Planning the future using optimisation

BAM, November 2012
Simon Dunstall, CSIRO

Acknowledgements

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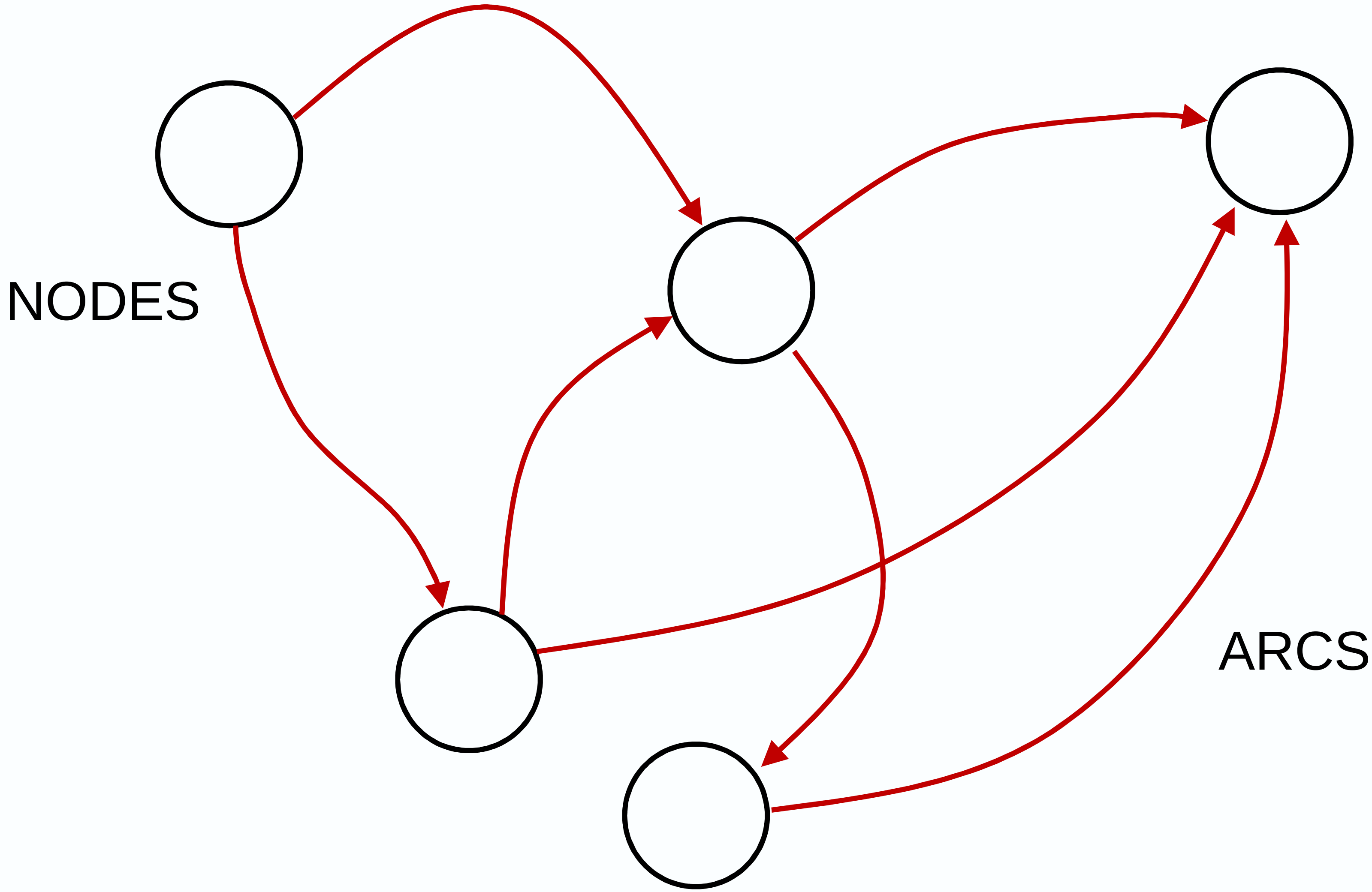
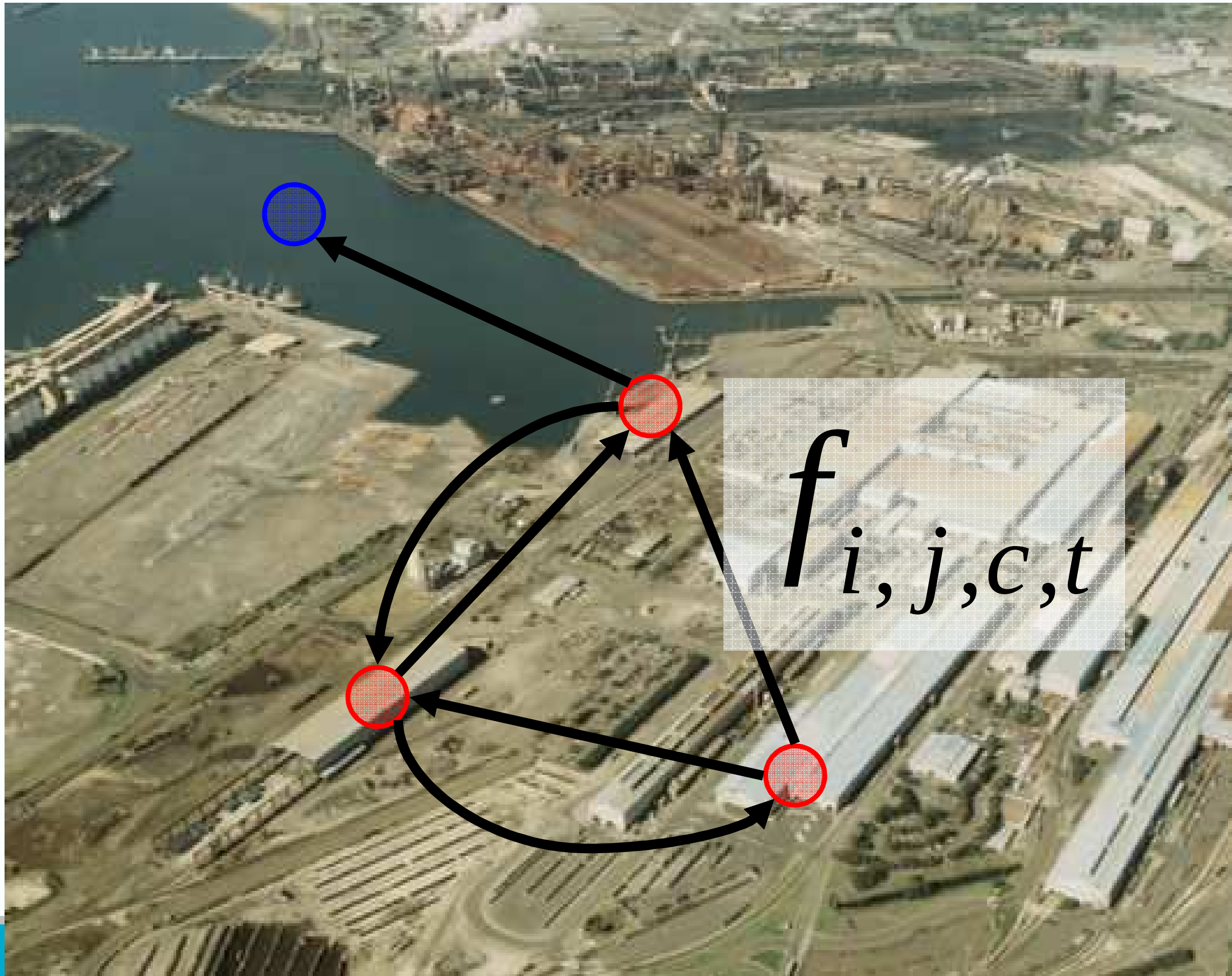
The projects referred to in this presentation have been funded from a variety of sources, from both the public and private sectors.

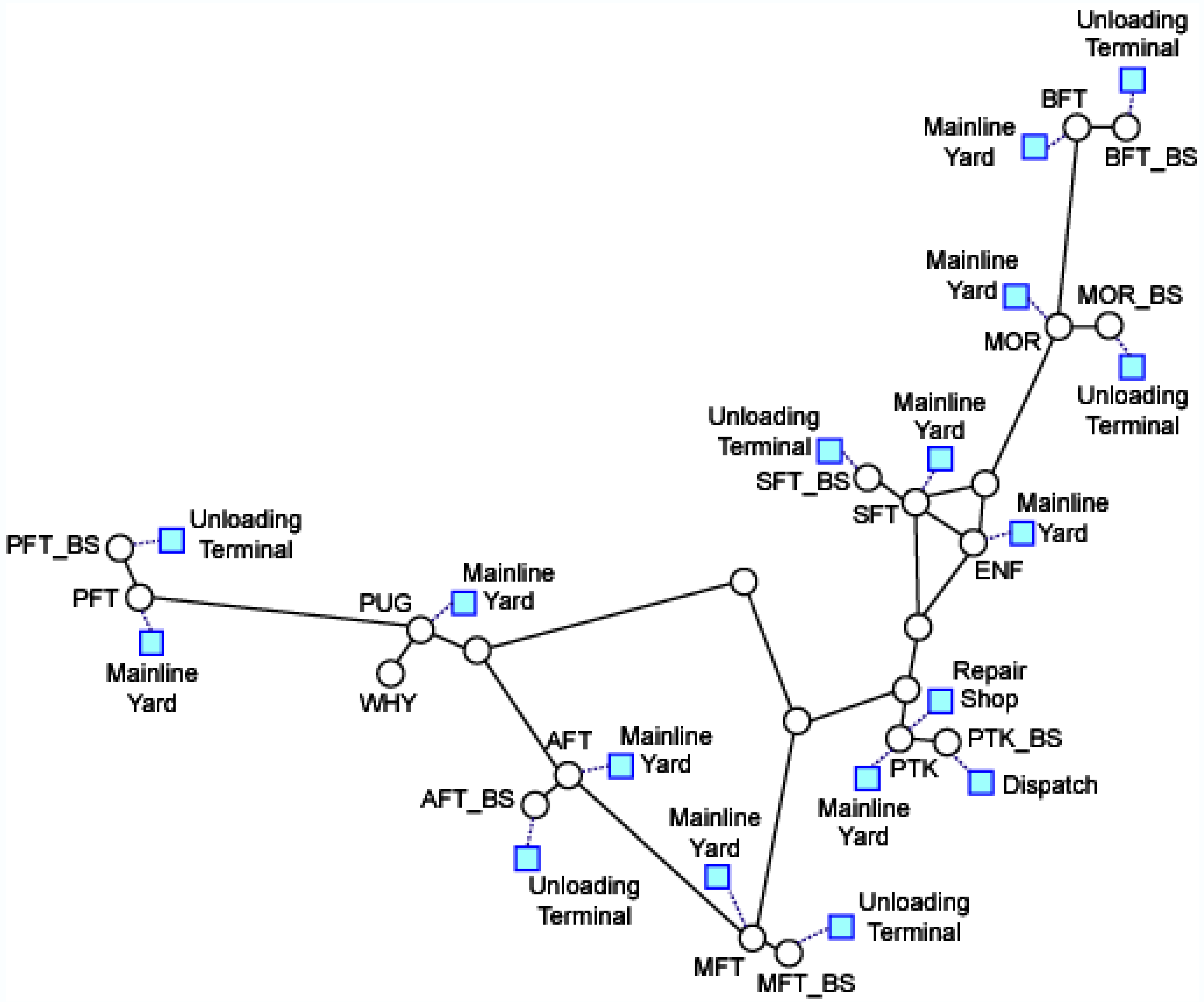
Graphs



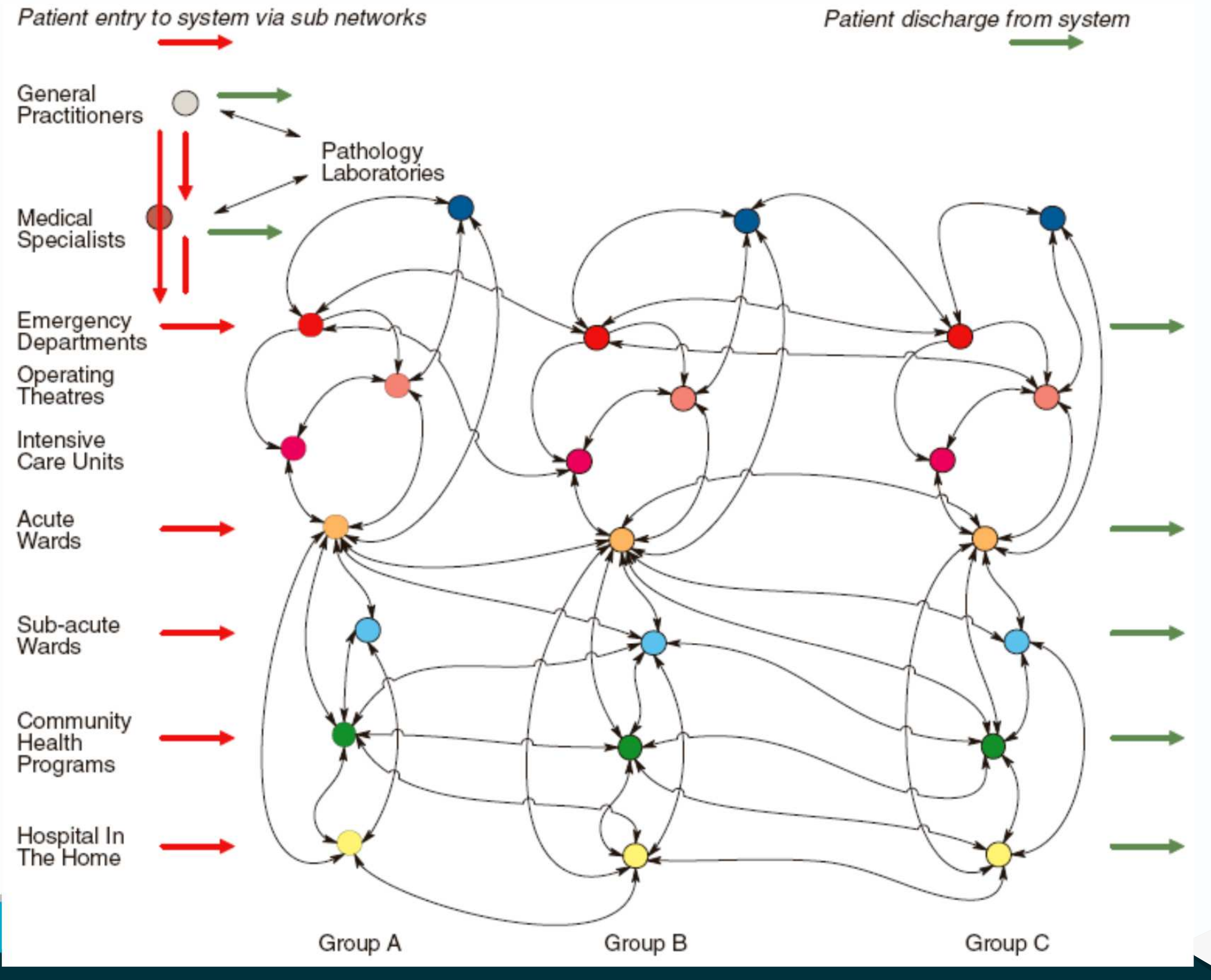
For example, for port asset (size) selection



Rail network as a graph



Health and service networks



When want to analyze today's systems…

Modelling for futures: what are we trying to achieve?

Impact of policies and decisions over time

Determining sequences of decisions that lead to favourable futures

Future requirements for assets, systems and networks

Understand biophysical limits and their implications

Cost-optimal ways of meeting future demands

2020 2030 2040 2050

Why use optimisation?

Systems constrained in weird and wonderful ways

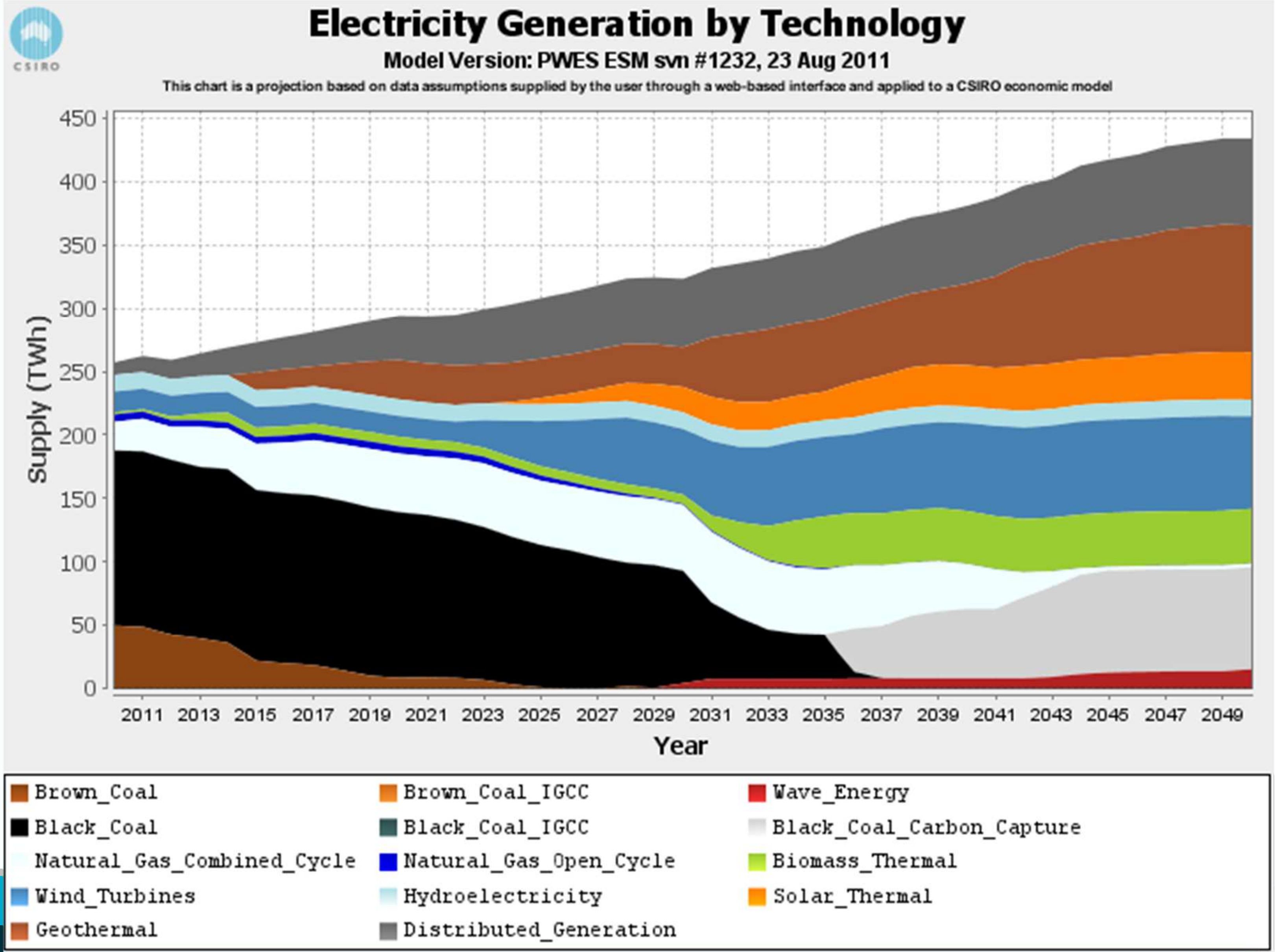
Multi-objective tradeoffs

Huge decision spaces

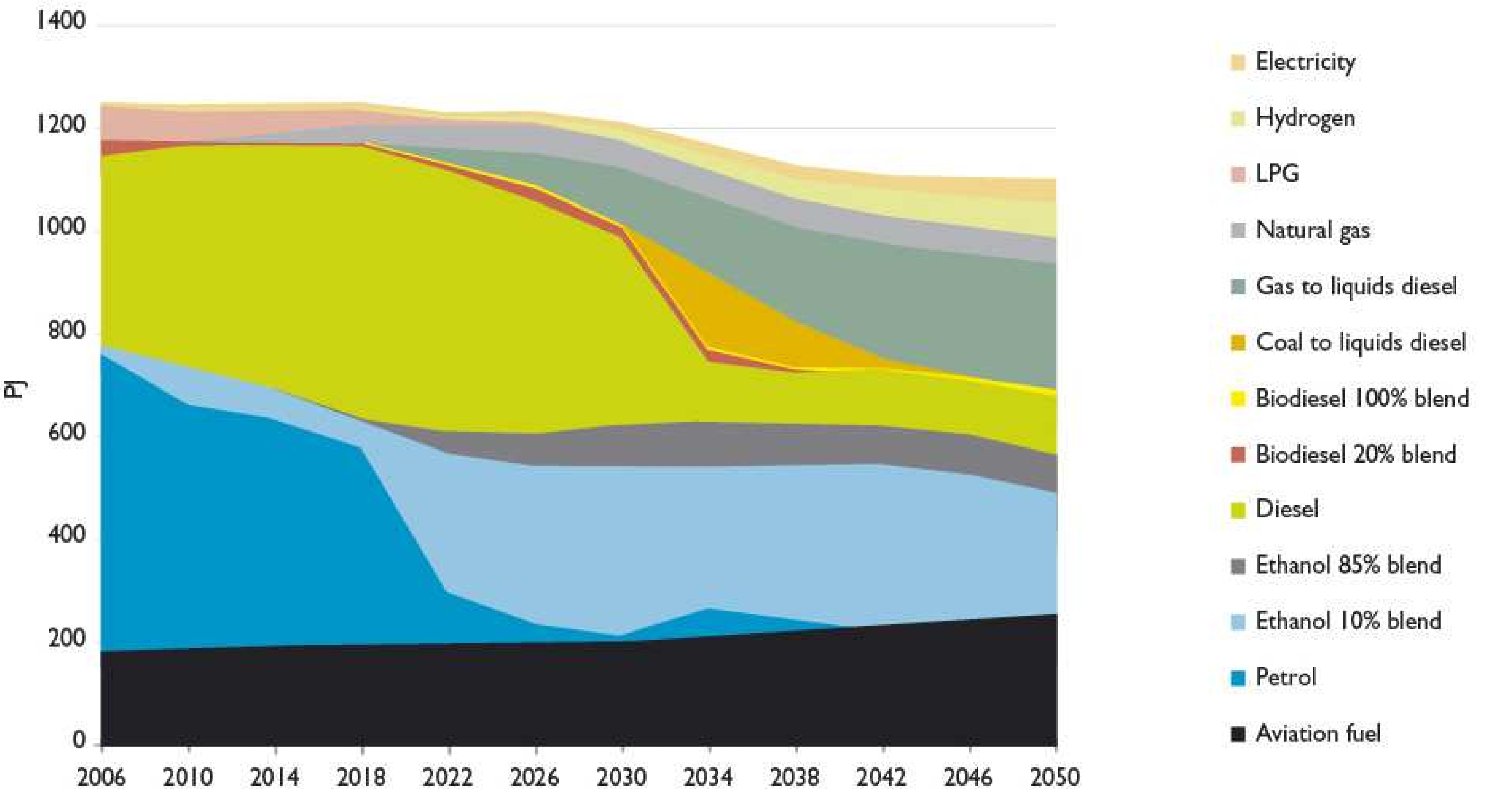
Situations where discrete decisions are important

Situations where managers think deeply about decisions

Energy generation mix

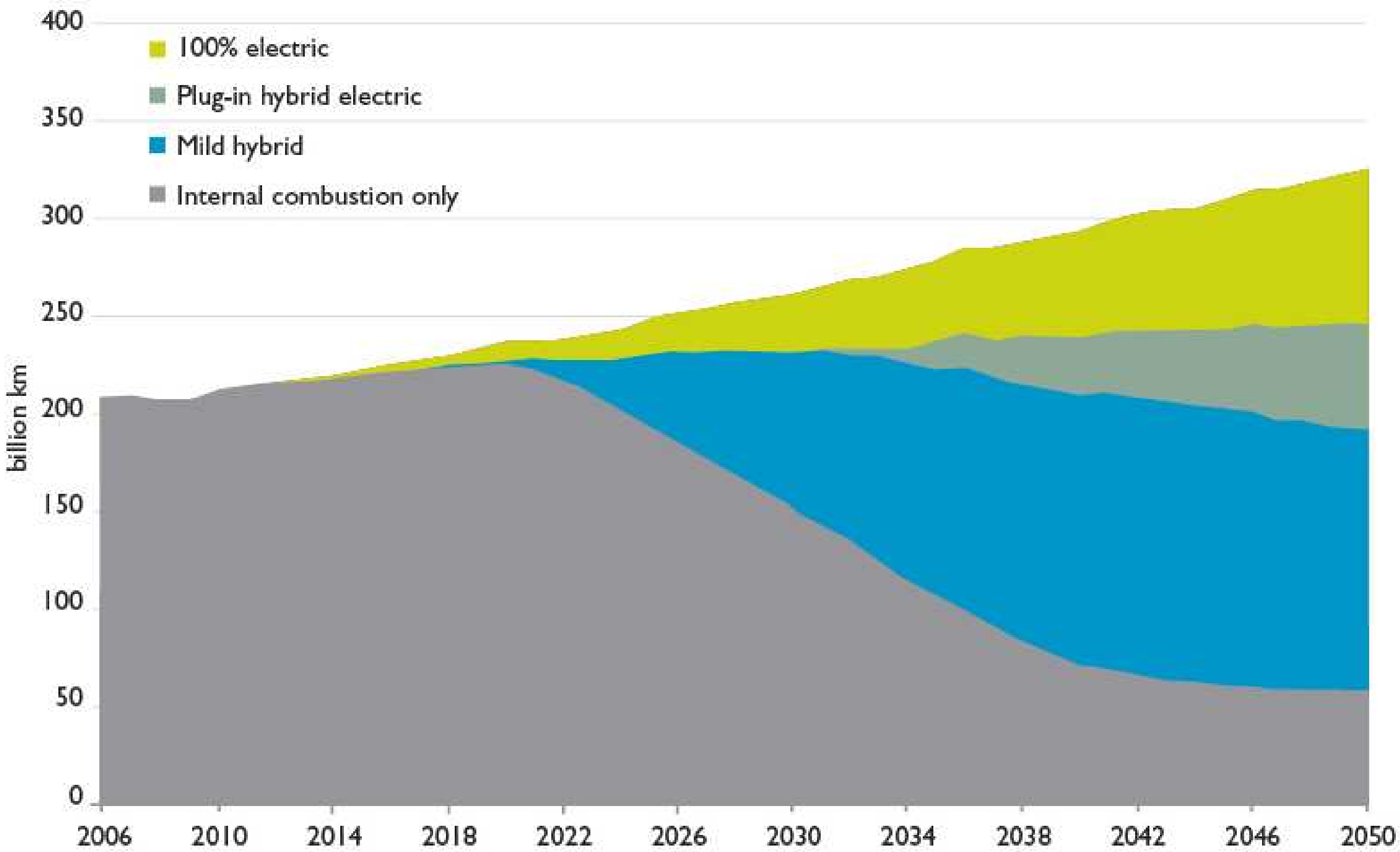


Fuels



PJ
1400
1200
1000
800
600
400
200
0
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046
2050
Electricity
Hydrogen
LPG
Natural gas
Gas to liquids diesel
Coal to liquids diesel
Biodiesel 100% blend
Biodiesel 20% blend
Diesel
Ethanol 85% blend
Ethanol 10% blend
Petrol
Aviation fuel

Vehicles



100% electric
Plug-in hybrid electric
Mild hybrid
Internal combustion only
billion km
400
350
300
250
200
150
100
50
0
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046
2050

Beef supply chains

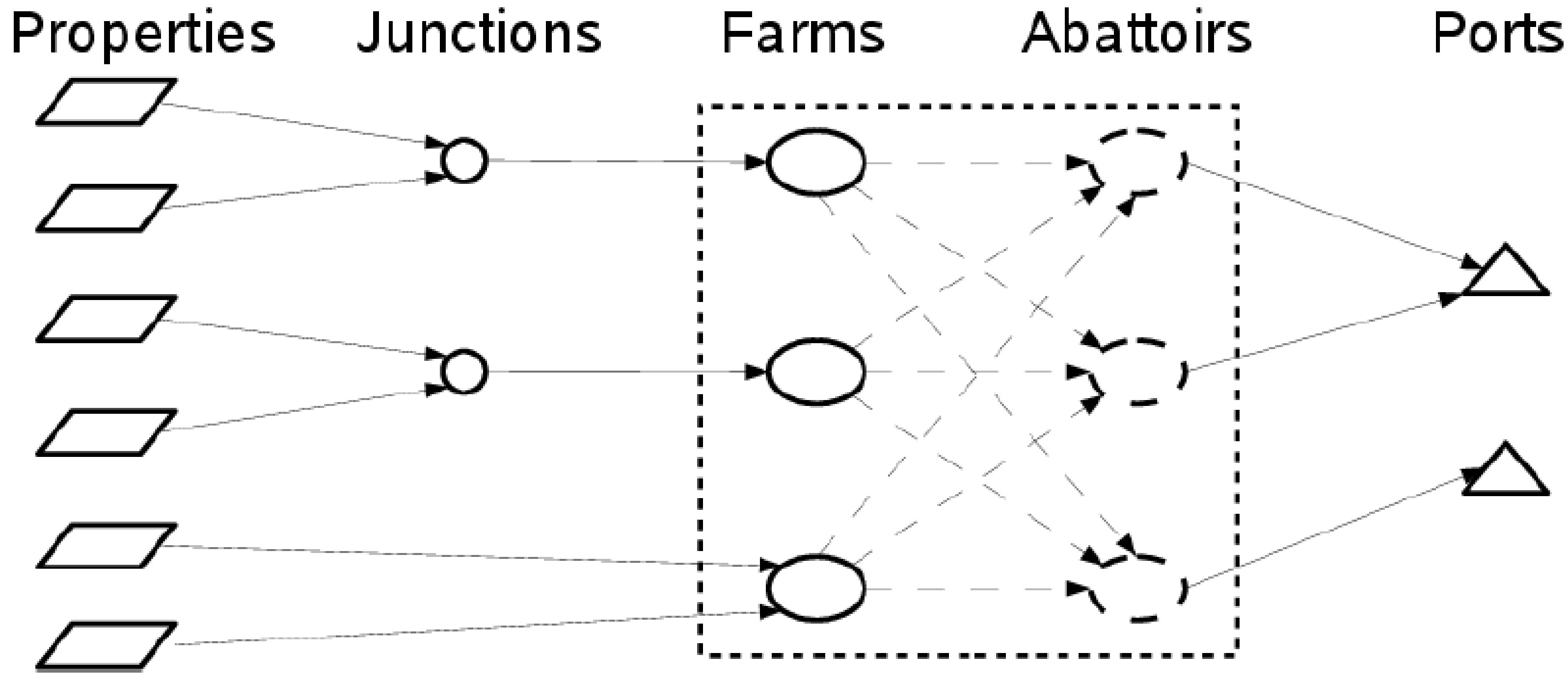


Figure 4.1: Diagram of the northern Australian beef supply chain. Truckloads of livestock are transported from properties to fattening farms, possibly through transshipment sites. After a number of periods in the farm, the cattle are taken to the abattoirs for processing. The final locations of the abattoirs are not known a priori, but determined as part of the optimisation problem from a set of candidate locations. In the final stage, meat is transported to the ports.

Beef: existing and future road links

Wet season interruption

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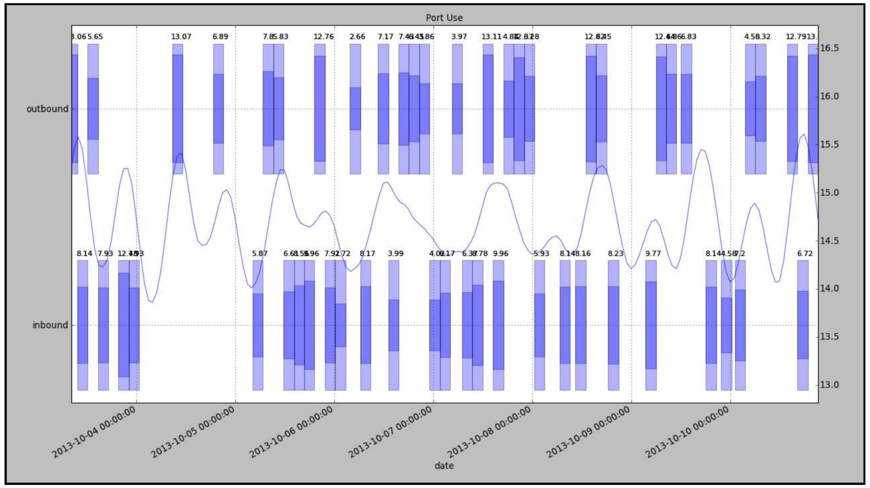
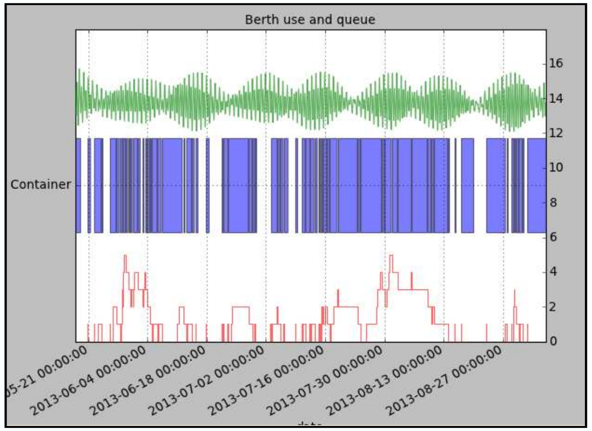
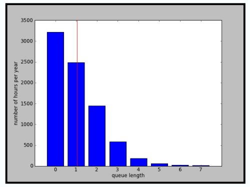
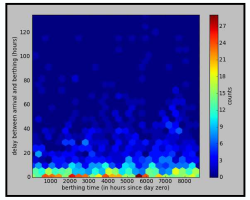
Port planning

Simulation and optimisation to analyse berth and shipping channel capacities









Role of optimisation models in projection, forecasting and planning

LP/MIP: well understood limitations

- Deterministic
- Perfect lookahead
- Rationality, centralized control
- No voodoo: mathematically verifiable and concisely expressible

Role for methods other than LP/MIP (including LR)

- Computational time
- Solution evaluation requires simulation of a system

Why not only opt?

- Detail
- Non-linearity (e.g., power flow)
- Incremental decisions (e.g., perfect lookahead is very bad)
- Non input-output systems (e.g., demand-infrastructure co-dependency)
- Assumption of determinism is poor

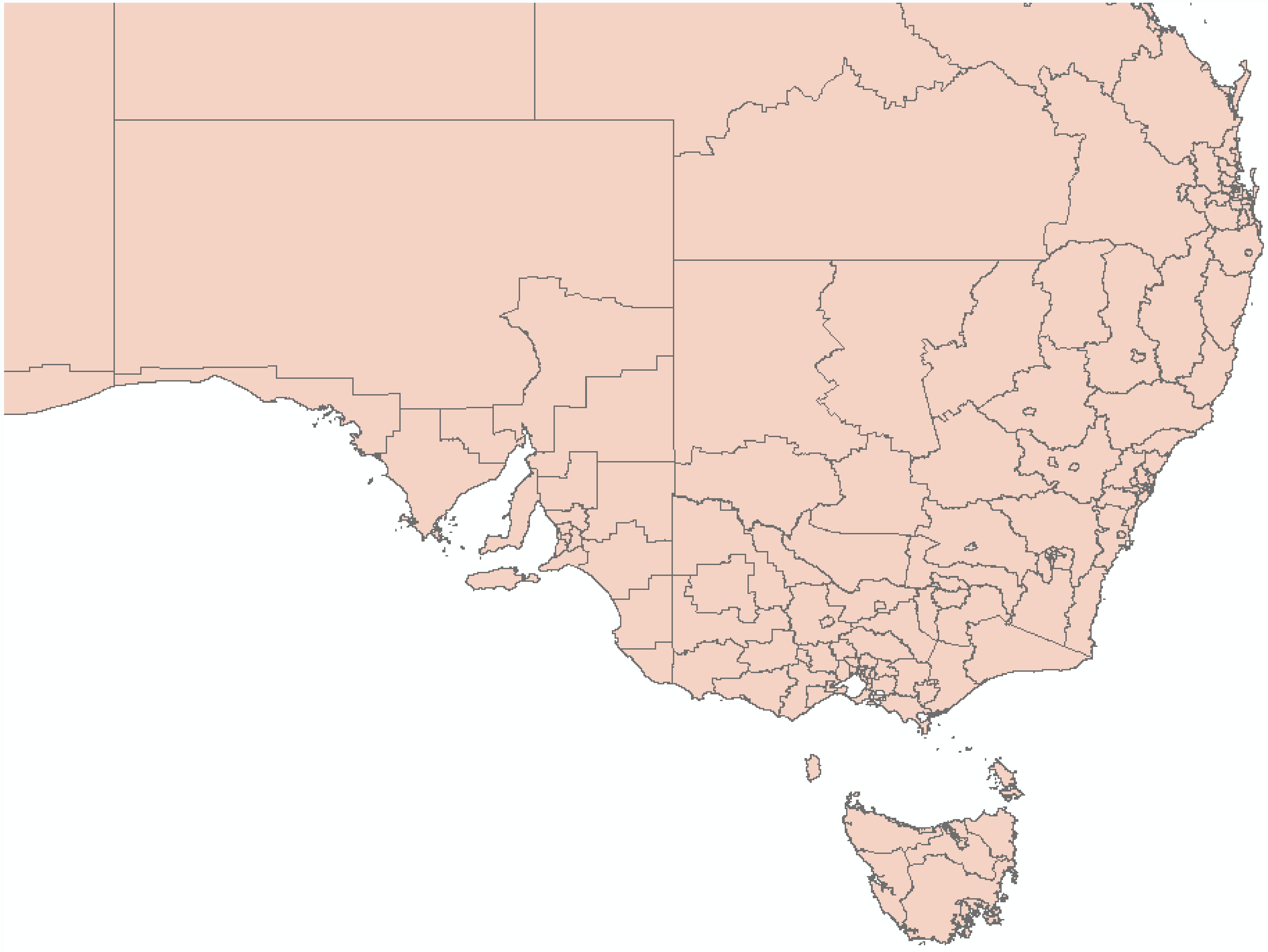
What is difficult about using optimisation for modelling the future?

In approximate order of difficulty, and in our experience:

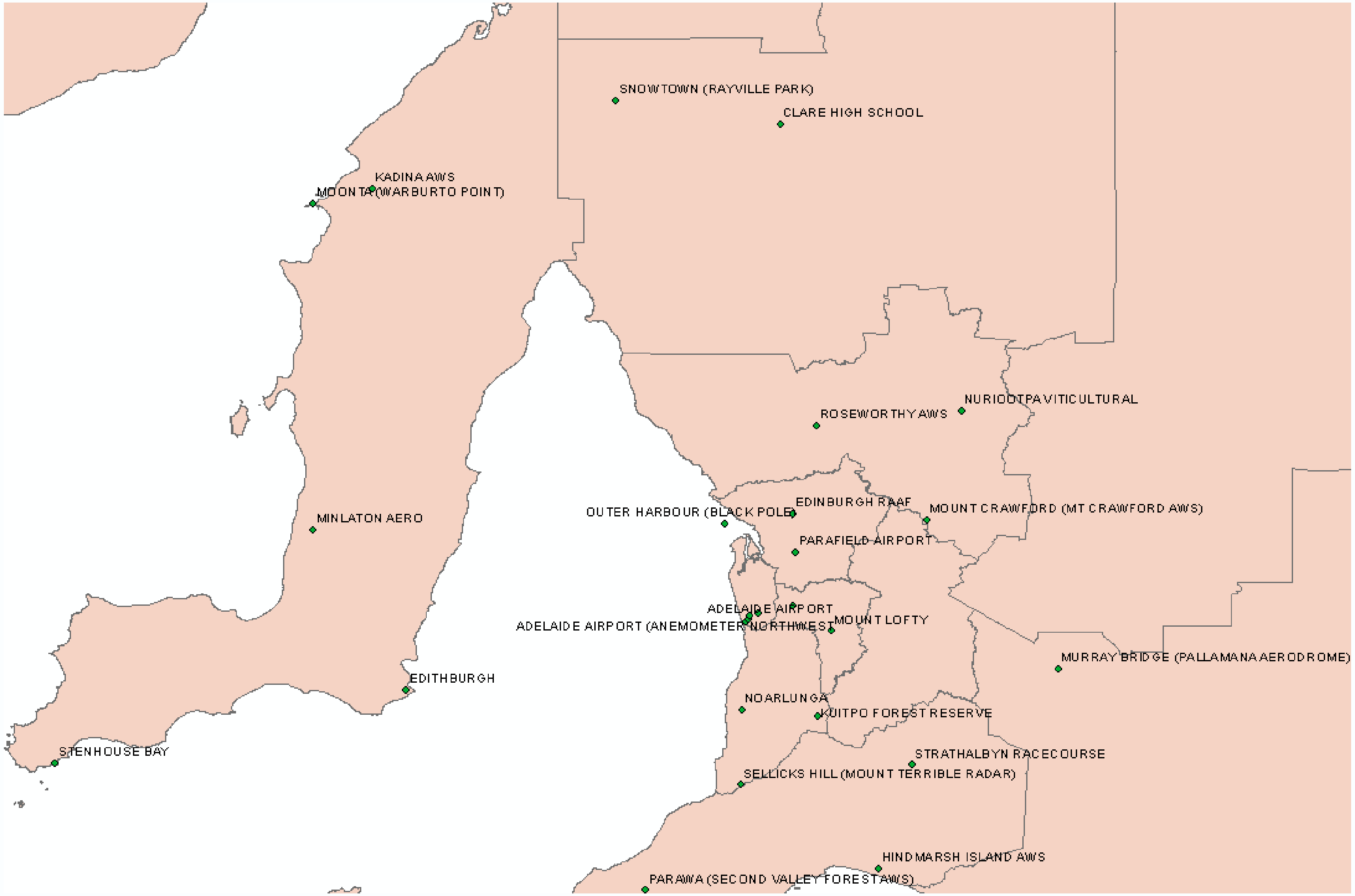
1. Formulating an LP
2. Heuristics and approximations to achieve acceptable running-time
3. Implementing the core software systems for the models
4. Getting data, managing data, translating data into model parameters and coefficients: doing this reliably and repeatedly, and where domain stakeholders are satisfied with the answers

Data

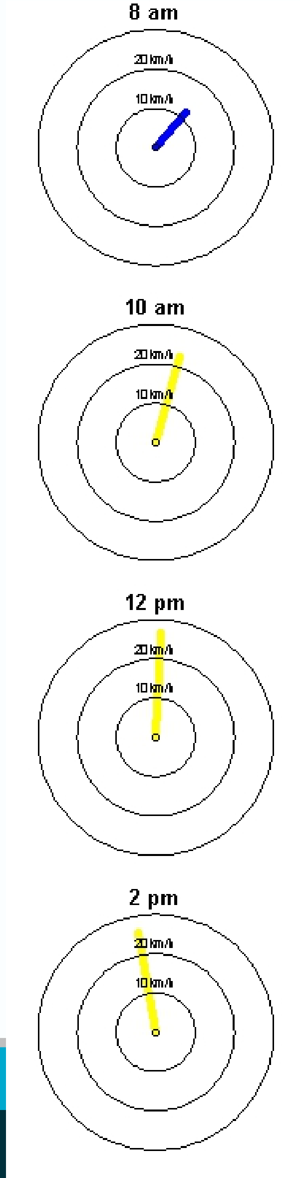
Statistical divisions

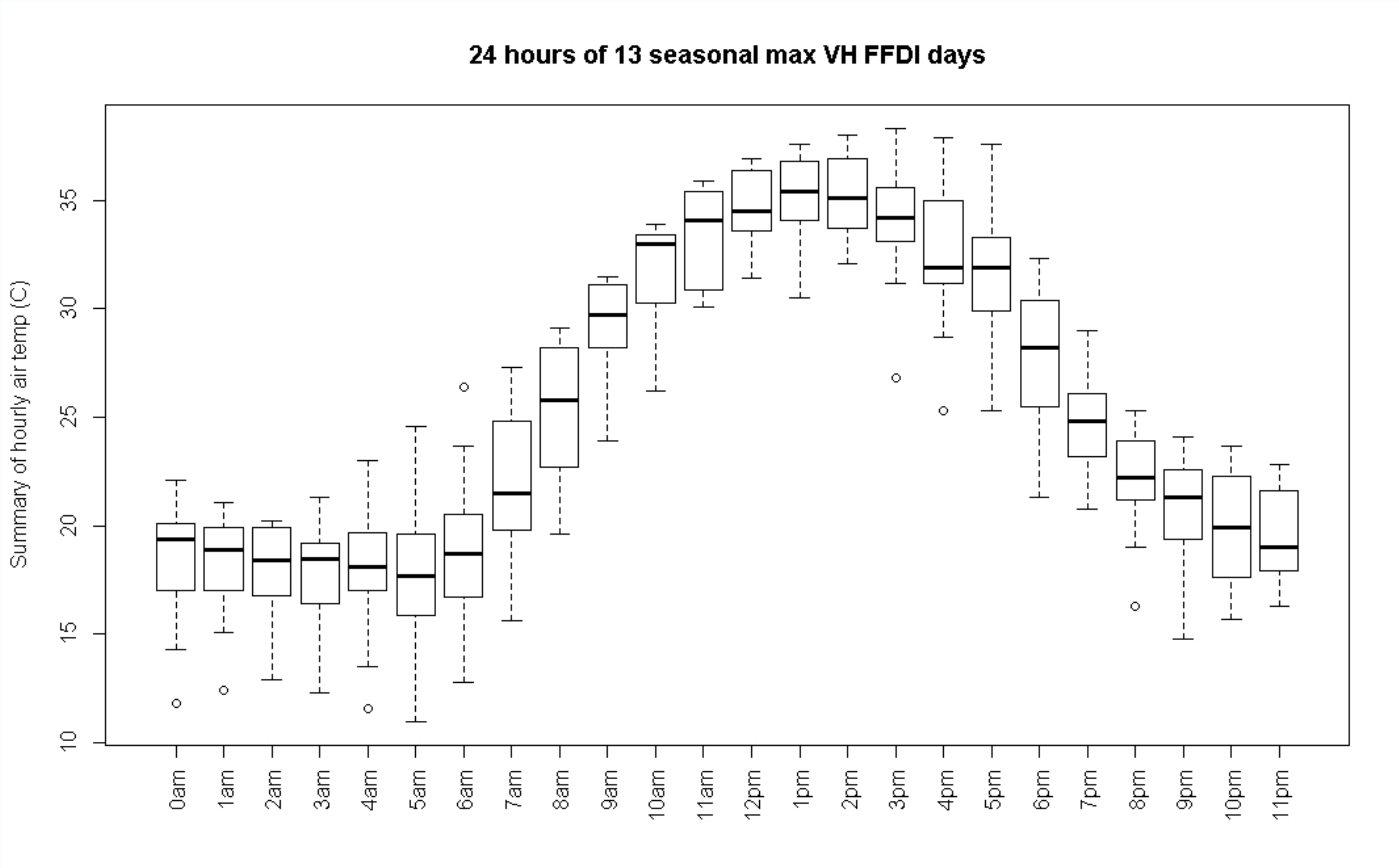


Weather stations

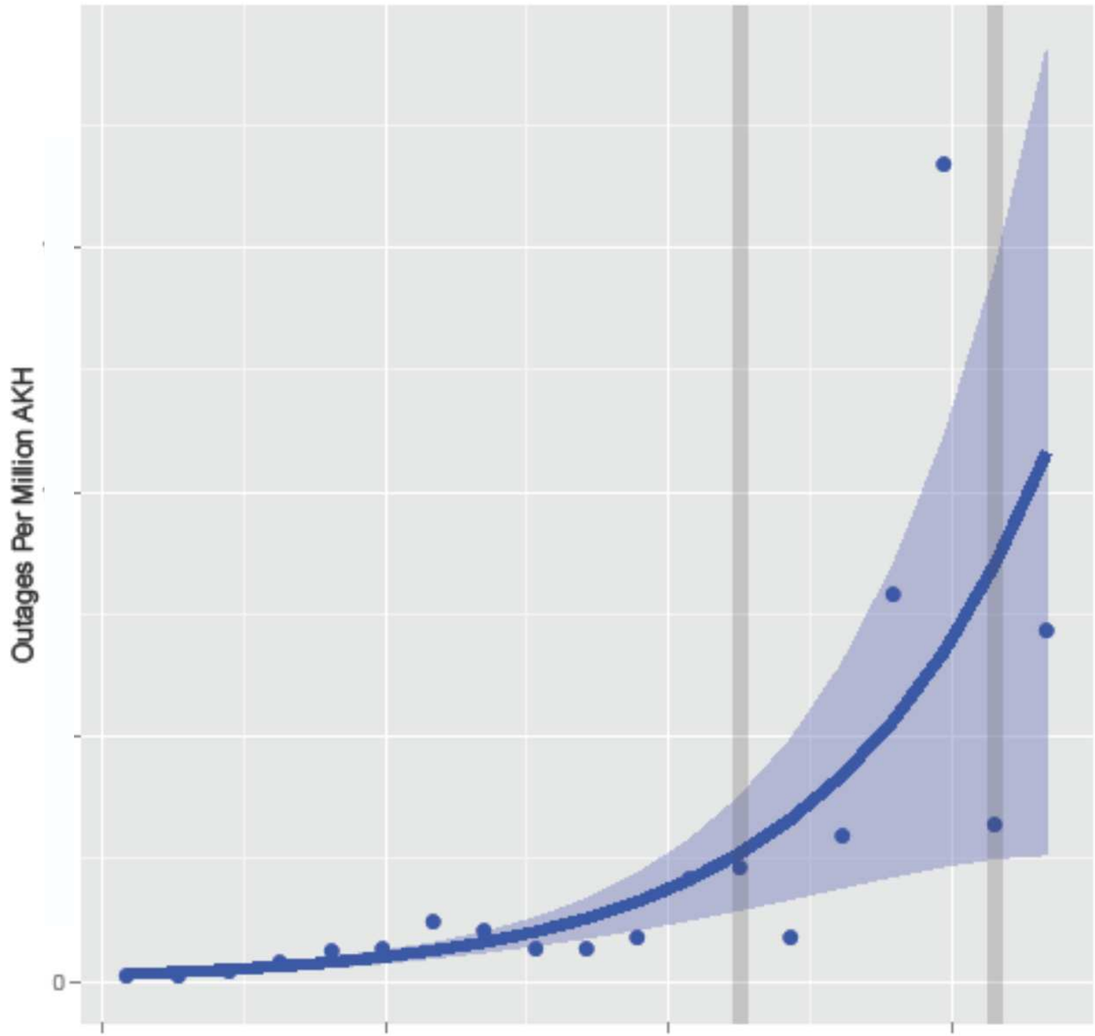


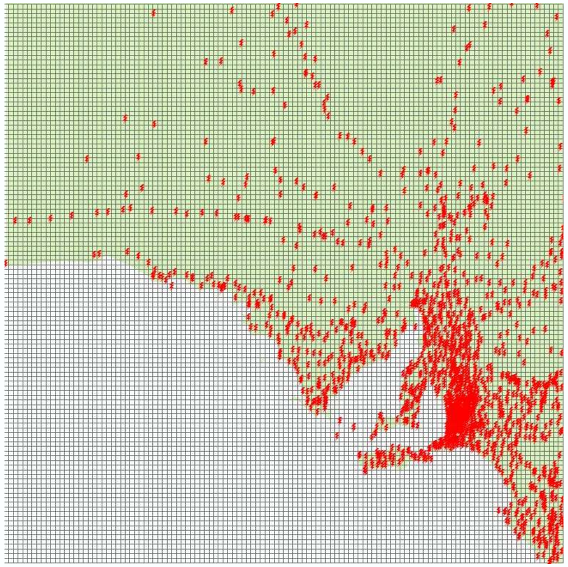
Fire weather conditions analysis





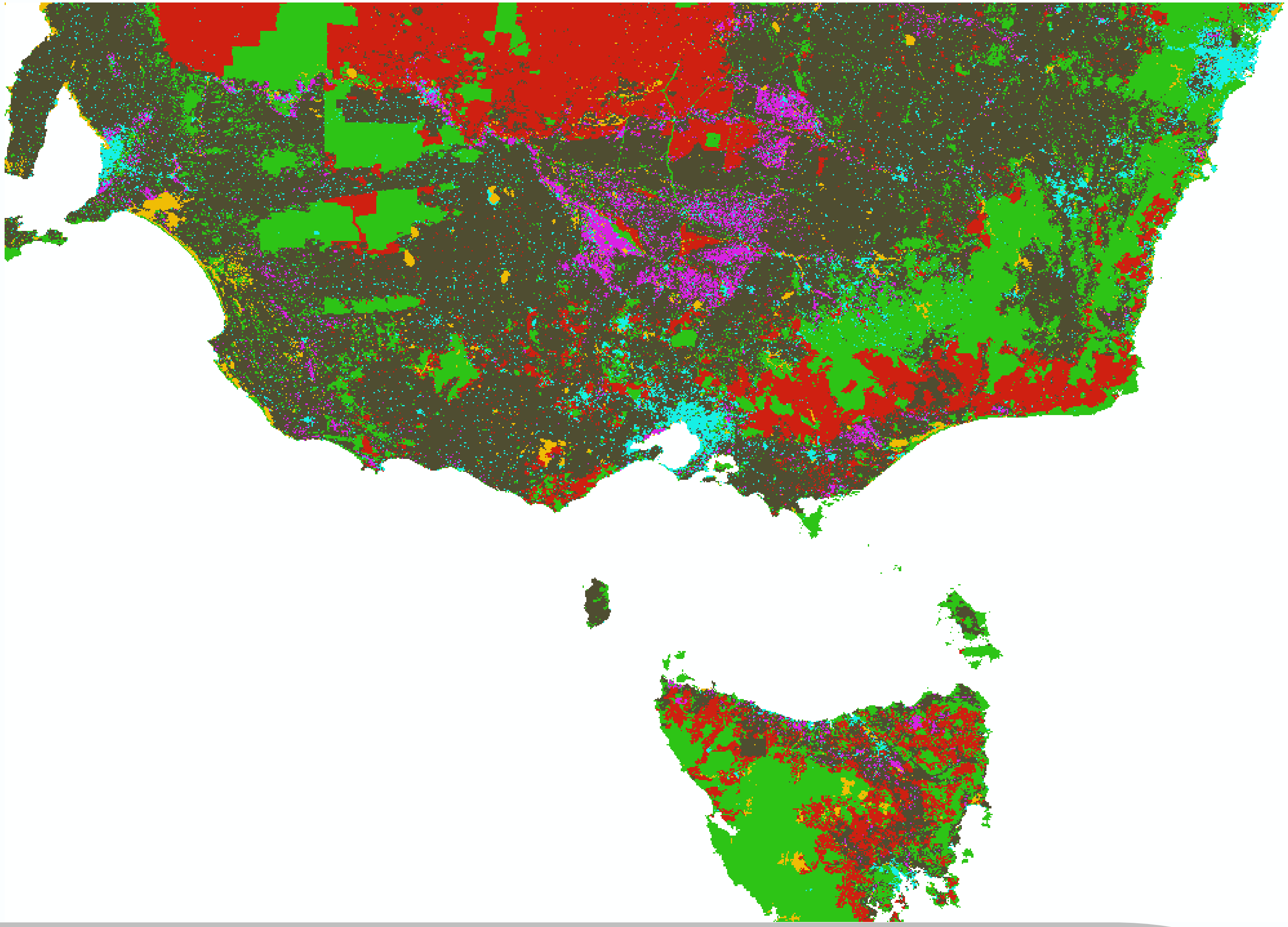
Distribution network outages





- 14400 grid squares
- 80 GB of wind data
- 77000 km of feeder
- 38000 outage events
(2000 wind and vegetation)

Land use

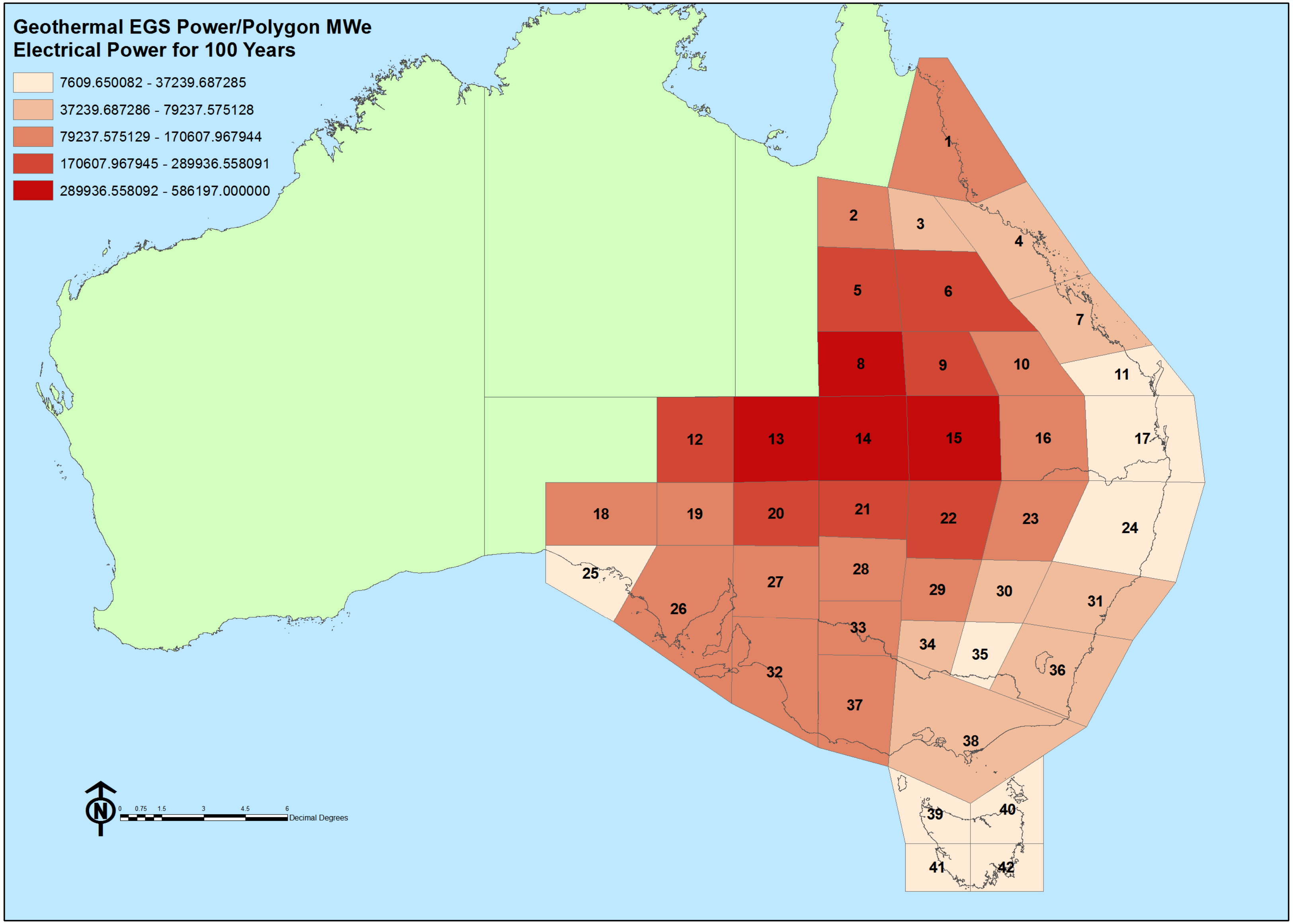


Costs and revenues

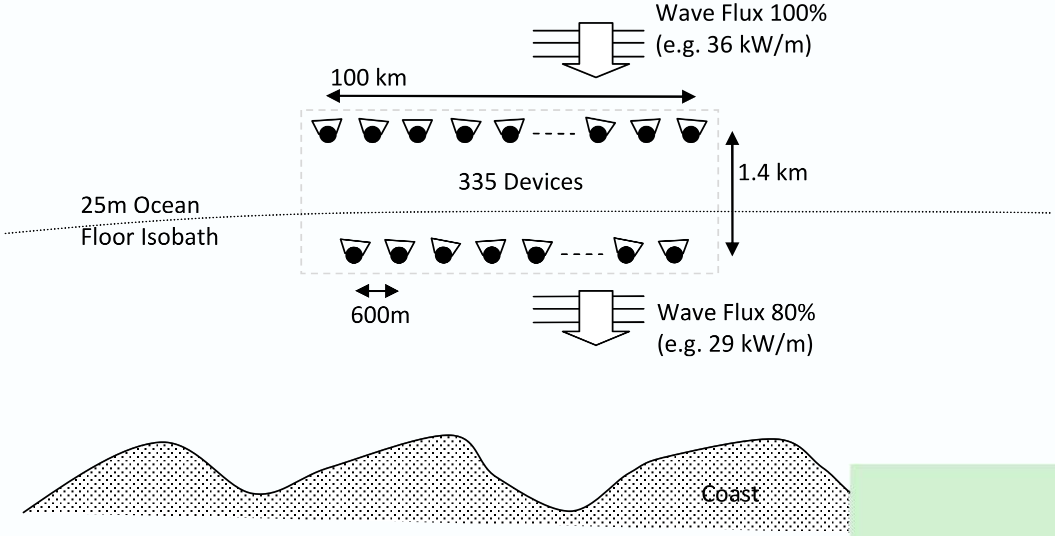
Table A1-1 Transmission costs for new generation projects

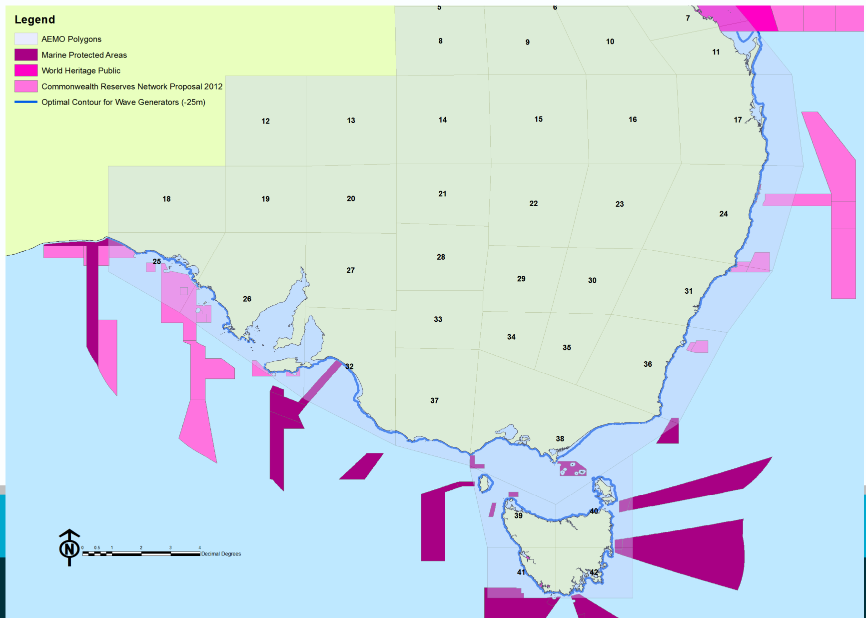
Region	Zone	Generation Type	Cost of Connection ($m/MW)	Line Upgrade Cost ($m/MW)	Total Cost of Connection ($m/MW)
SA	NSA	Wind	0.03	0.5	0.53
SA	NSA	Geothermal	0.29	0.5	0.79
SA	NSA	Solar Thermal	0.07	0.5	0.57
SA	NSA	Gas/Coal/Biomass	0.02	0.5	0.52
SA	SESA	Wind	0.03	0.5	0.53
SA	SESA	Biomass	0.04	0.5	0.54
SA	SESA	Geothermal	0.14	0.5	0.64
SA	SESA	Gas/Coal/Biomass	0.04	0.5	0.54
SA	ADE	Wind	0.03	0.3	0.33
SA	ADE	Geothermal	0.14	0.3	0.44
SA	ADE	Gas/Coal/Biomass	0.02	0.3	0.32
VIC	MEL	Wind	0.02	0.3	0.32
VIC	MEL	Gas/Coal/Biomass	0.01	0.3	0.31

Resource data



Where are renewable energy sources, and where is the transmission network needed?





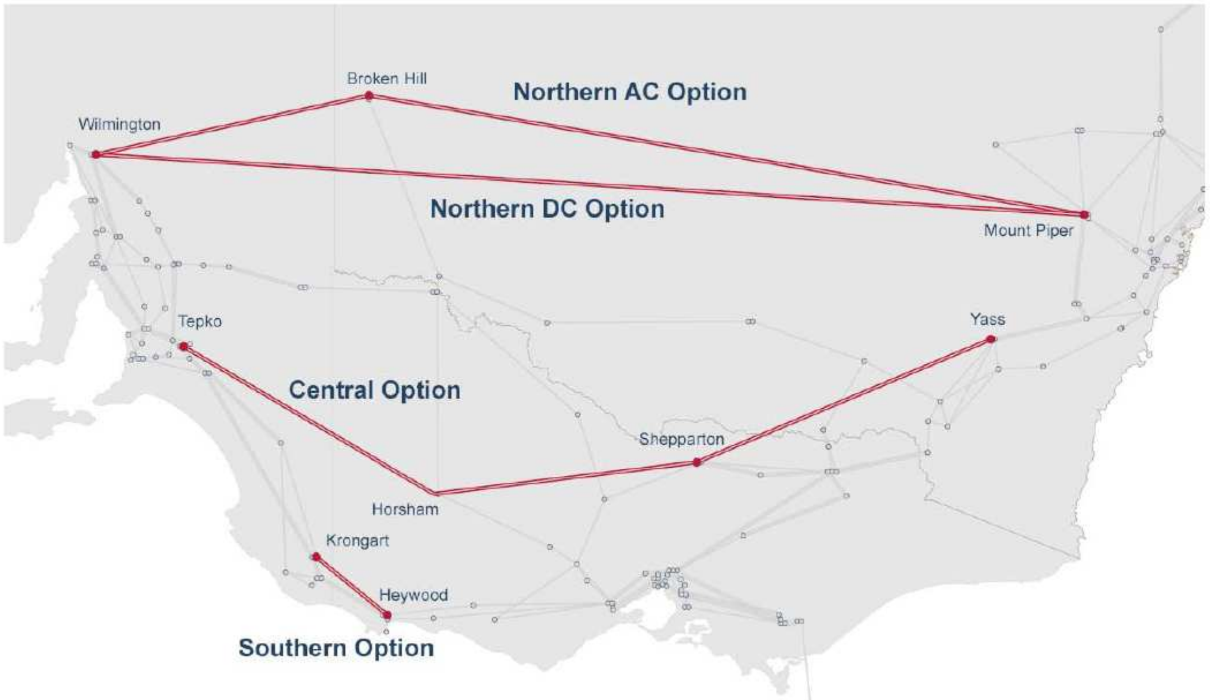
Long-term infrastructure planning

Transmission network expansion and generation site selection

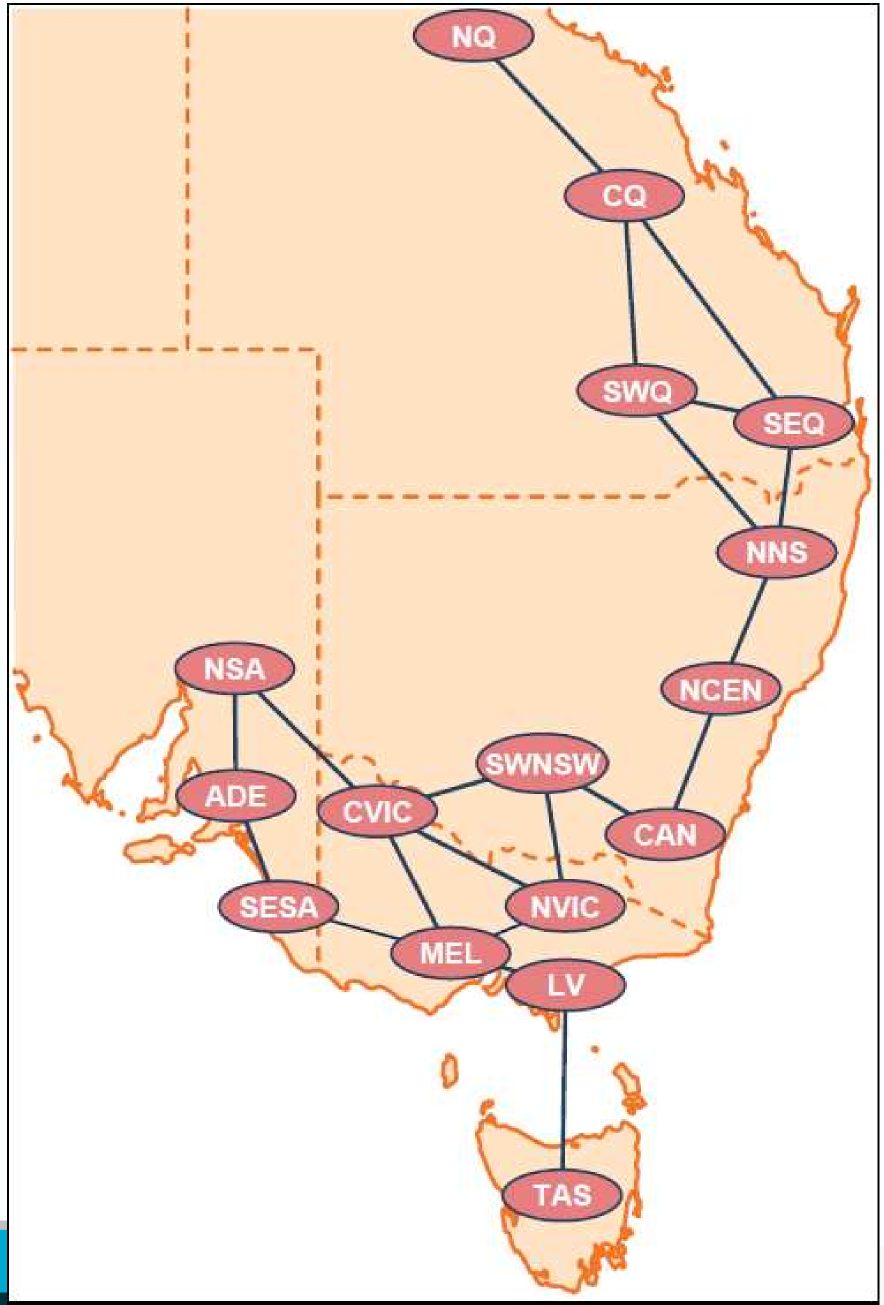
Devise a new model/tool to fill a gap between:

- Power flow analysis (on a fixed network) and the case-based analysis of transmission options
- Long-range planning models which decide on generation but which do not directly consider network changes

Figure 1 New high-capacity augmentation options



Transmission zones

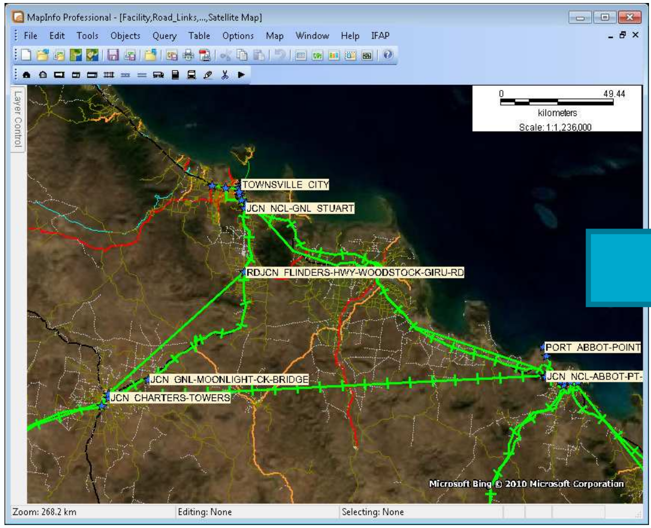


Freight transport network planning

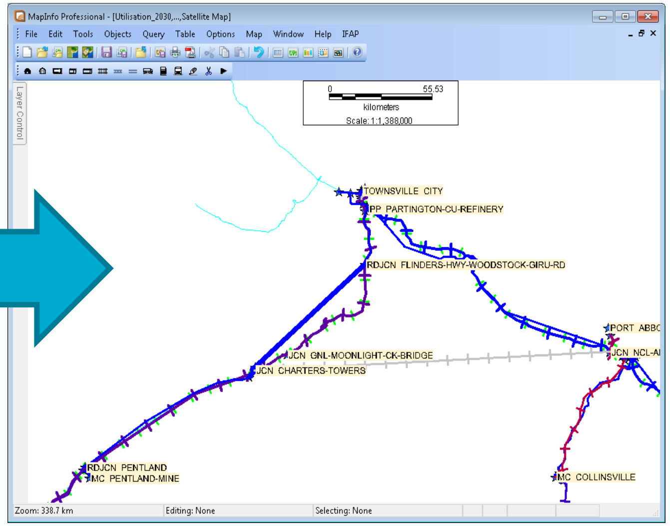
Decide on the capacity of transport links and facilities subject to time-varying demand

Link and facility capacities are associated with discrete pre-defined states.

- **Deciding on the state for each year = deciding on transport infrastructure investment**



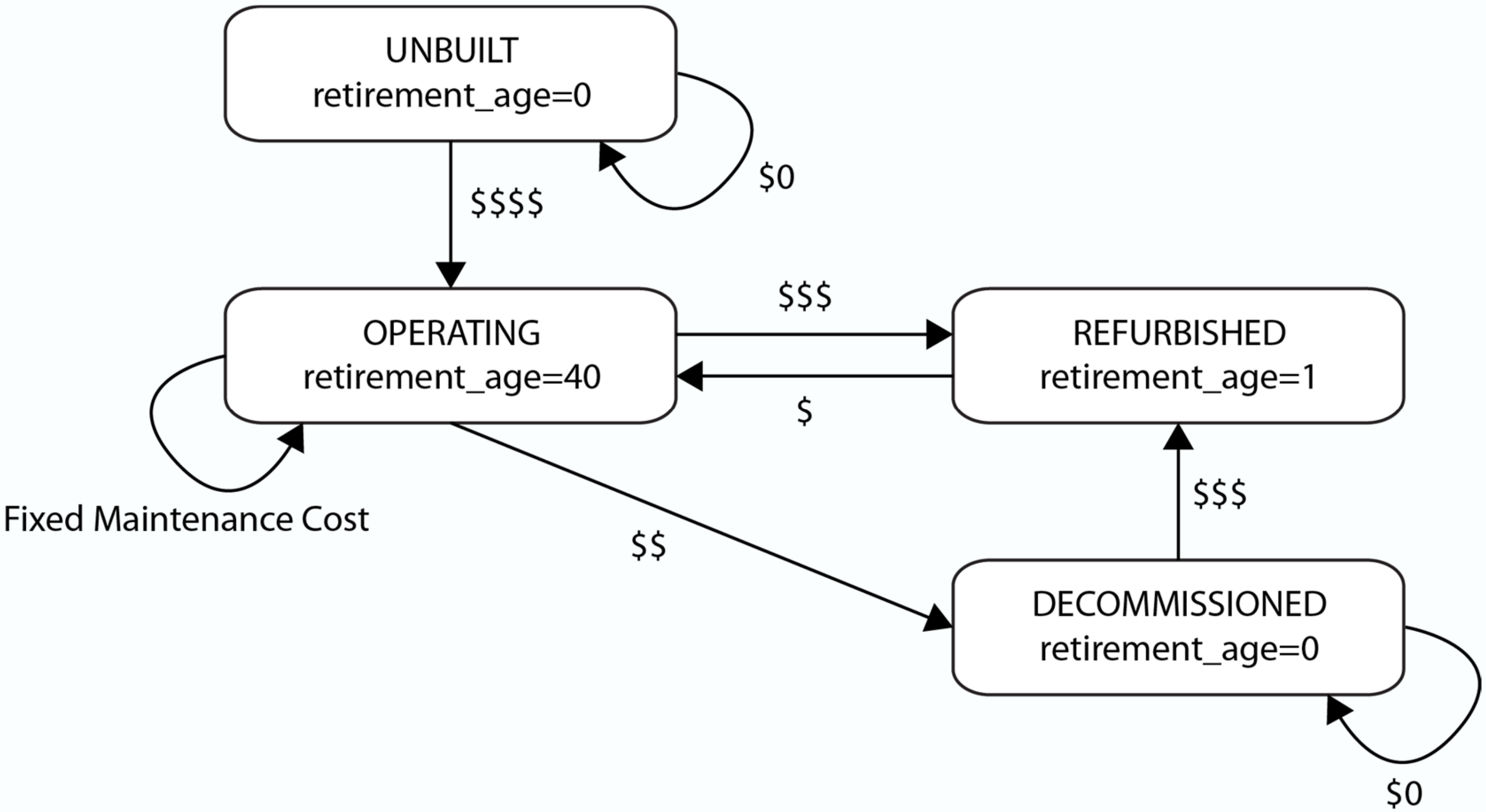
Data for a region, input using a GIS platform



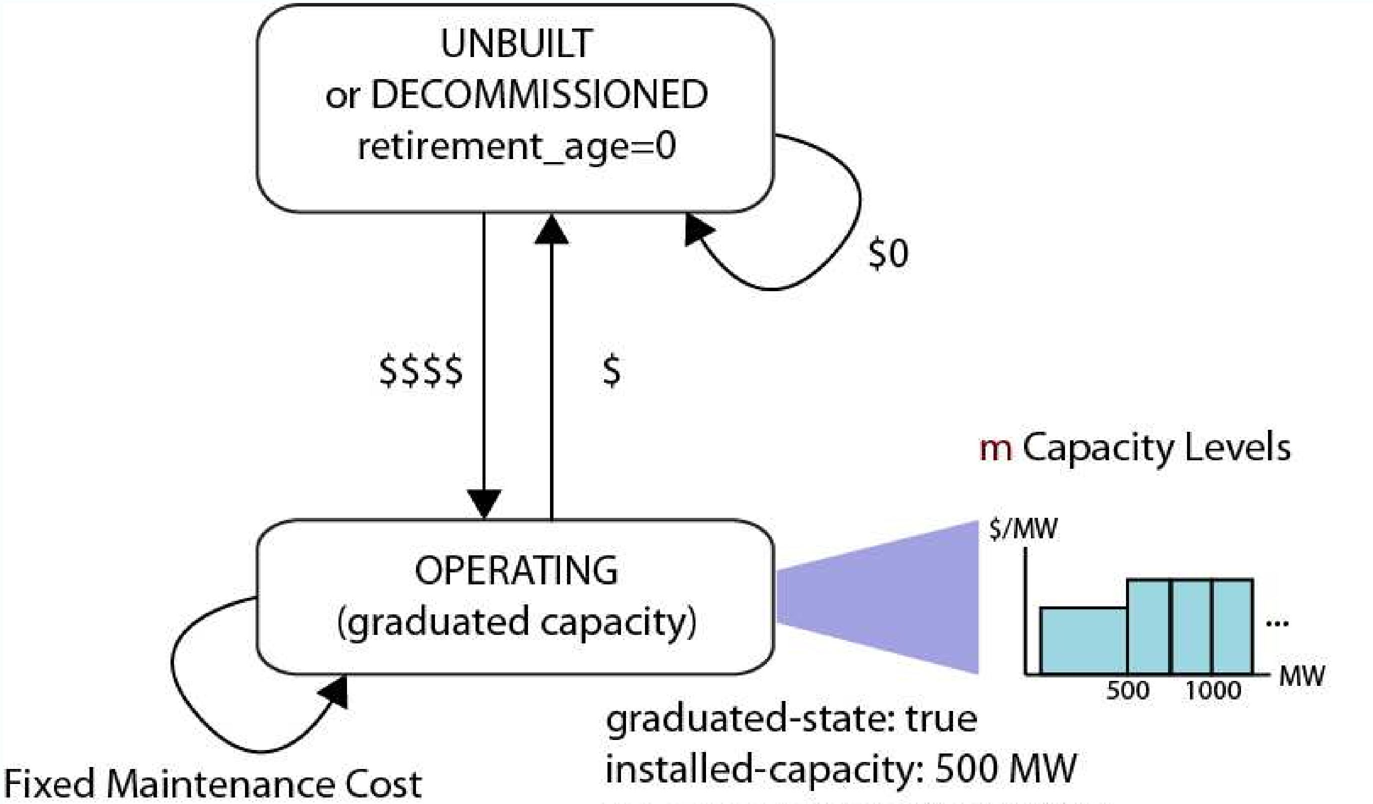
Optimal freight flows and infrastructure plans for each year

Asset states

Assets represented as projects



Assets represented as incremental capacity



graduated-state: true
installed-capacity: 500 MW
capacity-increment: 250 MW
retirement-age: 30 yrs
cost-per-increment: $200M
maximum-capacity: 2 GW
opex-per-MWh: $25

Essential elements of the freight model

Facilities

Sources and destinations for freight (mines, ports, farming regions. Junctions and other capacity-constrained locations.

Links

Roads, railways, pipelines, conveyors, sea lanes

Commodities

Products for transport: cattle, iron ore, copper concentrate, etc. Includes inputs for mining and agriculture

Vehicle types

Vehicle types include (trains of) mineral wagons, cattle trucks and trucks for general freight. IFAP respects **compatibilities** between vehicle types, facilities, links and commodities (this is via user-supplied rules and data). Fleet sizing, fleet flow balance and annual conversion between types is partially supported in IFAP at present.

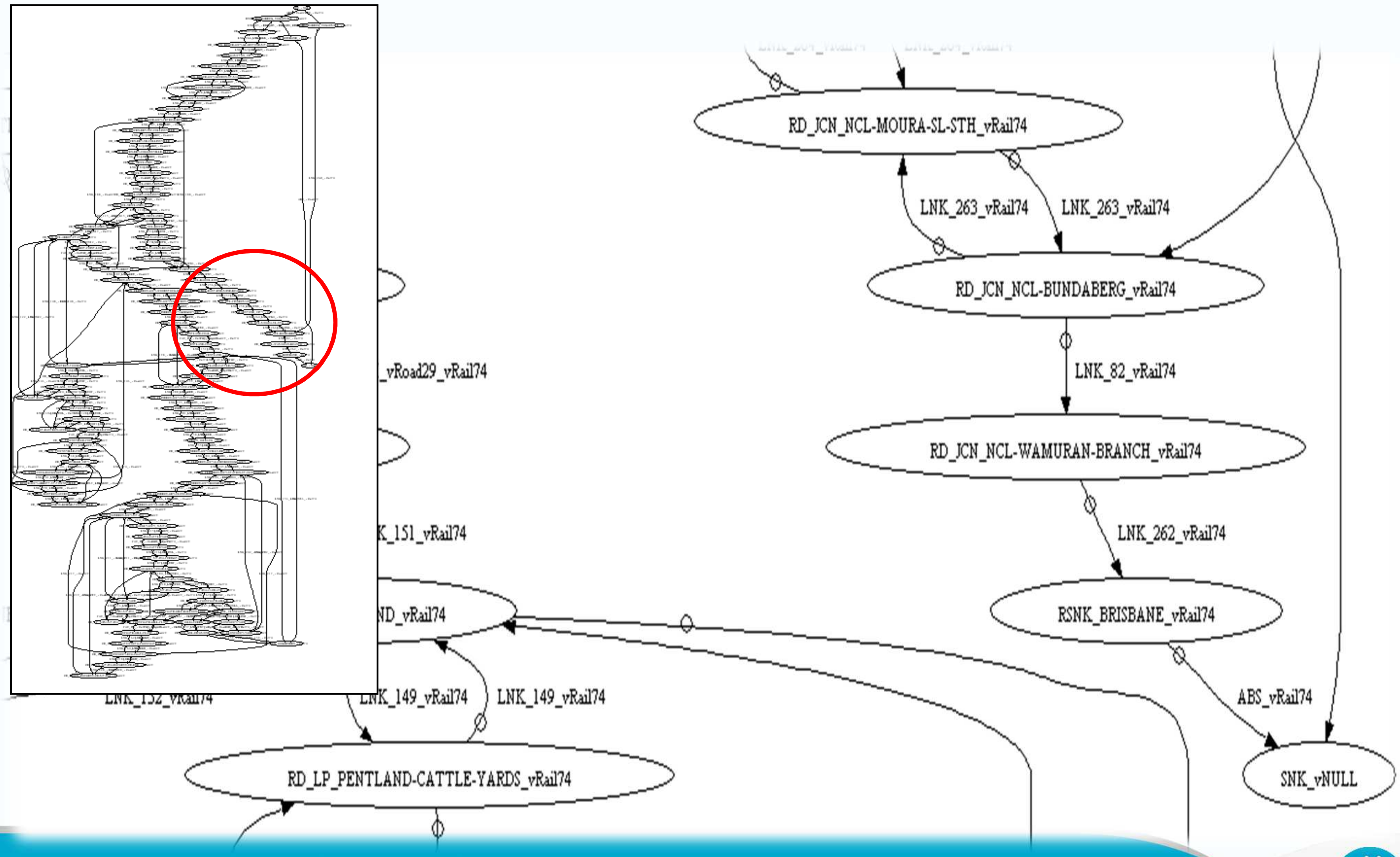
Processes

Logistics processes cover the **movement** of freight. **Transformation processes** cover the **production of commodities** using zero or more input commodities. This includes commodity extraction via mining. Demand is expressed in terms of **how many tonnes of each process is required in each period** (year)

IFAP, TNEP, CCS and Beef

	Freight	Electricity	CCS	Beef
Facilities	Ports, junctions, factories	Power stations, substations	Sources, sinks	Farms, abbatoirs, ports
Links	Roads, railways, pipelines	Powerlines	Pipelines	Roads
Commodities	Many physical goods	Electrical power	CO_2	Livestock, meat
Vehicle types	Dozens of types			Road trains
Processes	One for each demand or trans-formation	One for power flow	One for CO_2 flow	Livestock flow, meat flow, slaughter

Sugar transport process



TNEP

Optimized Transmission Network Expansion Planning and Generation Selection

- Transmission Network Expansion Planning
- Selection of generation regions/sites

Screening tool: identifying favourable options, first-cut costing

Inter-NTNDP zone (“network planning”)
or Intra-NTNDP zone (“harvesting”)

“Load block” approach: average and stress cases for supply/demand

Optimisation model with database system and GIS interface

Yearly timestep, 2012-2050

Optimise within specified generation mix

TNEP Scale

16 NTNDP Zones (+ WA to follow)

Up to 12 technologies per zone, approx 30 technologies in total

Over 100 relevant SSD *

Time series: one hour resolution, 2003-2050 *

Load blocks: 1, 8 or 24 per year

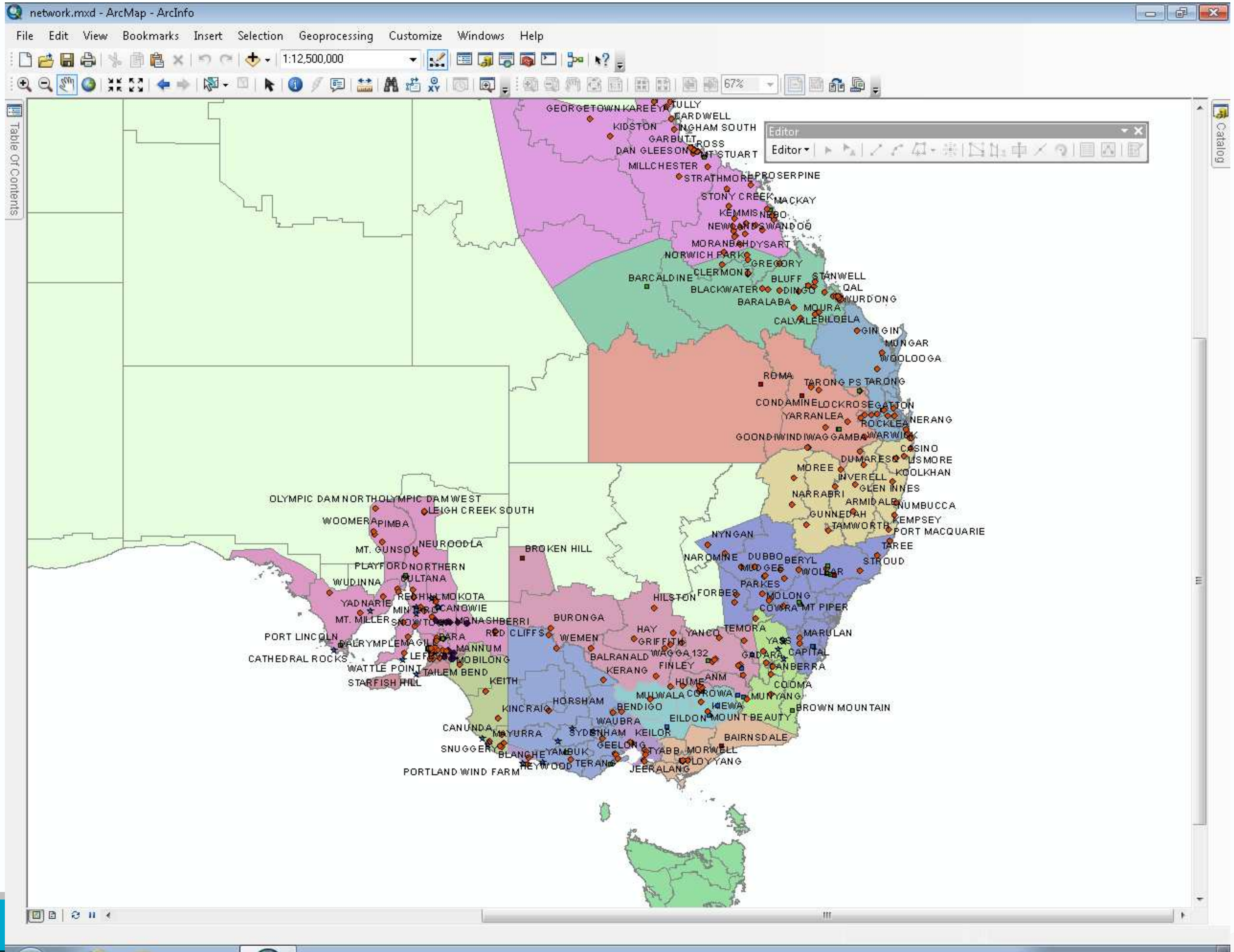
6 renewable (intermittent) supply series, by 43 regions *

100+ existing NEM points of interest

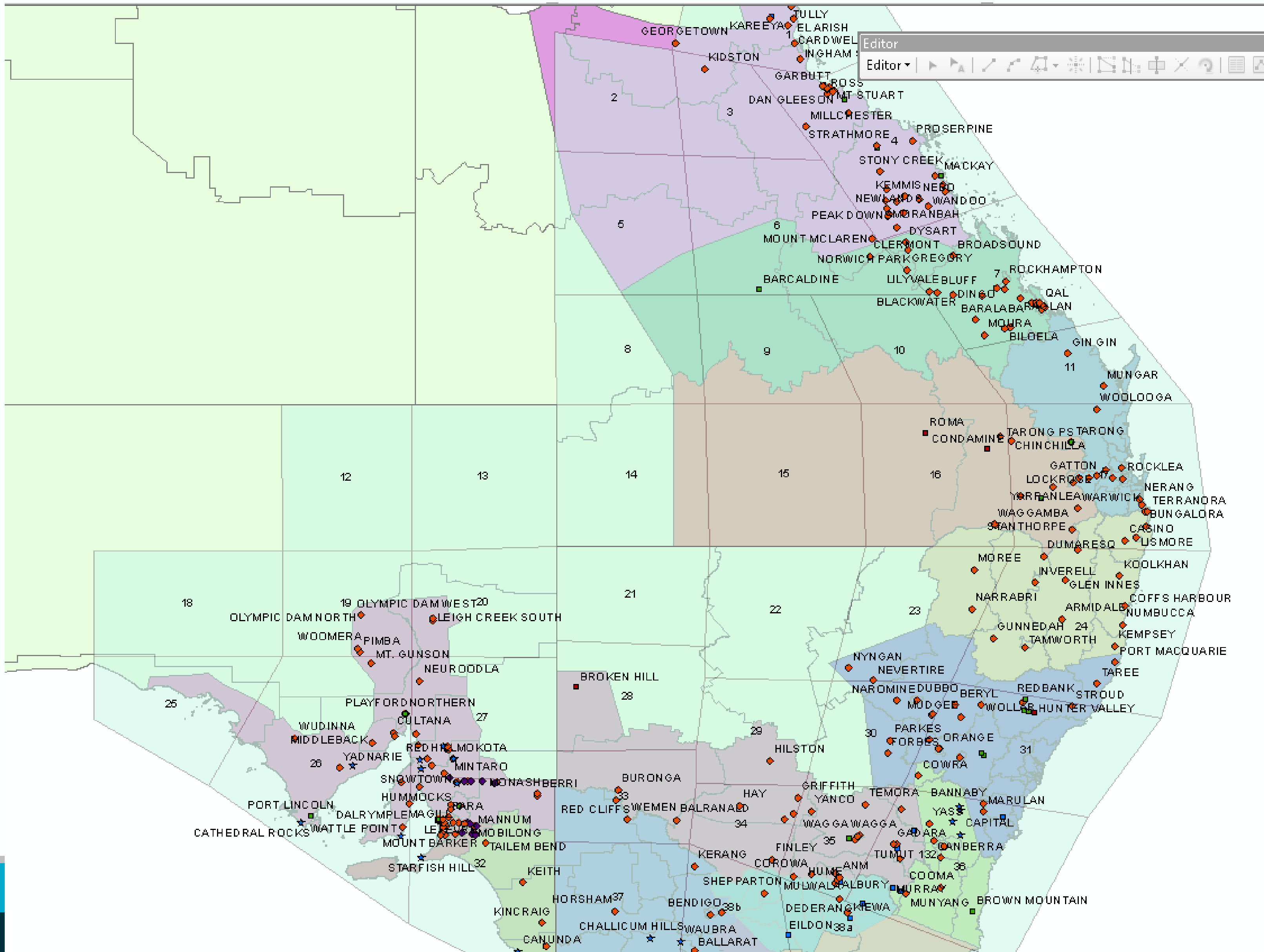
9800 (tech,year,state) points – double at NTNDP level

(* for finding network stress periods)

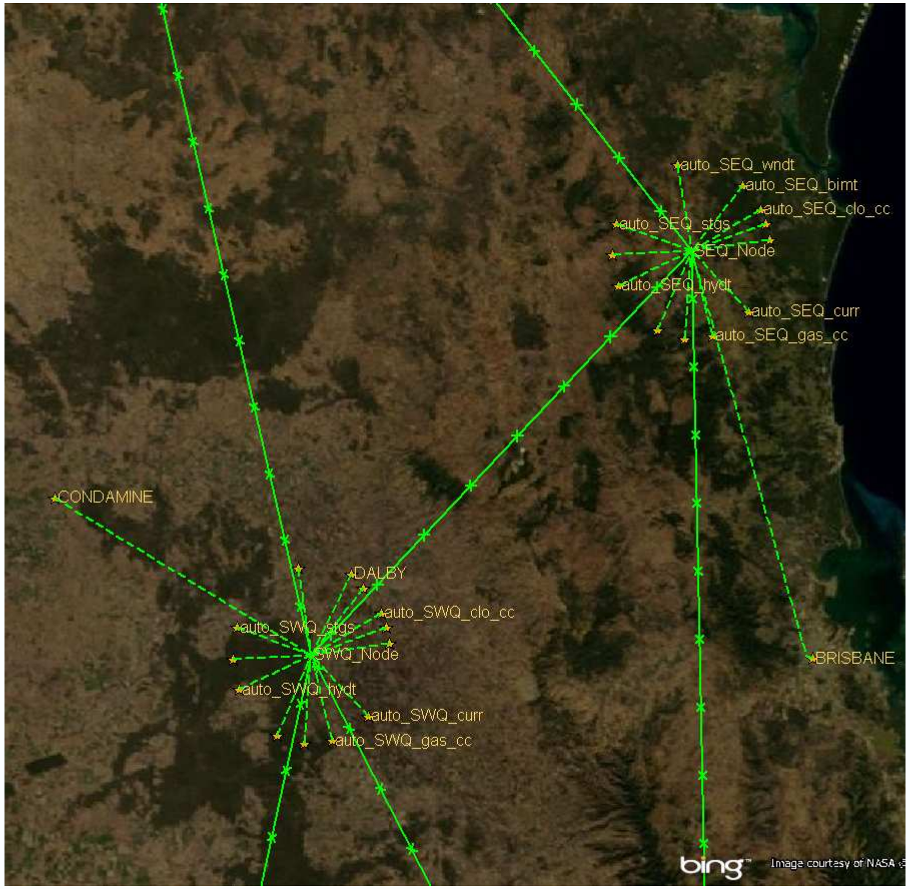
Mapping


network.mxd - ArcMap - ArcInfo
File
Edit
View
Bookmarks
Insert
Selection
Geoprocessing
Customize
Windows
Help
1:12,500,000
67%
Editor
Editor ▾
Table Of Contents
Catalog
GEORGETOWN
KAREEYA
TULLY
CARDWELL
KIDSTON
INGHAM SOUTH
GARBUTT
ROSS
DAN GLEESON
T STUART
MILLCHESTER
STRATHMORE
PROSERPINE
STONY CREEK
MACKAY
KEMMIS
NEBO
NEWLANDS
WANDOO
MORANBAH
DYSART
NORWICH PARK
GREGORY
BARCALDINE
CLERMONT
BLUFF
STANWELL
QAL
BLACKWATER
DINGO
BARALABA
MOURA
CALVALE
BILOELA
GIN GIN
MUNGAR
WOOLOOGA
ROMA
TARONG PS
TARONG
CONDAMINE
LOCKROSE
GATTON
YARRANLEA
ROCKLEA
NERANG
GOONDIWINDI
WAGGAMBA
WARWICK
CASINO
DUMARESQ
LISMORE
MOREE
INVERELL
KOOLKHAN
GLEN INNES
NARRABRI
ARMIDALE
NAMBUCCA
GUNNEDAH
KEMPSEY
TAMWORTH
PORT MACQUARIE
NYNGAN
TAREE
NAROMINE
DUBBO
BERYL
STROUD
MUDGEE
WOLLAR
PARKES
FORBES
MOLONG
HILSTON
COWRA
MT PIPER
TEMORA
MARULAN
YASS
CAPITAL
CANBERRA
COOMA
MUNYANG
BROWN MOUNTAIN
BAIRNSDALE
MORWELL
LOY YANG
JEERALANG
TYABB
OLYMPIC DAM NORTH
OLYMPIC DAM WEST
LEIGH CREEK SOUTH
WOOMERA
PIMBA
MT. GUNSON
NEUROODLA
BROKEN HILL
PLAYFORD
NORTHERN
WUDINNA
DALTANA
YADNARIE
MOKOTA
MT. MILLER
CANOWIE
PORT LINCOLN
DALRYMPLE
CATHEDRAL ROCKS
WATTLE POINT
STARFISH HILL
MANNUM
MOBILONG
TAILEM BEND
KEITH
BERRI
RED CLIFFS
BURONGA
WEMEN
HAY
GRIFFITH
YANCO
BALRANALD
WAGGA 132
KERANG
FINLEY
HUME
ANM
MULWALA
COROWA
KIEWA
MOUNT BEAUTY
EILDON
HORSHAM
BENDIGO
KINCRAIG
WAUBRA
SYDENHAM
KEILOR
GEELONG
CANUNDA
MAYURRA
SNUGGERY
BLANCHE
YAMBUK
HEYWOOD
TERANG
PORTLAND WIND FARM

Renewables supply



NEM-level model



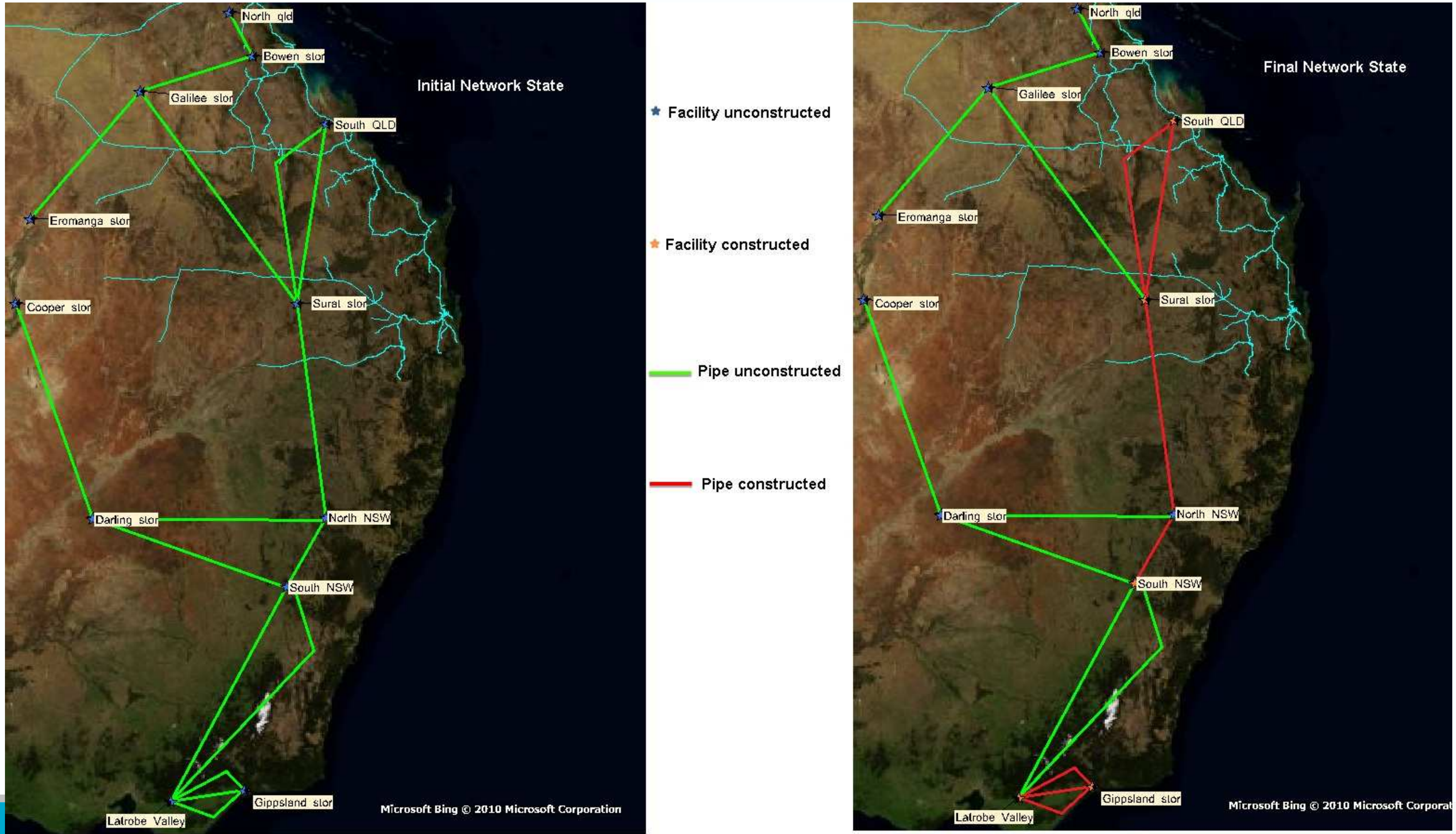
Model overview

Minimise opex, capex and penalties

Subject to:

- Demand satisfaction (8+ load blocks)
- Electricity flow (DC approx $P=B\theta$ for intra-NTNDP)
- Generation and transmission capacity
- Supply cost
- Generator profitability
- Generation technology mix
- Project state transition and retirement/refurbishment

What is the best layout of a future CO2 sequestration network?



CCS MIP model decision variables

The MIP model makes constrained decisions about capture, transportation and storage.

It takes as input the maximum amount of CO2 emitted, the amount that should be captured, and the sequestration capacity

Decision variables:

x_e^t : flow through edge e at time t

z_e^{dt}: whether edge e with diameter d exists at time t

s_t: shortfall at time t

v_c^t : carbon captured from capture site c at time t

w_s^t: carbon injected into storage site s at time t

y_c^t : whether capture site c exists at time t

y_s^t : whether storage site s exists at time t

CCS MIP model objective function

Minimize:

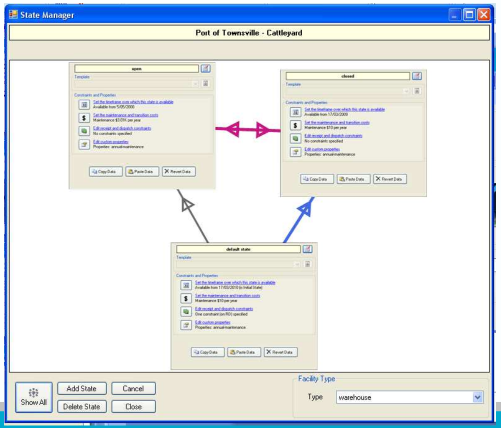
$$\underbrace{\sum_{t \in T} P_t s_t}_{shortfall\, penalty} + \underbrace{\sum_{e \in E, t \in T, d \in D} c_e z_e^{dt}}_{pipe\, maintainance\, costs} + \underbrace{\sum_{e \in E, t \in T, d \in D} C_e^d \left(z_e^{dt} - z_e^{d(t-1)} \right)}_{pipe\, building\, costs} + \underbrace{\sum_{c \in Cap, t \in T} B_c \left(y_c^t - y_c^{(t-1)} \right)}_{capture\, facility\, building\, costs} +$$

$$\underbrace{\sum_{s \in Stor, t \in T} B_s \left(y_s^t - y_s^{(t-1)} \right)}_{storage\, facility\, building\, costs} + \underbrace{\sum_{c \in Cap, t \in T} o_c v_c^t}_{capture\, facility\, operating\, costs} + \underbrace{\sum_{t \in T, s \in Stor} i_s w_s^t}_{storage\, facility\, injection\, costs}$$

Defining and solving freight scenarios

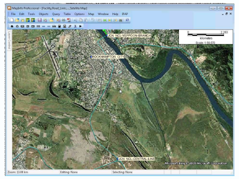
A range of facility types are available in IFAP:

- Ports and berths
- Production/processing facilities
- Farming centres
- Loading points and intermodal facilities
- Population centres
- Mines
- Capacity-constrained junctions
- Warehouses and stockpiles

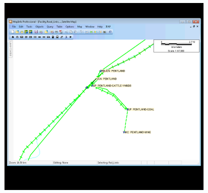


- Data is entered and solutions are explored using a GIS package with custom UI features:

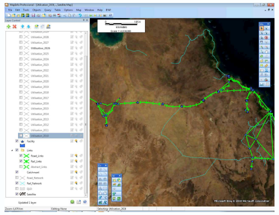
VIDEO: transport link definition



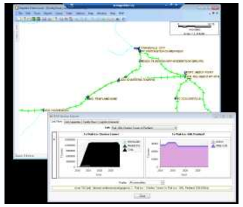
VIDEO: capacity option definition



VIDEO: macro solution exploration

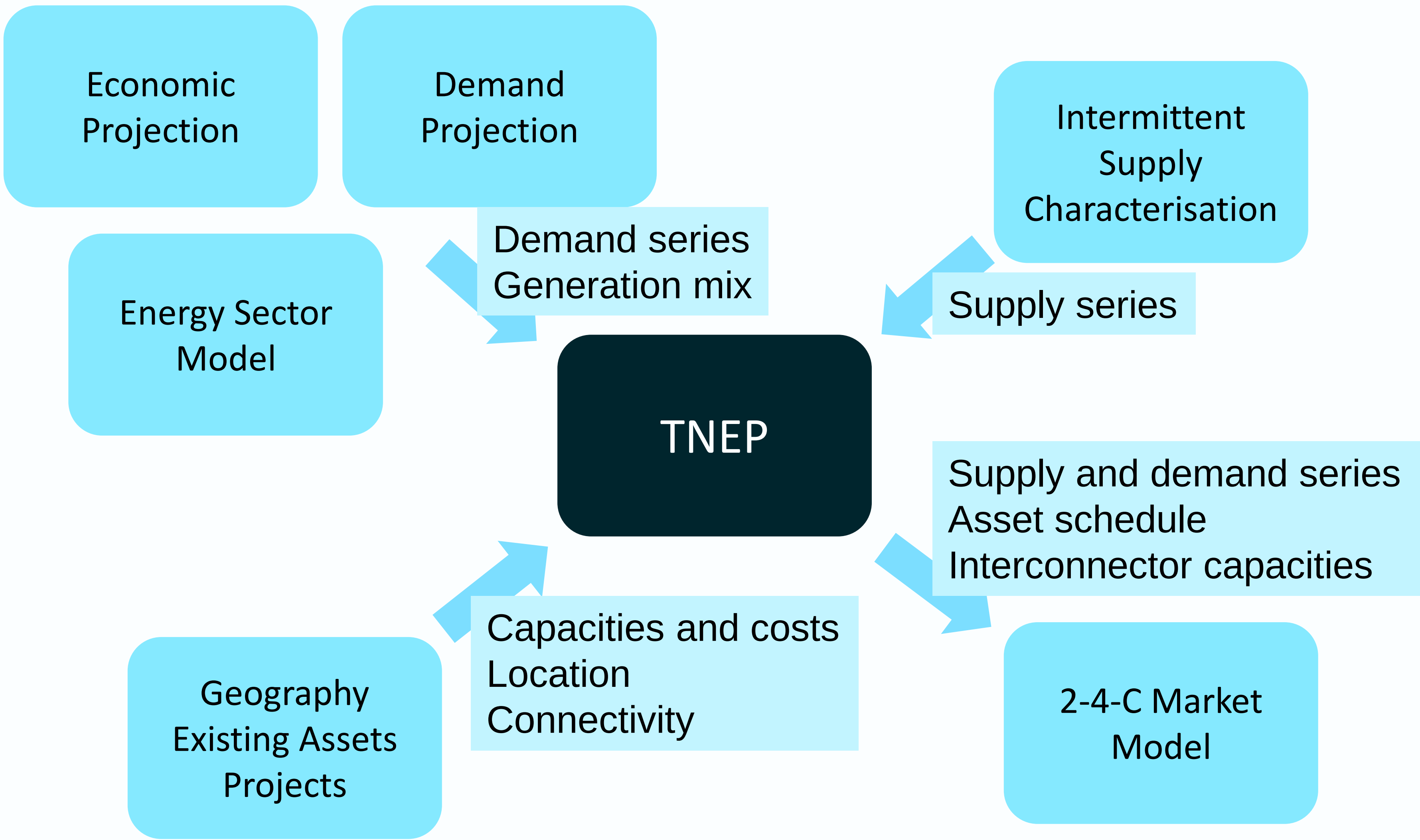


VIDEO: detailed solution exploration



- Long-term whole-of-system view is important for government, capital investors, port owners/ operators and major supply chain participants

Data and model linking



Closing remarks

OR methods are very useful for studying the future

The constraints of biophysical and socio-technical systems lead us to MIP, SD and simulation, with support from heuristics

State-based representation, time expanded networks

Visualisation, especially GIS

Big gap between fit-for-analysts and fit-for-users

The data task is the most burdensome

These systems are **big** – re-purposing for multi-domains is good