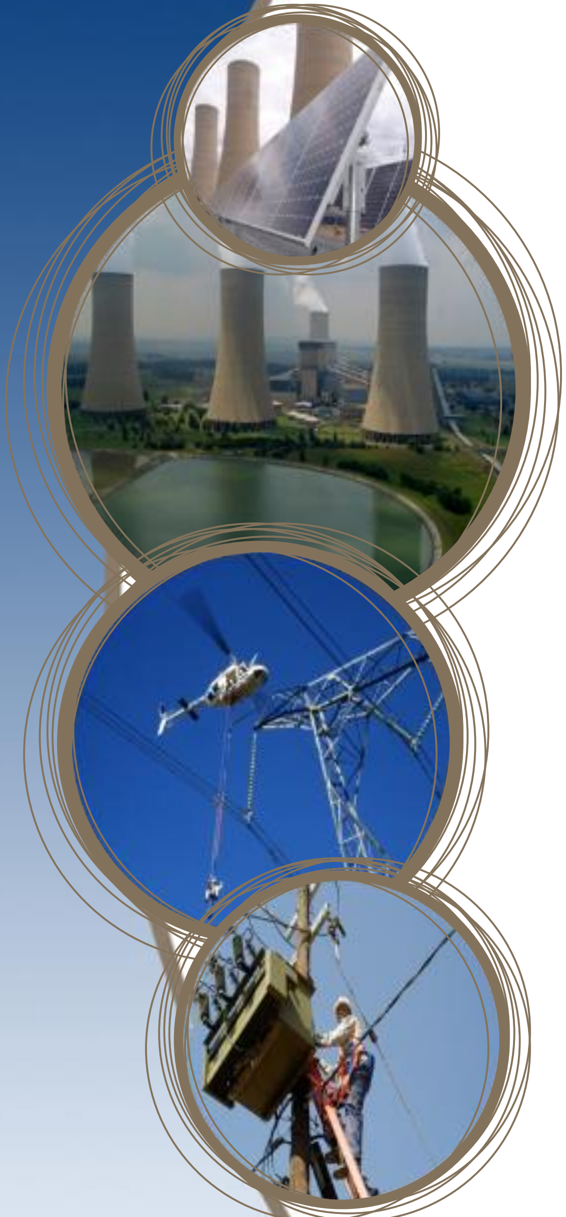


Modelling EV Uptake using a System Dynamics Approach

Dr Nalini Sooknanan Pillay Pr.Eng

Corporate Specialist: System Dynamics

Eskom Research Testing & Development

ELECTRIC VEHICLE TECHNOLOGIES SUMMIT 2019

Eskom eMobility Program
Research Testing & Development

e-Mobility Advocacy

eMobility Program Focus Areas

e-Mobility Platform-based services

Advanced e-Mobility Solutions

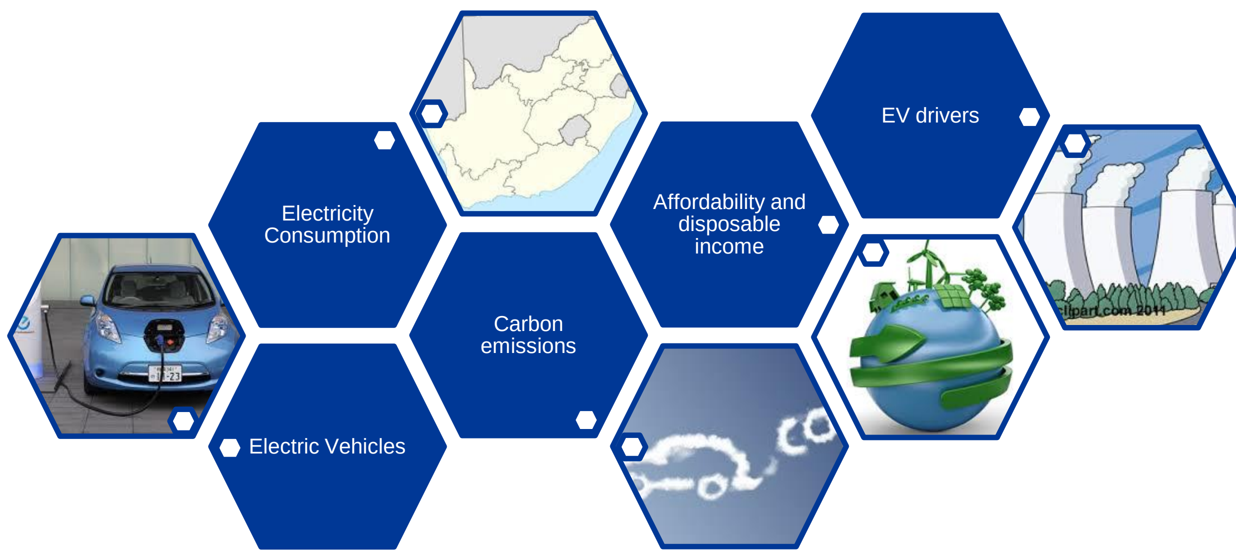
Daryl Chapman

Francois Van Geems

Orika Orrie

Sumaya Nassiep

General Manager (Acting)



Content of the presentation

Eskom

Modelling EV Uptake using a System Dynamics Approach

Background

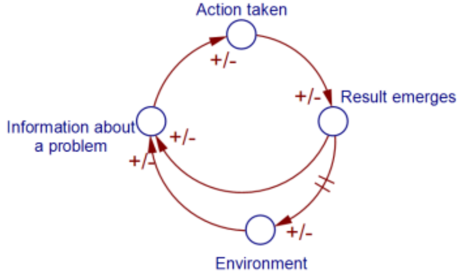
Economic development shares interdependence with energy investment, a complex interaction of systems. Thus, advanced modelling tools are required to support the development of strategic integrated energy plans, inclusive of the technological complexities in the electricity value chain.

Objectives

This study involved the use of an adapted system dynamics modelling approach with elements of control systems engineering to determine the impact of the electric vehicle (EV) technology market penetration on the electricity demand profile and the related environmental impact in the energy and transport sectors in South Africa.

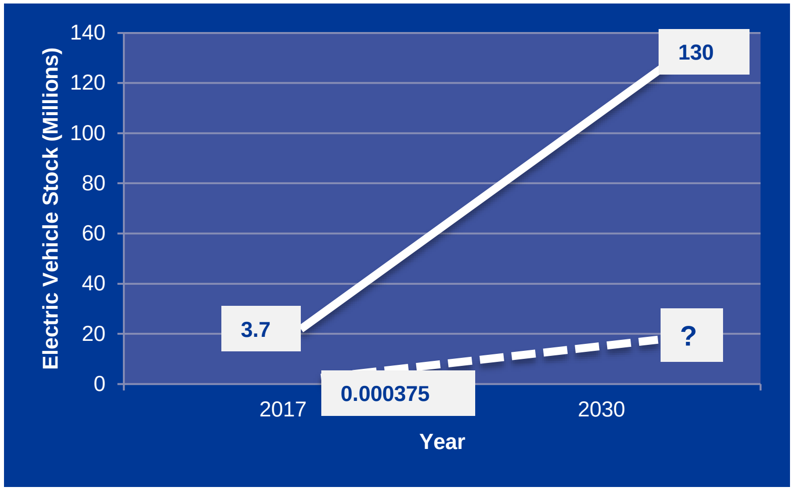
- Non-linear relationships
- Time lags and delays
- Feedback

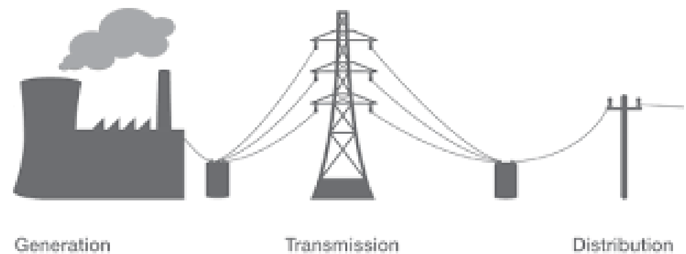
CLOSED-LOOP FEEDBACK

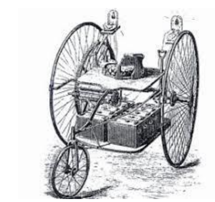


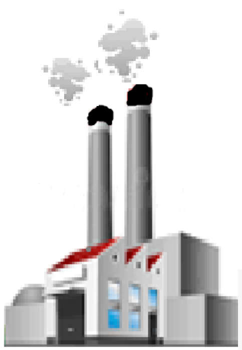
OPEN-LOOP, LINEAR

Contextualising the Eskom EV Study









Range: 330-560 km
Acceleration: 0-100 km in 1.9 seconds
Charge: 4 hours
Purchase price: ?

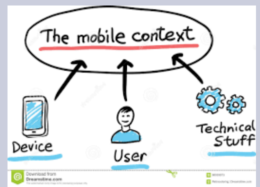
Range: 173 km
Acceleration: 0-100 km in 9 seconds
Charge: 7.5 hours

Range: 2.4 km
Speed: 6.4 km/hr
Charge: 3 hours

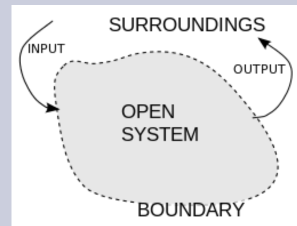
System Dynamics Modelling Process

1. Project inception

2. Concept to context

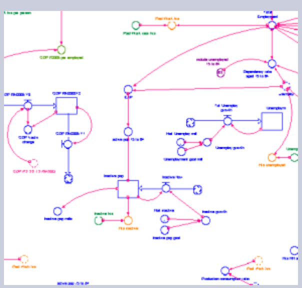


3. Boundary setting



4. System analysis

5. Model development and design



6. Validation and Policy insights

7. Model handover

8. Model maintenance and updates

System Dynamics Modelling Process

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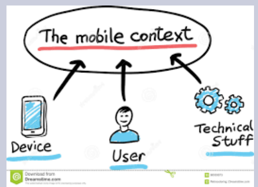
Establish the focusing question linked to the system problem,

Alignment with business strategic objectives,

Identify members to form a working group.

2. Concept to context



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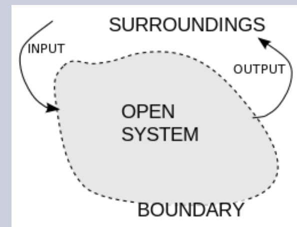

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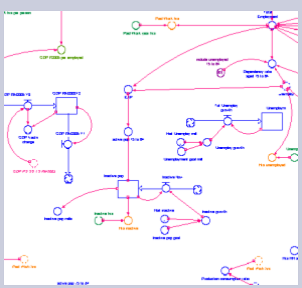

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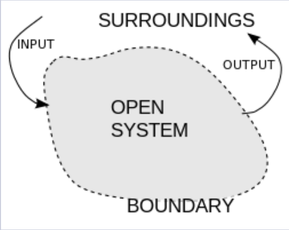

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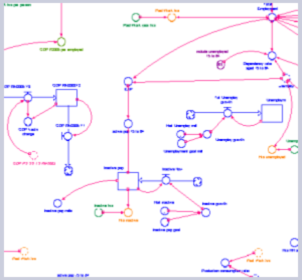

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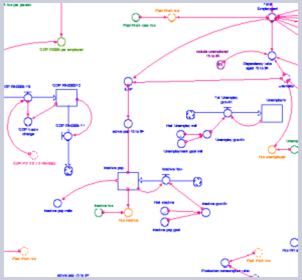

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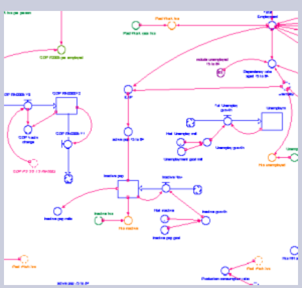
4. System analysis

Preliminary computations,

Perpetual linear growth trends are dismissed.

5. Model development and design



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Modules and sub-modules,
State variables, initial conditions of stocks and parameterization,
Mathematical linkages of variables,
Engagement platforms for scenarios.

6. Validation and Policy insights

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State variables, initial conditions of stocks and parameterization,
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6. Validation and Policy insights

Test the scenarios against the relevant policies,

Validation (structural, empirical, behavioral and application).

7. Model handover

8. Model maintenance and updates

System Dynamics Modelling Process

Eskom

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Establish the focusing question linked to the system problem,

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Identify members to form a working group.

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6. Validation and Policy insights

Test the scenarios against the relevant policies,

Validation (structural, empirical, behavioral and application).

7. Model handover

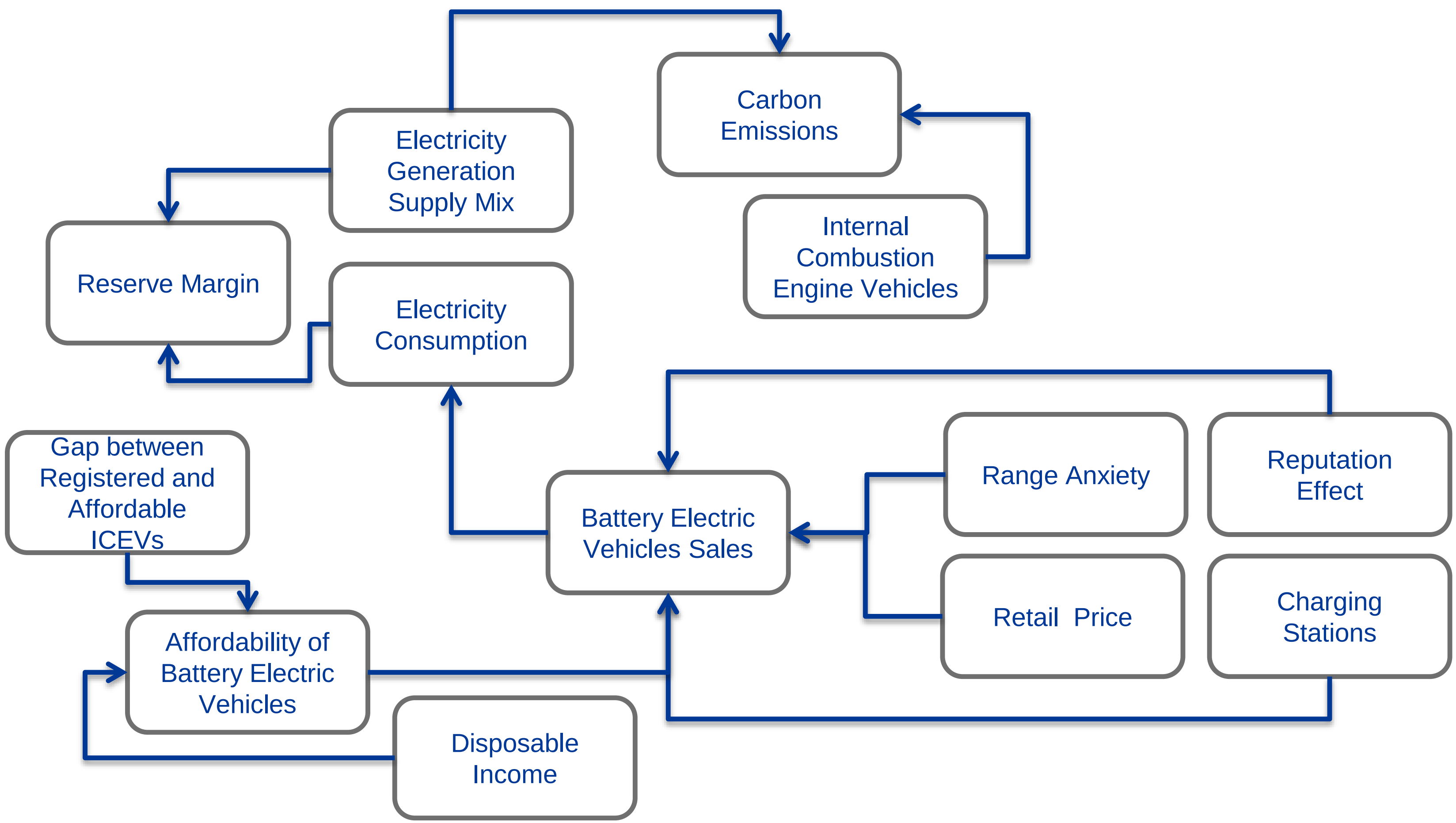
Run a series of training workshops for knowledge transfer and to equip model custodian with skills.

8. Model maintenance and updates

Short term support to the model custodian through follow up meetings,

Data updates and minor structural changes are included as part of the model maintenance.

Modelling EV Uptake using a System Dynamics Approach
Boundary Setting: System Architecture Map



Modelling EV Uptake using a System Dynamics Approach
Mathematical Prerequisites

1. Forecasted trends used the **logistics curve** (Equation 1):

$$P(t)=U_0+\frac{U_1}{1+\exp[-c(t-t_0)]} \tag{1}$$

where *P* is the dependent variable and *P(t)* is a function of time *t*; U_0 is the zero offset; U_1 is the increase (or decrease) above U_0, *c* is a growth rate exponent; and t_0 is the inflection point.

2. The performance measures used **weighted average performance formulas** (Equation 2):

$$M = \frac{\sum m_i C_i}{\sum C_i} \tag{2}$$

where *i* is the power station, *M* is the power station's capacity weighted average of performance measure *m;* m_i is the performance measure for the power station (e.g. load factor)*;* and C_i is the capacity of station, *i*.

3. **Regression equations** for mathematical structuring in the model (Equation 3).

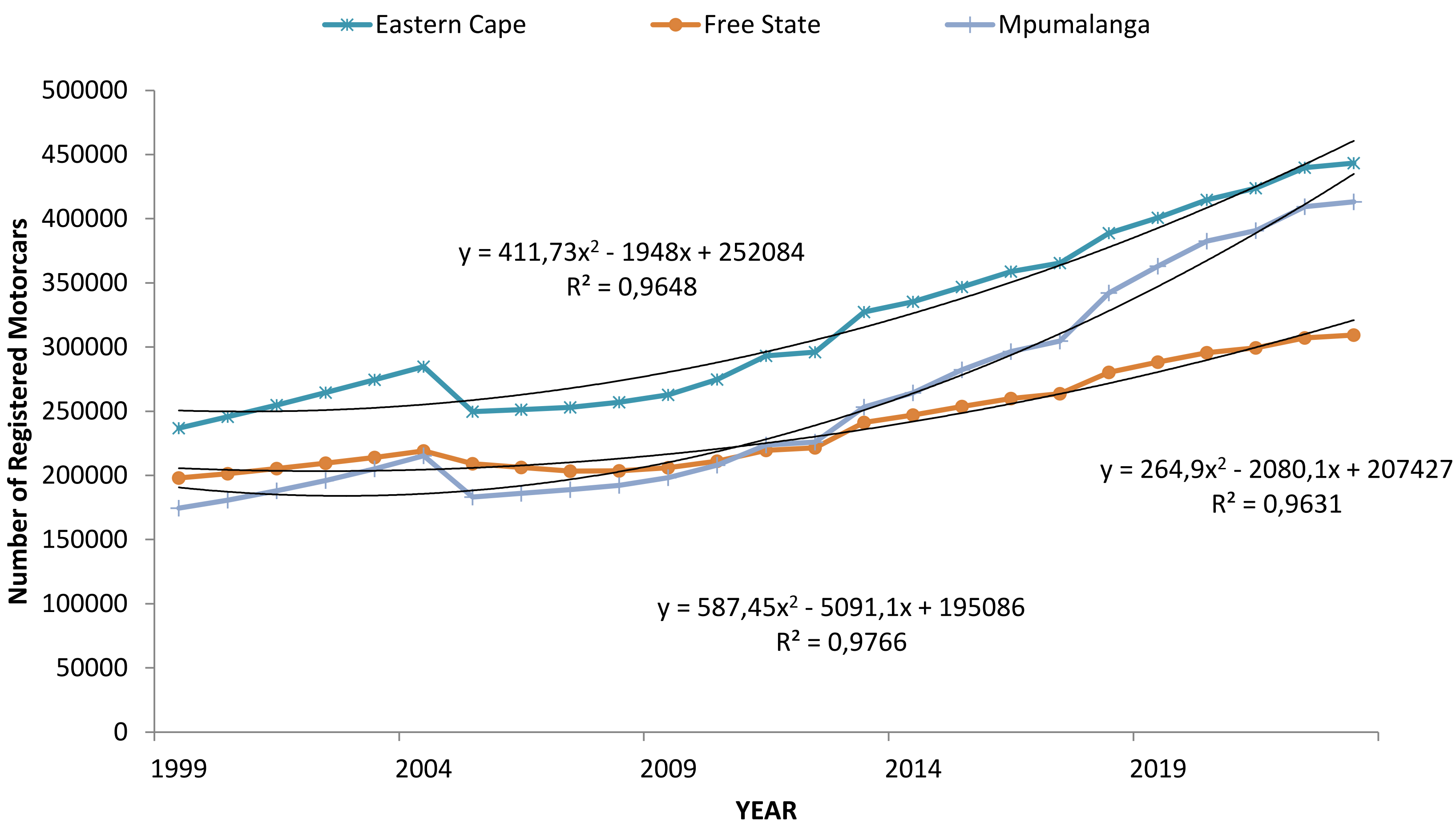
$$Range\ Anxiety(y)= -0.001\left(x^2\right)+0.1886(x)+85.035 \tag{3}$$

4. The **rate equations** for the stock flow structures in the model (Equation 4).

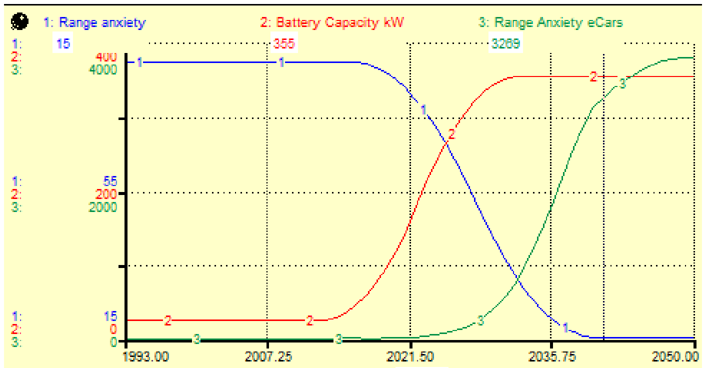
$$Stock\ (t)=Stock(t-dt)+(Inflow\ Rate-Outflow\ rate)\ x\ dt \tag{4}$$

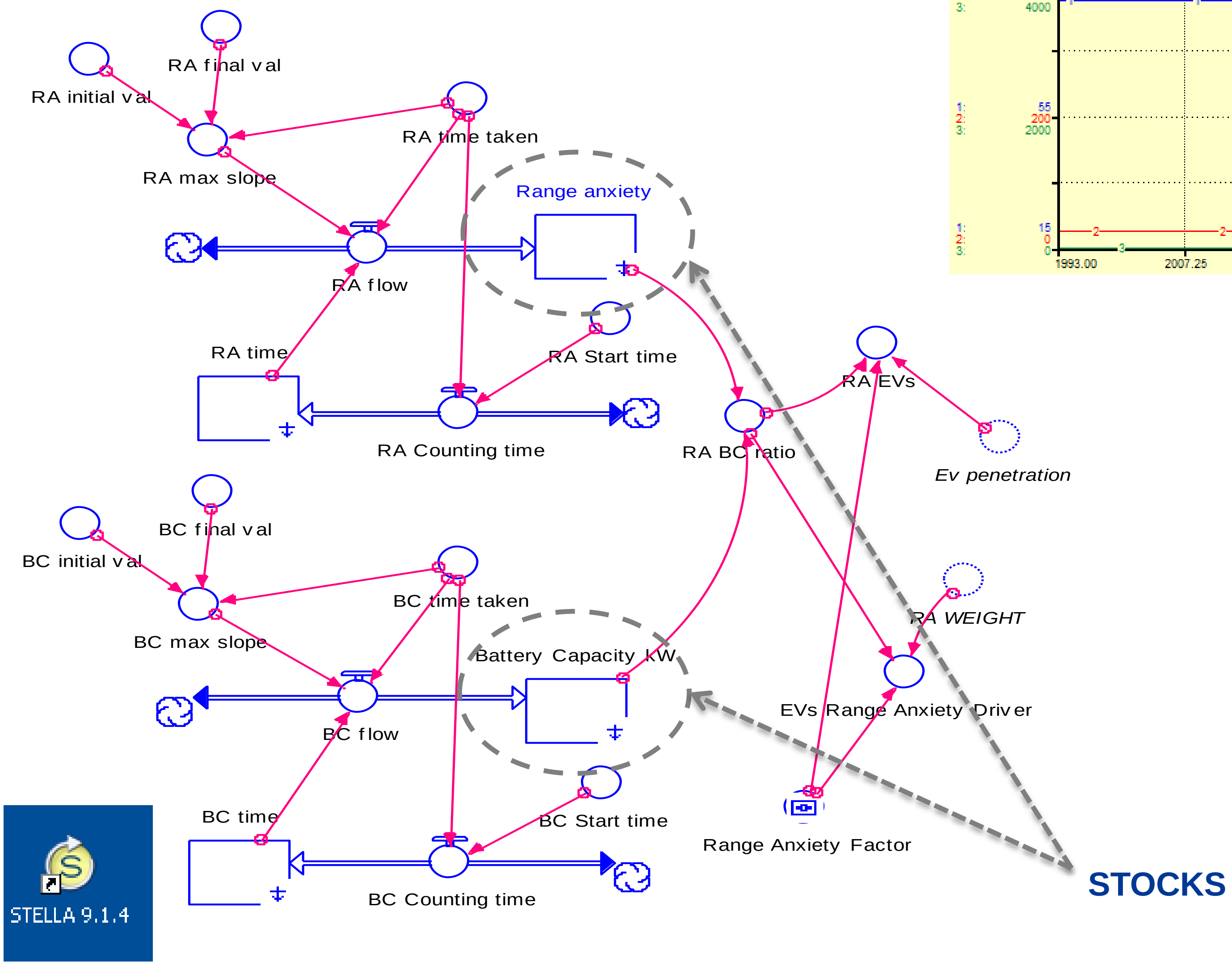
The differential equation tells us that the Stock at time *t* is found from the Stock at a previous point in time, *(t–dt)*, by adding the net quantity accumulated as the result of the inflow and outflow during the period *dt.*

Modelling EV Uptake using a System Dynamics Approach
System Analysis

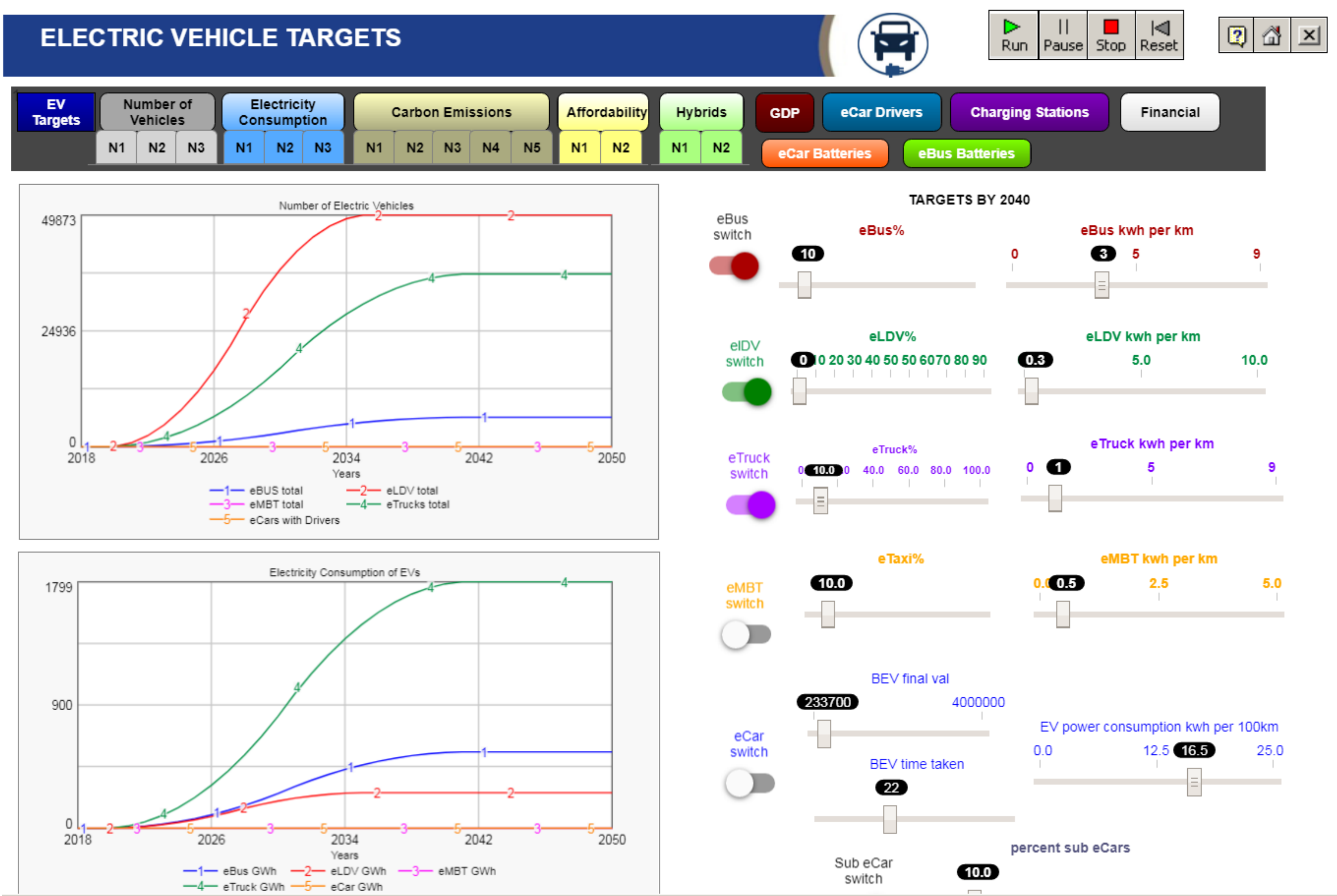


Modelling EV Uptake using a System Dynamics Approach
Model Development and Design





Modelling EV Uptake using a System Dynamics Approach Engagement Platform (1/4)



Modelling EV Uptake using a System Dynamics Approach Engagement Platform (2/4)

fraction petrol 0.80

ICEV scrapped % 0

Import taxes% 42.0

Subsidies % 0.0

Add subsidies

eCar w VAT R	465,405.0
ICEV retail cost wVAT R	247,307.5
EV Fuel Cost R	0.0
ICE Fuel Cost R	29,050.2

Diesel Car litre per 100km 11

Petrol car litre per 100km 8

Diesel Car Fuel Cost R per litre 12

Petrol Fuel Cost R per litre 14

Electricity cost R per kwh 1

ICEV Insurance 10000

eCar insurance% 10

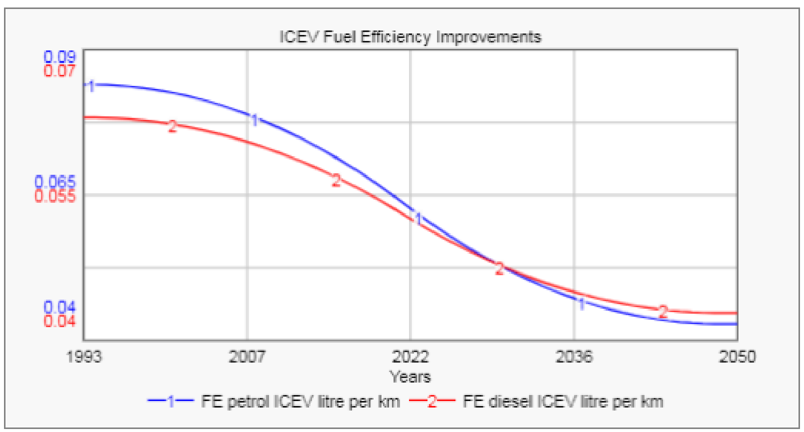
eCar insurance	132,000.0

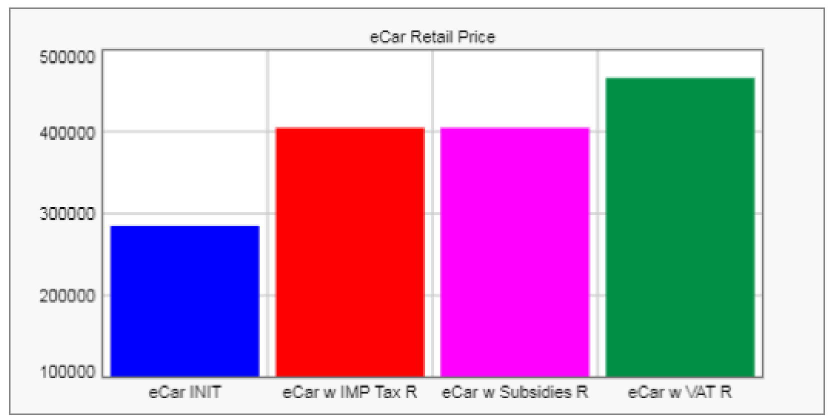
fuel switch

Reduce battery costs

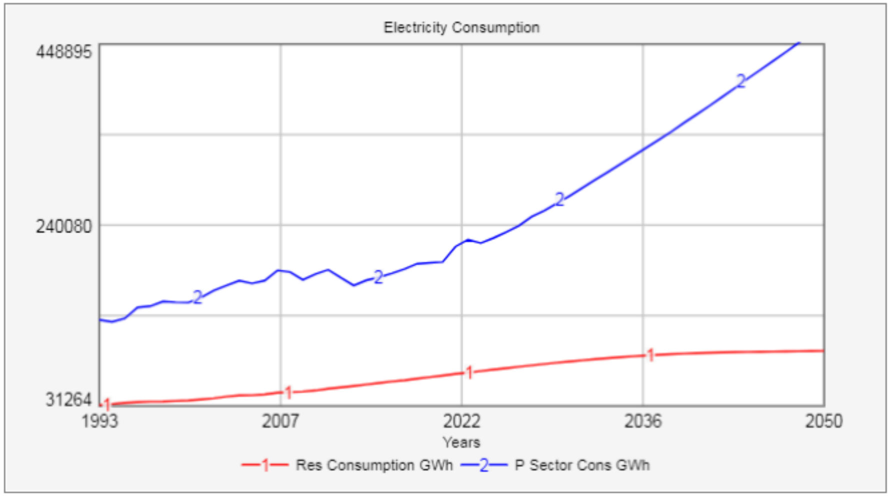
Battery percent 0.0 33.0 100.0

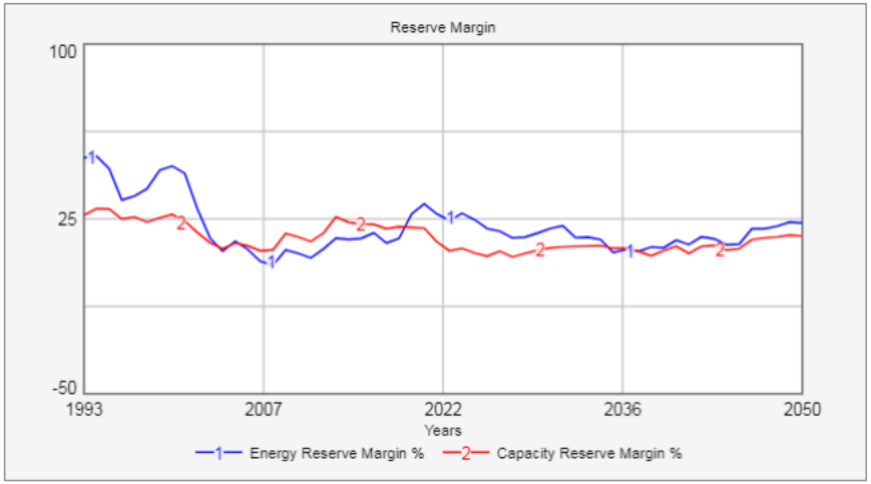
ICE monthly repayment	8,170.6
eCar monthly repayment	13,288.9





Modelling EV Uptake using a System Dynamics Approach
Engagement Platform (3/4)





GDP yearly increase %

2.0

Gini coefficient Goal

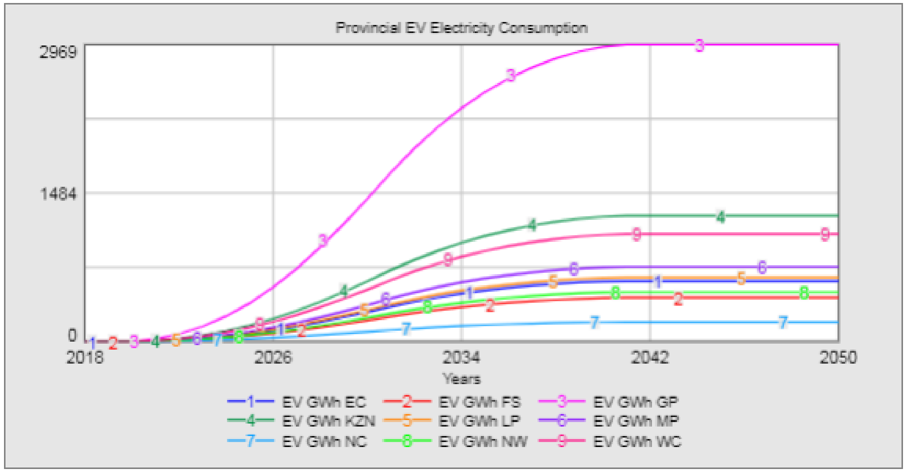
PROVINCIAL VEHICLE FRACTIONS BY:

- DI switch
- GDP switch
- ICEV switch
- POP switch

Electricity Consumption

	Total electricity GWh	Res Consumption GWh	P Sector Cons GWh	P Res Cons GWh	P Res Cons wEV
2037	437 957.87	91 149.71	348 016.42	88 873.89	89 941.46
2038	448 747.04	91 791.28	358 200.91	89 445.97	90 546.13
2039	459 061.68	92 335.77	367 995.92	89 943.62	91 065.75
2040	469 345.61	92 782.38	377 845.79	90 366.59	91 499.82
2041	479 815.10	93 130.38	387 967.29	90 714.59	91 847.81
2042	490 535.69	93 403.07	398 415.18	90 987.28	92 120.51
2043	501 513.09	93 657.71	409 137.95	91 241.92	92 375.14
2044	511 915.66	93 894.49	419 303.74	91 478.70	92 611.92
2045	522 299.04	94 113.61	429 468.00	91 697.82	92 831.05
2046	532 910.66	94 315.24	439 877.99	91 899.45	93 032.68
2047	543 756.78	94 499.54	450 539.81	92 083.75	93 216.97
2048	554 842.63	94 666.64	461 458.56	92 250.85	93 384.07
2049	566 174.55	94 816.68	472 640.44	92 400.89	93 534.11

Modelling EV Uptake using a System Dynamics Approach Engagement Platform (4/4)



EV Electricity Consumption

	EV GWh EC	EV GWh FS	EV GWh GP	EV GWh KZN	EV GWh LP	EV GWh MP	EV GWh NC	EV GWh NW	E
2040	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	
2041	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	
2042	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	
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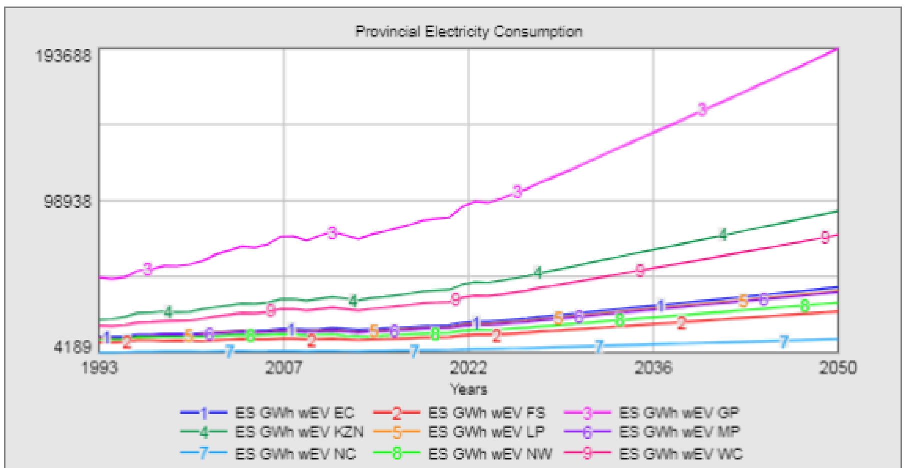
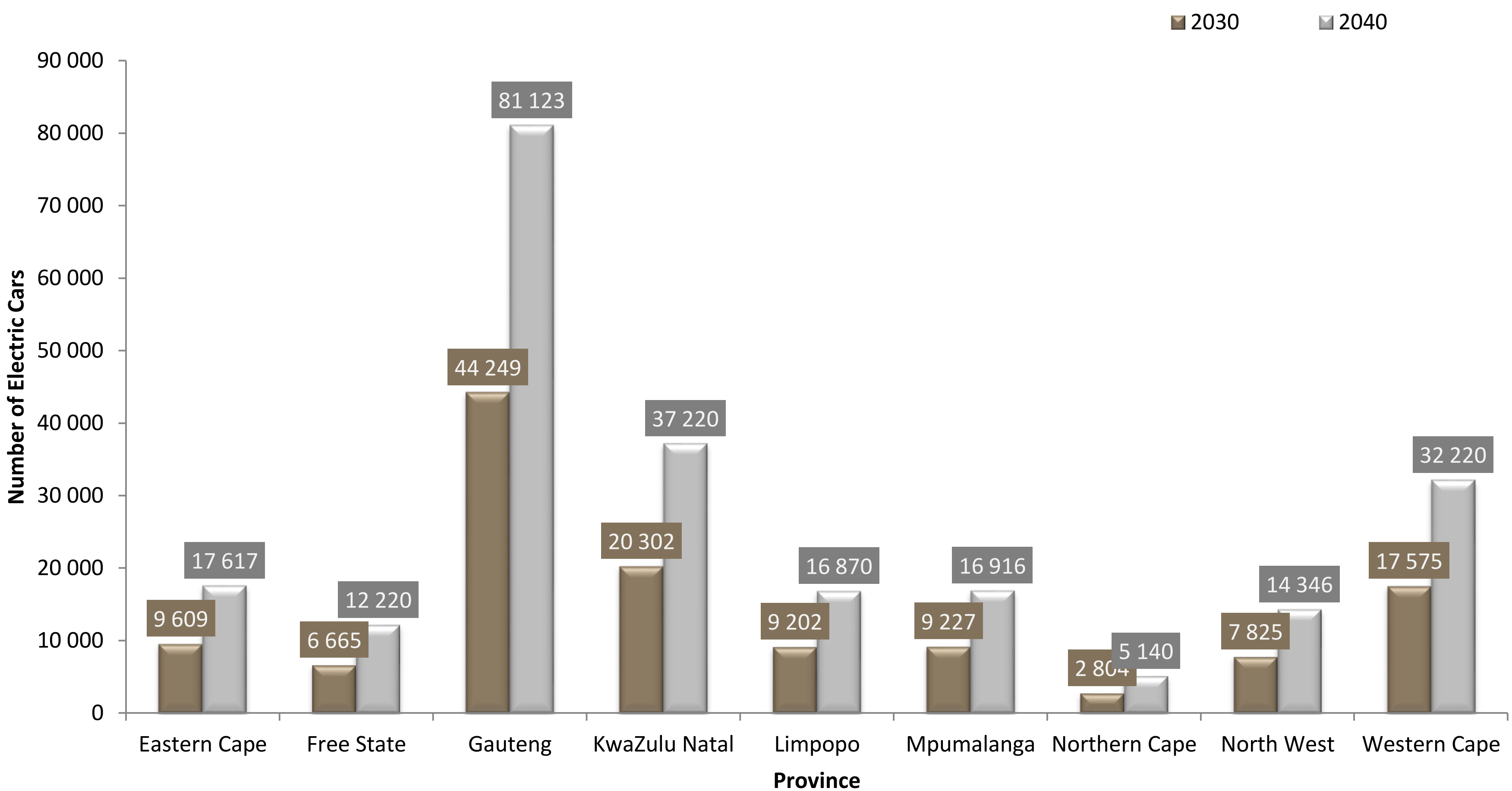
2047	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	
2048	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	
2049	604.60	437.66	2 968.66	1 257.54	640.15	747.55	194.42	492.3	



Energy Sector Electricity Consumption

	ES GWh wEV EC	ES GWh wEV FS	ES GWh wEV GP	ES GWh wEV KZN	ES GWh wEV LP	ES GWh wEV MP	ES GWh wE
2039	36 748.04	24 209.26	156 596.50	75 390.35	34 795.04	34 138.79	10
2040	37 533.01	24 748.33	160 158.10	77 039.16	35 544.78	34 888.35	10
2041	38 328.83	25 295.67	163 777.36	78 712.57	36 304.61	35 647.17	10
2042	39 141.92	25 856.17	167 487.77	80 424.47	37 081.42	36 423.89	10
2043	39 974.09	26 430.10	171 288.08	82 176.98	37 876.55	37 219.15	11
2044	40 762.60	26 973.99	174 889.58	83 837.64	38 629.99	37 972.75	11
2045	41 549.37	27 516.87	178 485.15	85 494.96	39 381.84	38 724.91	11
2046	42 353.07	28 071.69	182 160.68	87 188.35	40 149.95	39 493.54	11
2047	43 174.17	28 638.78	185 918.34	88 918.80	40 934.78	40 279.08	12
2048	44 013.09	29 218.40	189 759.93	90 687.15	41 736.71	41 081.93	12
2049	44 870.28	29 810.90	193 687.65	92 494.42	42 556.20	41 902.53	12

Results
Provincial: Low Growth Provincial Number of EVs (2019-2040)



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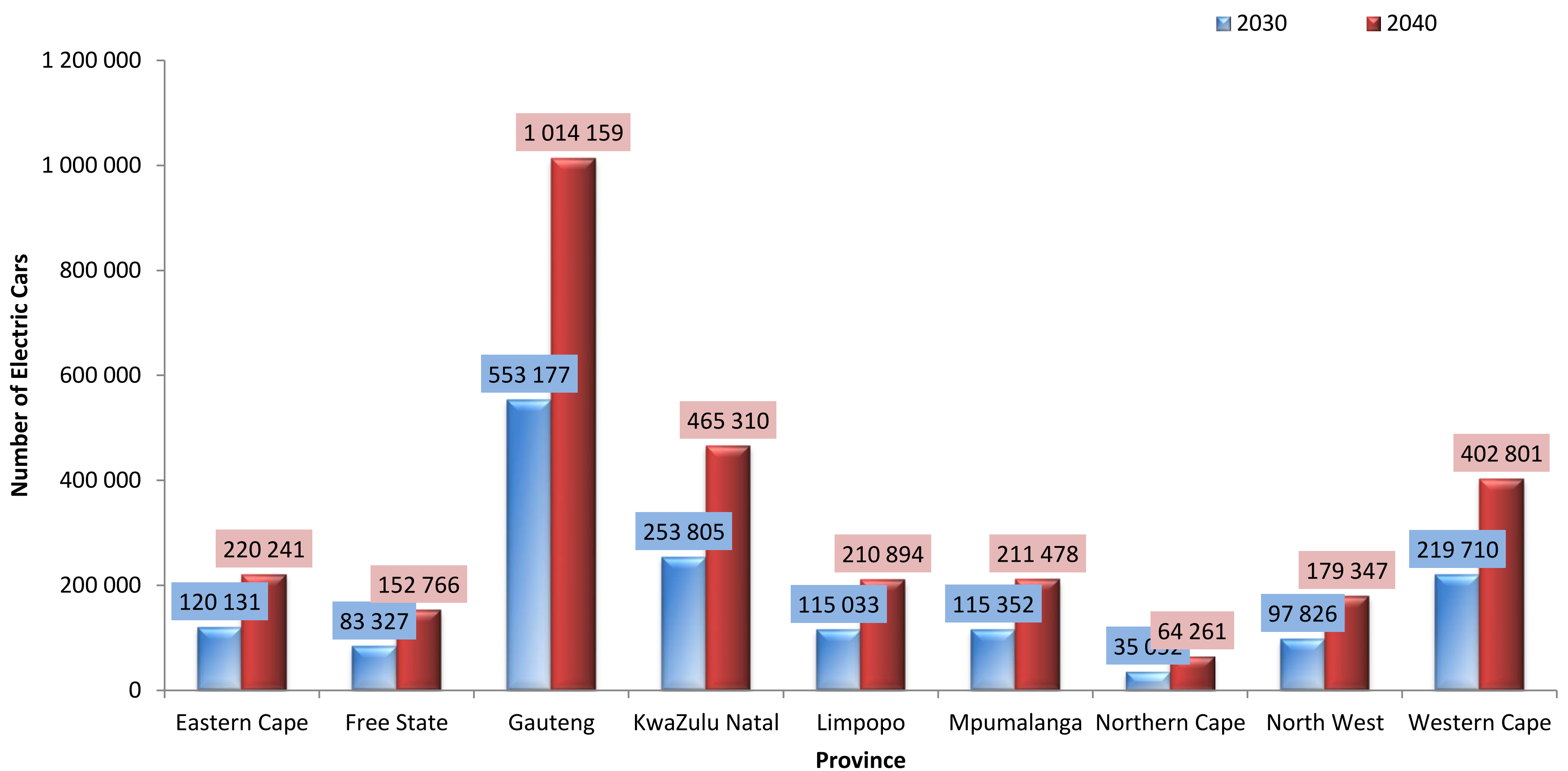
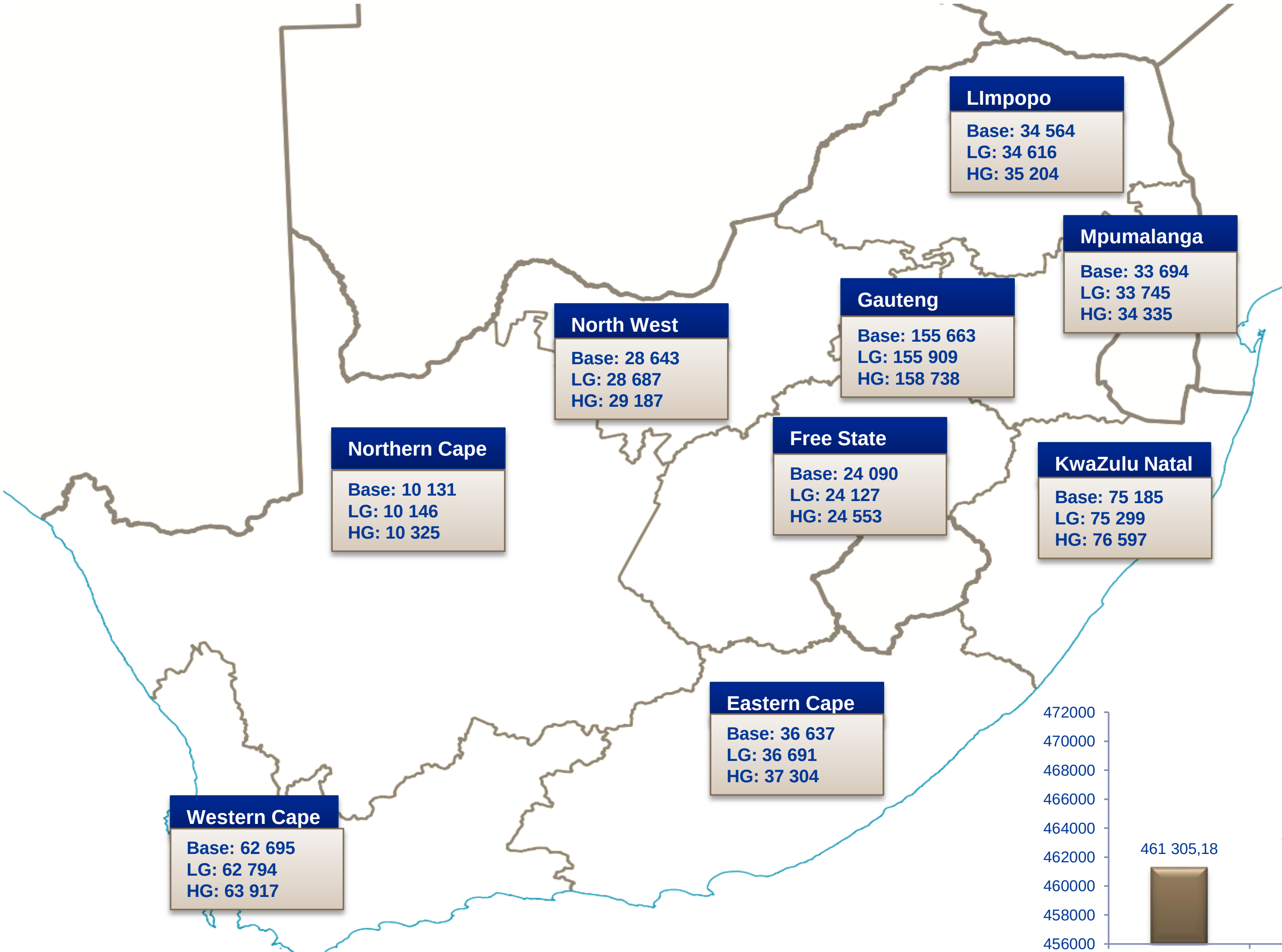
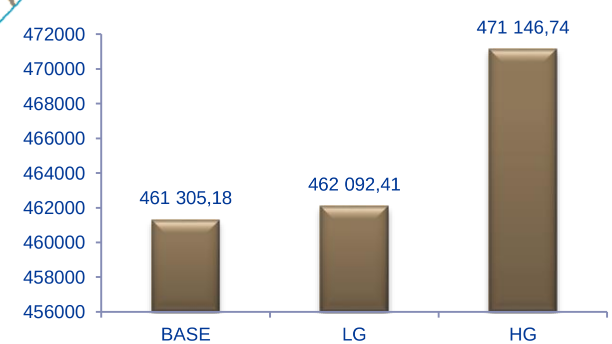


Results
Provincial: Electricity Consumption in 2040 (GWh)





Results
Provincial: Carbon Emissions (2020-2040)

	Transport Sector	% Change	Electricity Sector	% Change
Base	1668.16		4920.9	
Low Growth	1660.71	**-0.45%**	4925.55	**0.09%**
High Growth	1574.9	**-5.59%**	4979.21	**1.18%**

10% Market penetration	Bus	LDV	Minibus Taxi	Truck
Cumulative Carbon Emission Reduction in transport sector (%)	5.12	6.68	5.24	5.23
Number of EVs (2040)	6 300	249 763	31 900	37 168
Number of ICEVs (2040)	60 218	2 330 975	288 051	345 072

Validity aspect	Question
Structure	Is the model's influence structure consistent with that of the real system?
Behaviour	Does the model qualitatively produce the same results as the real system with respect to rates of change, oscillations, stability, etc.?
Empirical	Do the model outputs correspond quantitatively (within the bounds of its purpose) with empirical results from the real system?
Application	Is the modelled domain, complexity and functionality aligned with the purpose of the simulation.

Conclusions

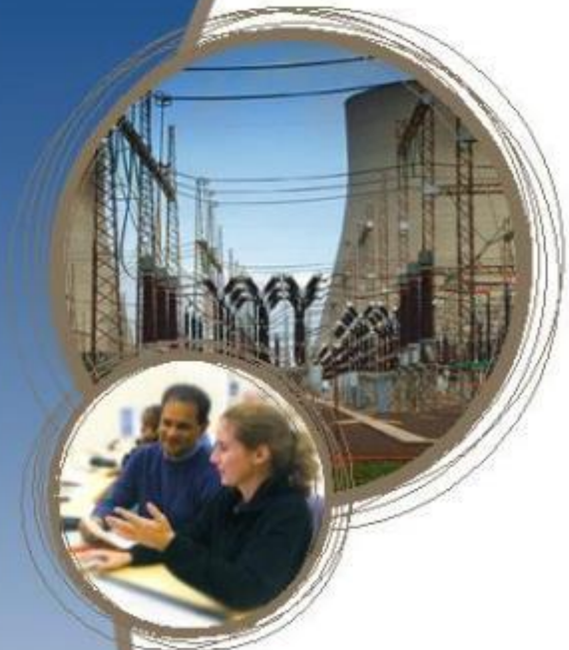
DEMO

Conclusions

- The adapted system dynamics modelling processes, which include **elements of group model building** necessary for strategy implementation, are an effective and rigorous modelling process for the practical development and implementation of system dynamics tools for use in an electricity utility.

- The modelling method provides **quantitative insights** into variations of the impact and expectations of various scenarios - more value if used for exploratory modelling and descriptive comparative scenario analysis as opposed to predictive system behaviour down to the last decimal place.

- The use of the system dynamics methodology to develop energy models allows **sensitivity and scenario analysis** of hundreds of causally linked qualitative and quantitative dependencies, and allowed the structural linkage of feedback loops involved in complex systems due to the various drivers.



Thank you

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