Project 3: Economic and Investment Models For Future Grids Deliverable 2: The Scenarios

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CSIRO Future Grid Flagship Cluster
Project 3: Economic and Investment Models
For Future Grids
Deliverable 2: The Scenarios

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1.1 Introduction

This chapter sets out the design of a scenario framework for the CSIRO Future Grid Cluster's Project 3. It sets out how the various influences, or driving forces, are separated into four categorised. These being: Policy, States of the World, Sensitivities, and Linkages. The first two, policy, and states of the world, are then further broken down into two sub-categories: supply side influences, and demand side influences.

Additionally, we take into account the reports from the CSIRO's Future Grid Forum (CFGF), describing the comprehensive supply chain end-to-end study that used four major scenarios that are related to the scenario framework described her to be used in this cluster. The Forum also conducted sensitivities around these four scenarios. In section 1.3 of this document we describe the relationship between the CFGF scenarios and our scenario framework.

1.2 Project 3 Scenarios

The approach we are taking in setting up the scenarios is based on a "first-principles" analysis of the influences [1]. That is, we explicitly take account of the interactions between government policies and regulatory settings, technological and economic developments, and market behaviours that affect actions and decisions taken by market participants. For example, when governments set policies on renewable targets, or set up energy efficiency schemes, these impact market prices of certificates. These prices become inputs into investment decisions on new generating plant. By explicitly putting these drivers foremost in the scenario development we can take account of the chain of influences ensuring that the resulting key assumptions are transparent and justifiable.

As stated above, the scenarios are formulated based on separation of energy system influences into the following four areas: Policy (and regulatory) decisions, States of World, Sensitivities, and Linkages. These are represented into two ways as an aid to analysis as well as model implementation:

Firstly, these are aggregated into ten scenario kernel elements that are independent of each other. These are then used to generate a humanly manageable set of Reduced Scenarios that will be used for discussion and scenario selection.

Secondly, these can be broken down into their explicit sub components that include the "micro" inputs that need to be modelled explicitly. These are shown in section 5 a spreadsheet attachment. This is an expanded representation of the reduced scenarios. As an example the spreadsheet shows the casting the five scenarios in the University of Queensland report "Delivering a competitive Australian power system Part 2: The challenges, the scenarios" - into the expanded representation.

1.2.1 The four influences

The four categories of key influences and their relationships are set out in this section. In Figure 1.2.1 we show the relationship between these categories and how they relate to an arbitrary scenario.

1. Policy (and regulatory) decisions - These are actions in the policy and regulation space which are under the control of Australian policymakers and stakeholders. The policy actions are partially orthogonal to states of the world meaning they are to a great extent independent. There are of course, policy actions that can depend on outcomes of states of the world. However we anticipate that to ensure policy stability needed by the private sector for investment, whatever policy frameworks are put in place over the next 5-10 years will need to remain subsequently untouched. Policy and regulatory decisions can be classified into two main categories:

    - Supply Side
    - Demand Side

2. States of the world - These are forces or influences that are outside Australia's control and can be divided into three categories

    - Supply Side Forces: These include changes in the parameters of key supply side technologies, such as technology costs, costs of fuel feedstocks,
    - Demand Side Forces, that are further divided into two sub-categories, those being:
        (a) Structural and behavioural, and,
        (b) Technological development related
    - International Forces which includes actions of markets and policy decisions by other countries

3. Sensitivities Many policy and states of the world need to be modelled as having two or three outcomes. That is, some are binary (yes/no) and some are sensitivities. We chose to limit sensitivities to 3 levels, that is, low, medium, and high, in order to limit the extent of the combinatorial explosion that arises when combining all the different possible outcomes. Much of the data for the sensitivities, for example, the rate of technology cost decline, will be sourced from the CFGF scenario assumptions.

4. Linkages There are also interactions between the various forces and their sensitivities. In particular it is important to note that there can be linkages within and between forces in the following two categories:

    - States of the world
    - Policy

The exact nature of the linkages is obvious in some cases; such as domestic gas reservation policy leads to lower domestic natural gas prices while others are subtler. The exercise of incorporating is important but due to its complexity its implementation may be best managed in the process of the explicit modelling effort itself. How to represent these linkages and how many to represent is left for a later discussion between and within the four cluster projects.

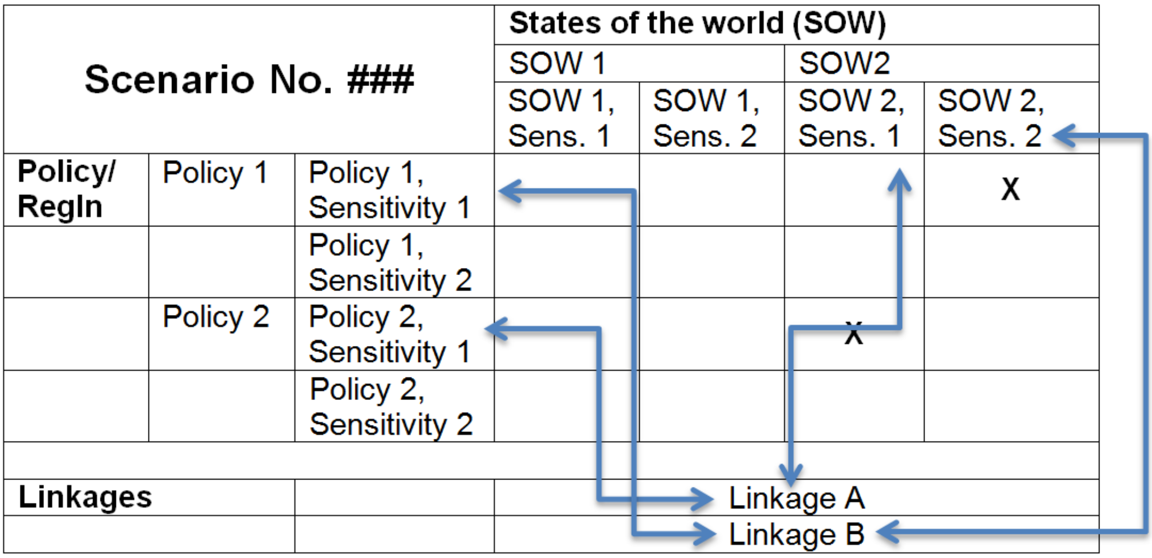

Figure 1.2.1: The four influence categories and how they interact

Figure 1.2.1 shows how a scenario would relate to its drivers. It puts the states of the world and policies/regulation drivers on orthogonal axes in the same way that the expanded scenarios are set out in section 1.5's worksheets

The table shows a fictitious scenario where Policy No. 1 is selected, with an associated Sensitivity No. 1 being active represented by the "X" in the top right-hand cell. At the same time the world is in State No. 2 with an associated Sensitivity No 2. By way of a practical example these could correspond to:

1. Policy No. 1: Carbon pricing

   Sensitivity No. 1: Low targets (Y)

2. State of World No. 2: Carbon price is at a certain level (X)

   Sensitivity No. 2: High renewable technology costs

In addition to this, there is a linkage (Linkage B) between the policy and its sensitivity and the state of world and its sensitivity. This could be, for example: A low emission reduction target carbon-pricing scheme (carbon trading is assumed) could translate into a medium carbon price due to the fact that the renewable technology cost state of the world has the high technology cost sensitivity active. This would contrast a scenario where technology costs are low and thus the carbon price would be low.

1.3 Scenario kernels

In order to make modelling decisions for scenarios that are intuitive and relevant to policy and investment decisions we need to work at an appropriate level of detail. Since in this cluster we are only interested in impacts of policies and external forces on large-scale infrastructure investments and wholesale market behaviour, it makes sense that the kernel scenarios should be handled at the same level. In our case this means we need to aggregate the demand side policies and forces to a higher level. Overall we propose the following structure for deciding on scenarios:

Table 1.3.1: Kernel elements

		Kernel Element	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1			
	Renewable/Zero emission Technology costs reduction	2			
Fossil Fuel Costs		3			
Climate Policy	Carbon Pricing	4			
	Renewable Energy Target	5			
Electricity Demand			**Decline**	**BAU**	**High**
Energy Growth (GWh)		6			
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7			
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8			
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9			
Scale Efficient Network Extensions		10			

The above table (1.3.1) sets out ten kernel elements grouped into three major groups, supply side, electricity demand, and policy support.

It is important to note that there are independent and with eight having three sensitivities and two having 2 leading to a total of 26,244 possible combinations! This is not easily manageable for human assessment but can be handled automatically by software that will be developed in project 3. While the supply side scenarios are relatively simple to characterise and understand, there is some complexity in describing the aggregated demand side impacts of relevant policies and technological trends. Thus we separated the impacts of various demand side trends such as time-of-use pricing or electric vehicles, amongst many, into distinct impact types. These are:

- Energy growth (or decline) This corresponds to the total energy drawn from the central grid. It can be influenced by several different trends such as those cited as causing the recent (since

2009) energy decline. These are, solar PV uptake, price elasticity response to increases in retail prices, rollout of energy efficient appliances, and so on.

- Demand shape changes The influences on energy growth mentioned above can also impact the load shape, and they are joined by a range of other influences such as additional growth of air conditioner uptake, increasing incidence of prolonged heat waves, time-of-use pricing, direct load control, uptake of electric (including vehicle to grid capability), and many more. The impacts of any of these can be separated into a change in load factor (the ratio of average to peak demand), and the time of day that the peak demand occurs.

  i. Load factor change This is a phenomenon that has already been seen over the last ten or more years with the uptake of air conditioners causing peak demand to grow faster than average energy demand, at least before 2009. Since then peak demand has been stable in many regions (such as the distribution network in south east Queensland operated by Energex) while energy has been declining. Again this mean

  ii. Day-Night peak change (including intra day peak movement) The range of influences discussed in this section can have quite unexpected impacts on when peaks will occur. In particular, electric vehicle charging could cause the peak to move to some time in the early morning. Equally, time of use pricing can cause shifts in peak demand.

1.4 Relationship to CSIRO Future Grid Forum Scenarios

The CFGF took a related approach to developing their scenarios but focussed more on the detailed modelling levers that translated into modelling and simulation inputs. The scope of their study was also broader as it incorporated: distribution system expansion and asset replacement costs and end use customer price impacts. The CSIRO Scenarios are constructed along three main axes:

- Centralised versus decentralised generation
- Severity of peak demand growth (or flattening of load profile)
- Deployment of large scale renewables

All these are captured in our framework and the relationship between our scenario Kernels and reduced scenarios is shown in Table 3. The CFGF scenarios and their drivers are shown in Table 4. Table 3 shows the relationship between our supply and demand side drivers, and the CFGF scenario drivers. As there is a variety of ways that drivers can be categories, we use the mapping matrix in the table as a guide to translating between the two approaches. For example, we break the growth of distributed generations share (DG) into three drivers, these being: energy efficiency, and load profile changes of two type, load factor changes, and shifts of the peak to different times of the day. The matrix is not exhaustively detailed and the modeller will still need to use their expertise to transform the input data the CFGF provided for their drivers into inputs using our framework. We will do this in project 3 in setting up the assumptions database. Also note that the CFGF's energy efficiency driver also maps to the same three drivers in our framework as it can influence all of the above to varying degrees.

1.4.1 Use of CSIRO Future Grid Assumptions

Furthermore, the CFGF modelling reports provided a comprehensive set of assumptions data in the following categories that we will use to seed our model assumptions. These are:

- Demand Profiles
- Technology costs
- Fuel costs
- Renewable output profiles
- Electric vehicle demand profile impacts
- Rooftop solar uptake projections
- Residential disconnection projections
- Generation and transmission expansion

These usually provide high, medium and low sensitivities that correspond closely to relevant influences that were intend to model.

Table 1.4.1: CSIRO Future Grid Forum - "Modeling The Future Grid Forum Scenarios"

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
DG share	Low	High	High	High
EV uptake	Modest Managed charge profile	Medium-high Managed charge profile	Medium-high Absent charge profile	High Managed charge profile
Demand response (storage)	Equivalent to Resi. 1kW for 5 hours 0-20% 2015-2030 but centrally located in suburb	Resi. 1kW for 5 hours 0-20% 2015-2030 in individual homes	Used off-grid. 5kW batteries plus 2.2kW diesel back-up	Resi. 1kW for 5 hours 0-20% 2015-2030 In individual homes
Demand response (HVAC)	Both resi. and comm. managed	Both resi. and comm. managed	Unmanaged, remaining customers can't afford upfront costs	Both resi. and comm. managed
Demand response (Industrial)	Managed	Managed	Unmanaged, remaining customers can't afford actions	Managed
Disconnections	RAPS only	RAPS only	All existing and new DG owners by 2020	RAPS only
GHG reduction commitment	Moderate carbon price	Moderate carbon price	Moderate carbon price	Moderate carbon price plus extended RET to 100%
Technology costs	AETA projections for CG, CSIRO for DG, storage, large scale solar PV	AETA projections for CG, CSIRO for DG, storage, large scale solar PV	AETA projections for CG, CSIRO for DG, storage, large scale solar PV	Accelerated based on stronger global abatement commitment
Energy efficiency	AEMO moderate growth case based on current price pressures	AEMO moderate growth case based on current price pressures	Low energy consumption due to relatively higher costs for those left on grid	Low energy consumption based on expected higher prices due to lower emissions
Network	Modest expansion. Load factor maintained	Flat. Significant decline in load factor	Flat. Significant decline in load factor	Load factor declining. Expansion to connect renewables
Gas price assumption	AETA Medium	AETA Low supporting gas on-site generation	AETA Low supporting gas on-site generation	AETA Medium
Customer pricing framework	Cost reflective supporting engagement	Cost reflective supporting engagement	Non-cost reflective encouraging disconnection	Cost reflective supporting engagement
Large scale renewables	Substantial but some technologies limited by cost of back-up	Substantial but some technologies limited by cost of back-up	Substantial but some technologies limited by cost of back-up	Very high supported by storage and lower costs

Table 1.4.2: Project 3 and CSIRO Future Grid Forum Scenarios

CSIRO Future Grid Forum Scenario			DG Share [5]	EV Uptake [6]	Demand Response (Storage)	Demand Response HVAC)	Demand Response (Industrial)	Disconnections	GHG reduction commitment	Technology Costs	Energy Efficiency	Network	Gas prices	Customer Pricing Framework	Large Scale Renewables
Project 3 Scenarios		**Kernel Element**													
Supply Side															
Technology costs and selection	Fossil Technology costs	1								X					
	Renewable/ Zero emission Technology costs reduction	2								X					
Fossil Fuel Costs		3											X		
Climate Policy	Carbon Pricing	4							X						
	Renewable Energy Target	5							X						X
Electricity Demand															
Energy Growth (GWh)		6	X	X				X			X	X†		X	
Demand profile changes	Load Factor Change	7	X	X	X	X	X	X	X			X		X	
	Day to Night Load peak shift	8	X	X	X	X	X	X				X		X	
Policy Support for renewable generation			**Yes**	**No**											
Transmission Superprojects		9													
Scale Efficient Network Extensions		10													

1.5 Reduced Scenarios

In order to select a set of scenarios that is manageable for human analysis we must reduce the combination to something manageable. For this to be valuable it must have scenarios that include:

1. The status-quo or business as usual
2. The most likely scenario or set of most-likely scenarios
3. Extremum scenarios, which cover the realistic deviations from the most likely scenario.

It is challenging to quickly arrive at these and thus a good starting point is a set of 9 scenarios below:

Table 1.5.1: BAU/UQ BAU

Scenario 1		**Kernel Element**	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2		X	
Fossil Fuel Costs		3		X	
Climate Policy	Carbon Pricing	4		X	
	Renewable Energy Target	5		X	
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6		X	
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7		X	
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.2: Most Likely

Scenario 2		**Kernel Element**	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2		X	
Fossil Fuel Costs		3		X	
Climate Policy	Carbon Pricing	4		X	
	Renewable Energy Target	5		X	
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6	X		
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7			X
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.3: Batteries (grid or distributed) or V2G

Scenario 3		**Kernel Element**	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2		X	
Fossil Fuel Costs		3		X	
Climate Policy	Carbon Pricing	4			
	Renewable Energy Target	5		X	
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6			X
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7	X		
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.4: Electric Vehicles

Scenario 4		Kernel Element	States of the World		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2		X	
Fossil Fuel Costs		3		X	
Climate Policy	Carbon Pricing	4		X	
	Renewable Energy Target	5		X	
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6			X
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7	X		
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8			X
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.5: High Fossil - No CCS No Nuclear

Scenario 5		Kernel Element	States of the World		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1	X		
	Renewable/Zero emission Technology costs reduction	2	X		
Fossil Fuel Costs		3	X		
Climate Policy	Carbon Pricing	4	X		
	Renewable Energy Target	5	X		
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6		X	
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7		X	
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.6: UQ Renewables

Scenario 6		**Kernel Element**	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1			X
	Renewable/Zero emission Technology costs reduction	2			X
Fossil Fuel Costs		3			X
Climate Policy	Carbon Pricing	4			X
	Renewable Energy Target	5			X
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6	X		
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7	X		
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9	X		
Scale Efficient Network Extensions		10	X		

Table 1.5.7: UQ Consumer Action

Scenario 7		**Kernel Element**	**States of the World**		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1			X
	Renewable/Zero emission Technology costs reduction	2		X	
Fossil Fuel Costs		3			X
Climate Policy	Carbon Pricing	4		X	X
	Renewable Energy Target	5		X	
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6	X		
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7			X
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8	X		
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.8: UQ Nuclear

Scenario 8		Kernel Element	States of the World		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2	X		
Fossil Fuel Costs		3			X
Climate Policy	Carbon Pricing	4		X	X
	Renewable Energy Target	5	X		
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6		X	
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7		X	
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

Table 1.5.9: UQ CCS

Scenario 9		Kernel Element	States of the World		
Supply Side			**Low/Slow**	**Medium**	**High/Fast**
Technology costs and selection	Fossil Technology costs	1		X	
	Renewable/Zero emission Technology costs reduction	2			X
Fossil Fuel Costs		3			
Climate Policy	Carbon Pricing	4		X	X
	Renewable Energy Target	5	X		
Electricity Demand			Decline	BAU	High
Energy Growth (GWh)		6		X	
Demand profile changes			Decrease	Status Quo	Increase
	Load Factor Change	7		X	
			-> Day	Status Quo	-> Night
	Day to Night Load peak shift	8		X	
Policy Support for renewable generation			**Yes**	**No**	
Transmission Superprojects		9		X	
Scale Efficient Network Extensions		10		X	

1.6 Expanded Scenarios

The expanded scenario format incorporates all actual economic, technological and policy levers such as coal costs or natural gas costs, electric vehicles or batteries, and domestic and international natural gas reservation policies as well as a rangle of domestic energy policies such as energy efficiency schemes.

We use a tabular graphical representation of these levers or forces and cast the 5 UQ scenarios from the GCI reports [2, 3, 4, 7] in this framework as an example. These are:

- UQ BAU Scenario
- UQ Large Scale Renewables Scenario
- UQ Consumer Action Scenario
- UQ Carbon Capture and Storage Scenario
- UQ Nuclear Scenario

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