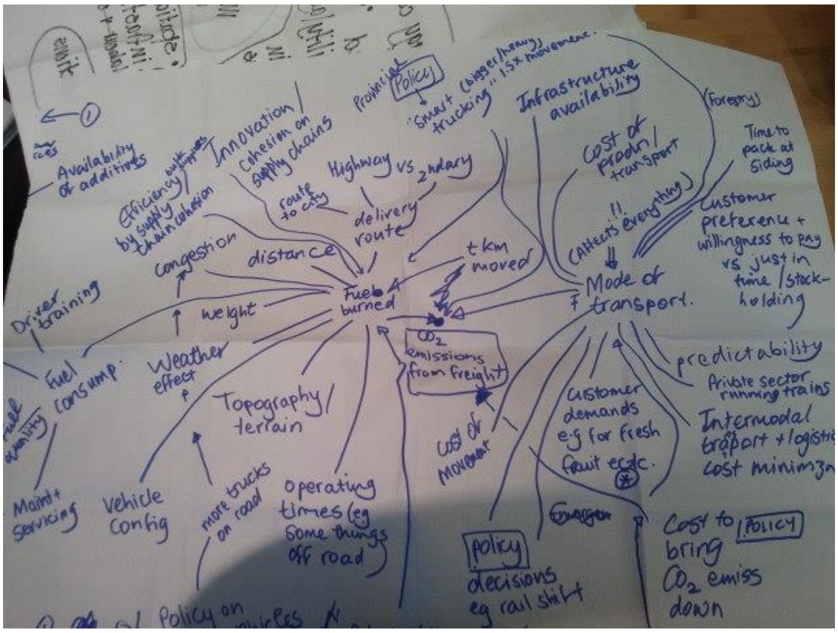
Meetings with experts from the following organisations were also held:

- Transnet
- Road Freight Association
- RailRoad Association
- Council for Scientific and Industrial Research (CSIR)
- Growth and Intelligence Network (GAIN) / University of Stellenbosch
- Retailers
- Food processing companies
- Logistics service providers.

Company names are not provided, since companies participated on the basis of confidentiality.

2.2 System dynamics modelling

System dynamics (SD) modelling was selected as the modelling platform for the study. SD is a type of simulation modelling that allows for the exploration of the evolution of a complex system, by taking on board the knock-on effects and feedback loops, and dynamic behaviour of the system. SD models are initially established through drawing up causal loop diagrams, which demonstrate which variables impact on each other and how. Causal loop diagrams are then translated into models that are populated with equations that describe the interrelationship between variables, and how these evolve with time.



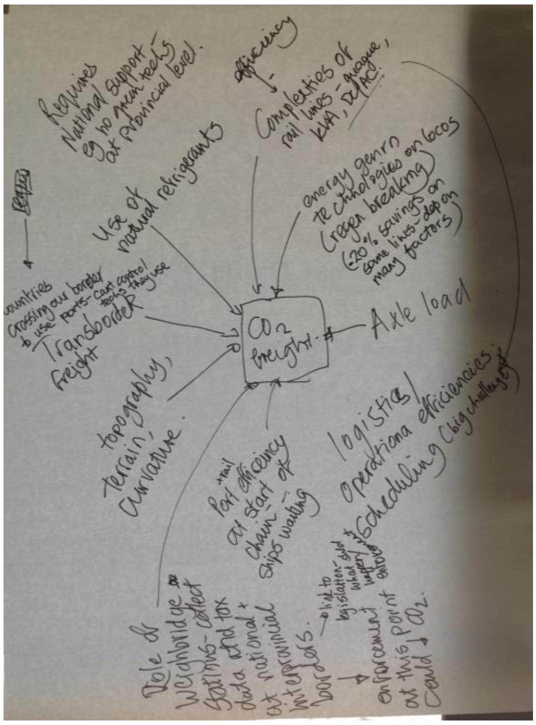
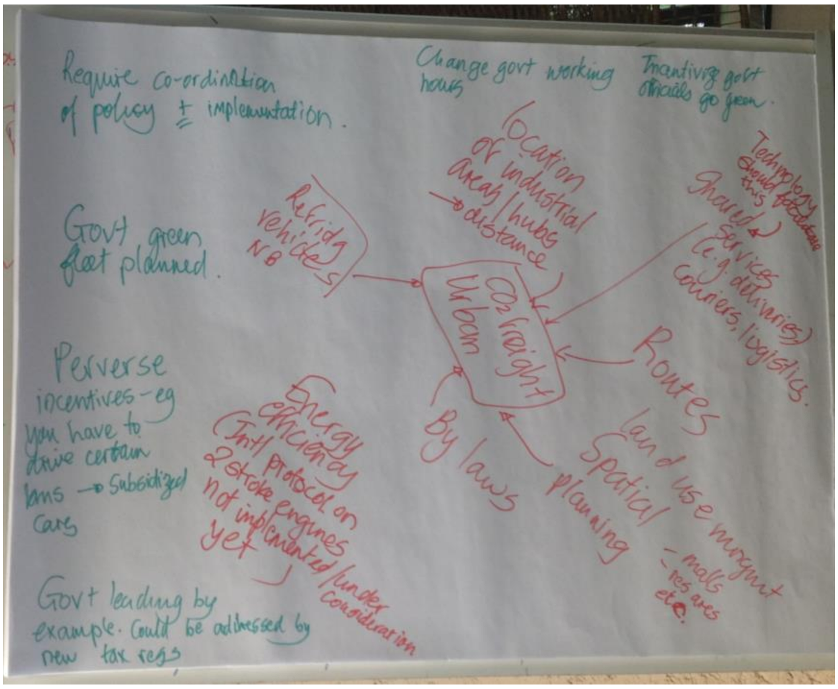


FIGURE 4: INFORMAL CAUSAL LOOP DIAGRAMS CONSTRUCTED BY BUSINESS (ABOVE) AND GOVERNMENT IN WORKSHOPS



SD models provide a powerful additional functionality over and above other simulation models given their ability to incorporate feedback loops. They are well suited to collaborative model building, and interfaces can easily be built which allow for exploring the impact of changing individual parameters and relationships on the overall system performance. One framework for conducting such collaborative model building is known as mediated modelling.

SD models are particularly well suited to analyses of the energy sector, and in climate mitigation and adaptation modelling, due to the complexity of interactions within these systems (Radzicki and Taylor, 1997). SD modelling has been used for strategic energy planning and policy analysis for more than 25 years (Naill, 1977; Sterman et al, 1988; USA DOE, 1988).

A number of graphical programming languages are available that can be used in an SD model which includes mediated modelling. Perhaps the most versatile of these is the STELLA software package developed by isee systems (www.iseesystems.com). A model built using the STELLA platform includes a number of "layers" which provide different means by which a programmer or user can interface with the model (Figure 5):

- An interface layer that provides tools to lay out the structure of the model and enable non-modellers to easily grasp the model structure, to interactively run the model and to view and interpret its results.
- A model construction layer where the components[4] of the model and their interconnections are specified, thereby defining the dynamic system.
- A model equation layer where the underlying model equations are generated automatically in response to above. These equations are solved in STELLA with numerical techniques and the equations, initial conditions and parameter values can be imported into other modelling languages.

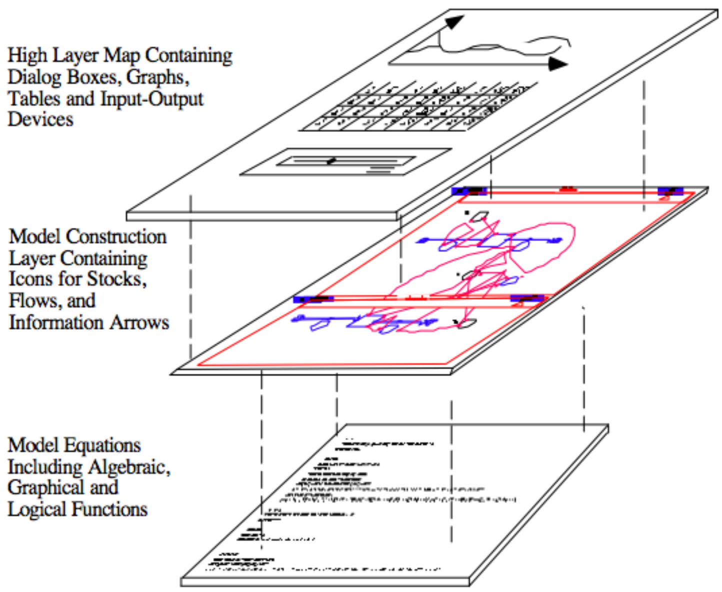


FIGURE 5: THE STELLA SOFTWARE FRAMEWORK SHOWING THE THREE LAYERS: INTERFACE, MODEL CONSTRUCTION, MODEL EQUATIONS

An attractive feature of the STELLA modelling software is the first layer that allows a model interface to be developed which assists model users, stakeholders and other interested parties to understand the dynamics of the system. Switches, sliders, buttons and dials allow the user to choose alternative parameter values and be able to immediately see the implications of alternative assumptions on model outputs in tabular or graphical form.

[4] Being the stocks, flows and parameters.

Provision of this functionality allows the resulting SD model to not only be dynamic with respect to the behaviour of the system itself, but also with respect to the learning process that is initiated among decision makers as they observe the system's dynamics unfold (van den Belt, 2004). The ability to easily get to grips with the system dynamics is particularly attractive in the context of this project, enabling the model to not just remain the property of the experts, but to be disseminated to a much wider audience.

The United Kingdom *Guardian* newspaper's online carbon calculator (Figure 6) provides an excellent example of a user interface developed to explore a dynamic web-hosted model (note that this example is for a linear model and not a SD model).

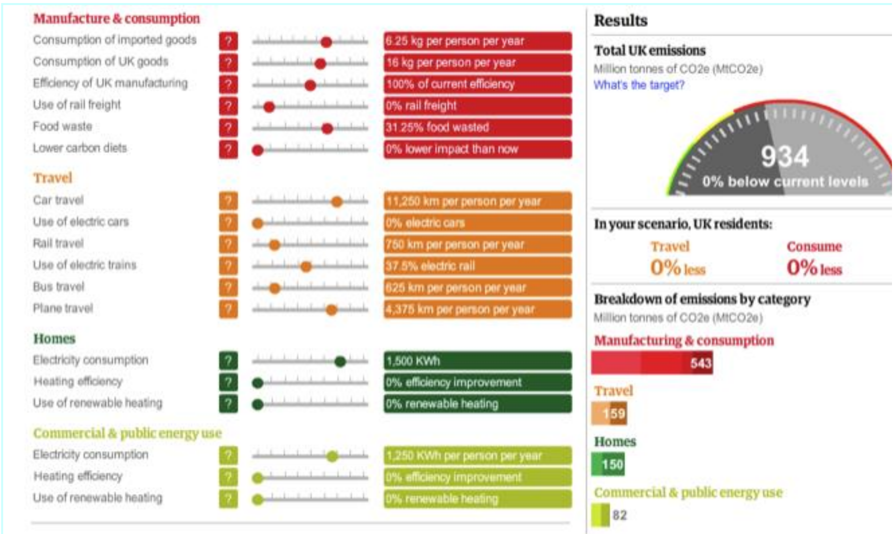


FIGURE 6: AN EXAMPLE OF "SLIDERS" (ON THE LEFT), WHICH ALLOW INPUT VALUES TO BE CHANGED, USED TO INVESTIGATE THE BEHAVIOUR OF SYSTEM OUTPUTS (ON THE RIGHT)

http://www.guardian.co.uk/environment/interactive/2010/apr/21/national-carbon-calculator, (September 2014)

Another attractive feature of the STELLA software is that there is supporting software available from the STELLA developers, isee systems, to enable web-based simulation sharing. Using this software, the completed model can be shared with a broader range of stakeholders for them to interrogate and explore, provided they have access to a computer and an internet connection. This serves the objective of seeing this project and its underlying models integrated into wider society. The online user interface for this model can be found at https://forio.com/simulate/ab755188/13013-freight-sd-model-v-100.

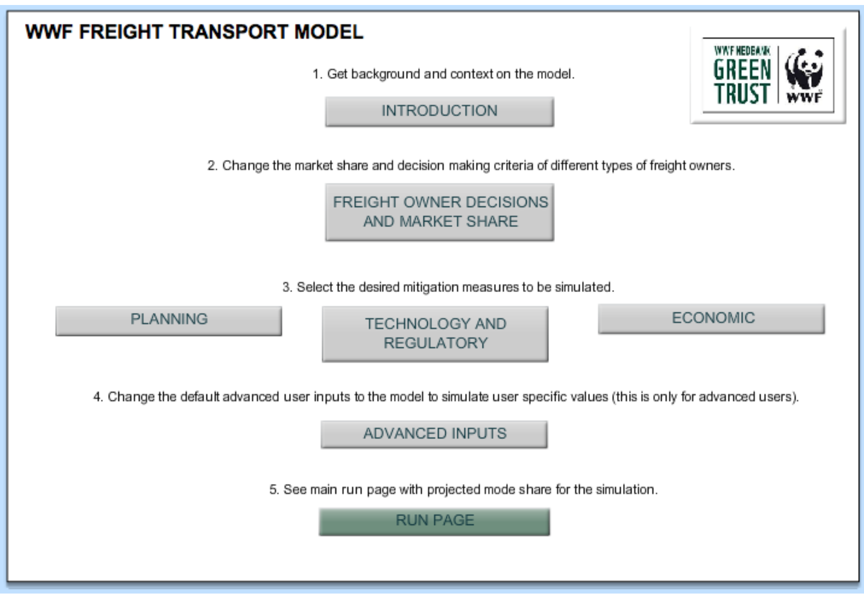


FIGURE 7: LANDING SCREEN FOR THE ONLINE MODEL INTERFACE

HOW TO

Throughout:

- Clicking on a "?" button provides explanations.
- Clicking on a "U" button returns the settings to the default Base Case.

3 CONCEPTUAL MODEL DEVELOPMENT

This section describes the scope of the model, the key system parameters and the relationships between these parameters. Together these are used to structure casual loop diagrams that are the first step in STELLA model construction. The conceptual model was developed based on outcomes of the stakeholder consultations.

3.1 Scope

The model covers the time period from **2012 to 2050**, with the end year being chosen to align with South Africa's National Climate Change Response White Paper's National Benchmark Trajectory Range.

From a literature review on emissions from freight transport in South Africa[5], **corridor road freight** has been identified as the most significant freight typology from an emissions perspective, and indications are that the transport of **processed foods** makes up a particularly large proportion of this freight segment (van Eeden & Havenga, 2010). The nature of processed food also makes it suitable for intermodal transport solutions, although most of this freight is currently carried only by road (Transnet, 2012). Processed foods transported on corridors have therefore been selected as the focus commodity in this work.

The **Cape Town–Gauteng corridor** (called Capecor) is one of the most significant in South Africa, particularly on an emissions basis (due to both the distance and volume of freight transported). For the purpose of model development the Cape Town–Gauteng corridor is used as a case study, but the corridor is modelled using a set of parameter values (e.g. distance, average speed, toll costs, etc.), which could be easily adjusted to represent other corridors. For this study only one corridor is modelled, because simultaneous modelling of a network of multiple origin–destination pairs introduces considerable complexity that would detract from the core objective of examining emission mitigation options. A simplified representation of metropolitan freight to incorporate the end effects of the metropolitan travel at either end of the journey is also included in the structure (as in Figure 8).

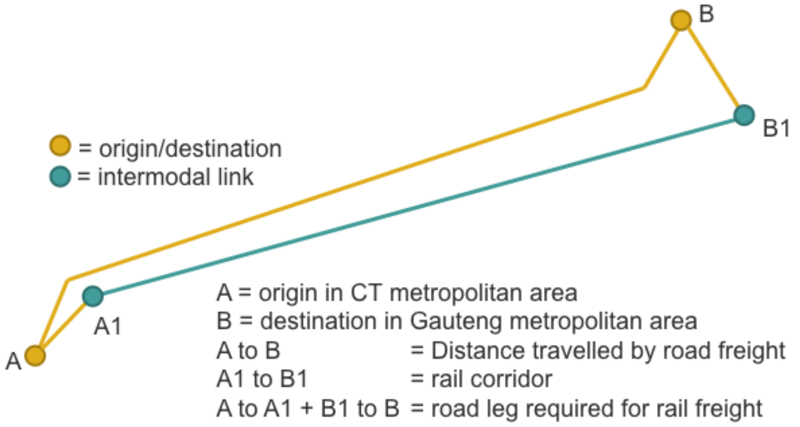


FIGURE 8: CONCEPTUAL ROUTES MODELLED FOR ROAD AND RAIL TRANSPORT

The limitations of this simplified model structure are that by not considering the entire national road and rail system, the effects of congestion and capacity constraints cannot be considered explicitly. Nevertheless, this limited scope is well suited to the objectives of this study.

LIMITATION

[5] *Unpacking Freight Emissions and Mitigation Opportunities in the South African Context*, commissioned by WWF from The Green House, available at www.wwf.org.za/freight_mitigation_opportunities (accessed 4/5/2016).

3.2 Decision makers

With the model aiming to simulate decisions regarding the mode of freight transport, the system is built around two decision makers:

- **Freight owners**
- **Vehicle fleet owners**.

The freight owners make the decision as to which mode of transport to use, based on characteristics of the different modes (e.g. cost, reliability, emissions, etc.). Characteristics of the road vehicle fleet therefore impact on the decisions made by the freight owner. The vehicle fleet owner makes decisions on truck technology improvements, which influence transport cost and emissions associated with moving the freight owner's goods.

The following characteristics of these decision-makers are captured (as arrays, see section 3.4):

- **Freight owner types** with different needs and priorities which impact on decision making surrounding the mode of transport used. The freight owner types considered ranged from "cost-focused" companies that prioritise the lowest logistics cost to "reputation-focused" companies that prioritise quality of service - this being a matter of emphasis since all companies care about both aspects
- **Vehicle fleet company types** with different decision making behaviour and access to resources, ranging from large companies with extensive fleets to one-person-one-vehicle operators.

It is recognised that some freight owners operate their own fleets, with the extent of logistics outsourcing varying between companies. The distinction between freight owner companies and companies running vehicle fleets is thus more blurred in practice. There are however two sets of decisions being made, one about what mode suits the logistics requirements, and the other about what kind of vehicle fleet to operate. It can be argued that logistics departments or external logistics companies seek to satisfy their clients and deliver on service level agreements, and thus their decisions about mode are aligned to those of their freight-owning clients.

An area of blurring is that vehicle fleet companies may also subcontract smaller operators as required, so it can be the case that the decision making of the small operators is encapsulated in the character of larger companies. The model cannot accommodate all the company-specific and temporary permutations of this, so the behaviour of vehicle fleet company types may be somewhat simplified in the modelling.

LIMITATION

3.2.1 How government and Transnet decisions are represented

The model sets up a system and models how modal choices by freight owners might respond to changes in the system. It does not dynamically model decisions by government, Transnet and labour, who are also decision makers in the transport sector. The outcome of decisions by government and Transnet (and Eskom) are represented in the model by parameters which can be changed.

Government decisions can affect the road corridor speed through speed limits (section 4.1.1.2); and road transport costs through licence fees, the fuel levy (4.1.5.1), condition of roads (4.1.5.1.3) and toll fees (4.1.5.1.4). Regulation on minimum vehicle standards (4.2.2.1), "green" driver training (4.2.2.2), biodiesel blending (4.2.2.3) can drive fleet owners to be "even earlier adopters", and will impact fuel consumption and the GHG externalities from fuel combustion. Other externality costs could be affected by anti-congestion measures and policing, which changes are not modelled. Rail transport costs are affected by the electricity price determined by NERSA, based on Eskom's electricity supply plans (4.1.5.1.6). The level of carbon tax (addressed in sections 4.1.5.1.8 and 4.3.7) comes into the criteria considered by freight and fleet owners.

The electricity supply mix (section 4.3.2) and emissions from the production of diesel (4.3.3) are pertinent in terms of GHG emissions, and could be affected by government’s plans for emission reduction targets.

Transnet decisions affect route characteristics (0), rail speed (under 4.1.1.2 Travel Time), improved rail operational performance (4.1.1.2.3), punctuality of rail transport (under 4.1.4 Reliability), Transnet infrastructure (4.1.4.1), failure rates and delays (4.1.4.2), punctuality (4.1.4.3), tariffs (4.1.5), labour costs (4.1.5.1.7), warehousing costs due to intermodal transfers (4.1.5.2), job intensity (4.3.6), and assumptions made for the Base Case input parameters (section 5.1).

The model allows for a “sustainability-focused” freight owner (section 3.4.3). This is an abstraction since no private sector company will prioritise sustainability criteria purely for their own sake over profitability. Government, Transnet and other disinterested users of the model can cast themselves as a “sustainability-focused” freight owner, by setting the market share for this type of freight owner to 100% (see section 4.1.1.3).

3.3 Factors influencing decisions

The following factors are considered in the model (also captured as arrays, see section 3.4)

- **Freight classifications** based on parcel size, packaging and destination
- **Total logistics cost** per mode (road or rail) paid by the freight owner, which includes direct transport cost and other costs such as inventory carrying and warehousing costs (see section 4.1.5)
- **Non-cost influences** on decision making on preferred mode of transport, such as reliability, emissions, job creation and externality costs (which do not impact on the total logistics cost paid by the freight owner and are therefore defined as a non-cost influence) (see sections 4.1.4 and 0)
- **Vehicle fleet improvements** that result in reduced fuel consumption (see section 4.2.2.1).

3.4 Parameter values and variables

A parameter is a value used in the model, which doesn’t change over time. It is usually an input to the model. A variable is a value that changes over time and is calculated by the model. Parameters and variables can be single numbers. A collection of parameter values or variables is captured in what is called an “array dimension”. The different array dimensions and their elements are described in the following sub-sections. Applications of these in the model will be explained in section 4.

SYNTAX

Arrays can be one-dimensional (being a vector) or multi-dimensional (a matrix). Arrays in this study are limited to two dimensions. The syntax used to describe model variables and parameters that form array dimensions is:

- To refer to a vector: <variable/parameter name>*(<vector dimension>)*
- To refer to a specific element within a vector: <variable/parameter name>*(<element>)*
- To refer to a matrix: <variable/parameter name>*(<matrix dimension 1>,<matrix dimension 2>)*
- To refer to a specific element in one of the matrix dimensions: <variable/parameter name>*(<element 1>,<matrix dimension 2>)*
- To refer to a specific element in a matrix: <variable/parameter name>*(<element 1>,<element 2>)*

3.4.1 Mode of transport

Some variables/parameters in the model have different values depending on the mode of transport. The first array dimension name is therefore <mode of transport>, which consists of the elements: <*rail*> and <*road*>.

3.4.2 Freight classification

Transnet classifies freight based on parcel size, packaging and destination into the following broad categories (Transnet, 2014a):

- **Rail suitable**: Typically containerised or palletised freight transported in bulk to a single destination.
- **Competing**: Freight that can be transported on either rail or road. Freight might be boxed and packaged, but can require further packing for pallets or have more stringent storage and handling requirements than the "rail suitable" category. Possibly smaller quantities transported to many destinations.
- **Road suitable**: Freight that is most suitable for road transport due to the type of packaging, volumes and dispersed destinations.

These three elements form the <freight classification> array dimension (in this case a vector). In the model the freight demand forecast for processed food is used as an input into the model, which projects rail suitable, competing and road suitable processed food freight along a particular corridor (see section 4.1.2.1 for detail).

3.4.3 Freight owners

Three types of freight owners are captured in the model (<freight owners> vector dimension), each with their own characteristics and requirements regarding transportation, based on stakeholder interaction:

- **Cost focused**: Cost is identified as the main driver for this type of decision maker; the least cost option is always sought. Typical companies in this category are those with large volume products that serve the majority of consumers looking for the lowest price.
- **Reputation focused**: Providing a quality product that is always on time and available to customers is important to this type of decision maker, and reliability of the transportation is therefore an important parameter in decision making. This decision maker might also consider environmental issues as part of enhancing the brand value. Typical companies are those catering for a higher-end market with consumers willing to pay more for better quality and consistent availability of products.
- **Sustainability focused**: This is an proxy placeholder for making decisions "for the greater good". The priorities of such a decision maker are to reduce emissions, increase employment and reduce externality costs. By definition, no company will prioritise such criteria purely for their own sake over profitability, and hence the market share for this type of freight owner is typically set to zero. If a user wants to see in abstract how the system might operate if all decisions were weighted in the public interest, the market share can be set to 100%.

All companies seek to maximise returns, by minimising costs and increasing revenue through gaining market share or expanding into new markets or niches. So "cost focused" and "reputation focused" describe *relative* emphases companies may have – different companies, or one company at different periods. The two characterisations can be understood as corresponding to business strategy. A cost-focused strategy is typically one where the price a company can offer to customers is paramount and its brand identity (or reputation) is centred on this; or where its market penetration is such that increased profitability can only be achieved through cost cutting. A so-called reputation-focused strategy is centred on growing market share or new markets with a brand offering beyond price - if required to achieve a certain level of service, availability, product range or product quality, the company may at times be more open to entertaining some flexibility on the cost side.

3.4.4 Fleet owners

Based on stakeholder interaction, two vehicle fleet company types are defined (<fleet owners> vector dimension):

- **First adopters**: Companies at the forefront of adopting new technologies to improve vehicle efficiency. These are characterised as larger companies with more capital at their disposal, which therefore allows for longer payback periods on investment in new technologies. Typically they will have stringent maintenance and driver training programmes.
- **Late adopters**: These types of fleet owners rarely consider adopting new technologies if not required by law. They are characterised as smaller companies or one-person driver and truck operations, with limited capital. They typically use second-hand trucks and drivers don't receive driver training.

Photo: Elsabe Gelderblom

4 MODEL STRUCTURE AND INPUT DATA

The freight transport model consists of three modules, each of which acts as a self-contained model with specified input parameters and output variables. Input parameters are specified by the user. Variables and parameters from one module can be connected to and used as inputs for other modules. Input variables and parameters are connected to all other variables via equations that capture the relationships. Within each module, functionally related variables and parameters are grouped into sectors.

A representation of the modules (black blocks) and sectors (grey blocks) in the model is provided in Figure 9, and highlights the circular nature of information flow in the model. The arrows in this diagram illustrate the directions of information flow, i.e. each arrow indicates where the output from one sector or module is used as an input to another. The model will be discussed in this document in terms of these modules and sectors.

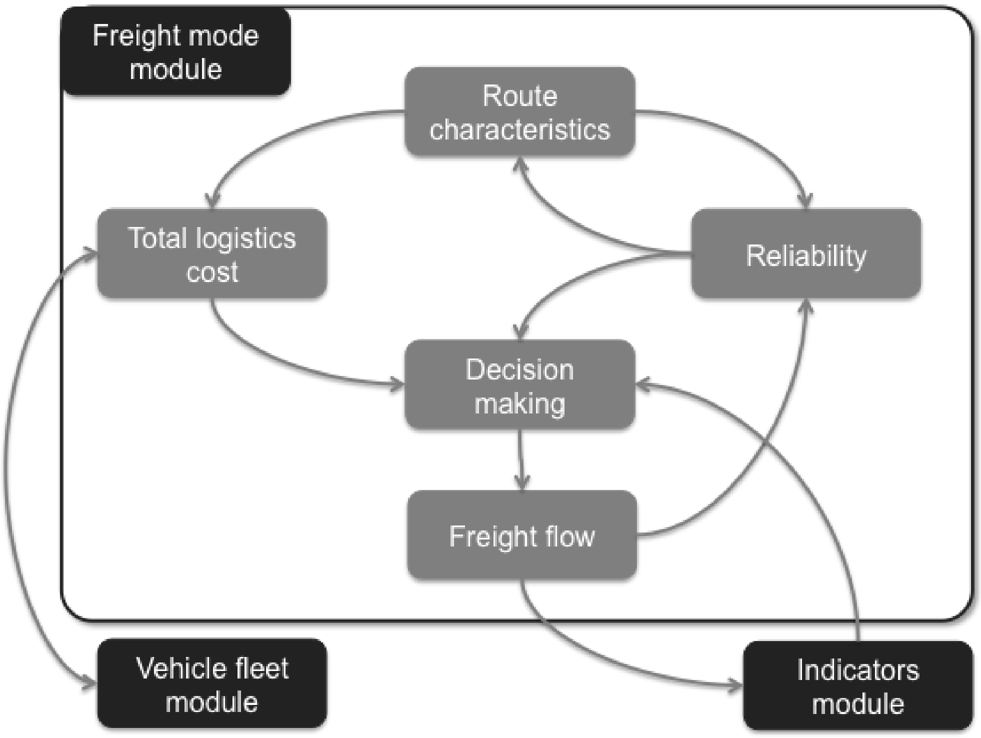


FIGURE 9: MODULES AND SECTORS IN THE MODEL

4.1 Freight mode module

The freight mode module defines the route and freight volumes transported, and captures the decision making process regarding what mode is utilised to move the freight along this route. All the cost influences and reliability (non-cost influence) are included in this module.

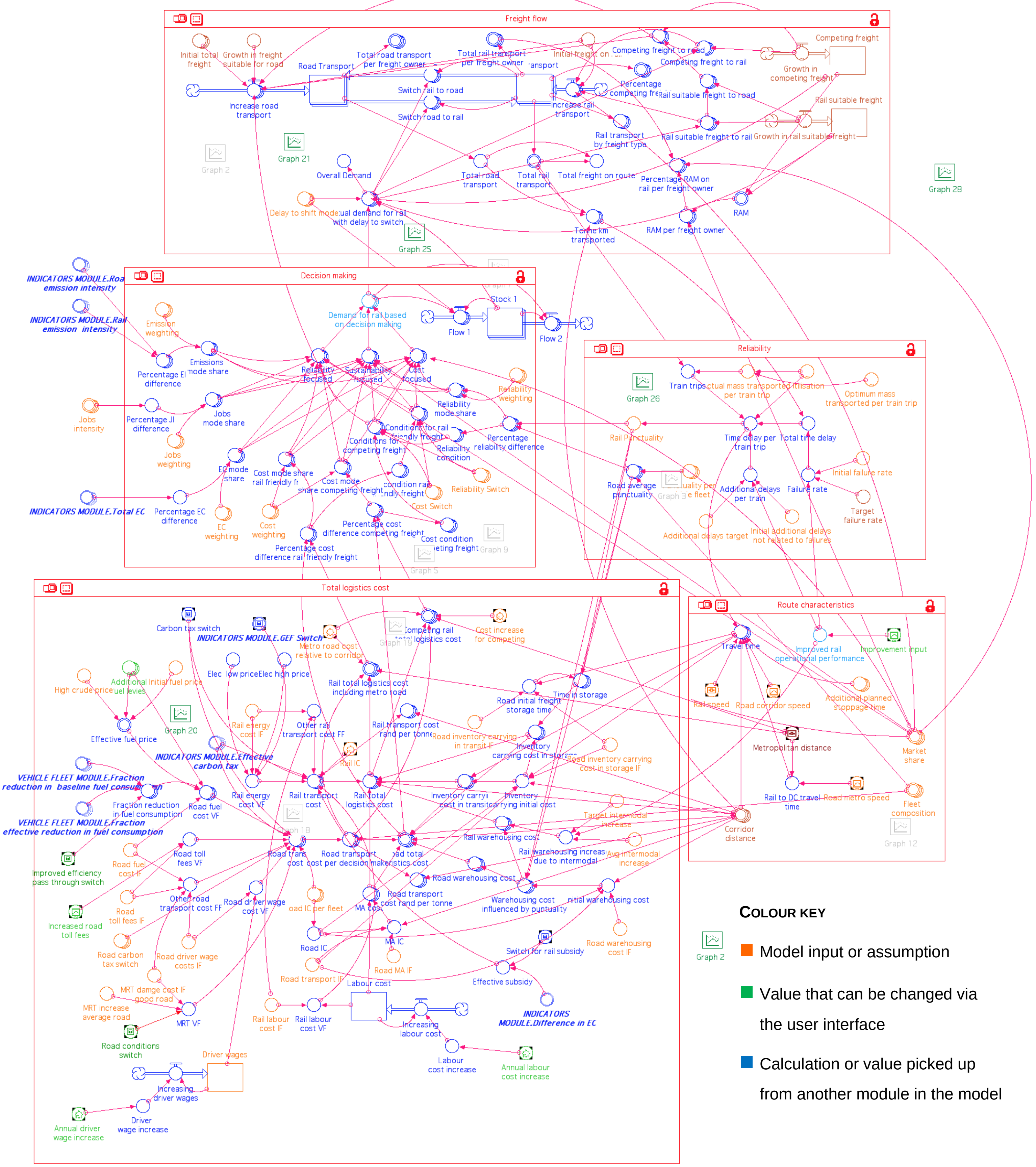


FIGURE 10: STRUCTURE OF FREIGHT MODE MODULE

4.1.1 Route characteristics

This model sector defines all the aspects that are specific to the Cape Town to Johannesburg corridor. The input parameters and calculated variables for this sector are presented in Table 1. One can adjust all parameters when using the model interface, except the distance of the transport corridor which has to be changed in the computer coding of the model.

TABLE 1: ROUTE CHARACTERISTICS PARAMETERS AND VARIABLES

Input parameter [unit]	Value	Adjustable in user interface	Calculated variable [unit]
<Corridor distance>*(<mode of transport>)* [km]	Rail: 1 400 Road: 1 400	No	<Travel time>*(<mode of transport>)* [hours]
<Metropolitan distance> [km]	*Base case values provided in section 5*	Yes	
<Rail speed> [km/h]	70	Yes	
<Road corridor speed> [km/h]	Year 1 (2012): 75 Year 39 (2050): 60	Yes	
<Road metropolitan speed> [km/h]	Year 1 (2012): 46 Year 39 (2050): 30	Yes	
<Additional planned stoppage time>*(<mode of transport>)* [hours]	*Base case values provided in section 5*	Yes	
<Improved rail operational performance> [%]	*Base case values provided in section 5*	Yes	Impacts on reliability and cost sectors (*see sections 4.1.4.2 and 4.1.5.2*)
<Market share>*(<freight owners>)* [%]	*Base case values provided in section 5*	Yes	Impacts on decision making and freight flow sectors (*see sections 4.1.3 and 4.1.2*)
<Fleet composition>*(<freight owners>)* [%]	*Base case values provided in section 5*	Yes	Impacts on reliability and cost sectors (*see sections 4.1.4.2 and 4.1.5.2*)

4.1.1.1 Travel distance

Corridor distance: Specified with a distance of 1 400 km for both road and rail.

Metropolitan distance: Based on the conceptual routes simulated in the model (see section 3, Figure 8), the rail transportation mode will require metropolitan road transport from the distribution centre (DC) to the rail station and again from the rail station to the DC at the destination. The <metropolitan distance> input parameter is the total distance that metropolitan trucks travel for a specific shipment, i.e. the combined distance of truck travel from DC to rail station and from rail station to DC at the destination. This is a user input for which a default base case value is provided in section 5. Road transport already has the metropolitan transport leg built into the overall road transport distance.

4.1.1.2 Travel time

Travel time (<travel time>(<*mode of transport*>) variable) is calculated from the average speed of a mode of transport over the travel distance (see section 4.1.1.1), plus additional planned stoppage time for that mode.

4.1.1.2.1 Average travel speed

Travel speeds are defined separately per transport mode and typology (corridor versus metropolitan). A user can change these input values, so as to test the impact of increased traffic volumes (by decreasing the travel speed over time) and the impact of high-speed rail.

Road corridor speed: From stakeholder inputs, it is understood that trucks are currently limited to travelling no faster than 80 km/h on highways. An average speed of 75 km/h was assumed for corridor travel, which is the same as the value used in the annual State of Logistics (SOL) study for calculating the average travel time on corridors (de Jager, 2009). Based on the Gauteng 25-year Integrated Transport Management Plan (ITMP) (Gauteng Roads and Transport, 2013), the speed on freeways in Gauteng is anticipated to decrease to 57 km/h in 2037[6] as a result of congestion. The impact of congestion on corridor transport speed was assumed to be less than this, and an average of 65 km/h was assumed for 2037. This was then projected linearly to obtain a value of 60 km/h in 2050. The <road corridor speed> input parameter is simulated as a linear decrease from 75 km/h in 2012 to 60 km/h in 2050.

Road metropolitan speed: In this current study, for metropolitan travel, an assumption was made that 30% of the travel will occur on freeways within metro boundaries, 50% on major roads with more than 1 lane per direction, and the remaining 20% on major roads with only 1 lane per direction. Due to a lack of data, it was further assumed that travel speeds in both Gauteng and Cape Town metropolitan areas are the same. The 75 km/h average travel speed on corridors in 2012 was also assumed applicable to freeway travel. From stakeholder input, it is understood that trucks are currently limited to travelling no faster than 40 km/h in urban areas. To account for congestion and delays at intersections, the average speed in 2012 was assumed to be 35 km/h on major roads with more than 1 lane per direction and 30 km/h on major roads with only 1 lane per direction. This resulted in an average metropolitan travel speed of 46 km/h in 2012.

Based on the outcomes of Gauteng's 25-year ITMP (Gauteng Roads and Transport, 2013), the speeds are anticipated to decrease to the following values in 2037[7]:

- Freeway: 57 km/h
- Major roads with more than 1 lane per direction: 28 km/h
- Major roads with only 1 lane per direction: 21 km/h

Similar to that of the calculation for corridor speed, linear projections were made up to 2050, which resulted in an average metropolitan travel speed of 30 km/h in 2050. Therefore, the <road metropolitan speed> is simulated as a linear decrease from 46 km/h in 2012 to 30 km/h in 2050.

Rail speed: The <rail speed> input parameter is based on the current average Transnet freight rail speed, which was obtained from literature as 70 km/h (Frost & Sullivan, 2012). This is assumed to remain unchanged throughout the modelling period.

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[6] Based on Scenario 4b in the referenced ITMP, which has the least amount of travel speed decrease from the study's base year (2011).
[7] As in footnote 6.

4.1.1.2.2 Additional planned stoppage time

Stakeholders consulted advised that in addition to the average travel speed, additional stoppage time must be factored into the total journey time. Anecdotally, for trucks it is merely a few hours on a long trip for weighbridge, food, toilet and rest stops; for rail, this can vary between a few hours and ten days depending on the number of stops made. The <additional planned stoppage time>(<*mode of transport*>) input parameter accounts for these stoppages. For example, the user can change it for rail transport to test the impact of direct dedicated rail between Cape Town and Johannesburg without stoppages. Default base case values are provided in section 5.

4.1.1.2.3 Improved rail operational performance

Reductions in delays experienced by trains and the operations of intermodal points are linked to investment by Transnet to improve the operational performance of the rail network. The rate of improvement in the network is an important route characteristic that impacts on reliability and cost. Transnet is transparent about planned investment for capacity expansions on the corridor as a whole (Transnet, 2014b), however the nature of individual investments is unknown. Additionally, the impact of these investments on operational performance of the service provided by Transnet (train performance and intermodal point efficiency) cannot be determined explicitly. <Improved rail operational performance> is therefore modelled as a user input parameter.

The model variables affected by the <improved rail operational performance>, a user input parameter, are:

- <Failure rate> (see section 4.1.4.2)
- <Additional delays per train> (see section 4.1.4.2)
- <Rail warehousing cost increase from intermodal transfers> (see section 4.1.5.2)

These each have an initial value and a target value and the difference between these two values is the potential change that can be realised by the specific variable.

The value of improved rail operational performance can be changed to test the impact of rail operational performance on modal shift decisions, or the required rail improvement to obtain desired outcomes. Default base case values are provided in section 5.

4.1.1.3 Market share

This parameter characterises the simulated market. The <market share>(<*freight owner*>) input parameter is a percentage of the total freight in the model that belongs to a specific type of freight owner. Each of the three <freight owner> types (<cost focused>, <reputation focused> or <sustainability focused>) is given a percentage of the freight moving in the model, broken down per <freight classification> (being <rail suitable>, <competing>, <road suitable>). So a freight owner type will have a percentage (perhaps nil) of rail suitable, of competing, and of road suitable freight to transport, and together that adds up to their share of the overall market of freight volume. Default base case value are provided in section 5.

SYNTAX

Array dimensions <freight classification>, <freight owners> and <fleet owners> are mapped to construct the <market share> and <vehicle fleet composition> arrays:

- a 3 x 3 matrix <market share> (<*freight classification*>, <*freight owners*>)
- a 3 x 2 matrix <vehicle fleet composition> (<*freight owners*>, <*fleet owners*>)

4.1.1.4 Fleet composition

Each <freight owner> type uses a mixture of the two <fleet owner> types, being <Early Adopters> and <Late Adopters> (see section 3.4.4). The <fleet composition>(<*freight owner*>) input parameter is the percentage of Late Adopters that form part of a specific freight owner's fleet. Typically, but not always, cost-focused freight owners use Late Adopters, whereas reputation-focused owners might have more First Adopters in their choice of fleets. Default base case values are provided in section 5.

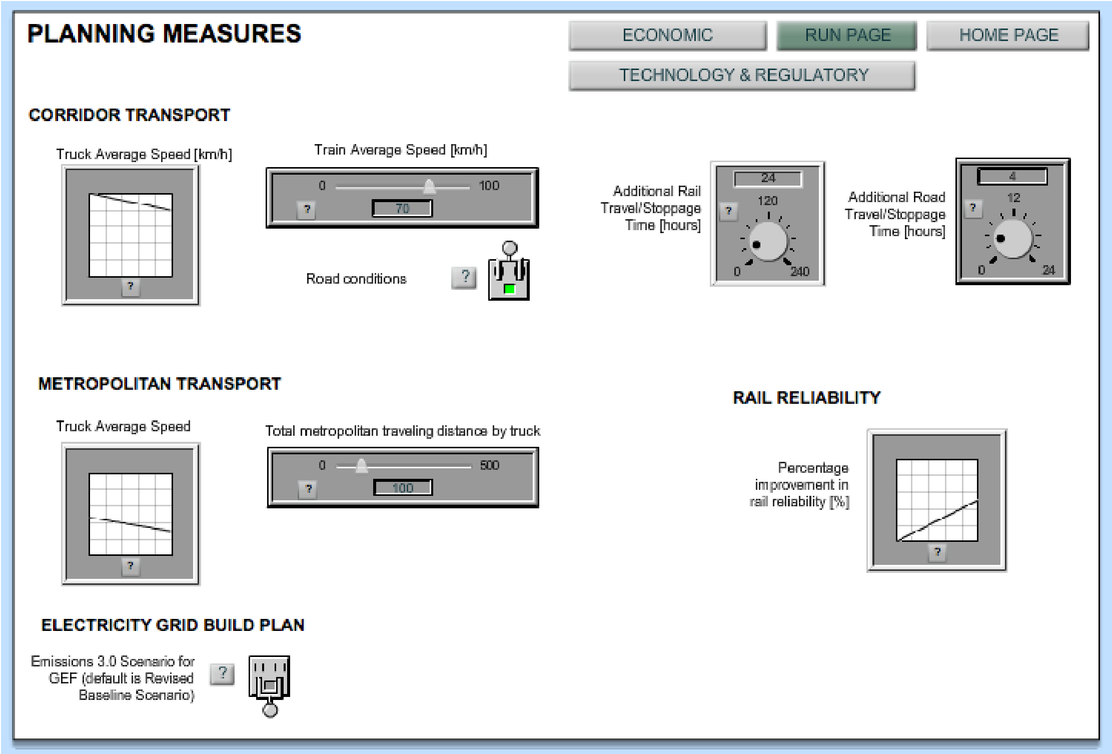

FIGURE 11: MODEL INTERFACE SCREEN WHERE PARAMETERS RELATING TO ROUTE CHARACTERISTICS CAN BE ALTERED

The parameters set on this screen capture **planning measures** which government (or in some cases the private sector) could undertake, which have implications for climate change mitigation. For example, in urban areas, distribution centres (DCs) can be located closer to railway stations or stations positioned close to key industrial hubs, thereby shortening the distance between station and DC. The average speed of trucks on corridor or metropolitan roads is a function of speed limits, congestion, number of stops, road condition, and so on, which can partly be managed by regulation and state road maintenance. The average speed of trains is under Transnet's control, as is additional stoppage time on rail.

- Click on **graphs** to get a pop-up screen which enlarges the graph and shows the labels, scales and values of the axes. The x-axis is always time: the 39-year model period. In the pop-up, the values for any of the graph points can be changed. For example, on the "Truck Average Speed" graphs (one for corridors, one for metro roads) the vertical axis is speed, from 0 to 75 or 100 km per hour.
- Move the **sliders** to set the "Train Average Speed" and the "Total metro travelling distance by truck" (being there-and-back from station to distribution centre).
- The corridor road condition is classified as "good". When this toggle is switched off, it will simulate a lack of road maintenance reducing road condition to "average" with impacts on truck maintenance and repair costs.
- Swivel the "Additional Rail Stoppage Time" **dial** to add from 0 to 240 extra hours, with the value selected showing in the "window" above the dial.
- When the "Electricity Grid Build Plan" **toggle switch** is "off" (down), the model will use the "Revised Balanced Scenario" in government's IRP2010 electricity build plan for the price path and Grid Emissions Factor for electricity. Click the switch "on" (up, when it will turn green) to use the "Emission 3" build plan.

HOW TO

4.1.2 Freight flow

In describing freight flow in the model, it makes sense to distinguish between the freight demand forecast and the mode selection sub-sectors. The former is largely determined by input parameters in the freight flow model sector, while the latter is governed by the dynamic demand for rail transport from the model's decision making model sector.

Table 2 summarises the input parameter values and the calculated variables for the freight flow sector.

TABLE 2: FREIGHT FLOW PARAMETERS AND VARIABLES

Input parameter [unit]	Value	Adjustable in user interface	Key calculated variables [unit]
<Initial total freight>*(<freight classification>)* [tonne/year]	* initial values <Rail suitable> 2 485 661 <Competing> 2 901 402 <Road suitable> 6 659 067	No	<Road transport>*(<freight classification>,<freight owners>)* [tonne]
<Growth in freight suitable for road> [tonne/year]	*see Figure 12*	No	
<Initial freight on rail> [tonne/year]	* initial value 135 740	No	<Rail transport>*(<freight classification>,<freight owners>)* [tonne]
<Growth in rail suitable freight> [tonne/year]	*see Figure 12*	No	<Rail suitable freight> [tonne] <Road transport>*(<freight classification>,<freight owner>s)* [tonne]
<Growth in competing freight> [tonne/year]	*see Figure 12*	No	<Competing freight> [tonne]
<Rail suitable freight> [tonne]	initial value 2 485 661	No	<Actual demand for rail with delay to switch>*(<freight classification>,<freight owners>)* [tonne]
<Competing freight> [tonne]	initial value 2 901 402	No	
<Delay to shift mode>*(<freight owner>)* [years]	<Reputation focused>: 2 <Cost focused>: 2 <Sustainability focused>: 2	Yes	

* These initial values are for 2013, at the outset of a model run all other year values are set to 0.

4.1.2.1 Freight demand forecast for processed foods

The freight demand forecast used in this model is obtained from Transnet's Rail Forecast from April 2013[8]. Demand for processed food on the Cape Town to Gauteng corridor in the direction "from port" is used. For more information on how the Transnet demand forecast was derived, see Chapter 2 of the Long Term Planning Framework (LTPF) (Transnet, 2014a).

This demand projection data from Transnet is already segregated into the different freight classifications as explained in section 3.4.2. Transnet refers to the rail suitable freight and competing freight together as the "rail addressable market" (RAM). This is the maximum volume of processed food freight that can theoretically be transported by rail. Only RAM freight will be shifted from road to rail; road suitable freight cannot shift. Figure 12 graphically illustrates the cumulative projected demand for the different types of freight relating to processed foods. The RAM is the total shaded area of rail (black) and competing (grey) freight. As this Transnet data only runs up to 2042, the last 10 years of data (2033-2042) were projected linearly to estimate values up to 2050.

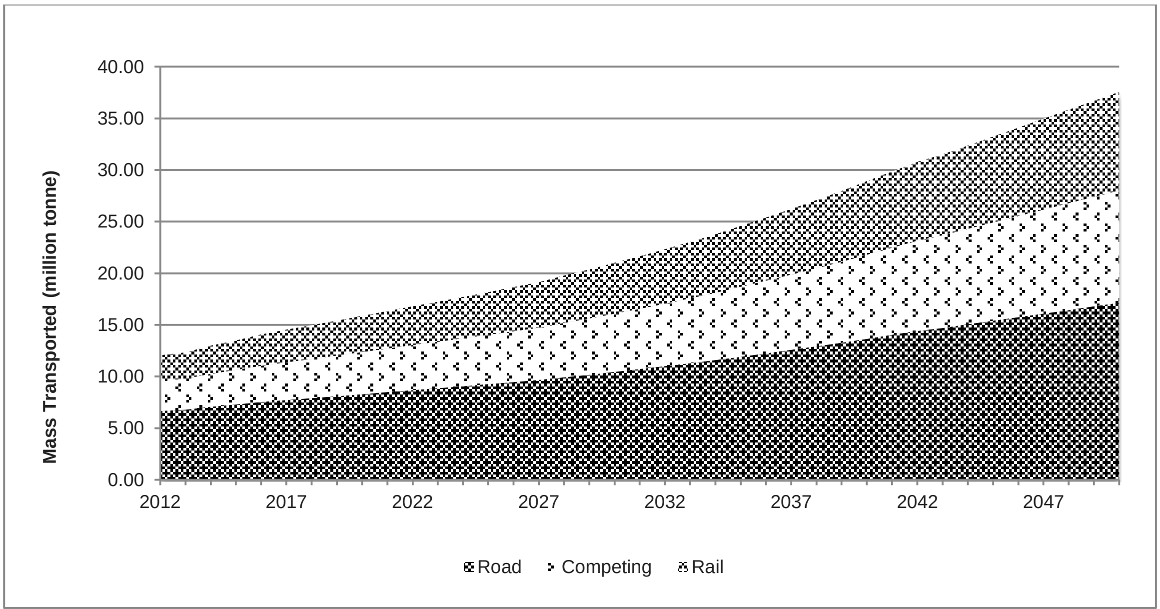

FIGURE 12: TRANSNET DATA FOR CUMULATIVE FREIGHT DEMAND, PROJECTED TO 2050

Dummy input parameters called <initial total freight>(*<freight classification>)* and <initial freight on rail> are initially set using actual values for 2012. These input parameters are used in calculating the <road transport>(*<freight classification>, <freight owners>)* and <rail transport>(*<freight classification>, <freight owners>)* variables. After the first year of simulation (2012-2013), these dummy parameters allow the calculated variables to have the correct values, as per Figure 12, in 2013.

In the absence of other information, a simplifying assumption was made that all freight that is on rail in 2013 belongs to the cost-focused decision maker, with the reputation-focused freight owner not choosing to use rail in 2013 as it does not satisfy some of their non-cost criteria. From 2013 onwards the mode selection will take place by means of a dynamic decision making process in response to the various system changes that affect decisions.

[8] Data shared by Transnet, not publicly available.

It is assumed that all new freight in subsequent years is road freight that will only be moved to rail if the demand for rail exists (discussed in section 4.1.2.2). Therefore, in addition to the initial volumes of freight, annual growth volumes are added to the <road transport>(*<freight classification>, <freight owners>*) variable through the growth input parameters:

- <Growth in freight suitable for road>
- <Growth in competing freight>
- <Growth in rail suitable freight>.

4.1.2.2 Mode selection

Freight will be moved from road to rail - <road transport>(*<freight classification>, <freight owners>)* to <rail transport>(*<freight classification>, <freight owners>)* - if the demand for rail transport is more than what is currently on rail. This demand for rail is calculated as the <actual demand for rail with delay to switch>(*<freight classification>, <freight owners>)* variable and governed by the decision making sector (see section 4.1.3).

The <growth in rail suitable freight> and <growth in competing freight> input parameters are used to calculate the cumulative <rail suitable freight> and <competing freight> variables, which in turn make up the RAM. Only RAM freight can be shifted from road to rail; road suitable freight cannot shift. If the demand for rail is higher than the current freight being transported on rail, freight will move from road to rail. If the demand for rail is lower than what is currently on rail, the freight will move back from rail to road.

4.1.2.2.1 Delay to shift

From stakeholder consultations with freight owners it was clear that even if it proves to be more favourable to shift freight from one mode to another, the freight owner's freight wouldn't necessarily be shifted all at once. The "waters will first be tested" by moving a fraction of the freight over to the new mode of transport, and then this fraction will be increased over time. There might also be contractual agreements with a transport provider or the freight owner might be utilising in-house trucks for transport, which can add to the delay to shift.

For these reasons it is assumed that the shift of freight from one mode to another would be phased in over an average period of 2 years. This phase-in period of 2 years is simulated in the model as a first-order material delay with delay duration of 2 years. This delay duration is an input parameter (<delay to shift mode>(*<freight owner>)*) that can be changed and specified separately for each type of decision maker.

4.1.3 Decision making

This model sector simulates the dynamic decision making process of the freight owner. The freight owner company decides which of the two modes (road and rail) to use to transport its freight, based on criteria that are derived from variables in the model. Weightings are put onto each criterion that reflect the views and preferences of the decision maker, and the criteria are then aggregated into a single score. The outcome of this sector drives the flow of freight from one mode to the other as described in section 4.1.2.

The only user inputs in this sector are the weightings assigned to the decision criteria for the different freight owners. Once assigned, these weightings do not change over the model period. The base case values for the weightings are provided in section 5.

4.1.3.1 Decision making criteria

The decision making criteria included in the model are:

- Total logistics cost: the total cost paid by the decision maker to transport freight (see section 4.1.5)
- Reliability: punctuality of the mode of transport (see section 4.1.4)
- Emissions: greenhouse gas emissions associated with the mode of transport (see section 4.3.2)
- Jobs: job creation associated with the mode of transport (see section 4.3.6)
- Externality cost: wider cost to the economy as a result of utilising this mode of transport (section 5).

Total logistics cost and reliability come into the decision making process as outputs from the sectors of the same names, and the others come from the Indicators module. Below is described how the freight owners make decisions about these criteria in the Decision Making sector.

4.1.3.2 Decision making theory

Two major theories of decision making are rational decision making and identity-based decision making. A third theory, called garbage can or chaos decision making, need not concern us.[9]

A **rational** decision maker is defined as one that makes consistent decisions that seek to maximise the value that they achieve from the decision outcome, within specified constraints. This type of decision maker would weight all the decision criteria and assess alternatives based on these weightings (Robbins et al., 2010).

A rational approach is conceived of as entailing the following linear steps:

1. Define the situation and decision to be made
2. Identify the important criteria for the process and the result
3. Consider all possible solutions
4. Calculate the consequences of these solutions versus the likelihood of satisfying the criteria
5. Choose the optimal option

Although a rational decision maker may be considered to be one who makes the “best” decisions (in that value is maximised), this approach to modelling decision making is critiqued as being unrealistic, for reasons including (Boundless Management, 2014):

- People rarely have full information at their disposal
- The more complex the decisions (more alternatives with various assessment criteria), the greater the limits to making rational decisions
- People often settle for a satisfying option rather than an optimal one.

Note that bias towards past decisions is also a common occurrence in organisations.

A refinement within rational decision making theory that is considered to be more representative of what occurs in practice is that of **bounded** decision making (Robbins et al., 2010). This considers that decision makers reduce problems to a level that can easily be understood and assessed based on the information and resources available to them, and what they consider to be important – these are the “bounds to rationality”. In this study, for example, effects relating to wider economic impacts of their choices would not be considered by freight or fleet owners.

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[9] This section draws on personal communications with Prof. T. Stewart from the University of Cape Town; and Jaco du Toit, graduate in Decision Making and Value Studies.

Identity-based decision making theory postulates that people make decisions based upon their identity as triggered in the situation, and how a person in their position “should” behave in certain circumstances. As a simplistic illustration: “I am a shareholder / senior manager / unionist / environmentalist / Christian / Scientologist / government official - and so decision x / y / z is the way to go in this case.” The values and culture of an organisation impact on the perception of decision makers, which in turn affect the types of alternatives identified as options and the strengths and weaknesses assigned to these alternatives (Robbins et al., 2010).

The model is structured to reflect the bounded decision making paradigm.

FIGURE 13: MODEL INTERFACE SCREEN TO SET MARKET SHARES OF TYPES OF FREIGHT OWNERS AND WEIGHTINGS OF THE RELATIVE IMPORTANCE OF THE DECISION CRITERIA TO THEM

HOW TO

- Move the “Market Size Distribution” **sliders** at top right to set the percentage market share enjoyed by the freight owner types. The model allows of a zero market share and insists shares add up to 100%, and handily indicates the % “Allocated” so far, and the “Unallocated” amount that must still be used.
- To model the performance of the system for the user’s own organisation only, choose the freight owner type that best matches the organisation and set its market share to 100%.
- For each type, the “Minimum Parity Requirements” **buttons** can be clicked on or off: Click on to make that freight owner type require that the cost and/or reliability of rail must match or better that of road. Only after this parity is satisfied, do the criteria weightings come into play.
- Under that there are the “Weightings for Decision Making” **sliders**, one for each of the decision making criteria listed above. Move them to weight their relative importance out of 100 to that freight owner type. Again the model requires they add up to 100.
- For interest, users might wish to give “Sustainability focused” 100% market share, and highly weight “Jobs”, “Emissions” and “Externality Costs” to investigate what happens if all decisions prioritised sustainability and public interest. Currently, private companies would not make decisions like this.

4.1.3.3 Decision makers simulated in the sector

Within a company, an individual or a management team will make the decisions on mode of freight transport, applying company criteria and following company procedures. The <freight owner> in the model simulates the decisions made by such a company process. The types of freight owners included in this model are explained in section 3.4.3, with each freight owner type prioritising different criteria (see section 4.1.3.1) in their decisions.

Weightings assigned to criteria thus characterise the decision maker, and these weightings are user inputs that can be adjusted to simulate the different preferences and perceptions within organisations. For each type of freight owner, the weightings assigned to the decision making criteria are applicable to all the freight classifications i.e. what the company is looking for does not change whether the freight is road suitable (won't shift to rail), competing or rail suitable.

4.1.3.4 Modelling the decision making process

The bounded rationality decision making process is modelled by setting the freight owners such that they only consider some of the criteria (see 4.1.3.1) in their decision making process. In the base case simulation, cost and reputation-focused freight owners consider only cost and reliability criteria. The wider economic impacts of the decision of transport mode on jobs, externality cost, and emissions are not considered. The model user can adjust these bounds to rationality by adjusting the criteria considered by each type of decision maker.

Other bounds fixed in the model are[10]:

- If the values for road and rail are within 10% of each other for a specific variable, the criterion will not be considered in the decision making process; this difference is deemed insignificant
- A difference greater than 100% between road and rail is defaulted to 100% difference; larger differences cannot be "comprehended" by the decision maker and are therefore irrelevant to decision making.

Once the selected decision making criteria have been traded off against each other to provide a set of weightings, either a positive or a negative value per freight owner and freight classification will be assigned. A positive value indicates that rail is a more desirable mode than road, which will activate the demand for rail as discussed in section 4.1.2.2. A negative value will cause the freight owner to remain on road if already on road, or to shift from rail to road if on rail.

To address the fact that decision makers often settle for a satisfying option rather than an optimal one (section 4.1.3.2), a set of minimum requirements for cost and reliability must be met by rail (remembering that this is freight currently running on road):

- **Cost**: cost of rail must be equal to, or lower than, that of road
- **Reliability**: punctuality of rail must be equal to, or better than, that of road.

These are programmed into the model as user input buttons that provide hurdles that must be satisfied before the bounded rational decision making process is considered. See the "Minimum parity requirements" buttons in Figure 13. If these conditions are satisfied, the weighted decision making criteria (variables from the model with user assigned weightings per freight owner type) are evaluated for road versus rail as described above.

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[10] These bounds were informed by personal communication with Prof. T. Stewart from the University of Cape Town.

4.1.4 Reliability

Reliability is the probability of a transport system failing over time. The condition of the infrastructure and utilisation thereof will impact on the reliability of the mode of transport. Punctuality is the indicator used in this model to represent reliability. It is a measure of how on time the mode of transport is and is expressed as a percentage of shipments that is perceived to be on time by the freight owner. Different decision makers have different tolerances for delays, which means that different people will perceive a specific arrival time as punctual or not based on their tolerance level. For example, for some freight owners a delay of 48 hours may still be perceived as on time as it is within their tolerance levels. For others, only shipments with a delay of less than 8 hours will be perceived to be on time.

Information on the **punctuality of road transport** was gathered through stakeholder interaction with both freight and fleet owners. Stakeholders were asked what percentage of their deliveries is made on time. First adopter fleets are typically more punctual due to better planning and more reliable trucks, but they also have more stringent delivery windows, which mean that freight owners have lower tolerance levels on delays from these fleets. In the model it is assumed that the average punctuality for first adopter truck owners is 98%, and that of the late adopter fleet is 92%. These values are specified as inputs to the <punctuality per vehicle fleet>(*<fleet owners>)* parameter, and used to calculate the <road average punctuality>(*<freight owners>)* based on the <fleet composition>(*<fleet owners>)* (see section 4.1.1.4).

To determine the **punctuality of rail transport**, the average time delay per train must be calculated, and the tolerance levels of different freight owners for delays understood. In the 2014 LTPF, Transnet provides failure rates for rail per corridor, in the unit of minutes delay per million tonne.km (Transnet, 2014b). This can be used to calculate the time delays experienced per tonne of freight transported on a specific route. Punctuality is however based on the arrival of an entire shipment (truck or train), rather than being related to the tonnes of freight moved. The mass transported per train and the number of train trips therefore need to be determined in order to derive the time delay per train trip. This means that aspects relating to Transnet's rail infrastructure must be defined in the model to more accurately model delays.

Table 3 summarises the input parameter values and the calculated variables for the reliability sector.

TABLE 3: RELIABILITY PARAMETERS AND VARIABLES

<table>
<tr><th>Input parameter
[unit]</th><th>Value</th><th>Adjustable in user interface</th><th colspan="3">Calculated variables
[unit]</th></tr>
<tr><td><Utilisation>
[%]</td><td>Increase linearly from 80% (2012) to 100% (2050)</td><td>No</td><td rowspan="2"><Train trips>
[number]</td><td rowspan="5"><Time delay per train trip>
[hours]</td><td rowspan="5"><Rail punctuality>
[%]</td></tr>
<tr><td><Optimum mass transported per train trip>
[tonne]</td><td>6 000 tonnes (initial value, see section 5)</td><td>No</td></tr>
<tr><td><Initial failure rate>
[minutes/million.tonne.km]</td><td>5.8</td><td>No</td><td rowspan="2"><Failure rate>
[minutes/million.tonne.km]</td></tr>
<tr><td><Target failure rate>
[minutes/million.tonne.km]</td><td>1.4</td><td>No</td></tr>
<tr><td><Initial additional delays not related to failures>
[hours]</td><td>5</td><td>No</td><td><Additional delays per train trip>
[hours]</td></tr>
</table>

Input parameter [unit]	Value	Adjustable in user interface	Calculated variables [unit]
<Additional delays target> [hours]	2	No	
<Punctuality per vehicle fleet>*(<fleet owner>s)* [%]	<First adopters>: 98% <Late adopters> 92%	Yes	<Road average punctuality>*(<freight owners>)* [%]

As punctuality of road transport is a predefined input parameter, this will not be discussed further. All further headings under this section 4.1.4 Reliability are specific to rail transport.

4.1.4.1 Transnet infrastructure

4.1.4.1.1 Utilisation

Utilisation is an indicator of how hard the infrastructure is working and is expressed as a percentage of the installed infrastructure capacity that is being used due to demand for the transport mode. Utilisation is used in the model to determine the mass transported per train trip (which impacts on the number of train trips, see section 4.1.4.1.2) as well as the average delay times experienced on route (see section 4.1.4.2).

Utilisation is typically a property of a corridor or entire network, and is not specific to the commodity being transported. As only one commodity is simulated in this model, however, and due to a lack of infrastructure capacity data, the capacity utilisation of rail infrastructure could not be modelled. <Utilisation> is therefore specified as an input parameter to the model.

LIMITATION

Based on the latest available Transnet LTPF (Transnet, 2014b), utilisation on the Cape Town – Gauteng corridor is classified as light (<60%) to moderate (60–80%) on most sections of the route, with some sections experiencing heavy utilisation (80–95%). Transnet projected the demand for rail transport up to 2043, which will result in some sections of this corridor experiencing capacity utilisation by 2043 that will cause system failure, if no infrastructure upgrades and expansions are done. System failure is defined by Transnet as occurring when utilisation is greater than 130%. Based on this, Transnet has made development plans as reflected in the LTPF (Transnet, 2014b). With these development plans the capacity constraints are fairly well addressed over time, with the majority of the sections on the route experiencing heavy utilisation (80–95%) in 2043 and only a few sections nearing the capacity limit (95–105%). All these numbers are however based on Transnet planning, and utilisation will in practice depend on the actual rate that road freight shifts to rail and the extent to which Transnet addresses capacity constraints in future.

Based on the above discussion, it was assumed that <utilisation> increases linearly from 80% in 2012 to 100% in 2050 in the model.

4.1.4.1.2 Number of train trips

Utilisation impacts on the mass transported per train trip. Trains on this route have an **axle tonnage rating** of 20 tonne/axle (Transnet, 2014b), which results in a wagon with 4 axles having a maximum gross weight of 80 tonnes. Based on Transnet data for trains transporting coal (Transnet, 2013), the **gross weight of an empty wagon** is 20 tonnes. This was assumed to be the same for wagons used for general freight. Furthermore, the maximum **train length** on this Cape Town to Johannesburg route is 104 wagons (Transnet, 2014b). Such a train with empty wagons therefore weighs 2 080 tonnes and a fully loaded train will weigh 8 320 tonnes, which means that the **maximum payload** that can be transported on this route is 6 240 tonnes.

An increase in train capacity will most likely happen step-wise and at different increments based on investment in specific technologies by Transnet e.g. rolling-stock with larger axle tonnage capacity or loop extensions that allow more wagons.

Although Transnet is transparent about the planned capacity expansion investments, the exact impact of these investments on train capacity is not known, as some investments relate to rolling stock, whereas others are for infrastructure (e.g. doubling of the line), which will increase the number of trains and capacity on route, but not train capacity.

LIMITATION

In the modelling it is assumed that in Year 1 the <**optimum loading capacity per train**> is 6 000 tonnes if all trains are 100% utilised. This is specified as the initial value for the <optimum mass transported per train trip> input parameter. The loading capacity in 39 years' time (end of modelling period) is an assumption specified in section 5. The <**actual mass transported per train trip**> will be the <optimum mass transported per train trip> multiplied by the <utilisation>.

The <**train trips**> variable is the number of train trips required to transport the rail freight demand within a specific year. It is calculated by dividing the total freight on rail transport within the year by the calculated actual mass transported per train trip. This assumes that all train trips in the model are dedicated to transporting the single simulated commodity.

In reality a train trip will most likely contain various commodities, and transportation of this one commodity will be dispersed over many more train trips. However, for this singular purpose of using train trips to calculate the delay per train trip, this method is considered sufficient. The total annual time delay experienced will increase if the total tonnes transported for all commodities on this corridor is considered, but so will the number of trains transporting these goods with the same proportion, meaning that the delay experienced per train trip will remain unchanged.

4.1.4.2 Failure rates and delays

Delays on rail are mainly caused by infrastructure failures or poor system operation. A study based on the European rail sector revealed that 30% of the average delay causes relate to infrastructure failures, 43% to operations, and the remaining 27% are due to other and external causes (BSL Management Consultants, 2008). These various problems have different effects on the overall delay duration experienced per train trip.

Infrastructure failure rates for Transnet are provided in the LTPF 2014 (Transnet, 2014b), which are made up of issues relating to the perway (bridges and platforms), telecoms, signalling and electrical failures. Failure rates for the sections on the simulated corridor are expressed in minutes delay per million tonne.km transported:

- Cape Town to De Aar – 2.9
- De Aar to Kimberley – 1.4
- Kimberley to Houtheuwel (final destination in Gauteng) – 5.8
- Network average (entire Transnet network) – 3.5

For the modelling it is assumed that the <initial failure rate> input parameter is 5.8 (being the worst case above) and that 1.4 (best value above) is the <target failure rate> input parameter. <Improved rail operational performance> drives change in the <failure rate> variable (see discussion in section 4.1.1.2.3).

With the infrastructure failure rates and the volumes of freight transported over the distance of the corridor, the simulated total delay per train trip is less than 60 minutes in 2013. Infrastructure failures are taken as accounting for only 30% of all causes of delays, a figure taken from the European rail study (BSL Management Consultants, 2008) in the absence of data regarding delays due to operations or "other" reasons on the simulated corridor.

In 2011 Transnet reported average delays on their coal line of 468 minutes against a target of 248 minutes per trip, and delays on the iron ore line of 285 minutes against a target of 160 minutes (Business Report, 2011). From personal communication with Transnet, it was clear that their iron ore line is the most efficient and punctual line in their network due to the single commodity transported and with a low number of stops along the route. If trains on this route experienced average delays of 285 minutes (4.75 hours), the total delay experienced on the Cape Town to Johannesburg corridor, which carry various commodities and have multiple stops, should be much higher.

A variable called <additional delays per train trip> is built into the model to capture **other delays not related to infrastructure** failures. The initial value for additional delays is specified in the input parameter <initial additional delays not related to failures> with a nominal value assumed as 5 hours. The value of the input parameter <additional delays target>(target for additional delays not related to infrastructure failures) is set at 2 hours. As with the infrastructure failure rate, change in <additional delays per train trip> is brought about by an increase in <improved rail operational performance>.

With these assumptions from the <infrastructure failure rate> and <additional delays per train trip>, the total simulated <time delay per train trip> variable amounts to 5.7 hours per train trip for 2013.

The average delay times are also affected by network utilisation, as mentioned in section 4.1.4.1.1. If the utilisation is high, more incidents occur and more trains are affected by one incident (BSL Management Consultants, 2008). This relationship between <time delay per trip> and <utilisation> is generally exponential, and is modelled as such (Schlake et al., 2011).

4.1.4.3 Punctuality

Freight owners have different tolerance levels for delays by which they classify the arrival time of a shipment as being punctual or not. Due to a lack of local market data, a market survey from a European railroad study was used (BSL Management Consultants, 2008). In this study, hundreds of logistics service providers answered questionnaires on various aspects of freight rail transport, including their delay tolerance levels.

The results are presented in Figure 14, which gives a percentage of companies (y-axis) that perceive the arrival of a train as punctual after a specific time delay (x-axis).

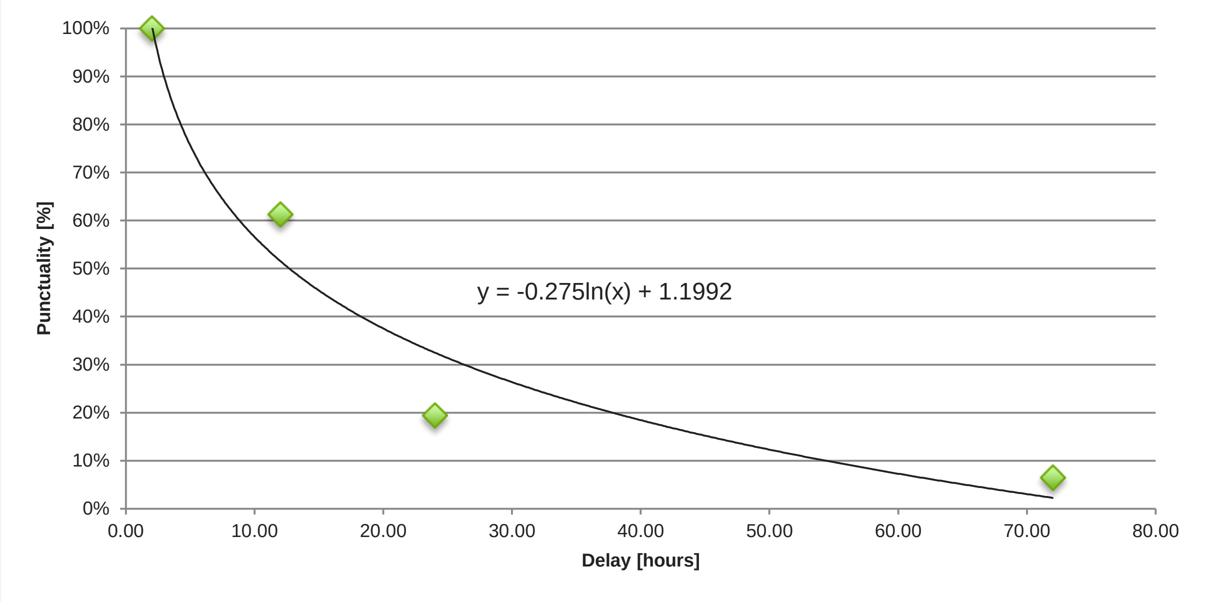


FIGURE 14: DELAY TOLERANCE LEVEL TO CONSIDER ARRIVAL AS PUNCTUAL

The trend line added to the data in Figure 14is used in the modelling to derive the <rail punctuality> variable based on the calculated <time delay per train trip>(described in section 4.1.4.2).

4.1.5 Total logistics cost

All costs in the model are deflated to 2012 Rand values, as Year 1 in the model is 2012.

The model aims to accurately capture the total logistics cost per tonne kilometre to the freight owner, as this is the cost used in the decision making process by the freight owner for selecting a mode of transport.

LIMITATION

The total cost of "running a transport system", which entails infrastructure, rolling stock and maintenance costs is not modelled. These latter costs form part of the separate service provider's business models, being Transnet, South African National Roads Agency (SANRAL) and various logistics providers.

A top down approach was followed for the calculation of cost as the only publicly available cost data that are both corridor and commodity specific were total logistics cost obtained for 2007 (de Jager, 2009). The data for break bulk on the Cape Town to Gauteng corridor from that study is used. Break bulk is defined as freight that is either palletized or in boxes, cartons, bags etc., and can be transported in containers on rail or on flatbed trucks by road. Processed foods fall within this category.

Total logistics cost for road was escalated from R0.54 per tonne.km in 2007 to R0.63 per tonne.km in 2012 using increases as per Figure 15, obtained from the 10th State of Logistics Survey for South Africa (SOL) (CSIR, 2014). Data in the SOL covers transportation of all freight by all modes, but there is no breakdown of costs per mode and the majority (88,6% in 2011 (CSIR, 2014)) of national freight captured in the SOL is on road. Data from the SOL will thus be most representative of the road transport situation and in the model SOL data is therefore mostly applied to road transport; for rail transport, other sources were used to try to get more specific to rail.

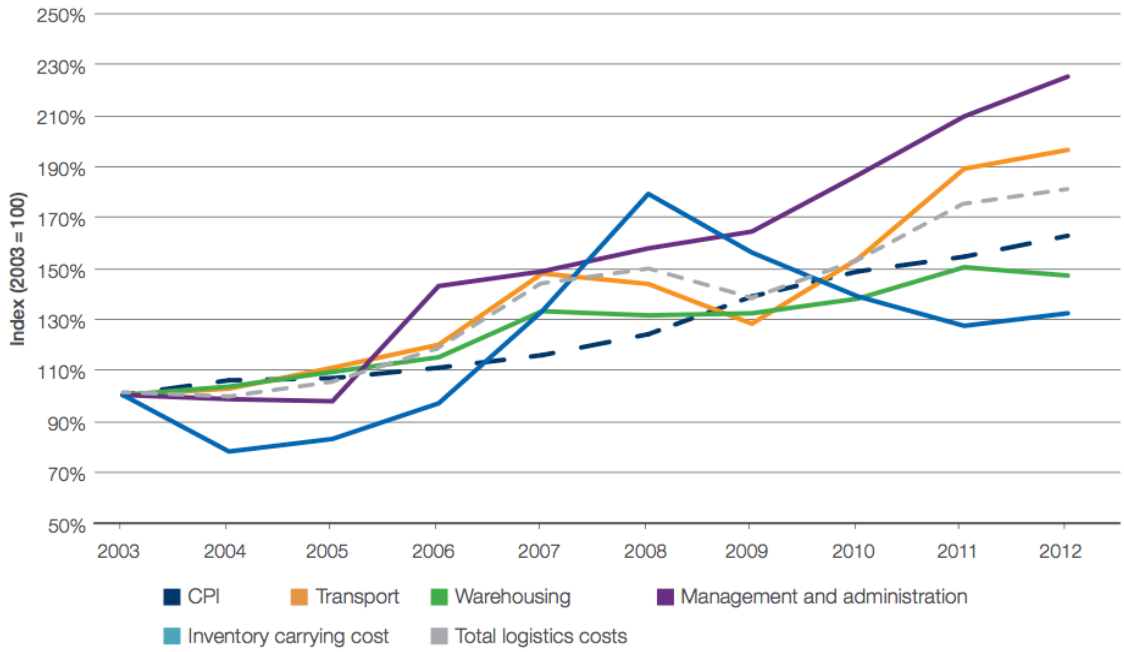


FIGURE 15: GROWTH IN LOGISTICS COST (CSIR, 2014)

Cost increases for rail transport are different to those of road transport. The most common drivers for increased **rail total logistics cost** are electricity, labour, and general tariff hikes by Transnet (which can relate to infrastructure upgrades).

Average Transnet Freight Rail (TFR) increases for 2010 and 2011 were obtained from a news article as 18% and 26% respectively (Business Day, 2012). No reported increases could be found for 2008, 2009 or 2012. For these years, it was assumed that the increases were equal to the national annual average consumer price index (CPI)[11] for the specific year, plus 2%. This resulted in an increase from R0.25 to R0.49 per tonne.km from 2007 to 2012.

These road and rail total logistics cost for 2012 were used to derive transport costs, as explained in section 4.1.5.1. The model simulates total logistics cost through the calculated variables <road total logistics cost>(*<freight owners>)* and <rail total logistics cost>(*<freight owners>)*.

Due to additional packaging, handling and transport requirements, it is assumed that competing freight will be slightly more expensive to transport on rail than rail suitable freight. The percentage cost increase for competing freight is an input parameter in the model (named <cost increase for competing>) that can be adjusted by the user. For the assumed default value, see section 5. This parameter is used to calculate the increase in the <competing rail total logistics cost>(*<freight owners>)* variable based on the <rail total logistics cost>(*<freight owners>)* variable.

[11] Inflation rates obtained from http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa-2013.aspx.

In order to assess changes in **other costs** that impact on the total logistics costs, the main contributing costs according to SOL were used (contributing percentages given in brackets according to 2012 national costs):

- Transport costs (which comprises fuel, wages, depreciation, maintenance, insurance, tyres, toll fees and license fees) (61%)
- Warehousing (14%)
- Management and administration (13%)
- Inventory carrying cost (12%).

Initial transport costs for both road and rail in Year 1 of the model are user specified input parameters (see section 4.1.5.1). From these input values, all other logistics costs for 2012 were derived based on the above percentages of contributing costs in the SOL.

Table 4 summarises the input parameter values and the key calculated variables for the total logistics cost sector.

TABLE 4: TOTAL LOGISTICS COST PARAMETERS AND KEY VARIABLES

<table>
<tr><th>Input parameter
[unit]</th><th>Value</th><th>Adjustable in user interface</th><th colspan="2">Key calculated variables
[unit]</th></tr>
<tr><td rowspan="2"><Road initial transport cost>(<fleet owners>)
[R/tonne.km]</td><td rowspan="2">First adopters: 0.41
Late adopters: 0.37</td><td rowspan="2">Yes</td><td><Road transport cost>(<freight owners>)
[R/tonne.km]</td><td><Road total logistics cost>(<freight owners>)
[R/tonne]</td></tr>
<tr><td><MA initial cost>
[R/tonne]
<Initial warehousing cost>
[R/tonne]
<Inventory carrying initial cost>
[R/tonne.hour]</td><td><Road total logistics cost>(<freight owners>)
[R/tonne]
<Rail total logistics cost>(<freight owners>)
[R/tonne]</td></tr>
<tr><td><Rail initial transport cost>
[R]</td><td>0.15</td><td>Yes</td><td><Rail transport cost>(<freight owners>)
[R/tonne.km]</td><td><Rail total logistics cost>(<freight owners>)
[R/tonne]</td></tr>
<tr><td><Improved efficiency pass-through switch></td><td>see section 5</td><td>Yes</td><td><Road fuel cost>(<fleet owners>)
[fraction]</td><td rowspan="7"><Road transport cost>(<freight owners>)
[R/tonne.km]</td></tr>
<tr><td><Initial fuel price>
[R]</td><td>10.10</td><td>No</td><td rowspan="3"><Road fuel cost>(<fleet owners>)
[fraction]</td></tr>
<tr><td><Crude price forecast>
[2011 US$ values used as index]</td><td>see Figure 17</td><td>No</td></tr>
<tr><td><Additional fuel levy>
[R/litre]</td><td>see section 5</td><td>Yes</td></tr>
<tr><td><Increased road toll fees>
[%]</td><td>see section 5</td><td>Yes</td><td><Road toll fees>
[fraction]</td></tr>
<tr><td><Annual driver wage increase>
[%]</td><td>see section 5</td><td>Yes</td><td><Road driver wage cost>
[fraction]</td></tr>
<tr><td><Road conditions switch></td><td>Switched off (road conditions are “good”)</td><td>Yes</td><td><Maintenance, repair and tyres (MRT) cost>
[fraction]</td></tr>
</table>

Input parameter [unit]	Value	Adjustable in user interface	Key calculated variables [unit]	
<Grid emission factor (GEF)[12] switch>	Switched off (“revised balanced scenario” and “low electricity price” applied)	Yes	<Rail energy cost> [fraction]	<Rail transport cost>*(<freight owners>)* [R/tonne.km]
<Annual labour cost increase> [%]	*see section 5*	Yes	<Rail labour cost> [fraction]	
			<Management and Administration (MA) cost>*(<mode of transport>)* [R/tonne]	<Rail total logistics cost>*(<freight owners>)* [R/tonne] <Road total logistics cost>*(<freight owners>)* [R/tonne]
<Carbon tax switch>	*see section 5*	Yes	<Road transport cost>*(<freight owners>)* [R/tonne.km]	<Road total logistics cost>*(<freight owners>)* [R/tonne]
			<Rail transport cost>*(<freight owners>)* [R/tonne.km]	<Rail total logistics cost>*(<freight owners>)* [R/tonne]
<Road carbon tax switch>	*see section 5*	Yes	<Road transport cost>*(<freight owners>)* [R/tonne.km]	<Road total logistics cost>*(<freight owners>)* [R/tonne]
<Cost increase for competing> [%]	*see section 5*	Yes	<Competing rail total logistics cost>*(<freight owners>)* [R/tonne]	
<Metro road cost relative to corridor > [%]	*see section 5*	Yes	<Rail transport cost>*(<freight owners>)* [R/tonne.km] <Competing rail total logistics cost>*(<freight owners>)* [R/tonne]	

4.1.5.1 Transport cost

The <**road initial transportation cost**>*(<freight owners>)* variable is expressed in R/tonne.km and was derived top-down based on the 61% contribution of transport cost to total logistics cost as provided in the SOL for 2012 (CSIR, 2014). It was further assumed that a gap of 10% in costs exists between the different types of vehicle fleet owners due to the different characteristics of the fleets (see section 3.4.4). The transport cost value is therefore adjusted 5% higher for first adopter fleets and 5% lower for late adopter fleets. The input parameter <road initial transport cost>*(<fleet owners>)* is therefore specified with the 2012 values of 0.41 R/tonne.km for first adopters and 0.37 R/tonne.km for late adopters. The transport costs applicable to each type of freight owner are then calculated based on the <fleet composition> (see section 4.1.1.4).

The <**rail initial transport cost**> input parameter is obtained iteratively using the ratio between the road and rail total logistics cost in 2012 (based on the logistics costs as derived in section 4.1.5). With all other variable costs that impact on the <rail total logistics cost>*(<freight owners>)* fixed for 2012 (see discussions in following sections on how these were derived), the <initial rail transport cost> could be determined as 0.15 R/tonne.km.

[12] GEF is the emissions intensity of power supplied via the electricity grid, measured in tonnes of CO_2 emissions per MWh.

Based on the conceptual routes simulated in the model (see Figure 8), the rail transportation mode will require metropolitan road transport from DC to rail station and again from rail station to DC at the destination. Due to insufficient data, this input parameter is assumption based, for which a base case value is specified in section 5. The **cost of metropolitan road transport** is an input parameter called <metro road cost relative to corridor> that can be adjusted in the user interface. This parameter is a percentage multiplied with the corridor road transport cost to obtain metropolitan cost. The impact of metropolitan transport on cost (in R/tonne of transported freight) is also subject to the <metropolitan distance> as specified in section 5.

Transport costs are further broken down to capture the impact of changes in the transport environment. For road transport, the main contributing components of national road freight transport cost for 2012 were used from the SOL (CSIR, 2014), and are presented in Figure 16.

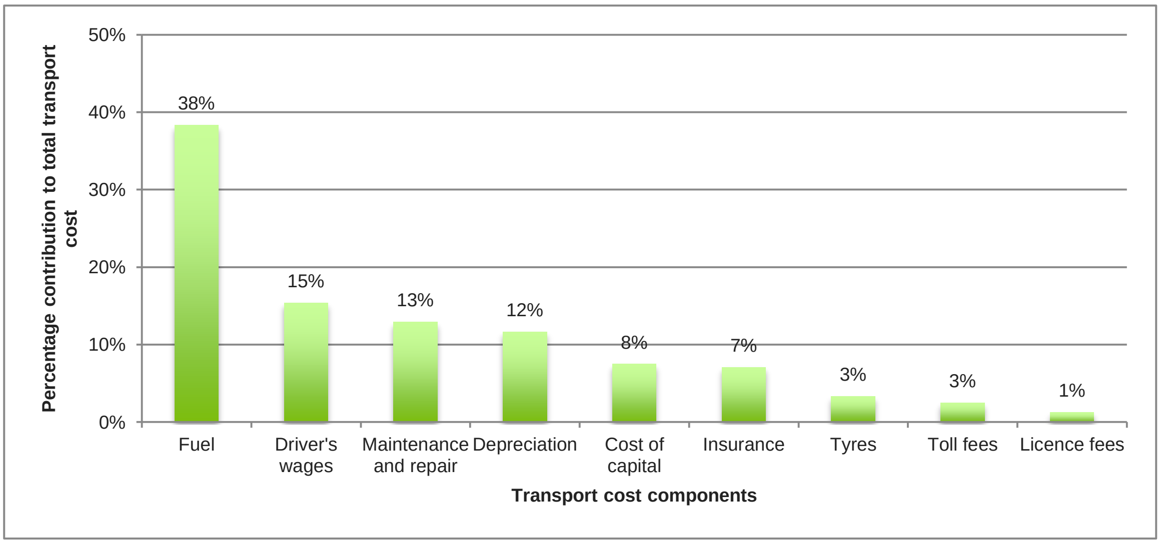


FIGURE 16: COMPONENTS OF NATIONAL TRANSPORT COST IN 2012

Due to the complex **tariff structures of railways**, the breakdown of the rail transport cost is not publically known. Tariffs are normally determined independently from the actual running cost of a rail service, and are influenced by markets, customers, institutional arrangements, pricing regulations and social and economic norms (although things like energy cost, new investments and utilisation of the rail service also impact on tariffs) (PPIAF, 2014). It is therefore difficult to draw a direct link between changes in the rail environment and the tariff charged to the freight owner.

As the simulated corridor operates electric locomotives, and with the recent large increases in **electricity tariffs** in South Africa, the impact of electricity cost on rail transport cost is important. A cost analysis on TFR indicated that energy (fuel and electricity) constituted 19% of the operational cost to the company, and labour 44% (Frost & Sullivan, 2012). These percentages are used to model the contribution of electricity and labour to the <rail transport cost>(*<freight owners>)* variable. It is assumed that all other cost that can impact on rail transport costs will remain unchanged throughout the modelling period. These other costs are grouped and their resultant 37% contribution to the total transport cost assumed fixed over time, resulting in this proportional cost contribution to decrease over time if electricity and labour costs increases.

The **contributing cost components** of the different modes to the transport costs are simulated in the model based on their contributing fractions. The sum of all fractions is multiplied by the mode specific initial transportation cost in 2012. For all these components initial values are specified as input parameters to the model. Some components are assumed to stay fixed over time and will therefore keep their initial value throughout the simulation period, meaning that its proportional cost contribution will decrease if values of other components increase over time. Components that change over time are simulated as variables, with other input parameters and variables affecting the contributing fraction of the component over time.

The components that impact on road and rail transport cost are discussed below, with the mode of transport it applies to indicated in brackets.

4.1.5.1.1 Fuel (road)

The fuel cost component is simulated as the <road fuel cost>(*<fleet owners>)* variable, which is dependent on the fuel consumption (specific to a fleet owner type) and fuel cost.

Fuel consumption is determined in the vehicle fleet module (see section 0). The baseline fuel consumption is the fleet fuel consumption with no additional technology improvements applied (see section 4.2.1). In linking the fuel consumption to the price paid by the freight owner for the transport service, it is assumed that a more efficient fleet will provide a cheaper service. This is however not always true as the first adopter fleets will most likely be more efficient, but also offer a more expensive service – the monetary savings achieved from using less fuel might be offset by other costs such as operational costs to achieve service levels. For this reason a user switch called <improved efficiency pass-through switch> is available to toggle if the efficiency improvements achieved with vehicle fleet technology improvements would be passed through to customers. When switched off (default), the baseline fuel consumption will be used to determine the impact of fuel cost on transportation cost.

The average **diesel price** at the pump in January 2012 was R10.10 per litre, which includes the fuel levy. This price is used as the <initial fuel price> input parameter in the model. Future fuel price fluctuations are governed by the projected crude oil price provided in the 2013 International Energy Outlook (U.S. EIA, 2013) (see Figure 17). Based on 10 years of EIA data from 2031–2040 (where it stops), the price was linearly extrapolated to 2050.

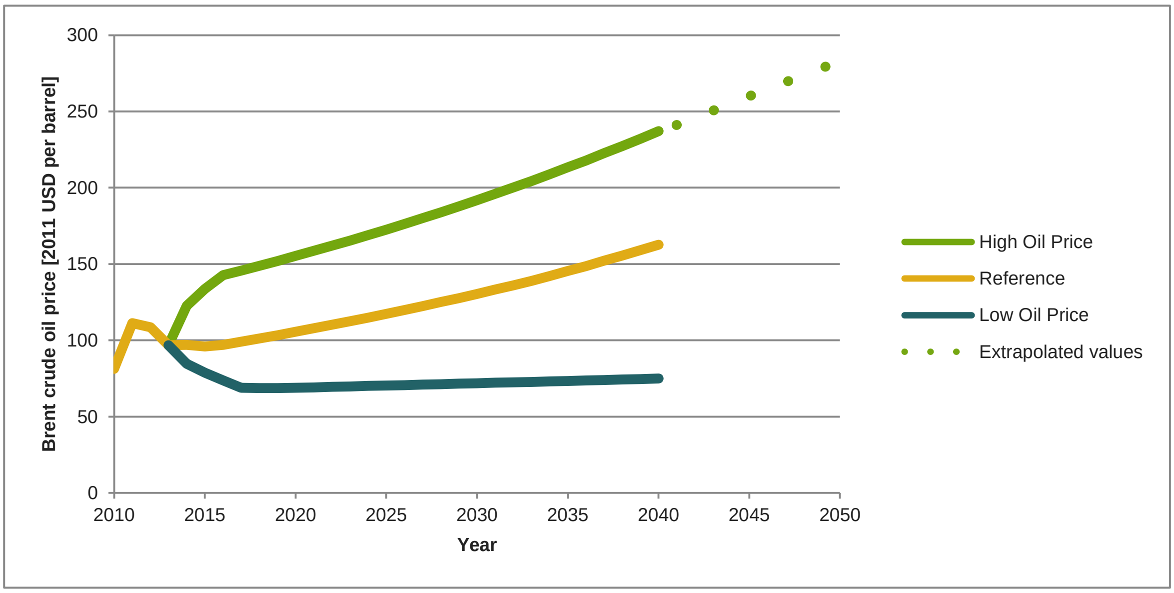


FIGURE 17: PROJECTED CRUDE OIL PRICE (U.S. EIA, 2013)

The “high oil price” scenario in the USA EIA projected crude oil price data was used as this correlates best with the actual historical values of 2012−2014. With using this data to govern future fuel price fluctuations, it is assumed that the fuel price at the pump changes proportionally to international Brent crude oil prices expressed in 2011 US$ per barrel. This inherently also assumes that the fraction that the fuel levy contributes to the pump price stays fixed at approximately 25% as in 2012, and that a change in the exchange rate from 2011 onwards does not affect fuel price.

Another input parameter built into the model that impacts on the <road fuel cost>(*<fleet owners>)* is the <**additional fuel levy**>. This parameter can be used to test the impact of an increase in the fuel levy over time.

4.1.5.1.2 Driver wages (road)

The driver wages component is simulated as the <road driver wage cost> variable. It is impacted by a user specified parameter <annual driver wage increase>, which is a percentage compound growth in driver’s wages (over and above CPI). For the default values/starting points, see section 5.

4.1.5.1.3 Maintenance, repair and tyres (road)

Maintenance, repair and tyres cost (MRT) together account for 16% of road transport cost (CSIR, 2014). **Road conditions** impact on vehicle damages, which form part of MRT costs. For road conditions classified as “good”, vehicle damages are approximately 4% of total cost (de Jager, 2009). If the road condition were to deteriorate to “average”, it can potentially result in the cost of vehicle damages increasing by 684% (de Jager, 2009). In the model, initial road conditions are assumed as “good” and therefore the MRT costs from vehicle damages are 4% of the transport cost. This 4% of MRT is simulated as a variable dependent on road conditions and a user switch called <road conditions switch> is built into the model to test the impact of deteriorating road conditions from “good” to “average”. The remaining 12% associated with MRT cost is assumed fixed in the model.

4.1.5.1.4 Toll fees (road)

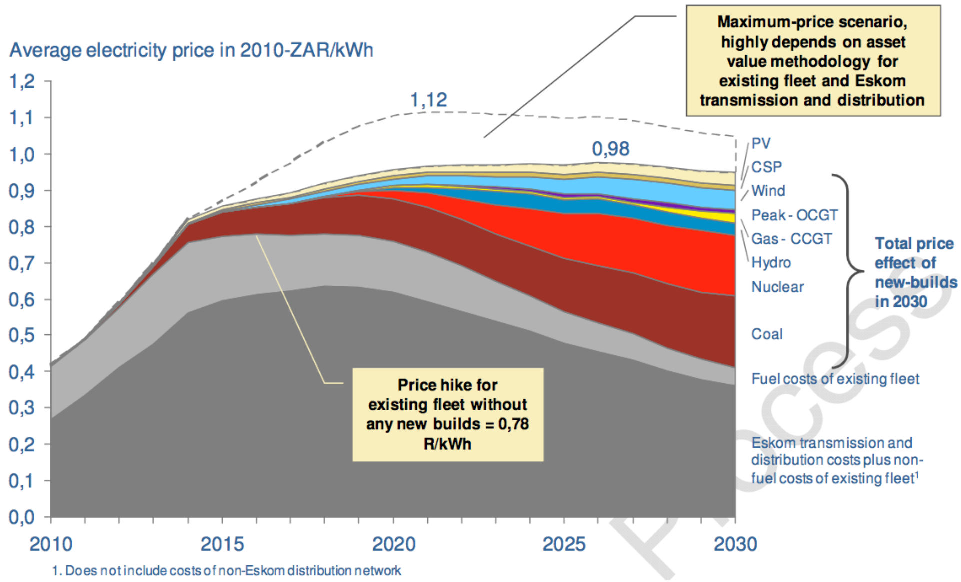
This component is simulated as a variable called “road toll fees”. It is influenced by the user input parameter <increased road toll fees>, which is the annual percentage increase to toll fees. For the default increases as specified in the base case, see section 5.

4.1.5.1.5 Other (road)

Contributions to transport cost from Figure 16 that are assumed to stay fixed for the modelling period are **depreciation**, **cost of capital**, **insurance**, **licence fees**, and the 12% of **MRT** costs (as discussed in section 4.1.5.1.3).

4.1.5.1.6 Electricity (rail)

The **electricity price** in the model is based on the anticipated average electricity price path from the Integrated Resource Plan (IRP) (DoE, 2011), as presented in Figure 18. This projection provides an anticipated average price and a maximum price up to 2030. For the purpose of this model, the anticipated price path is linked with the “Revised Balanced Scenario” build plan and the maximum price path with the “Emission 3” build plan (see section 4.3.2 for more details on the build plans and associated grid emission factors (GEF)). This assumption was made as the “Emission 3” build plan includes more expensive nuclear plants to reduce future emissions.



[13]

FIGURE 18: ANTICIPATED AVERAGE PRICE PATH FROM IRP 2010 (DOE, 2011)

The user can select the **electricity build plan** simulated by means of the <GEF switch>, with the “Revised Balanced Scenario” being the default in the model. Based on the selected build plan, the associated price path will be applied and impact on the <rail energy cost> variable fraction, which in turn will impact on the <rail transport cost>(<*freight owners*>*)*.

4.1.5.1.7 Labour (rail)

<Rail labour cost> is a variable fraction impacted by a user specified parameter <annual labour cost increase>. This input parameter is a percentage compound growth in labour cost. For the default increases as specified in the base case, see section 5.

Apart from the impact of labour cost increases on rail transport cost, management and administration costs (<MA cost>(<*mode of transport*>*)* variable) is also affected by the <annual labour cost increase> parameter. This impact is discussed in section 4.1.5.3.

4.1.5.1.8 Carbon tax

If the South African carbon tax is implemented[14] it might become another component that contributes to road and rail transport costs. The tax does not feature yet in the SOL or Transnet cost breakdowns, but is included in the model to test the effects of the carbon tax on modal shift decisions. It is added as a R/tonne.km value to the transport cost of the specific mode it applies to. A “carbon tax switch” is available in the model to toggle to include or exclude a carbon tax from a model run. In addition, switches are available (<road carbon tax switch>(<*freight owners*>*)*) to toggle if the carbon tax will apply to a specific freight owner utilising road transport. See section 4.3.7 for more details on how carbon tax is simulated and section 5 for default values used in the base case.

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[13] “Fleet”’ in Figure 18refers to Eskom’s fleet of power plants. PV = photovoltaic solar power; CSP = concentrated solar power; OCGT = open cycle gas turbine.

[14] As at August 2016 Treasury is considering stakeholder comments made to the Davis Tax Committee, and company “carbon budgets” are also on the cards. WWF’s May 2015 *Submission to Davis Tax Committee on the Carbon Tax* is available (accessed 5/8/2016) at http://awsassets.wwf.org.za/downloads/wwfs_position_on_carbon_tax___submission_to_davis_tax_committee___final_media.pdf.

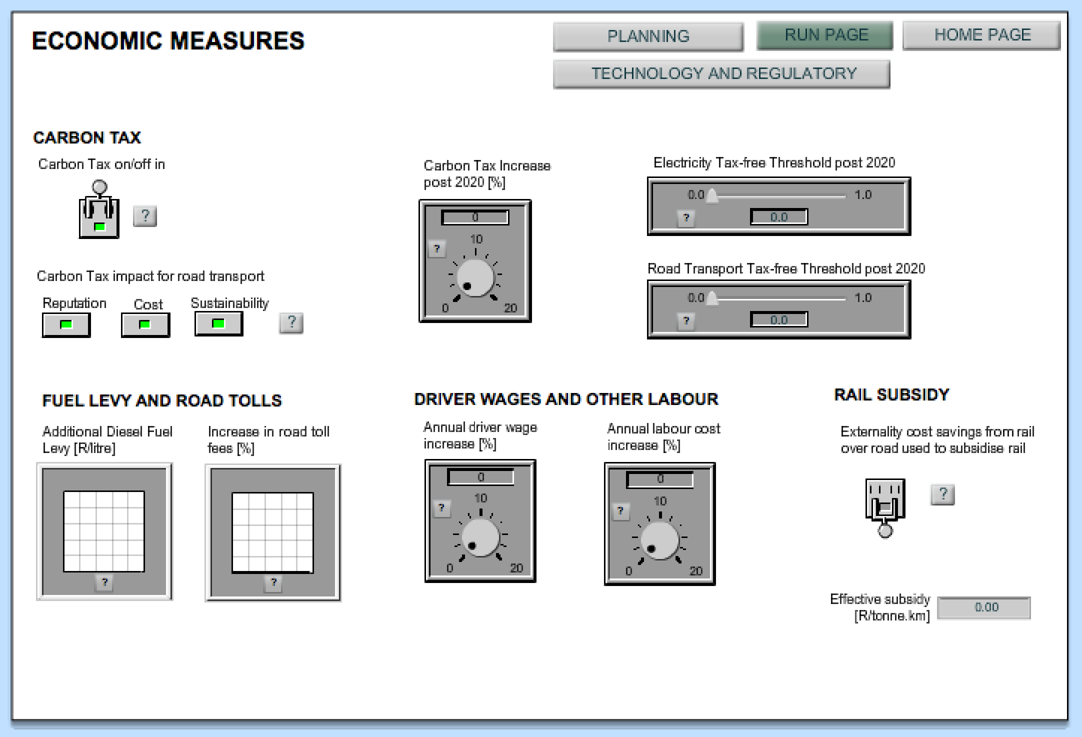


FIGURE 19: MODEL INTERFACE SCREEN WHERE PARAMETERS RELATING TO TRANSPORT COST CAN BE ALTERED

The parameters set on this screen impact on the cost of transport, and other than labour cost increases, capture **economic measures** which government could undertake, which have implications for climate change mitigation.

- To 2020, the proposed carbon tax is R120/tonne CO2e. For the tax rate after 2020, swivel the **dial** to specify the percentage increase per annum.
- Due to policy uncertainty at the time of model construction, the sliders and switches can be used to fine tune its application in the model:
  - Up to 2020, the proposal is that companies emitting less than a threshold of 0.1 megatonnes CO_2e per annum will be exempt from the carbon tax. Move the **sliders** to adjust the post-2020 threshold down from 0.1 up to 0. Separate sliders for electricity and road cater for different possibilities of how the tax might be applied, for example to Eskom or fleet owners.
  - The toggle **switches** “Carbon tax impact for road transport” can be used to fine tune its application in the model. An “up” switch (goes green) means the carbon tax will impact to raise the cost of that freight owner type’s use of road transport, for example if the fleet owner passes through the tax or if the freight owner’s Scope 2 emissions are taxed.
- Click on the **graphs** to get a pop-up graph, with labels, scale and values of the vertical axis (horizontal axis is the 39-year model period). Edit points to specify the increase in the fuel levy in R/litre from R0 to R10/litre, and the percentage increase in road tolls from 0 to 1000%.
- Rotate the **dials** for truck driver wage increases, and other labour cost increases (for rail labour, and for management and administration work required by both modes), to allow for annual increases of between 0 and 20%. If switched up (goes green), the “Rail subsidy” toggle switch allows for the externality costs saved to the economy through shifting freight from road to rail to be redirected to subsidise rail transport. This mimics a form of “revenue recycling” to a public entity.

HOW TO

4.1.5.2 Warehousing

Warehousing cost is a combination of the cost to store and handle freight during transfers. The time to store freight is dependent on the reliability of freight shipments, and the handling time depends on the efficiency of DCs and intermodal points.

The initial **warehousing cost** for road is R124 per tonne, based on its 14% contribution to total logistics cost and the travel distance of 1 400 km. With rail transport having to make use of intermodal points for transferring of freight from trucks to rail, and back on to trucks, warehousing requirements were assumed to initially be 50% more than that of road, at R186 per tonne. As efficiency of these intermodal points improves over time, warehousing requirements and associated costs will shrink. Improvement is driven by the <improved rail operational performance> as discussed in section 4.1.1.2.3. The minimum possible value for rail warehousing cost relative to road as a result of improved intermodal transfers is 10% (i.e. if 100% improvement in the performance of intermodal transfers is made, the warehousing cost of rail will be 10% higher than that of road).

As mentioned, warehousing is also influenced by the **reliability of shipments**, which in this model is modelled as punctuality (the percentage of freight that is delivered on time, see section 4.1.4.3). The lower the punctuality (i.e. longer delays that are less predictable), the more freight will need to be stored due to larger buffer stock requirements. For road freight, the initial warehousing cost of R124 per tonne is assumed to be applicable to the sustainability-focused decision maker as this decision maker by default utilises a balanced road fleet (50% first adopters and 50% late adopters, see section 5). Warehousing costs of other freight owners for road freight are adjusted based on their punctuality relative to that of the sustainability-focused decision maker. For rail freight the punctuality is the same for all decision makers, but the change in punctuality over time (section 4.1.4.3) will change the warehousing cost for rail.

4.1.5.3 Management and administration

The management and administration (MA) cost for road is R111 per tonne, based on its 13% contribution to total logistics cost and the travel distance of 1 400 km. This cost value is assumed to be the same for rail transport.

It is assumed that 50% of the total MA cost is for labour. Thus the <annual labour cost increase> input parameter provided (as discussed in section 4.1.5.1.7) also impacts on the <MA cost>(*<mode of transport>)* variable.

4.1.5.4 Inventory carrying cost

Inventory carrying cost is a component of the total logistics cost that includes the opportunity cost of capital and the cost associated with insurance and damages to freight. According to de Jager (2009), inventory carrying cost for the economy can be split into the cost while freight is in transport (11%) and that while freight is in storage (89%) (de Jager, 2009). This split is used in the model to allocate road inventory carrying cost in 2012, and resulted in the different carrying costs contributing to road total logistics cost as follows:

- Carrying cost in transit: 1%
- Carrying cost in storage: 11%

The time freight spends in storage is not explicitly simulated in the model as this is a variable that is subject to the specific freight owner's business model. It is calculated in the model as a variable relative to road travel time, and differs by type of decision maker and mode of transport. Time in storage is a function of the punctuality of the freight transport mode. The lower the punctuality (longer delays that are less predictable) the larger the buffer stock required at DCs and warehouses, which will lead to larger inventory carrying cost in storage.

In the absence of actual information, the initial road freight **storage time** was calculated by making the assumption that the proportion of storage time to total road travel time is equivalent to the ratio of the costs of transit to the carrying cost in storage. Using the figures presented in section 4.1.1.2, the initial road freight storage time was estimated at 185 hours. For road freight, this initial freight storage time is assumed to be applicable to the sustainability-focused freight owner as this decision maker by default utilises a balanced road fleet (50% first adopters and 50% late adopters, see section 5). The other two types of freight owners will have different compositions of the road fleet they use, with related punctualities, thus storage time is adjusted based on punctuality relative to that of the sustainability-focused decision maker's road fleet's punctuality.

The initial **inventory carrying cost** of freight is calculated as R0.53 per tonne.hour, based on the contribution of carrying cost in transit to total logistics cost, the road travel distance, and road travel time in 2012. This initial inventory carrying cost is fixed in the model and used with the total travel time per mode (which includes delays) and the freight storage time to calculate the different inventory carrying costs for the different modes of transport.

Photo www.made4net.us/solutions/wms/wms-for-sap-b1

4.2 Vehicle fleet module

This module simulates the change in the average fuel consumption of trucks utilised for road transport over time. The current fuel consumption of the average vehicle fleet and its anticipated improvement over time (based on literature) is assumed as the baseline. Changes to this baseline resulting from the implementation of improved vehicle technologies, driver training, or the utilisation of biodiesel are simulated. The calculated fuel consumption impacts on road logistics cost, emissions, and water consumption.

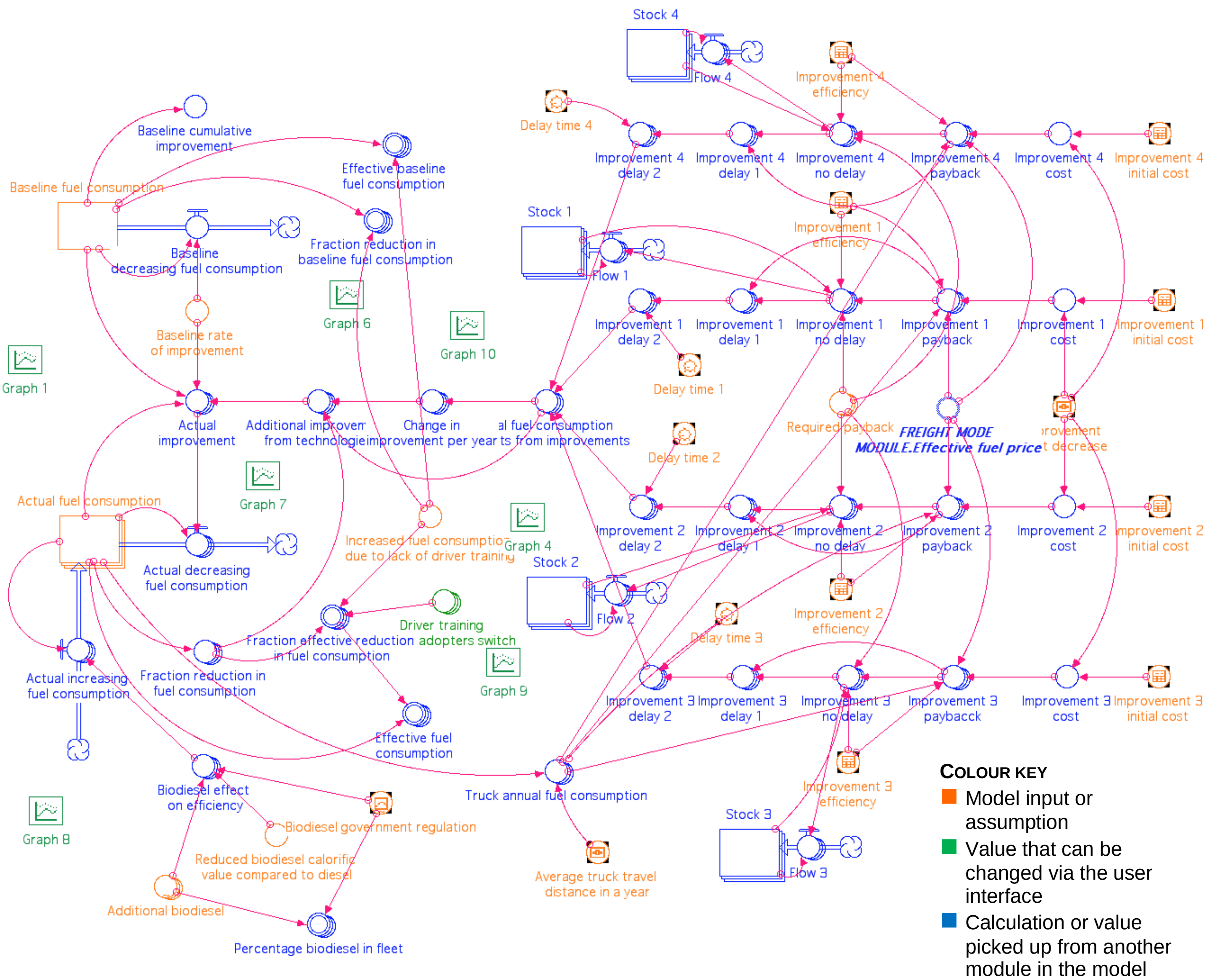


FIGURE 20: STRUCTURE OF VEHICLE FLEET MODULE

Table 5 summarises the input parameter values and the key calculated variables for this module.

TABLE 5: VEHICLE FLEET MODULE PARAMETERS AND KEY VARIABLES

Input parameter [unit]	Value	Adjustable in user interface	Key calculated variables [unit]
<Improvement initial cost> [R]	*See Table 6 for costs related to improvements*	Yes	<Improvement payback>(*<fleet owners>)* [years] <Total fuel consumption benefits from improvements>(*<fleet owners>)* [fraction]
<Improvement cost decrease> [%]	*Base case value provided in section 5*	Yes	
<Improvement efficiency> [fraction]	*See Table 6 for fuel consumption benefits related to improvements*	Yes	
<Required payback>(*<fleet owners>)* [years]	First adopters: 1 Late adopters: 0	Yes	
<Average truck travel distance in a year> [km]	*Base case value provided in section 5*	Yes	
<Delay time 1> [years]	1	Yes	<Total fuel consumption benefits from improvements>(*<fleet owners>)* [fraction]
<Delay time 2>, <Delay time 3>, <Delay time 4> [years]	6	Yes	
<Baseline fuel consumption (initial value)> [litre/100 km]	39.1	No	*Used for calculating output indicators*
<Baseline rate of improvement> [fraction]	0.01	No	<Baseline fuel consumption> [litre/100 km]
<Increased fuel consumption due to lack of driver training> [fraction]	0.06	No	<Baseline fuel consumption> [litre/100 km] <Actual fuel consumption (initial value)>(*<fleet owners>)* [litre/100 km]
<Actual fuel consumption (initial value)>(*<fleet owners>)* [litre/100 km]	39.1	No	-
<Driver training for late adopters switch>	Switched off (Late adopter fleets don't receive training)	Yes	<Baseline fuel consumption> [litre/100 km] <Actual fuel consumption (initial value)>(*<fleet owners>)* [litre/100 km]
<Biodiesel government regulation> [%]	0-10% (see section 4.2.2.3)	No	<Actual fuel consumption>(*<fleet owners>)* [litre/100 km]
<Additional biodiesel>(*<fleet owners>)* [%]	*Base case value provided in section 5*	Yes	
<Reduced biodiesel calorific value compared to diesel> [%]	8	No	

4.2.1 *Baseline fuel consumption*

The <baseline fuel consumption> variable is based on the ERC's vehicle parc model in which heavy commercial vehicles (HCV) carry an average of 15 tonnes per load and consume diesel as fuel (Merven et al., 2012). According to this research, the average fuel consumption of HCVs on the road in 2010 was 39.1 litres per 100 km, with an expected average annual improvement of 1%. This latter value is used as the <baseline rate of improvement> variable in the model. The <baseline fuel consumption> is used for calculating indicator outputs in the business as usual (BAU) case simulation (see section 0).

4.2.2 *Actual fuel consumption*

It is assumed that the 1% annual improvement in vehicle fuel consumption in the baseline is only as a result of gradual improvement in vehicle technology, i.e. only new vehicles that come into operation will lower the average fuel consumption of the fleet. Over and above this, fuel consumption can also change if the fleet owner can afford the early uptake of improved vehicle technologies, driver training, or use biodiesel as fuel. The effects of these changes are simulated as the <actual fuel consumption>(*<fleet owners)*> variable, which ultimately impact on road total logistics cost and emissions.

The actual fuel consumption is simulated separately for each type of fleet owner company (First Adopters and Late Adopters, see section 3.4.4). Different characteristics of the companies will result in different decisions regarding the implementation of vehicle improvements, driver training, or biodiesel.

4.2.2.1 Vehicle improvements

Vehicle technology improvements considered in the model are over and above the gradual default 1% <baseline rate of improvement> in fuel consumption. If a technology improvement is implemented, and the actual fuel consumption variable is reduced below the baseline fuel consumption, the 1% annual improvement will not apply any more. The lower actual fuel consumption variable will remain unchanged over time (assuming no subsequent improvements are adopted) until the baseline fuel consumption variable reaches the same value as the actual fuel consumption variable, where after the default baseline improvement of 1% per annum will re-apply.

Specific technology improvements, their effect on truck fuel efficiency, and the capital cost of implementation are based on 2009 data from the American National Research Council for Class 8 trucks[15] (Transportation Research Board, 2010). This data was estimated for improvements to be implemented between 2015 and 2020. The capital costs in US$ were converted to Rand based on the average exchange rate in 2009[16], and inflated using CPI[17] for South Africa to 2012 Rand values. Cost and fuel consumption benefits of technology improvements used in the modelling are presented in Table 6.

[15] Class 8 trucks have a minimum gross vehicle weight of 15 tonnes, so also most tractor trailer trucks used as heavy commercial vehicles.
[16] Exchange rates obtained from http://www.x-rates.com/average/?from=ZAR&to=USD&year=2009, averaged over all 12 months in 2009.
[17] Inflation rates obtained from http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa-2013.aspx.

TABLE 6: VEHICLE TECHNOLOGY IMPROVEMENTS (TRANSPORTATION RESEARCH BOARD, 2010)

Category	Description	Fuel consumption benefit [%]	Capital cost [US$, 2009]	Cost per reduction [US$/%]	Capital cost [R, 2010]	Improvement classification in model
Tyres	Improved wide base single tyres on tractor and 3 trailers	11	3 600	327	34 389	Improvement 1
Transmission	Automated manual transmission, reduced driveline friction	7	5 800	829	55 404	Improvement 2
Aerodynamics	Improved SmartWay tractor and 3 aerodynamic trailers	11.5	12 000	1 043	114 629	Improvement 3*
Engine improvements	Advanced 11–15 litre diesel with bottoming cycle	20	23 000	1 150	219 705	
Hybrid	Mild parallel hybrid with idle reduction	10	25 000	2 500	238 809	Improvement 4

*Based on how similar the "cost per reduction" are for aerodynamics and engine technology improvements, these interventions were grouped in the model to have a combined fuel consumption benefit of 31.5% at a capital cost of R334 334.

The capital costs of technology improvements in Table 6 will most likely decrease over time as technology advancements are made. The rate of decrease can be specified as an input parameter, called <improvement cost decrease>, which is expressed as a percentage cost decrease per year. See section 5 for the base case value.

4.2.2.1.1 Payback period

A fleet owner investing in new technology requires that savings or other gains made from the investment must justify the investment over time. The required payback period is what a fleet owner can tolerate before the investment must pay for itself, through the fuel savings achieved. The <required payback>(*<fleet owners>)* is an input parameter that can be specified per type of vehicle fleet company. Interaction with vehicle fleet owners suggested that late adopter companies will most likely not consider new technologies and will experience fuel consumption improvements only as trucks are normally replaced over time. First adopters are more open to technology improvements provided that payback is within a year. For this reason the default required payback value for first adopters is 1 year, and that of late adopters is 0.

The viability of a fleet owner implementing the added improvements in Table 6 is determined in the model based on the calculated <improvement payback> variable and the required payback. The improvement will only be implemented if the <improvement payback> meets or is better than (i.e. equal to or less than) the <required payback>(*<fleet owners>)*. An <improvement payback> variable is calculated for each type of vehicle improvement technology and per fleet owner type. It is based on the <improvement initial cost> (which is the capital required to implement the improvement) and <improvement efficiency> (which is the fuel consumption benefits associated with the technology improvement) input parameters, and the <fuel price> (see section 4.1.5.1.1) and <truck annual fuel consumption>(*<fleet owners>)* variables. The <truck annual fuel consumption>*(<fleet owners>)* variable is calculated using the <actual fuel consumption>*(<fleet owners>)* variable and an <average truck travel distance in a year> input parameter, for which a default is specified in section 5.

4.2.2.1.2 Phase-in period

Once an improvement becomes viable to implement, it will most likely be phased in across the fleet over time. This phase-in period is simulated in the model as a first-order material delay. The delay duration for this function is an input parameter called <delay time>. This parameter is the time it takes to phase in a specific technology improvement over the entire fleet and is subject to the lifetime of the equipment the improved technology is aiming to replace, as it is assumed that equipment will only be replaced at the end of its life.

Tyres are replaced annually, and therefore it is assumed that Improvement 1 will be implemented across the entire fleet within a year. All other improvements relate to the engine or drivetrain, which are rarely retrofitted on trucks in operation and will most likely only be implemented when trucks are replaced. It is assumed that the lifetime of a truck is 6 years, and therefore Improvement 2 to Improvement 4 will be phased-in over the entire fleet within 6 years of becoming viable.

4.2.2.1.3 Realising fuel consumption benefits

The technology improvement with the lowest payback period will be adopted first, and as subsequent improvements are added, these will apply to the already reduced fuel consumption (not the baseline fuel consumption). The <total fuel consumption benefits from improvements>*(<fleet owners>)* variable ($P_{overall}$) that can be realised is therefore not simply the sum of the individual <improvement efficiency> parameter benefits (p) as in Table 6, but are calculated as follows (Transportation Research Board, 2010):

$$1 - P_{overall} = (1 - p_1)(1 - p_2)\ldots(1 - p_n)$$

The <actual fuel consumption>*(<fleet owners>)* variable is used to calculate the <road logistics cost> (subject to the <improved efficiency pass-through switch> as discussed in section 4.1.5.1.1), which means that if improvements are implemented, the effect of the improvement will be felt immediately by the freight owner utilising road transport (logistics cost will reduce as a result of reduced fuel consumption). In reality, if the fuel savings from an implemented technology improvement is used to reduce the transport cost to the customer (freight owner utilising road transport), it will most likely only be after the savings have paid off the capital cost of the technology. A delayed value using a time lag equal to the payback period is used to simulate this. The effect is that once a technology is implemented, the fuel consumption benefit will only impact on the actual fuel consumption variable after the payback period time. This will result in a slight over estimation of emissions associated with fuel consumption, but a more accurate road logistics cost, which in turn is an important variable for the decision making process on mode selection (see section 4.1.3).

4.2.2.2 Driver training

Driver training is the most cost effective intervention to reduce fuel consumption and is currently implemented by most logistics companies and large fleets[18]. First adopter companies are assumed here to have dedicated training programmes and tracking in their trucks to monitor driver behaviour. This is however assumed not to be the case with smaller companies and drivers that own and operate their own truck. It is therefore assumed that all first adopter fleets already have driver-training programmes and all late adopters do not provide driver training. An input parameter called “driver training for late adopters switch” is provided in the model interface to simulate the impact of diver training for late adopter fleets.

Driver training can result in fuel savings of between 1.9 and 17% depending on the truck and the conditions – there are higher potential saving in urban driving conditions (National Research Council, 2012). To be consistent with potential savings throughout the modelling, a 6% savings for driver training was used ((Transportation Research Board, 2010), being the same source as for Table 6).

The baseline and actual fuel consumption variables simulated are the technical capability of the trucks, and therefore a lack of driver training is simulated as a penalty to these consumption values. Thus the value of savings for driver training is added as the <increase fuel consumption due to lack of driver training> input parameter, which is removed when the <driver training for late adopters switch> is flipped.

[18] From stakeholder consultations with vehicle fleet owners.

4.2.2.3 Biodiesel

A review article on the effect of biodiesel on engine performance and emissions indicated that the majority of the studies reviewed concluded that an engine fuelled with biodiesel will have a higher fuel consumption due to the lower heating value of biodiesel compared to petroleum diesel, and that this increase in fuel consumption is proportional to the loss in the heating value (Xue et al., 2011). The net calorific value of biodiesel is 8% lower than that of petroleum diesel on a per volume basis (Defra, 2013). This value is used in the modelling for the <reduced biodiesel calorific value compare to diesel> input parameter, which is used to simulate the impact that a specified volume of biodiesel in the fuel mix has on the <actual fuel consumption>*(<fleet owners>)* variable.

- The volume of biodiesel in the fuel mix is specified by two input parameters in the model:
- <biodiesel government regulation>, which is government's minimum blending requirement
- <additional biodiesel>*(<fleet owners>)*, which is biodiesel over and above government requirements.

The governmental requirement is based on the Biofuels Industrial Strategy of the Republic of South Africa, in which a 5-year pilot phase, covering 2008 to 2013, was approved to achieve 2% biofuel penetration levels in the national fuel mix (Department of Minerals and Energy, 2007). The Biofuels Industrial Strategy has not been implemented, and in an attempt to advance the first phase of implementation of the strategy, government published the draft position paper on the South African Biofuels Regulatory Framework on 14 January 2014 (Department of Energy, 2014). This has also not resulted in any outcomes to date.

For modelling purposes, the government's position on the minimum requirements for biofuel in the national fuel mix is assumed to initially follow the pilot phase as proposed in the Biofuels Industrial Strategy (2% from 2015 to 2020) and then increase 0.5% annually up to a maximum of 10%.

The <additional biodiesel>*(<fleet owners>)* is a user input that can be specified per fleet owner company in the user interface. The default values are provided in section 5.

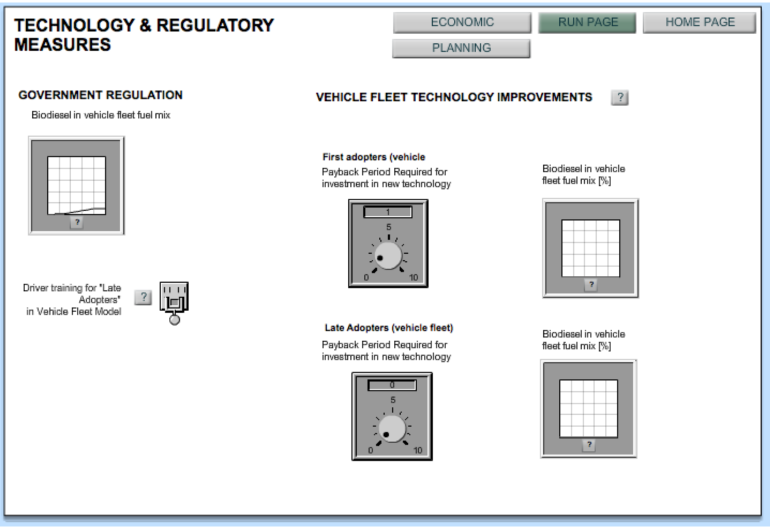


FIGURE 21: MODEL SCREEN WITH PARAMETERS THAT IMPACT ON FUEL CONSUMPTION

Set the regulated percentage of biofuel in the fuel blend using the graph at top left.

The rest of the parameters set on this screen capture the uptake of lower-carbon **technologies** by fleet owners, First Adopters above and Late Adopters below.

HOW TO

- Rotate the **dials** to set the payback period from 0 to 10 years as tolerated by the fleet owner.
- Click on the **graphs** get the pop-ups with labelled axes. The extra percentage (above the regulated minimum) of biodiesel that the fleet owner type incorporates in their fuel mix can be set from 0 to 2% at any point over the period.
- It is assumed that First Adopters are already doing driver training for lower fuel consumption, while Late Adopters are not. Click the "Driver training" **switch** up to bring this training into Late Adopter fleets.

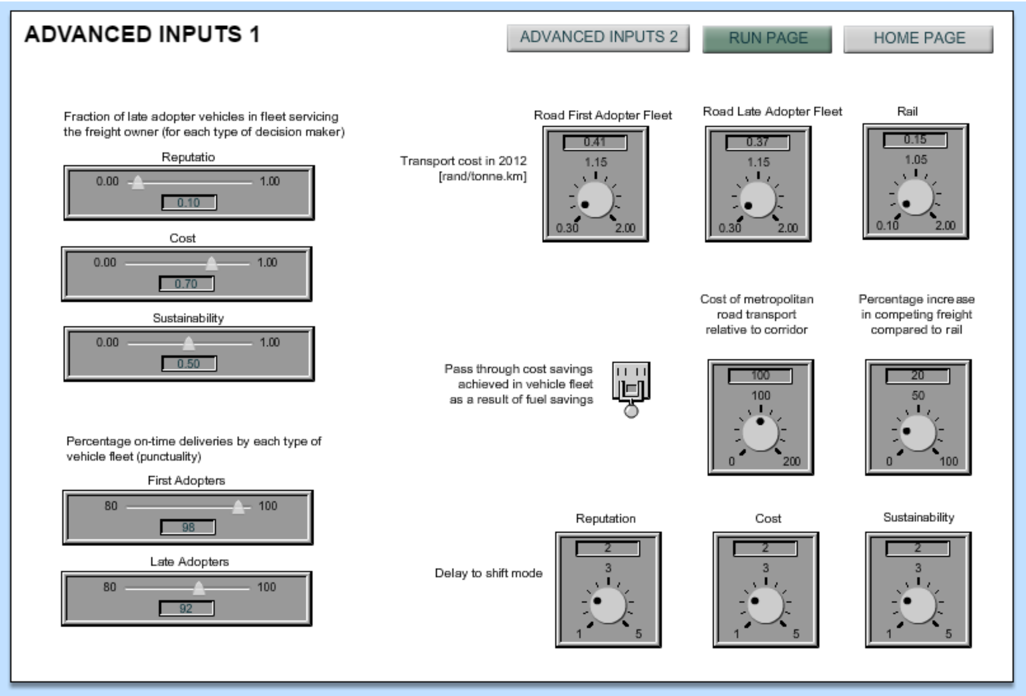


FIGURE 22: FIRST MODEL INTERFACE SCREEN WHERE ADVANCED INPUTS CAN BE ENTERED

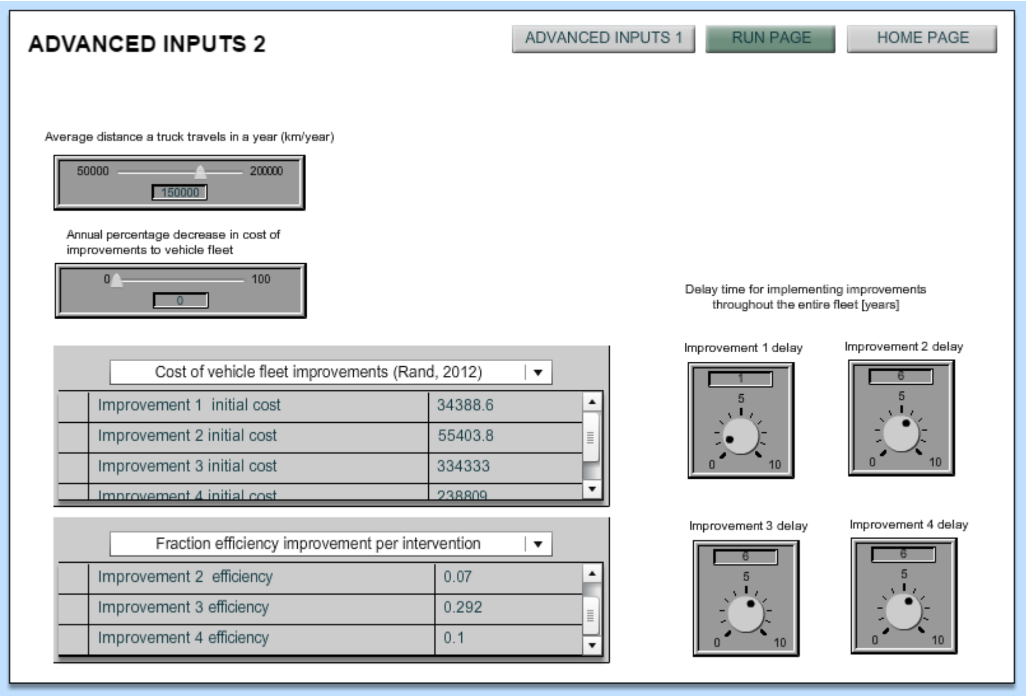


FIGURE 23: SECOND MODEL INTERFACE SCREEN FOR ADVANCED INPUTS

4.3 Indicators module

The model runs the dynamic system constructed as above, the decision makers (freight and fleet owners) make decisions, and the ultimate outputs are the impacts of those decisions on the following indicators:

- Greenhouse gas (GHG) emissions (Scope 1 and Scope 2)
- Other lifecycle GHG emissions
- Water consumption
- Externality cost
- Jobs.

All the output indicators from the model are calculated in this module. Each indicator is discussed under subsequent headings. In addition to the output indicators listed above, the carbon tax is also discussed under this module, as it is levied on calculated GHG emissions.

4.3.1 Business As Usual (BAU) case

In order to comparatively evaluate outcomes of each model run, a BAU case had to be established and outcomes for the BAU case calculated in parallel to the model outputs. The BAU scenario means that decisions of freight owners are fixed in a certain state reflecting the “current reality” (as understood), and do not change in response to interacting factors in the model. That allows the user to change parameters and variables and see how the system responds differently to what otherwise would have been the case, measured in terms of the indicators.

In this manual, a base case simulation is then run to compare to the BAU (see section 5). A set of sensitivity analyses is also conducted (see section **Error! Reference source not found.**).

The following assumptions are made for the BAU case:

- The starting ratio of freight (tonnes) on rail versus road as at 2012 stays fixed throughout the simulation period (see section 4.1.2.1)
- All rail freight belongs to cost-focused freight owners throughout the period, as the BAU will not consider dynamic decision making and cost-focused decision makers would usually be the first to move their freight on to rail (see section 3.4.3)
- The baseline fuel consumption is used for calculating road transport indicators (i.e. no technology improvements or biodiesel) (see section 5)
- Eskom’s Revised Balanced Scenario for electricity supply is used for the electricity grid emissions factor (GEF) (see section 4.1.5.1.6).

4.3.2 GHG emissions

GHGs are the gases that contribute to global warming and hence climate change. For comparability, their climate forcing effect is converted to “carbon dioxide equivalent” (CO_2e), as carbon dioxide is the most common GHG.

Direct (Scope 1) and energy indirect (Scope 2) emission sources are considered for the GHG emissions associated with transport. Other lifecycle emissions associated with the transport operations are also included in the model, and discussed in section 4.3.3.

For road transport, the major emission source is the **combustion of fuel** during transport, and this is the only source included (Scope 1 emissions). The total fuel volume (in litres) consumed in a year is calculated from the average truck fuel consumption (in litres per 100 km, see section 4.2.2) and kilometres travelled by trucks on the road. The kilometres travelled are calculated from the tonnage of freight transported on road and the loading capacity of the average truck, which is an input parameter with a value of 15 tonnes[19]. The emissions are then calculated from the total fuel volume variables via an emissions factor for each type of fuel (Defra, 2013):

- Diesel: 0.002605 tonne CO2e/litre
- Biodiesel[20]: 1.87x10-5 tonne CO_2e/litre.

All rail locomotives operating on the simulated corridor are electric and emissions associated with the **generation of electricity** are the only source included for rail (Scope 2 emissions). An energy intensity of 23.6 GWh/billion tonne.km[21] is specified as an input, used in the model to estimate electricity consumption associated with rail transport. The electricity grid emissions factor (GEF) used to calculate the emissions from electricity consumption depends on the power stations supplying the national grid. The South African national grid future build plans and associated GEFs up to 2030 are supplied in the Integrated Resource Plan (IRP) (DoE, 2011). GEFs for two of these build plans are included in the model as input parameters (see Figure 24):

- Revised Balanced Scenario: default option in model
- Emission 3: build plan with the lowest future emissions.

Selection of the build plan simulated in the model is discussed in section 4.1.5.1.6.

As these IRP build plans are only projected up to 2030, conservative straight-line estimates were constructed to 2050 based on the data from 2021 to 2030.

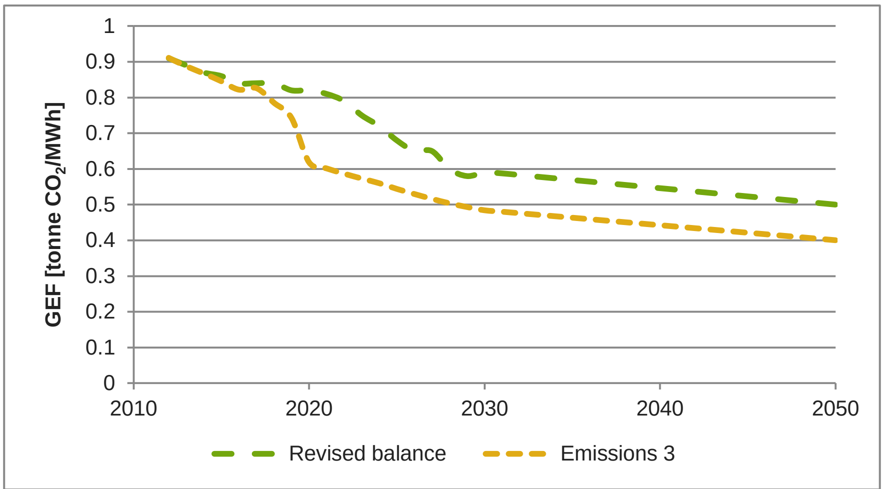


FIGURE 24: GEF FORECAST BASED ON IRP (DOE, 2011) AND EXTRAPOLATED TO 2050

The cumulative emissions are calculated and compared to that of the BAU case to obtain the total emission savings associated with the base case simulation being conducted.

[19] This loading capacity is similar to that of the data used for the baseline fuel consumption (based on higher calorific value (HCV), see section 5) and the technology improvements (based on Class 8 trucks section 4.2.2.1).
[20] This value is for the N_2O and CH_4 emissions, which are not absorbed during the growth of the bioenergy sources (plants and other).
[21] Obtained from a confidential data source, based on ERC modelling (Merven et al., 2012) and Transnet electricity consumption data for 2011/2012.

4.3.3 Other lifecycle GHG emissions

Other lifecycle GHG emissions are emissions additional to those discussed in section 4.3.2, and entail emission sources associated with the lifecycle of the transport service. A software tool, SimaPro[22], was used with data from the ecoinvent database[23] to calculate the lifecycle emissions associated with road and rail transport. The factors included as input parameters in this model are presented in Table 7.

TABLE 7: OTHER LIFECYCLE EMISSION FACTORS

Emission source	Value	Units	Description
Production of South African diesel mix	1.700	kg CO_2e/kg	GHG emissions associated with the production of the South African diesel mix, which consists of domestically refined diesel, imported diesel and SASOL diesel
Production of biodiesel from soybean oil	3.212	kg CO_2e/kg	GHG emissions associated with the production of biodiesel from soybean oil
Other freight road life cycle emissions	0.034	kg CO_2e/tonne.km	GHG emissions associated with production and maintenance of road and trucks allocated to a tonne of goods transported over a km
Lifecycle emissions related to coal electricity	0.071	kg CO_2e/kWh	GHG emissions associated with mining and beneficiation of coal
Other freight rail life cycle emissions	0.021	kg CO_2e/tonne.km	GHG emissions associated with production and maintenance of railway track, locomotive and goods wagon allocated to a tonne of goods transported over a km

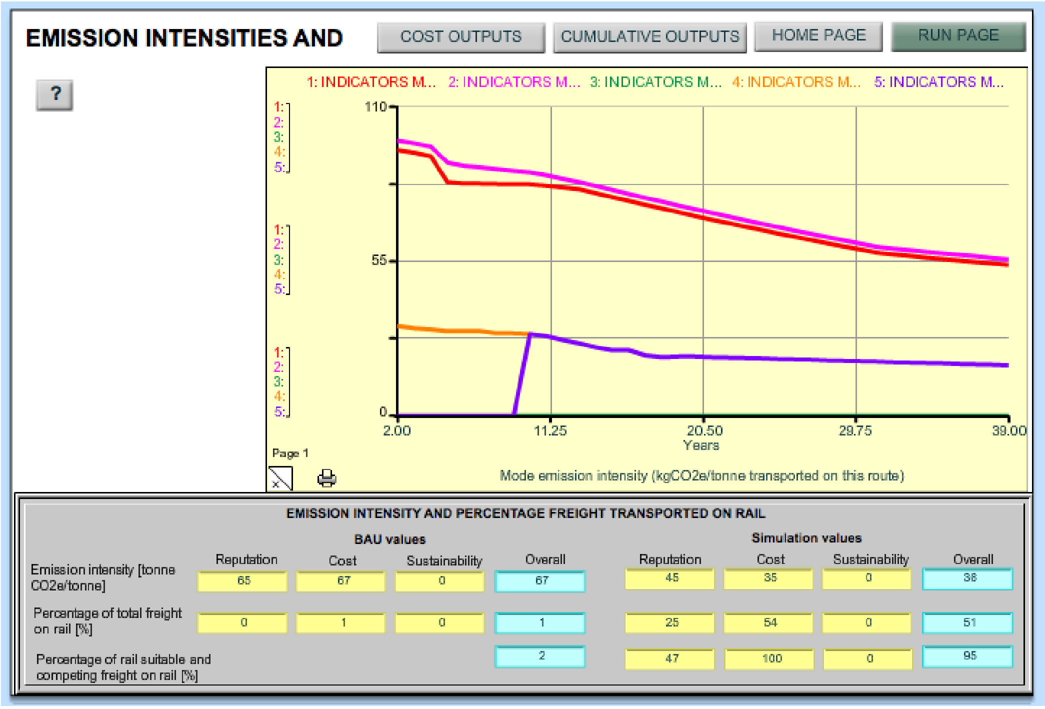
To convert the fuel emission factors by weight in Table 7 to volume, the following densities were used (Defra, 2013):

- Diesel: 0.832 kg/litre
- Biodiesel: 0.88 kg/litre.

The percentage of coal electricity on the grid is calculated as a variable and the <coal electricity related lifecycle emissions> are only applied to this fraction of total grid electricity consumed.

The cumulative other lifecycle emissions are calculated and compared to those from the BAU case to obtain the total lifecycle emission savings associated with the base case simulation being conducted.

[22] http://www.pre-sustainability.com/simapro.
[23] http://www.ecoinvent.org/database/.



GRAPH KEY

Greenhouse gas emissions intensity of freight transport running on:

- *reputation* focused cargo owner's freight on **road**
- *cost* focused cargo owner's freight on **road**
- *reputation* focused cargo owner's freight on **rail**
- *cost* focused cargo owner's freight on **rail**

FIGURE 25: EMISSIONS INTENSITY OUTPUTS FROM A MODEL RUN

To see graph keys on screen, hover over the colour-coded headings along the top of the graph. Values at any point along a graph can be seen by hovering over the graph line.

HOW TO

4.3.4 Water

As done for the main identified GHG emission sources in section 4.3.2, water requirements are only calculated for the production of the main energy sources for the different modes of transport. The input parameters for **water consumption in road transport** are (Omni Tech International , 2010):

- Diesel[24]: 0.0022 litres/tonne
- Biodiesel: 0.048 litres/tonne.

These values are converted to volumetric units using the densities provided in section 4.3.3.

The **water consumption associated with electricity supply** for rail transport is subject to the grid power stations. Water intensities for the national grid build plans are provided in the IRP and are used as input parameters to the model. For the period post-2030, the IRP's Revised Balanced Scenario and Emission 3 scenarios were projected using straight-line extrapolation to 2050, as was done for the GEF (see section 4.3.2). Figure 26 depicts the IRP water demand values (up to 2030), and the projections are shown in Figure 27. Selection of which electricity supply build plan is simulated in the model is discussed in section 4.1.5.1.6.

The cumulative water consumption calculated in the simulation is compared to that in the BAU case to determine the overall impact on water usage.

[24] According to source, the water usage data associated with crude oil exploration and production is incomplete, and hence this number underestimates the water use by an unknown amount.

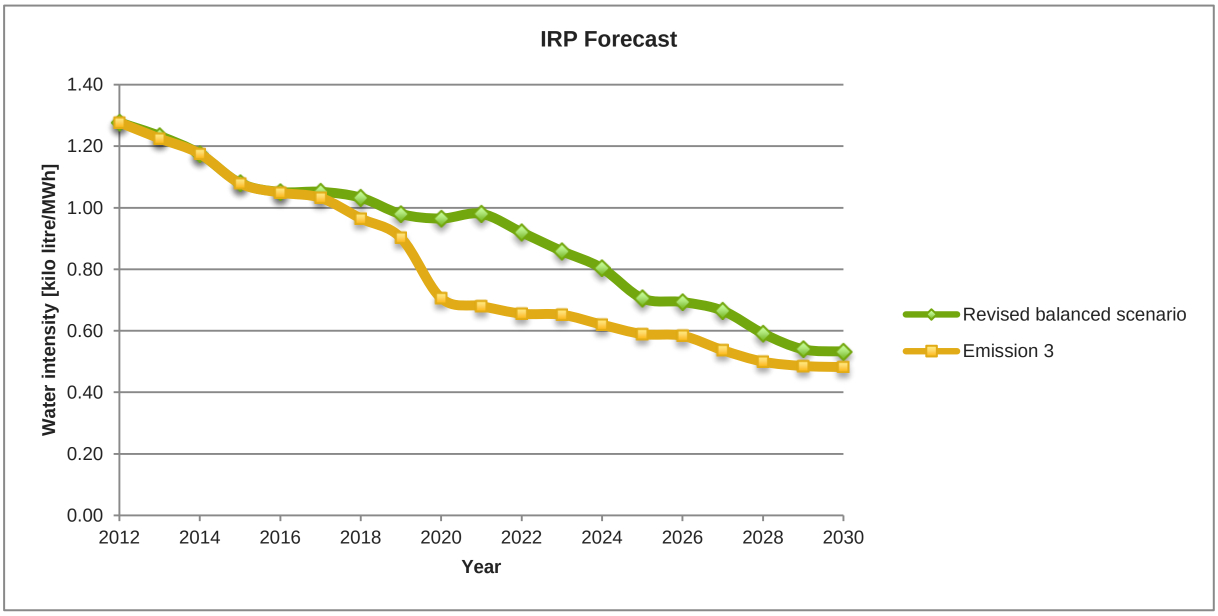


FIGURE 26: IRP WATER INTENSITY FORECAST (DOE, 2011)

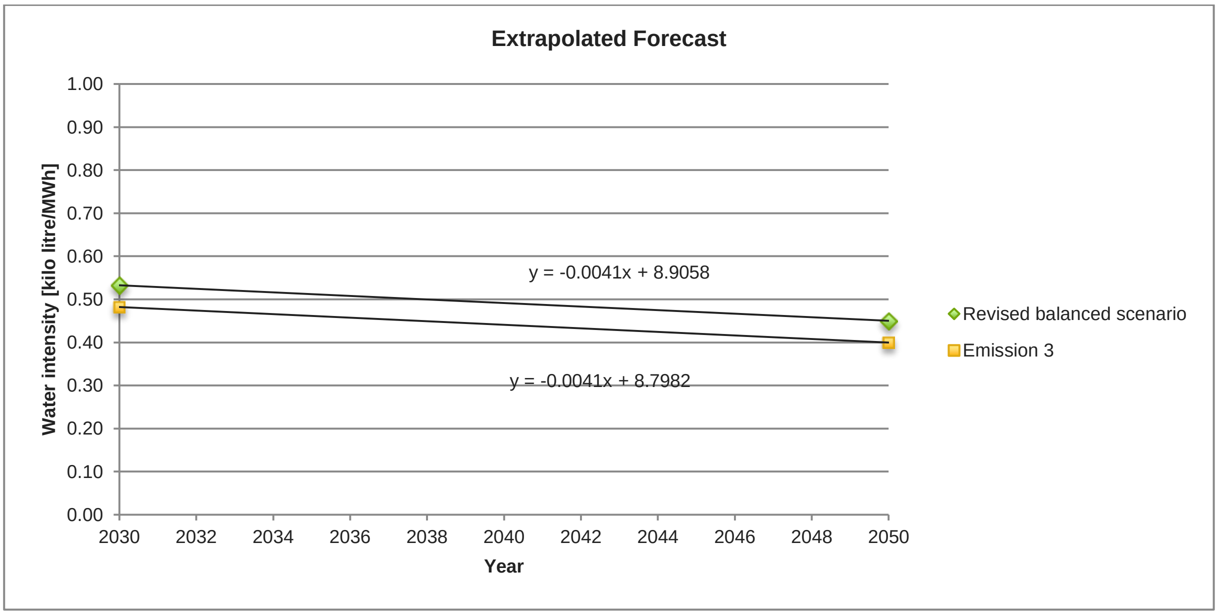


FIGURE 27: EXTRAPOLATED WATER INTENSITY FORECAST

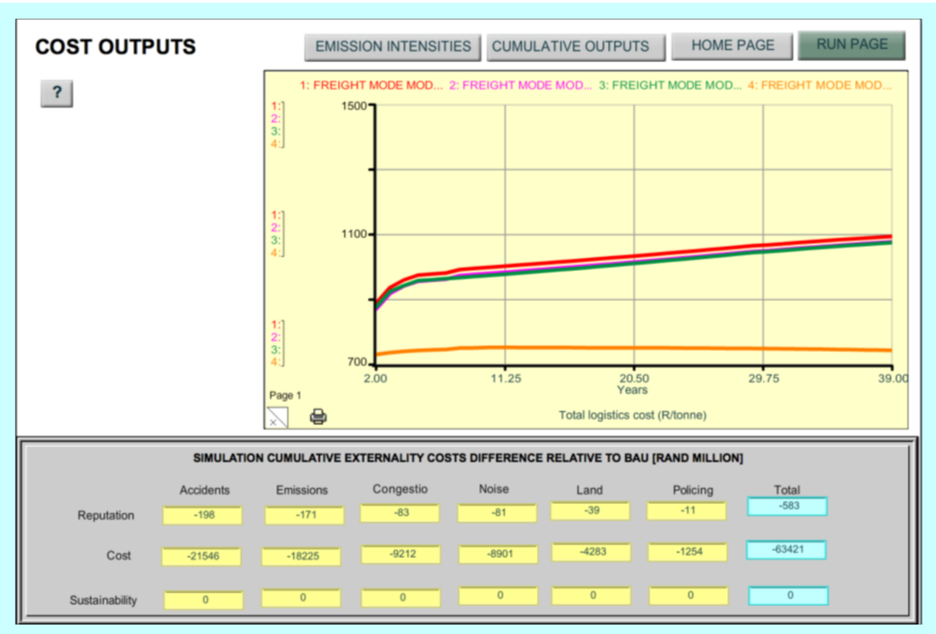
4.3.5 Externality costs

Externality costs are costs that are incurred by society when a private party utilises a public service. The input parameters used in this model to calculate externality costs associated with the tonne-kilometres transported per mode are provided in Table 8. The source data is for 2010 (Swarts et al., 2012), and is escalated to 2012 Rand values using CPI[25] for South Africa.

The overall change in externality cost is calculated by comparing the cumulative externality costs over the simulation period with that of the BAU case.

TABLE 8: EXTERNALITY COST INPUT PARAMETERS

Externality	Road cost intensity [Rand/tonne.km]	Rail cost intensity [Rand/tonne.km]	Description
Accidents	0.0545	0.0043	Road and rail accident costs including vehicle damages, towing, insurance, fatalities, traffic delays, legal costs, etc.
Emissions	0.0515	0.0086	Based on cost of offsetting emissions from transport through European Union
Congestion	0.0213	0	Based on national average delays
Noise	0.0208	0.0002	Extrapolated from countries similar to South Africa
Roadway land availability	0.0111	0.0011	Based on national average cost of land
Policing	0.0029	0	Based on budgets of Metro Police



GRAPH KEY

Total logistics costs of:

- *reputation* focused cargo owner's freight on **road**
- *cost* focused cargo owner's freight on **road**
- *sustainability* focused cargo owner's freight on **road**
- *cost* focused cargo owner's freight on **rail,** including metropolitan road transport leg

FIGURE 28: LOGISTICS (GRAPH) AND EXTERNALITY (TABLE) COSTS OUTPUTS FROM A MODEL RUN

[25] Inflation rates obtained from http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa-2013.aspx.

4.3.6 Jobs

Employment data from a South African Transport and Allied Workers' Union (SATAWU) research paper is used in the model. From this study, the number of **direct jobs** in 2011 is (Barrett, 2011):

- Road freight: 360 000
- Transnet Freight Rail: 23 000
- Transnet rail engineering (rolling stock): 15 000
- Transnet capital projects (track maintenance): 7 600.

Freight movement data for 2011 from the 9th State of Logistics Survey for South Africa (CSIR, 2012) was used to calculated the **job intensity** values as:

- Road freight: 1.21 jobs/million tonne.km
- Rail freight: 0.37 jobs/million tonne.km

These intensities are used to calculate the jobs created or lost per mode as a result of freight movement and mode shifts. It is assumed that these intensities will remain constant throughout the simulation period.

The model deals only with direct jobs in the organisations providing the transport services. For example, it does not incorporate existing or potential jobs in companies' distribution centres, or manufacturing of rail stock or vehicles.

LIMITATION

4.3.7 Carbon tax

The carbon tax in this model is based on the South African Carbon Tax Policy Paper (National Treasury , 2013). The first phase of implementation is simulated from 2016 to 2020[26], for which the following input parameters are specified with values from the Policy Paper:

- <Carbon tax initial value>: 120 R/tonne CO_2
- <First phase annual increase>: 4.75% (deflated with average CPI in 2013[27] from the 10% proposed increases as per the Policy Paper)
- <First period tax-free threshold>*(<mode of transport>)*: assumed 60% for both road and rail transport.

The policy paper does not provide values for the second phase (after 2020) and therefore input parameters can be specified in the user interface. Base case values for second phase parameters are provided in section 5.

Where a fleet owner company exceeds a certain threshold of emissions a carbon tax might become applicable, which could be passed on to the freight owner customer. It is not clear how "pass-through" of tax will affect customers downstream of the service they are utilising. If Eskom is subject to the tax, the price of electricity will most likely increase. The fuel price is regulated and currently no pass-through is allowed, which might mean that the carbon tax will have a larger impact on rail transport (utilising electricity) than on road. However as at August 2016, the design of the tax is still being finalised and there are opinions that Eskom should not be taxed.

Due to the uncertainty around the carbon tax implementation, different switches relating to the impact of carbon tax are provided in the model. A <carbon tax switch> is available to include or exclude a carbon tax from a model run; and <road carbon tax switch>*(<freight owners>)* switches are available to toggle if the carbon tax will apply to a specific freight owner utilising road transport.

[26] This was adapted from the first phase period of 2015-2019 as specified in the Policy Paper due to delays in implementation.
[27] Inflation rates obtained from http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa-2013.aspx.

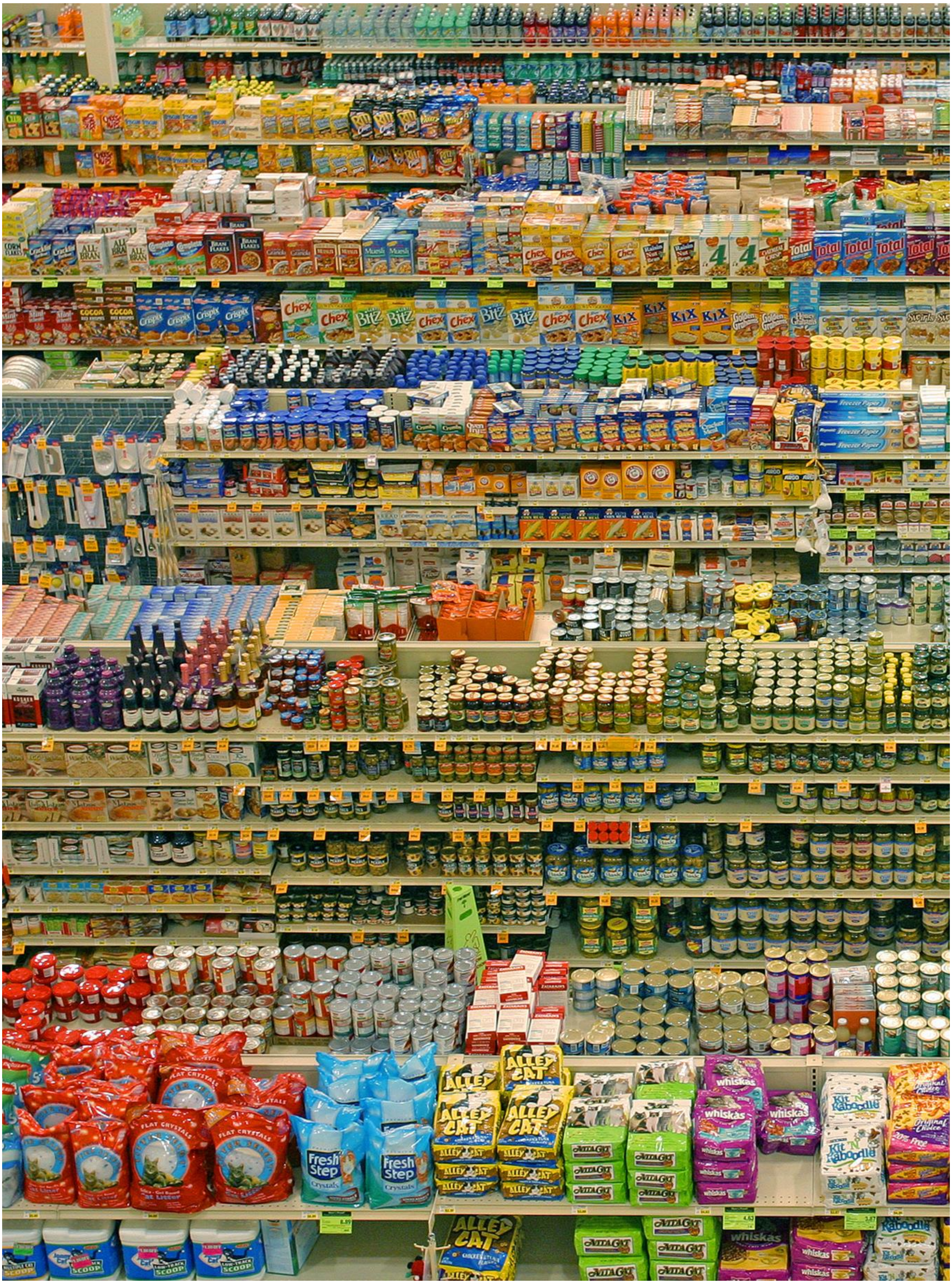


Photo Detail from 99 *cent ii diptychon* Andreas Gursky 2001

5 BASE CASE

5.1 Input parameters

The base case attempts to represent the current processed food freight market in South Africa. This section presents the default values used for the input parameters and the reasons they were chosen, in Table 9 to Table 11. Input parameters that could not be populated with data from literature or stakeholders were assumed based on stakeholder guidance or the modelling team's judgement. All the initial assumptions form part of a "base case" simulation (hereinafter "BC"), most of which can be adjusted in the web-based user interface.

TABLE 9: FREIGHT OWNER DECISION MAKING INPUTS

Input parameter	Reputation focused	Cost focused	Sustainability focused	Comment
<Market share>*(<freight owner>)*	10%	90%	0%	Assumed market share of Woolworths[28] plus other smaller reputation conscious retail stores
<Minimum requirements for parity between modes>*(<freight owner>)*	Cost	Cost	None	Based on stakeholder consultation with freight owners. Most stakeholders said that rail transport first needs to make sense financially (i.e. compete on price) for it to be considered as a viable option.
Decision making weightings This reflects to what extent a freight owner cares about each factor, or more precisely what relative weight they give to each factor in making their overall (100%) decision.				
Cost	40%	70%	10%	For reputation- and cost-focused freight owners, assumptions are based on stakeholder consultation and description of decision makers in section 3.4.3 For sustainability-focused freight owners, weightings are assumed
Reliability	55%	30%	10%	
Jobs	0%	0%	27%	
Emissions	5%	0%	26%	
Externality cost	0%	0%	27%	

TABLE 10: VEHICLE FLEET INPUTS

Input parameter [unit]	<First adopters>	<Late Adopters>	Comment
<Metropolitan distance> [km]	100		The distance from the City Deep train station in Johannesburg to Centurion where many of the large processed food DCs are located is about 50 km. The total metropolitan travel is assumed to be twice this distance or 100 km per shipment.
<Average truck travel distance in a year> [km]	150 000		Based on stakeholder consultation with vehicle fleet owners
<Additional biodiesel>*(<fleet owner>)* [%]	0	0	Assumed most fleets will only comply with national regulation and won't add additional biodiesel to fleet

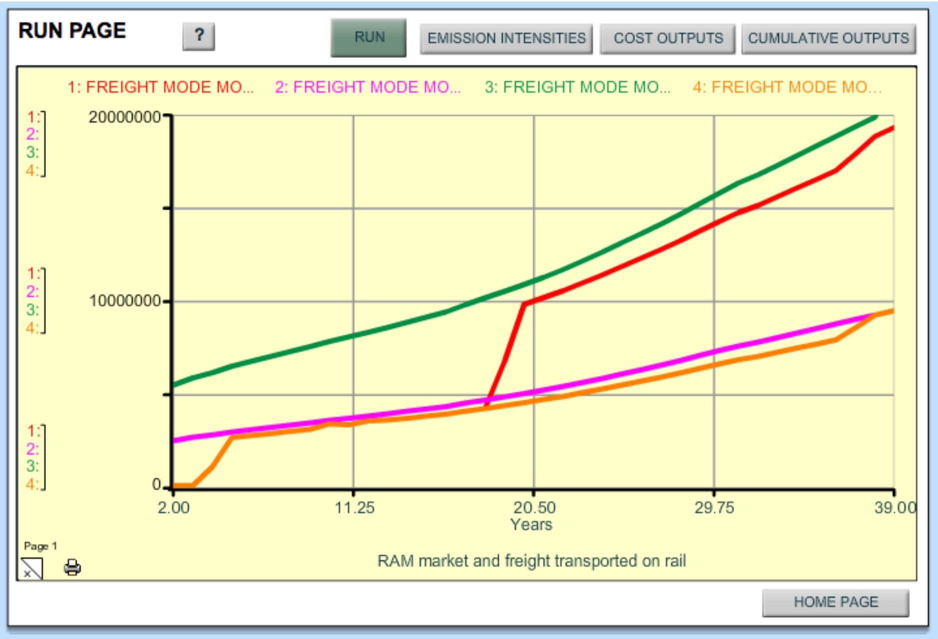
[28] See http://www.tv.camcom.gov.it/docs/Corsi/Atti/2013_11_07/OverviewOFTHESOUTHAfrica.pdf (page 13) and http://mg.co.za/article/2011-11-04-big-five-fight-for-food-market-share/

Input parameter [unit]	<First adopters>	<Late Adopters>	Comment
<Fleet composition>			
<Reputation focused>	90%	10%	Based on stakeholder interaction with fleet owners and logistics providers. *See fleets in section 3.4.4.* Reputation-focused freight owners predominantly use first adopter fleets. However, these fleet owners occasionally make use of late adopter trucks during times of high demand. It is assumed that cost-focused decision makers utilise mostly late adopter fleets, who offer cheaper prices. A 50:50 split is assumed for the sustainability-focused freight owner to simulate values for the average fleet.
<Cost focused>	30%	70%	
<Sustainability focused>	50%	50%	

TABLE 11: OTHER INPUTS

Input parameter [unit]	Value	Comment
<Improved rail operational performance> [%]	0%-50% linear improvement over simulation period	Assumption
<Additional rail planned stoppage time> [hours]	24	Assumption based on discussion in section 4.1.1.2.2
<Additional road planned stoppage time> [hours]	4	Assumption based on discussion in section 4.1.1.2.2
<Mass transported per train trip> [tonne]	Final value: 9 000	Assumed to increase linearly over the simulation period to 9 000 tonnes per train (*section 4.1.4.1.2*)
<Metro road cost relative to corridor> [%]	100%	Assumption
<Additional fuel levy> [R/litre]	0	Assumption
<Increased road toll fees> [%]	0%	Assumption
<Annual driver wage increase> [%]	0%	Assumption
<Annual labour cost increase> [%]	0%	Assumption
<Cost increase for competing category of freight> [%]	20%	Assumption
<Improved efficiency pass-through switch>	Switched off (fuel savings not passed through to customer)	Assumption
<Improvement cost decrease> [%]	0%	Assumption
Carbon tax		
<Carbon tax switch>	Switched on	Assumption that the carbon tax is implemented and added to transport cost
<Road carbon tax switch>>*(<freight owner>)*	Reputation: On Cost: On Sustainability: On	Assumption that the carbon tax is implemented and affects transport cost
<Second phase annual increase> [%]	0%	Assumption
<First period tax-free threshold>*(<mode of transport>)* [fraction]	Road: 60% Rail: 60%	Assumption.

5.2 Simulation results



Key

- ■ Rail addressable market (RAM), consisting of rail suitable and competing freight, which could shift to rail
- ■ Rail suitable freight market

Competing freight market is the difference between ■ and ■

- ■ Rail suitable freight which does shift to rail

Competing freight which does shift to rail is the difference between ■ and ■

- ■ Total freight which shifts onto rail

FIGURE 29: EXAMPLE OF THE MAIN RUN SCREEN FROM A MODEL RUN

The simulation results below are based on the BC assumptions presented in section 5. As per these assumptions the simulation is run with the proposed carbon tax and assumed governmental biodiesel blending regulations as the only mitigation measures. A 50% increase in rail operational performance is also assumed.

With these values, Figure 30 shows the volumes of the rail suitable freight and competing freight in processed foods, collectively known as the rail addressable market (RAM), which start to shift from road to rail over time. It shows “rail suitable freight” starts shifting to rail in large volumes between 2014 and 2017, and then stays on rail transport up to 2050. After 2017 the competing freight starts to shift to rail, which causes a large increase in the “total freight on rail” between 2017 and 2020. Despite the shifts to rail, there is still a gap between the “RAM” and the “total freight on rail” after 2020, which means that not all types of freight owners shifted their RAM to rail.

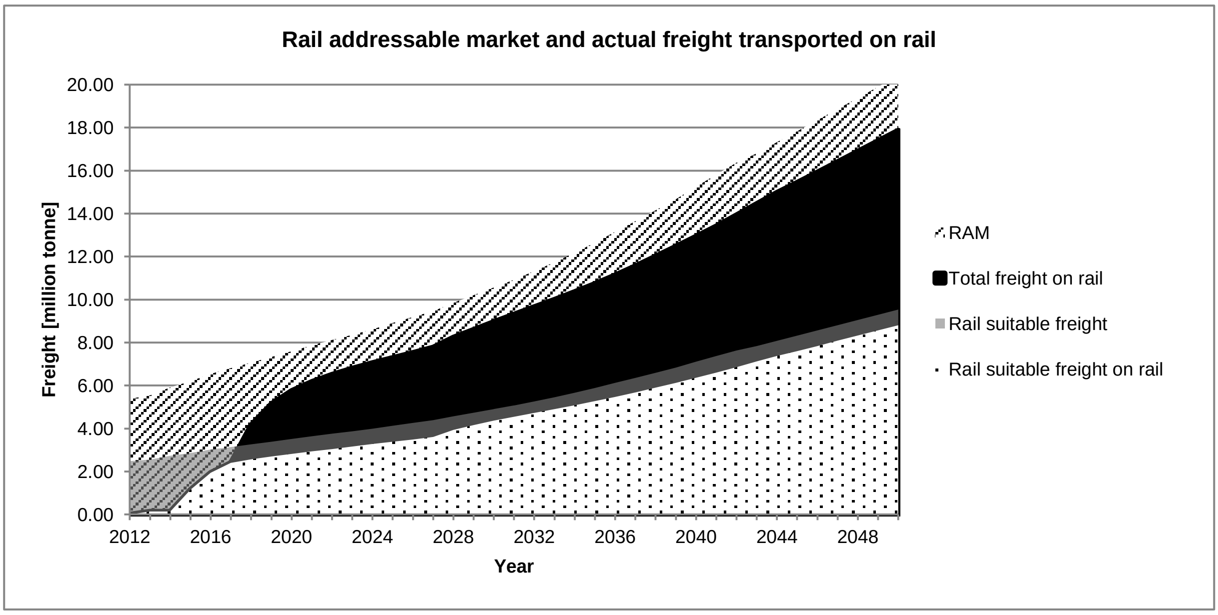


FIGURE 30: PROCESSED FOODS FREIGHT ON RAIL IN BASE CASE COMPARED TO THE RAM

Given their 90% market share, the cost-focused freight owners shift of freight from road to rail is clearly the reason for the bulk of the freight movement reflected in Figure 30.

Figure 31 shows a breakdown of when each type of freight is shifted by the different types of freight owners. “Cost focused, rail suitable” freight starts to shift after 2014 and “cost focused, competing” freight after 2017. Both these types of freight stay on rail transport up to 2050. “Reputation focused, rail suitable” freight briefly moves on to rail in 2016, only to move back off in 2017. In 2028 it sustainably moves on to rail up to 2050. Under BC conditions, “reputation focused, competing” freight never moves on to rail within the simulated timeframe.

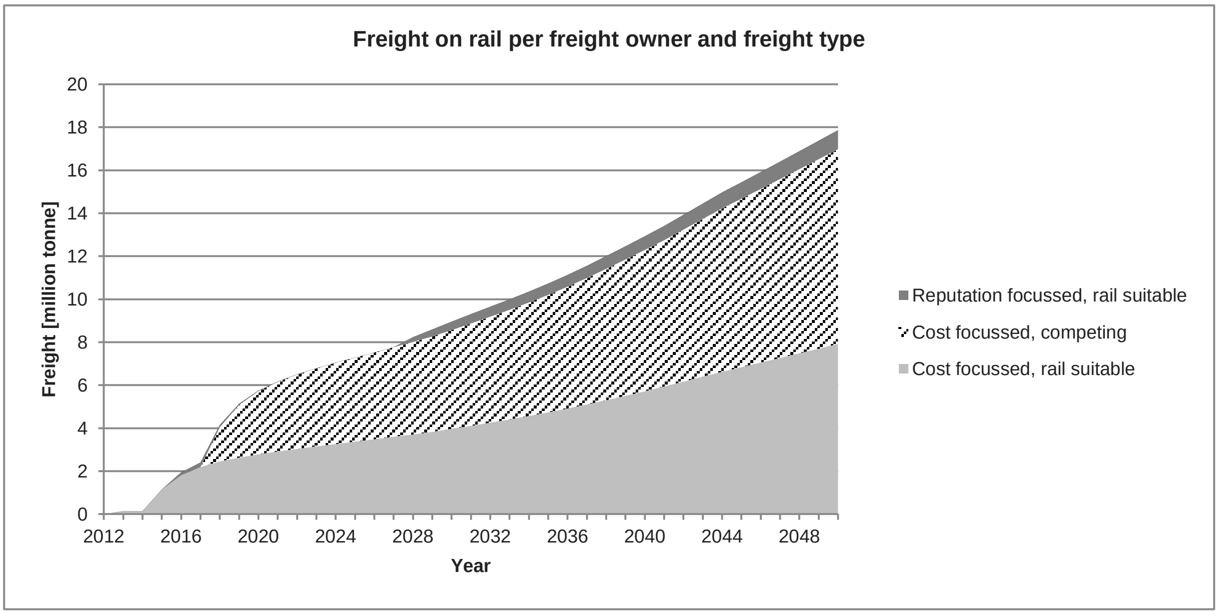
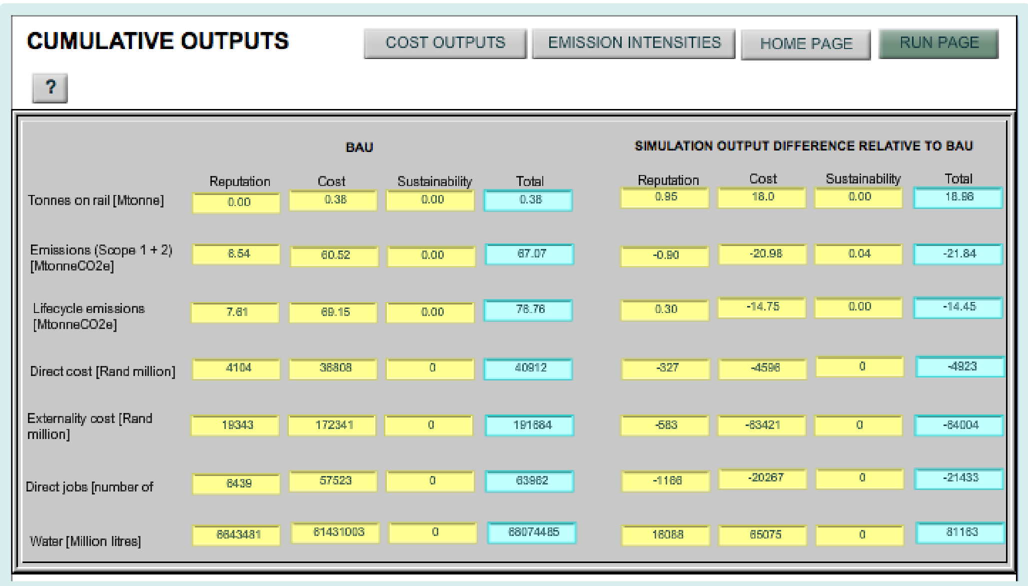


FIGURE 31: RAIL FREIGHT PER FREIGHT OWNER AND FREIGHT CLASSIFICATION

For presenting other model outputs, a comparison is made with the BAU case, as explained in section 4.3.1. The main assumption in the BAU scenario is that the fraction of freight on rail as in the base year (2013) stays constant throughout the modelling period, whereas the BC is a dynamic simulation with the default input parameter values as per section 5. The main outputs from the model are presented in Table 12.



CUMULATIVE OUTPUTS

COST OUTPUTS | EMISSION INTENSITIES | HOME PAGE | RUN PAGE

?

	BAU				SIMULATION OUTPUT DIFFERENCE RELATIVE TO BAU			
	Reputation	Cost	Sustainability	Total	Reputation	Cost	Sustainability	Total
Tonnes on rail [Mtonne]	0.00	0.38	0.00	0.38	0.95	18.0	0.00	18.98
Emissions (Scope 1 + 2) [MtonneCO2e]	6.54	60.52	0.00	67.07	-0.90	-20.98	0.04	-21.84
Lifecycle emissions [MtonneCO2e]	7.61	69.15	0.00	76.76	0.30	-14.75	0.00	-14.45
Direct cost [Rand million]	4104	36808	0	40912	-327	-4596	0	-4923
Externality cost [Rand million]	19343	172341	0	191684	-583	-63421	0	-64004
Direct jobs [number of	6439	57523	0	63962	-1166	-20267	0	-21433
Water [Million litres]	6643481	61431003	0	68074485	16088	65075	0	81163

FIGURE 32: EXAMPLE OF INTERFACE SCREEN FOR THE CUMULATIVE OUTPUTS

TABLE 12: OUTPUTS FROM BASE CASE SIMULATION COMPARED TO BAU

Output [unit]		Reputation focused	Cost focused	Total	Comments
<Tonnes transported on rail> [Mt]	BAU value	0	0.41	0.41	This is the total tonnage transported on rail in 2050.
	BC change	0.88	16.57	17.45	
<GHG Emissions (Scope 1+2)> [Mt CO_2e]	BAU value	6.52	60.24	66.76	The GHG emissions (Scope 1+2) are reduced by 23.92 tonnes in the BC compared to the BAU.
	BC change	-1.37	-22.55	-23.92	
<Lifecycle GHG emissions> [Mt CO_2e]	BAU value	7.58	68.81	76.39	The lifecycle GHG emissions are reduced by 16.94 tonnes in the BC compared to the BAU.
	BC change	-0.40	-16.54	-16.94	
<Direct cost> [Rand million]	BAU value	4 192	37 564	41 756	By shifting road to rail as in the simulated BC, over R5 billion in logistics cost can be saved by the freight owners.
	BC change	-289	-5 301	-5 590	
<Externality costs> [Rand million]	BAU value	19 263	171 436	190 699	By shifting road to rail as in the simulated BC, over R69 billion in externality cost can be saved.
	BC change	-2 835	-66 578	-69 413	
<Direct jobs> [number of jobs]	BAU value	6 360	56 754	63 114	Direct jobs are lost as a result of a shift from road to rail.
	BC change	-1 036	-19 485	-20 521	
<Water requirements> [million litres]	BAU value	6 619 252	61 140 876	67 760 128	The additional water requirements in the BC are as a result of biodiesel implementation.
	BC change	12 665	64 547	77 212	

6 FOCUS FOR IMPROVED DATA

A sensitivity analysis was conducted on the model for output emissions, which served to identify the input parameters that had the greatest impact on model results.

These sensitive input parameters were sorted to identify only those that were based on assumptions, data older than 3 years, or questionable data in the model, and these are presented in Table 13. The modelling would benefit from improvements or updates to assumptions and data for any parameter, but it is improvements to these sensitive-and-least-certain input parameters that would be most significant. Users may want to pay particular attention to their inputs for these, drawing on their own specialised or insider knowledge.

LIMITATION

TABLE 13: SENSITIVE INPUT PARAMETERS FOR FURTHER RESEARCH

Input parameter [unit]	Comment
<Utilisation> [%]	Utilisation of the installed rail infrastructure capacity is based on Transnet data, which assumes future demand and maintenance and improvement. With the model simulating a mode switch, it is not clear what impact switching of the simulated commodity or other commodities will have on utilisation. More research on the available capacity and impact of mode shifts on the rail network are required.
<Annual labour cost increase> [%]	There is no certainty on how much labour costs will increase during the simulation period
<Initial additional delays not related to failures> [hours]	Based on Transnet data for other lines in the network. Need more accurate data specific to this corridor
<Rail initial transport cost> [R] <Road initial transport cost>(*<Late adopter>)* [R/tonne.km] <Road initial transport cost>*(<First adopter>)* [R/tonne.km]	Initial transport costs were derived from 2007 data. More recent data, specific to processed foods are required.
<Baseline rate of improvement> [fraction]	This is a base case assumption for which more insight from Transnet and research are required.

Overall, the model is most sensitive to the reliability parameter, which is represented in the model as punctuality. South African specific research on how freight owners perceive and consider punctuality in mode shift decisions will be valuable to more accurately represent this concept in the model.

WWF and The Green House would be grateful for any comments or improvements on the assumptions and data in this manual, and feedback from using the model.

To invite WWF South Africa to present on the model or join an interactive session using the interface, contact Saliem Fakir at sfakir@wwf.org.za.

The interface of the WWF Freight Transport Model is freely available for anyone to use at https://forio.com/simulate/ab755188/13013-freight-sd-model-v-100. Any organisation wishing to go behind the interface is welcome to request the files from The Green House for a small fee. STELLA software, licensed by isee systems (www.iseesystems.com), will be needed to program and run the model.

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LIST OF ACRONYMS

ASTRA	Assessment of Transport Strategies
BAU	Business as usual
BC	Base case
Capecor	Cape Town to Gauteng corridor
CCGT	Combined-cycle gas turbine
CPI	Consumer Price Index
CSIR	Council for Scientific and Industrial Research, South Africa
CSP	Concentrated Solar Power
DC	Distribution Centre
DEFRA	Department for Environment, Food and Rural Affairs
DOE	Department of Energy, South Africa
GAIN	Growth and Intelligence Network
GEF	Grid emission factor
GHG	Greenhouse gas
HVC	Heavy commercial vehicles
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
ITMP	Integrated Transport Management Plan
IWW	Universität Karlsruhe Institut für Wirtschaftspolitik und Wirtschaftsforschung
LTPF	Long Term Planning Framework
MA	Management and Administration
MRT	Maintenance, repair and tyres
OCGT	Open-cycle gas turbine
PPIAF	Public-Private Infrastructure Advisory Facility
PV	Photovoltaic
RAM	Rail addressable market
SANRAL	South African National Roads Agency
SATAWU	South African Transport and General Workers' Union
SATC	Southern African Transport Conference
SD	System Dynamics
SOL	State of Logistics
TFR	Transnet Freight Rail
US$	United States Dollars
USA EIA	United States Energy Information Administration
WWF	World Wide Fund for Nature
ZAR	South African Rand