# Distributed Energy Storage in the National Electricity Market:

## An Assessment of Applications and Institutional Barriers

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# National Electricity Market

- Five Regions
  - New South Wales
  - Queensland
  - Victoria
  - South Australia
  - Tasmania
- Wholesale Market
  - 30 minute market interval
  - Operated by AEMO
  - MPC $12 900/ MWh
  - MFP $-1000/ MWh

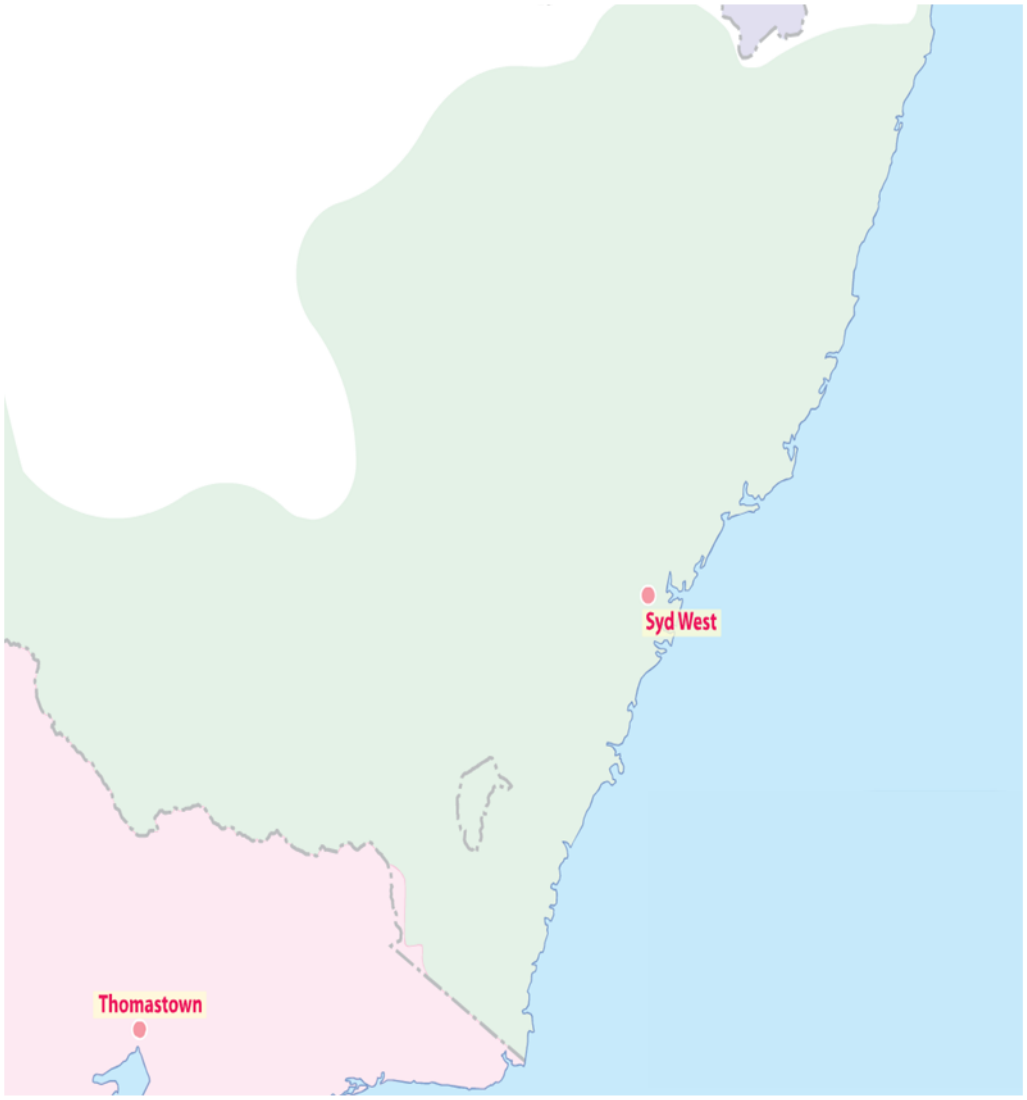



**Figure 1:** NEM regions, supply assets, and load centres (AEMO 2012)

# National Electricity Market

- Five Regions
- Generation Assets
  - Large scale and centralised
  - Bid into energy market
  - Ancillary services (i.e. FCAS)


**Figure 1:** NEM regions, supply assets, and load centres (AEMO 2012)

# National Electricity Market

- Five Regions
- Generation Assets
- Transmission Network
  - Connect generators to load centres
  - Allow inter-regional trade
  - RIT-T for expansion
  - Victorian VCR $57 880/ MWh (2011 – 2012)


**Figure 1:** NEM regions, supply assets, and load centres (AEMO 2012)

# National Electricity Market

- Five Regions
- Generation Assets
- Transmission Network
- Distribution Network
  - Transfer of electricity within load centres
  - Meet reliability standards (SAIFI/ SAIDI)


**Figure 1:** NEM regions, supply assets, and load centres (AEMO 2012)

# Demand Dynamics

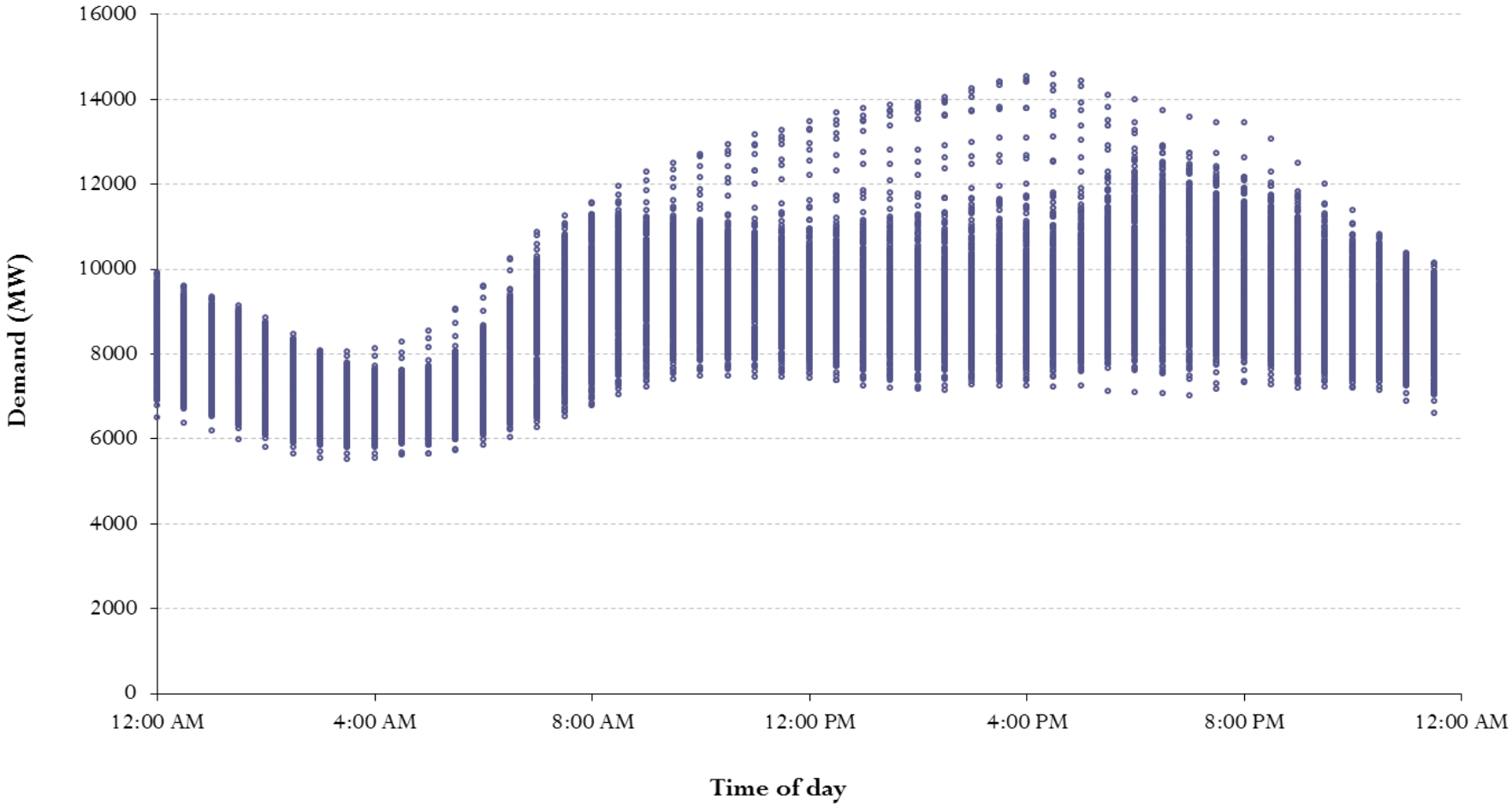



**Figure 2:** 30 minute demand for NSW over 365 days of 2011 (Data from AEMO 2012)

# Demand Dynamics

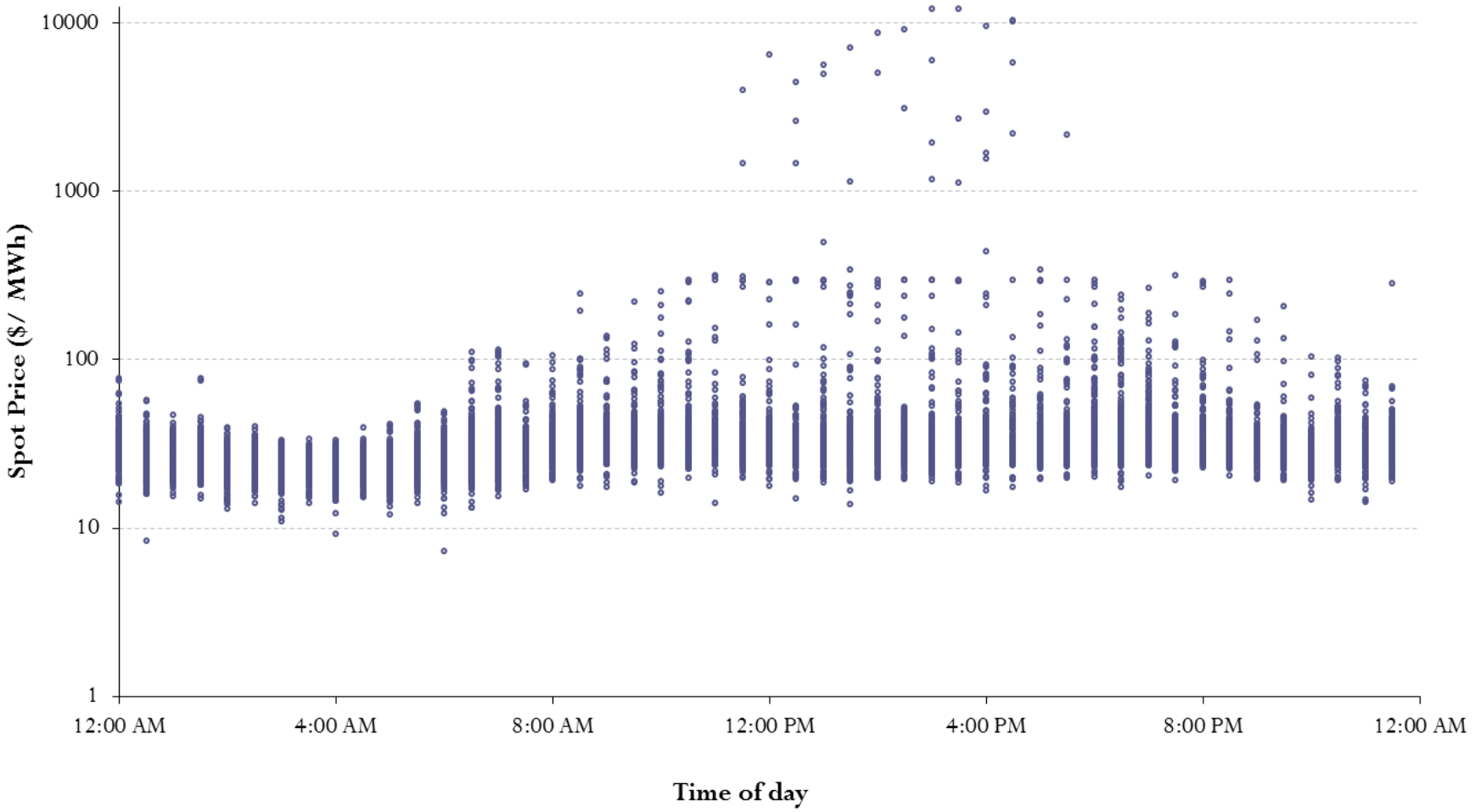



**Figure 3:** 30 RRP for NSW over 365 days of 2011 plotted on a log scale (Data from AEMO 2012)

# Demand Dynamics

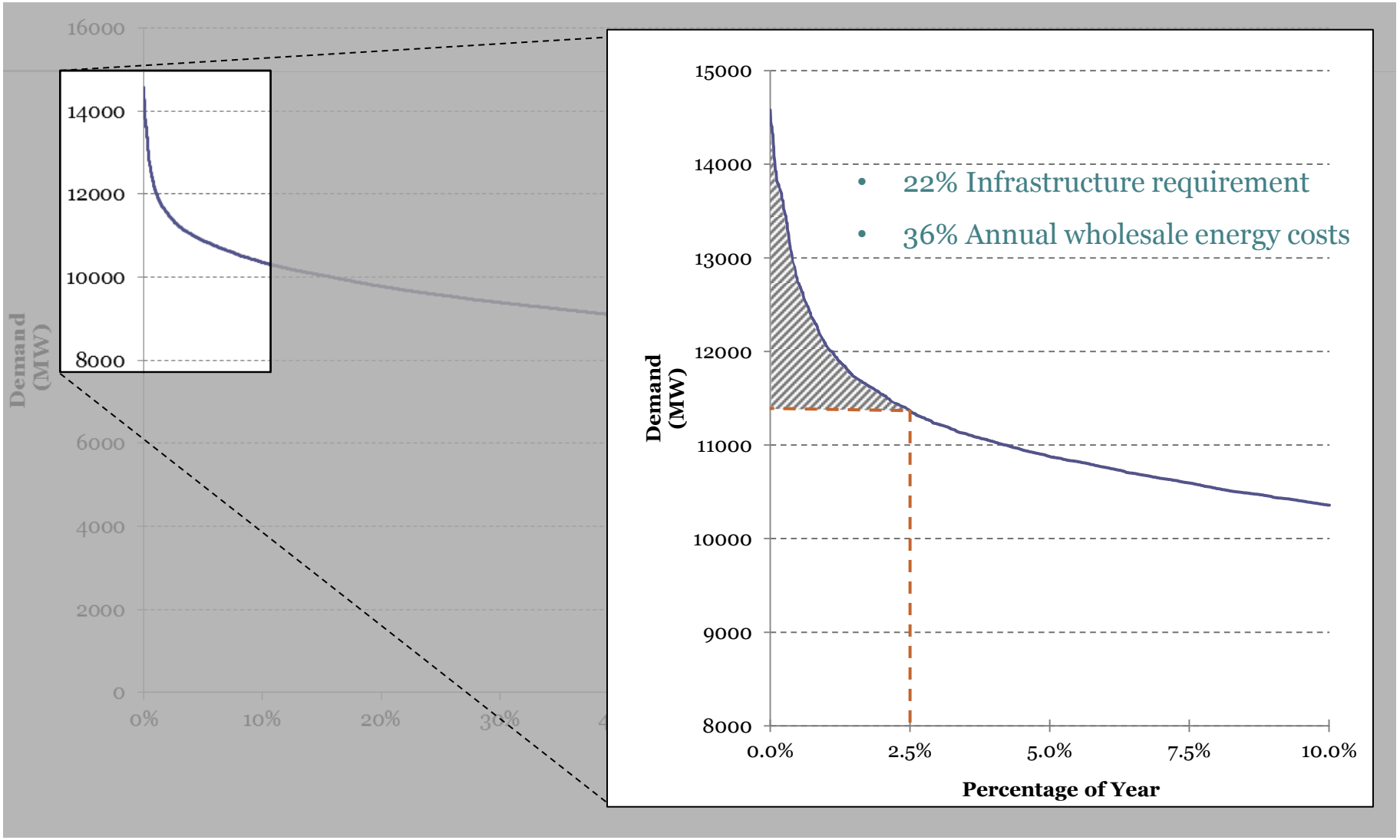
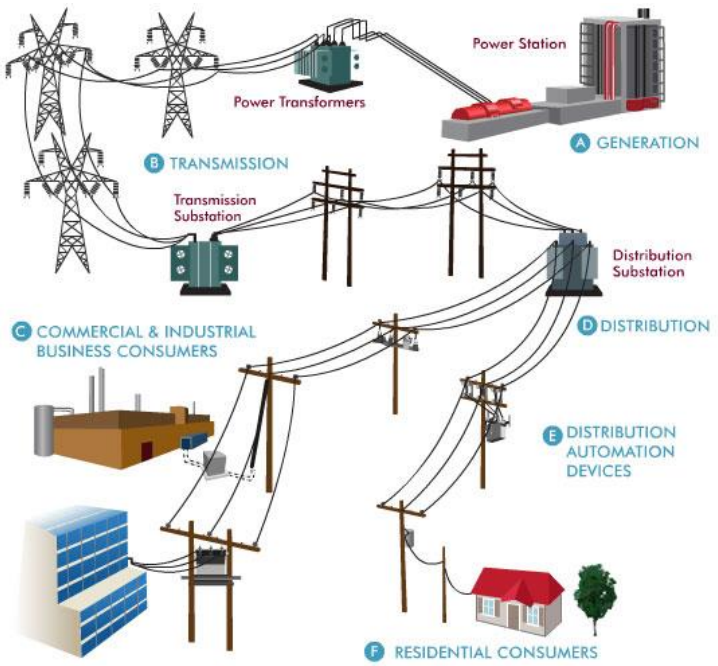



**Figure 4:** NSW regional demand 2011 (Data from AEMO 2012)

# Distributed Energy Storage

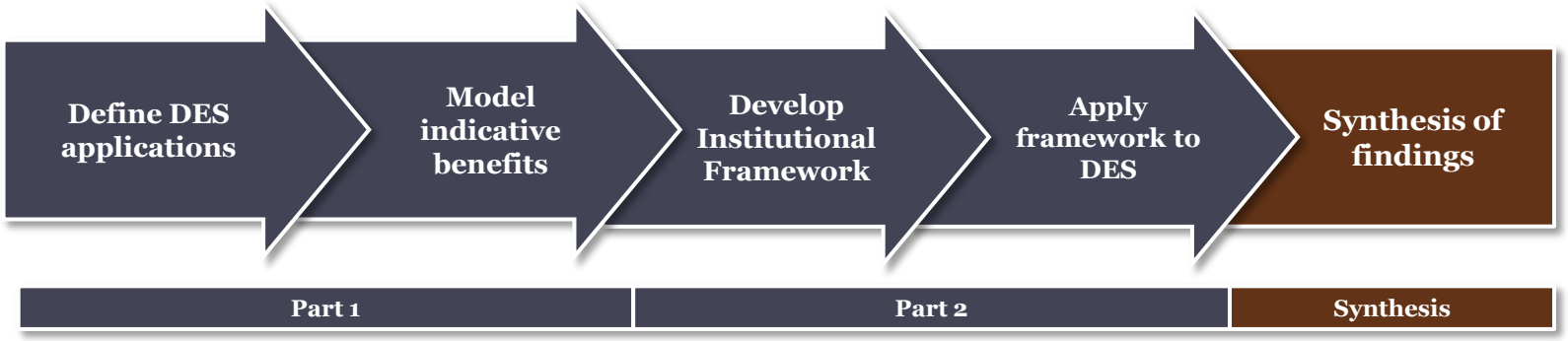
- Inter-temporal Electricity Transfer
  - ‘Temporal coupling’ of supply and demand
  - Range of temporal scales
- Utility Scale
  - Located within load centres
  - Connected to distribution network



# Distributed Energy Storage

- Range of Technologies
  - Batteries
  - Flow batteries
  - Fuel cells
  - Flywheels
  - Super-capacitors
- Barriers to adoption
  - Technical (control systems)
  - Cost
  - Is there more to this story?


# Approach




- Research Approach
  - Model indicative benefits
  - Synthesis combining key outcomes
- Scope of Research
  - Renewable energy integration not considered
  - Technology neutral
  - Utility scale

# Application Frameworks

- Storage Application Frameworks
  - Specific assessments (firm and market level)
  - *Energy Storage for the Electricity Grid* – Sandia Laboratories

| | | | | |
|---|---|---|---|---|
| **Consumer Applications** | Reliability | Demand Charge Management | ToU Cost Management | Power Quality |
| **Energy Market** | Energy Time Shift | Supply Capacity | | |
| **Network Support** | Upgrade Deferral | Sub-station power | Congestion Relief | Transmission Support |
| **Ancillary Services** | Frequency Regulation | Load Following | Reserve Capacity | Voltage Support |
| **Renewable Integration** | Energy time shift | Capacity firming | Wind generation integration | |

Eyer, J. and Corey, G., 2010. *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*

# Application Frameworks

- Storage Application Frameworks
  - Specific assessments (firm and market level)
  - *Energy Storage for the Electricity Grid* – Sandia Laboratories

- Applications Relevant to Scope
  - No end-user applications
  - No renewable integration applications

| | | | | |
|---|---|---|---|---|
| **Consumer Applications** | Reliability | Demand Charge Management | ToU Cost Management | Power Quality |
| **Energy Market** | Energy Time Shift | Supply Capacity | | |
| **Network Support** | Upgrade Deferral | Sub-station power | Congestion Relief | Transmission Support |
| **Ancillary Services** | Frequency Regulation | Load Following | Reserve Capacity | Voltage Support |
| **Renewable Integration** | Energy time shift | Capacity firming | Wind generation integration | |

# Application Models

| Category | Application | Model |
|---|---|---|
| Reliability | End- User Reliability | VoLL Model |
| | | **VCR Model** |
| Energy Market | Energy Time-shift | Prefect Foresight Model |
| | | Calibrated Transaction Model |
| | | Average Price Window Model |
| | | Stopping Rule Model |
| | | **High Price Point Model** |
| | Supply Capacity | **Call Option Model** |
| Network Support | Augmentation Deferral | Continuous Present Value Model |
| | | WACC Model * |
| | | DSM Pricing * |
| | Sub-station Power | Storage Pricing Model |
| Ancillary Services | Frequency Regulation | **Single Market Model** |
| | | **Dual Market Model** |

**Table 1:** Models used to assess indicative benefits for applications

# VCR Model

- Reliability Benefit
  - Calculated through hours x VCR
  - Hours calculated by outage probability x length of outage

$$RB_{sr} = \sum_{i=1}^{n} H_{ir} \times VCR_{is}$$

$$H_{ir} = p_i \times SAIFI_r \times B_i$$

- Results
  - Sectorial disparity
  - Situation and spatially dependent

| Annual Reliability Benefit ($k/ MWh) | | | | |
|---|---|---|---|---|
| Category | Residential | Industrial | Commercial | Agricultural |
| Urban | 48.14 | 95.43 | 179.98 | 381.65 |
| Short Rural | 120.34 | 236.57 | 449.95 | 954.11 |
| Long Rural | 185.29 | 367.33 | 692.79 | 1, 469.03 |

**Table 2:** Annual reliability benefit

# Energy Time Shift

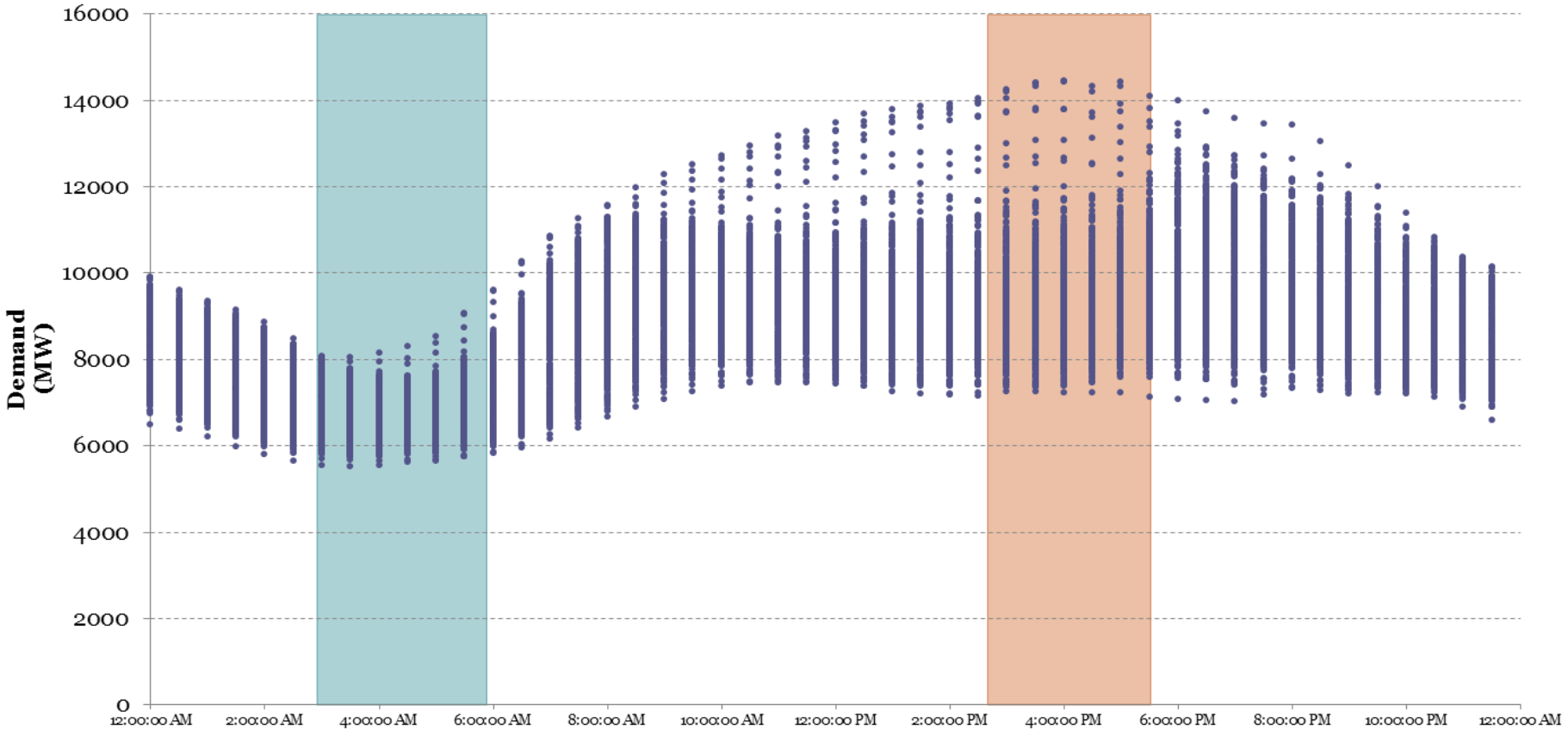



**Figure 5:** Generic energy time-shift strategy

# High Price Point Model (S4)

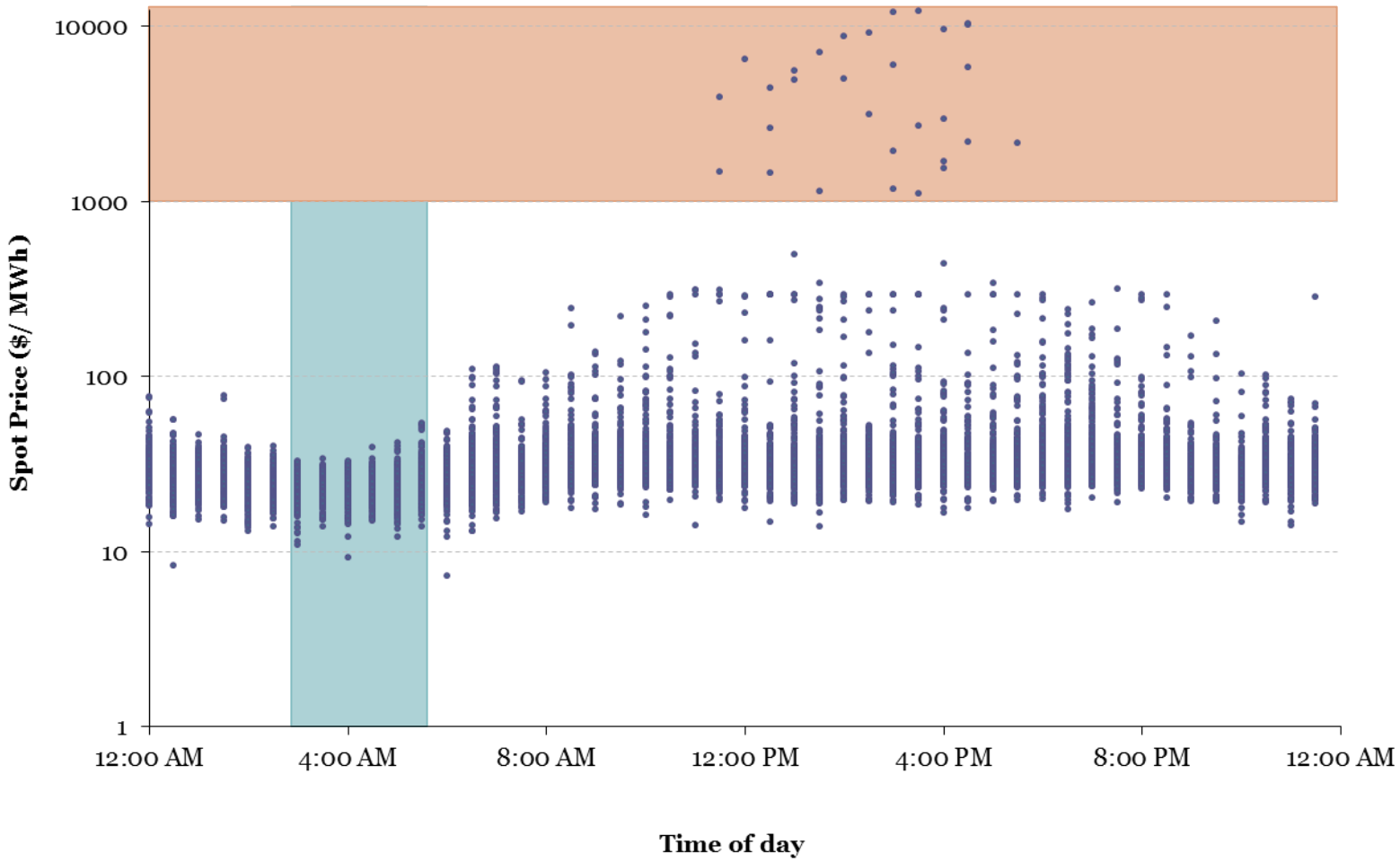



**Figure 6:** High price point model strategy

# Energy Time-shift

- Time Shift Benefit
  - Four strategies for buying and selling
  - Historical information for calibration
- Results
  - High price point strategy works
  - Performs better in certain years (2010)

**Annual Revenue from Time-shift ($k/ MWh)**

| | 2009 | 2010 | | | | | 2011 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | Perfect | Perfect | S1 | S2 | S3 | S4 | Perfect | S1 | S2 | S3 | S4 |
| QLD | 52.52 | 30.13 | 12.12 | **16.51** | 14.26 | 9.96 | 43.22 | 16.64 | 16.96 | 10.39 | **17.21** |
| NSW | 73.37 | 42.66 | 3.49 | 18.85 | 12.32 | **28.49** | 43.22 | **27.70** | 11.20 | 11.17 | 17.20 |
| VIC | 31.53 | 47.92 | 21.67 | 18.04 | 17.89 | **20.44** | 21.99 | 5.70 | **6.90** | 6.80 | 5.96 |
| SA | 106.76 | 73.45 | 36.44 | 25.17 | 25.13 | **42.66** | 39.64 | 12.17 | 12.68 | 12.63 | **17.65** |
| TAS | 98.54 | 59.10 | 2.85 | 6.85 | 7.15 | **31.38** | 14.69 | 0.90 | 2.84 | 3.29 | **3.33** |

**Table 3:** Annual sed energy time shift benefit

# Indicative Annual Benefits

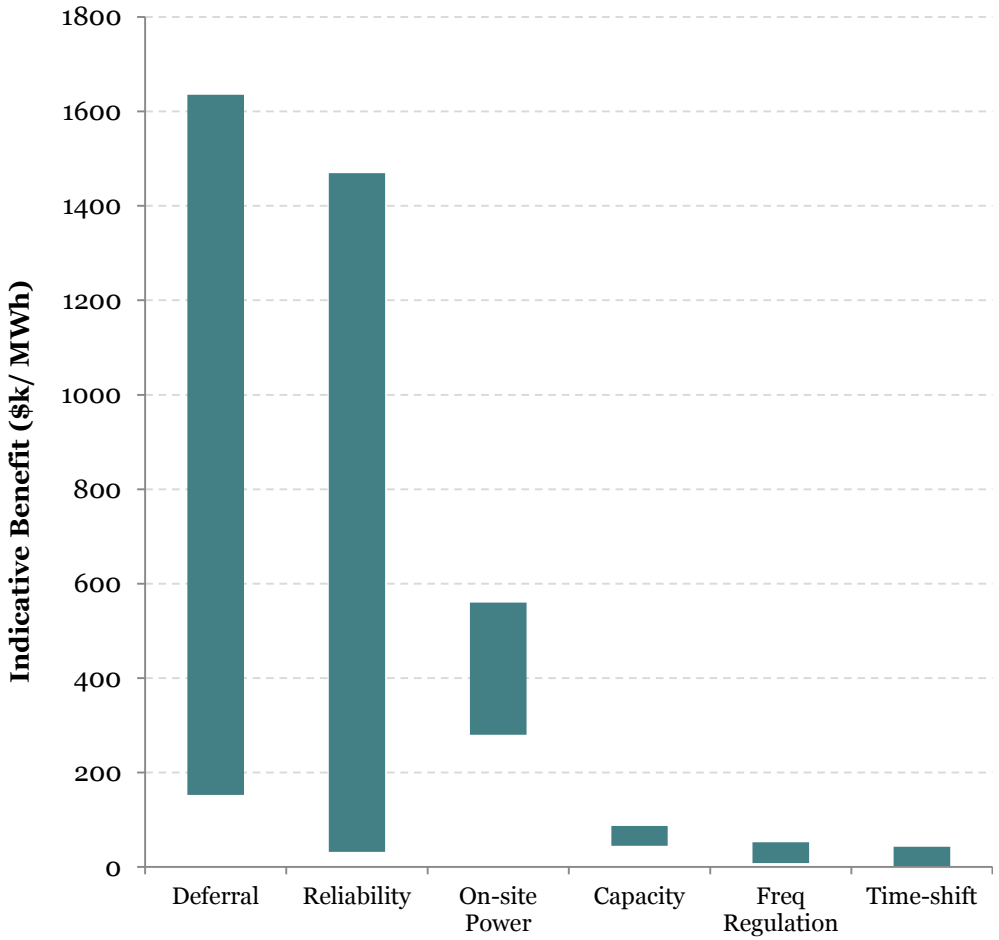



**Figure 7:** Indicative annual benefits of DES in the NEM

- High-value Applications
  - Network augmentation deferral
  - End-user reliability
  - Spatial variability
- Benefits Span Supply Chain
  - Network benefits
  - Wholesale energy benefits
  - Reliability benefits

# Investigating Institutions

- Institutions and Technology
  - Co-evolutionary and self reinforcing
  - Techno-Institutional complex
  - Technology lock-in
- Electricity Industries
  - Clear dominant designs
  - Rigid institutional structures
  - Difficult to influence

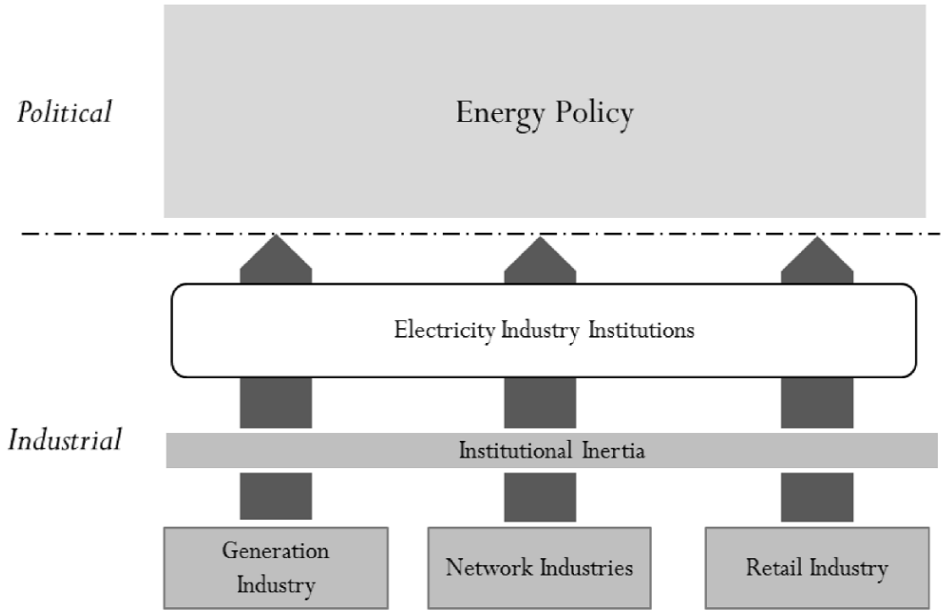



**Figure 8:** Institutional inertia in electricity industries

# Framework Development

| Regime | Role |
|---|---|
| **Governance** | The set of formal institutions, legislation, and policies that provide the framework in which a competitive electricity industry operates. This includes the formal regulatory arrangements for industry participants. |
| **Commercial** | The commercial arrangements for the competitive electricity industry. This may include spot and derivative markets for electrical energy as well as ancillary service markets and commercial interfaces for regulated industry participants, such as network service providers. |
| **Technical** | The set of rules that allow the various components of an electricity industry, when connected together, to function effectively as a single machine, providing a continuous flow of electrical energy of appropriate availability and quality between generation and end-use equipment. |
| **Security** | The task assigned to one or more system operators, of maintaining the integrity of a local or industry-wide core of an electricity industry in the face of threats posed by plausible large disturbances. |

**Table 4:** Decision making regimes for competitive electricity markets. Adapted from Outhred (2007)

- Previous Work
  - Institutional environment has received little attention
  - No established tool to assess integration of technologies
- Decision Making Framework
  - Four regimes
  - Considers industry as a whole
  - No ‘social’ aspect

# Social Regime

- Social Influence
  - Key consideration for technology integration
  - Tensions between aims
  - Course conduit for influence
- Social Regime
  - Inclusion is critical to efficacy as tool
  - Inclusion of normative dimension

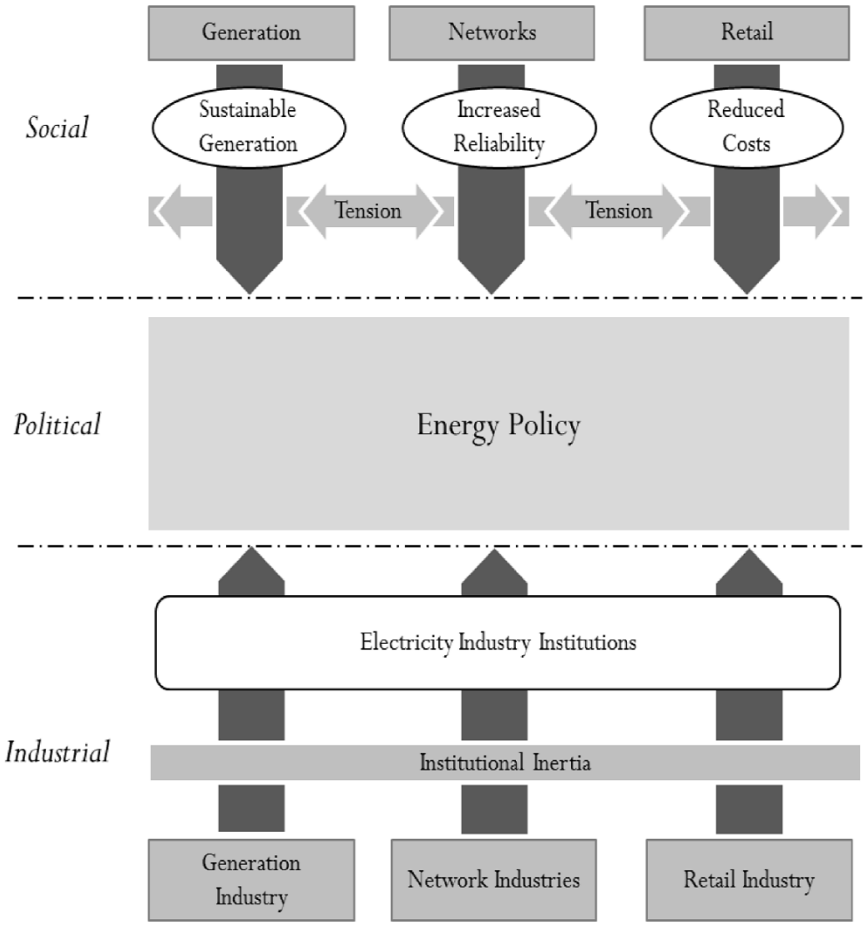



**Figure 9:** Social influence on electricity industry institutions

| Regimes | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

| Regimes | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | • Social/ political pressure on generation mix | • Social/ political pressure to increase reliability | • Social/ political pressure to increase reliability | • Social/ political pressure to reduce costs |
| **Governance** | | | | |
| *Political and Administrative* | • SCER instigates AEMC reviews<br>• Stakeholders submit to AEMC reviews<br>• CCA periodically reviews Clean Energy Act | • SCER instigates AEMC reviews<br>• Stakeholders submit to AEMC reviews<br>• Reliability and environmental policy defined by jurisdictions. | • SCER instigates AEMC reviews<br>• Stakeholders submit to AEMC determinations<br>• Jurisdictions direct distribution policies | • SCER instigates AEMC reviews<br>• Stakeholders submit to AEMC reviews<br>• Jurisdictions direct retail policies |
| *Legislative* | • NEL and NER with development by AEMC<br>• NEL applied by jurisdictional acts<br>• Renewable Energy Act for RET<br>• Clean Energy Act for large GHG emitters<br>• Jurisdictional acts for FiT schemes | • NEL and NER with development by AEMC<br>• Separate jurisdictional codes governing standards and responsibilities<br>• ACT rules on revenue decision appeals | • NEL and NER dictate connection and regulation requirements<br>• NERL and NERR dictate responsibilities to retailers and consumers<br>• Separate jurisdictional codes governing reliability standards and responsibilities<br>• ACT rules on revenue decision appeals | • NERL and NERR dictate supply arrangements and operation requirements<br>• NEL and NER dictate responsibilities as market customer<br>• Renewable Energy Act outlines RET responsibilities<br>• Jurisdictional acts for FiT schemes<br>• Jurisdictional energy efficiency schemes |
| *Regulatory* | • AER monitors competition<br>• RET instruments regulated by CER<br>• Carbon price mechanism regulated by CER<br>• Jurisdictional regulators determine FiT prices and arrangements | • AER regulates revenue<br>• Augmentation regulated by AER through RIT-T with regard to jurisdictional reliability values | • AER regulates revenue<br>• Augmentation regulated by AER through jurisdictional methodologies and reliability values.<br>• Jurisdictional regulators oversee licensing arrangements | • AER monitors competition<br>• AER oversees authorisation of retailers<br>• Jurisdictional regulators conduct retail price determinations<br>• CER for RET |
| **Commercial** | • Energy and ancillary market rules defined in NER. Market operation and operating standards controlled by AEMO<br>• Derivative trading on ASX and OTC markets<br>• RERT contracts for reserve capacity<br>• LGC and STC transactions under RET<br>• FiT revenue | • Regulated revenue for prescribed transmission services<br>• Negotiated revenue for negotiated transmission services<br>• Negotiated NSCAS contracts for services from external parties<br>• Negotiated DSM contracts for services from external parties | • Regulated DUoS revenue for direct control services<br>• Negotiated distribution services set out in contractual arrangements<br>• Negotiated DSM contracts for augmentation deferral<br>• DMIS payments regulated by AER<br>• Network payments to TNSPs | • Regulated return from energy sold<br>• Energy market rules defined in NER. Market operation controlled by AEMO<br>• Derivatives trading on ASX and OTC markets<br>• FiT payments to consumers<br>• LGC and STC liability under RET<br>• Network payments to TNSPs and DNSPs |
| **Technical** | • Technical standards set out in NER and by AEMO<br>• Obligations for connections defined in NER | • NER dictates requirements<br>• Direct connection requires negotiation with TNSP<br>• Jurisdictional codes for fault levels at connection points | • Connection to network managed by DNSP<br>• Jurisdictional distribution codes | |
| **Security** | • Short-term security managed by AEMO<br>• Long-term forecasting by AEMO (ESOO)<br>• AEMC-RP reviews MPC, MFP, CPT and reliability standard | • Long term planning by AEMO (NTNDP)<br>• APRs released by TNSPs as Jurisdictional Planning Body<br>• Jurisdictions set SAIFI, SAIDI, and N-x<br>• AEMC-RP has LRPP | • Planning delegated to DNSP<br>• Jurisdictions set SAIFI, SAIDI, and N-x | |

# Analysis of Technology

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- Technology in the Framework
  - Analysed in each element of institutional matrix
  - Output as a technology deployment analysis

**Figure 10:** Institutional framework matrix allows technology to be analysed in each element

# Analysis of Technology

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

Can it be registered as a generator?

**Figure 10:** Institutional framework matrix allows technology to be analysed in each element

# Analysis of Technology

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

Can it be registered as a generator?

Can it be registered as a Load?

**Figure 10:** Institutional framework matrix allows technology to be analysed in each element

# Analysis of Technology

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

Can it be registered as a generator?

Can it be registered as a Load?

Can it access network contracts for demand side management?

**Figure 10:** Institutional framework matrix allows technology to be analysed in each element

# Analysis of Technology

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- Technology in the Framework
  - Analysed in each element of institutional matrix
  - Output as a technology deployment analysis

**Figure 10:** Institutional framework matrix allows technology to be analysed in each element

| Regimes | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | • Understanding of peak demand | • Understanding of transmission losses | • Public input for distribution planning<br>• Amenity issues | • Market mechanisms for reliability<br>• Understanding of reliability costs |
| **Governance** | | | | |
| *Political and Administrative* | • Reliability and security focus<br>• SCER/ AEMC consideration of potential of storage options<br>• Preference for maintaining spot price peaks | • Preference for standard network solutions due to 'cultural' reasons and enhanced control<br>• Distributed resources risk to business model | • Preference for standard network solutions due to 'cultural' reasons and enhanced control<br>• Distributors may wish to maintain market power and not increase competition | • Framing of customer reliability at a jurisdictional level<br>• Preference for maximising throughput of energy<br>• Focused on retail competition |
| *Legislative* | • NEO focused on reliability and economic efficiency<br>• Connection rules for storage<br>• Registration as market generator | • Focus of NEO on reliability and economic efficiency<br>• Registration as network service for storage | • Storage connection classification: standard control service, alternate control service, or negotiated distribution service<br>• No ANM framework | • Registration as market customer for storage<br>• Availability of energy efficiency payments through jurisdictional schemes<br>• No ANM framework |
| *Regulatory* | • Presence of market power creating a barrier to entry | • Economic regulation encourages CAPEX over OPEX<br>• DSM consideration requirements | • Economic regulation encourages CAPEX over OPEX<br>• Jurisdictional licencing requirements restrict technology classes<br>• DSM consideration requirements | • Jurisdictional energy efficiency requirements |
| **Commercial** | • Structure of and accessibility to the wholesale market<br>• Accessibility to the ancillary market<br>• Accessibility to derivative markets<br>• Accessibility to reserve contracts | • Accessibility to service contracts<br>• Deep connection charges for storage operators at a distributed level | • Availability of information on non-network opportunities<br>• Lack of market for reliability<br>• Lack of wholesale energy market at the sub-regional level<br>• Lack of ancillary markets at the sub-regional level<br>• Transaction and connection costs | • Access to derivative markets for risk hedging by retailers<br>• Scope for retailer 'sell' network deferral/ ancillaries to DNSP<br>• Access to energy efficiency schemes<br>• Market for reliability |
| **Technical** | • Standards for storage to operate as a generator | • Technical implications of large-scale connection<br>• Standards for connection to the transmission network | • Standards for connection to the distribution network<br>• Arbitration of connection<br>• Technical implications of large-scale connection | • Little technical involvement (apart from Gentailers) |
| **Security** | • Dictated USE standard of 0.02%<br>• Consideration of storage in ESOO | • Reliability standards are prescribed and do not price reliability<br>• Consideration of storage for peak load management in NTNDP | • Reliability standards are prescribed and do not price reliability<br>• Level of DSP inclusion in distribution planning<br>• Consideration of storage in APRs | • Little real-time information on distributed supply /demand and consumers |

# Analysis of Energy Storage

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- Significant Outcomes
  - Connection rules
  - Registration rules
  - Lack of markets
  - No standards

**Figure 11:** Institutional framework matrix allows technology to be analysed in each element

# Analysis of Applications

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- High-value Applications
  - End-user reliability
  - Network augmentation deferral

**Figure 12:** The technology deployment analysis matrix

# Reliability

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- End-user Reliability
  - Lack of market mechanisms for reliability
  - Legislated reliability standards
  - Poor understanding of reliability costs to consumers

**Figure 13** Elements within the institutional framework which affected the end-user reliability application (shown in teal).

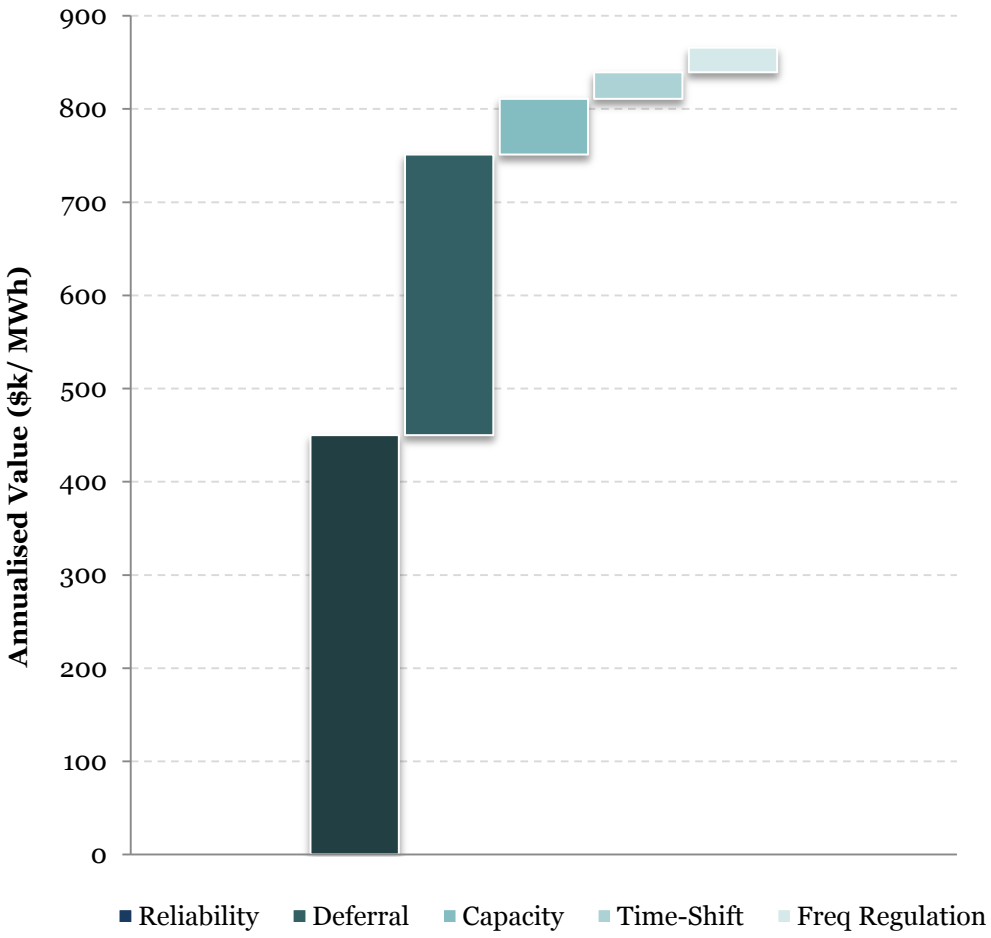
# Augmentation Deferral

| | Generation | Transmission | Distribution | Retail |
|---|---|---|---|---|
| **Social** | | | | |
| **Governance** | | | | |
| *Political and Administrative* | | | | |
| *Legislative* | | | | |
| *Regulatory* | | | | |
| **Commercial** | | | | |
| **Technical** | | | | |
| **Security** | | | | |

- Augmentation Deferral
  - Perverse economic regulation processes
  - Poor availability of investment information
  - Lack of DES consideration in planning processes

**Figure 14:** Elements within the institutional framework which affected the network augmentation deferral application (shown in teal).

# Aggregation is the Key…




- Benefit Aggregation
  - Aggregated stack of applications
  - Maximises benefits
  - Complete stack unrealistic

**Figure 15:** Aggregated benefit stack for a selected combination of application scenarios

# …But is Difficult

- Aggregation Constraints
  - Technical constraints (spatial aggregation)
  - Operation constraints (temporal aggregation)
  - Institutional constraints
- Institutional Constraints
  - Performing across supply chain
  - Key challenge for integration

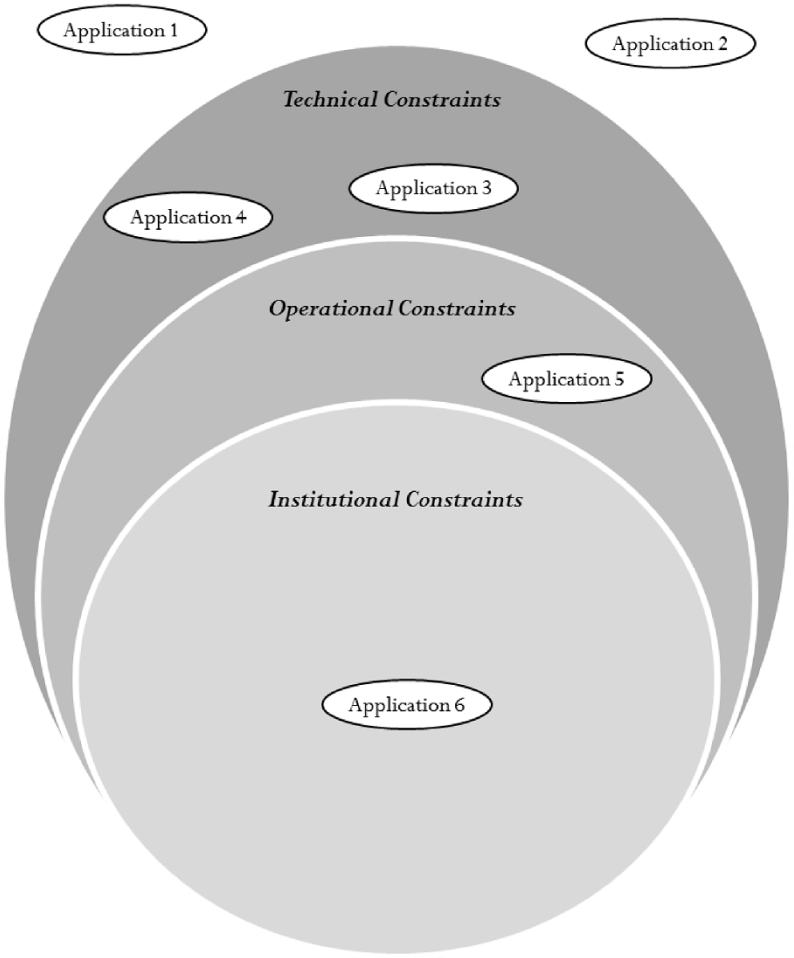
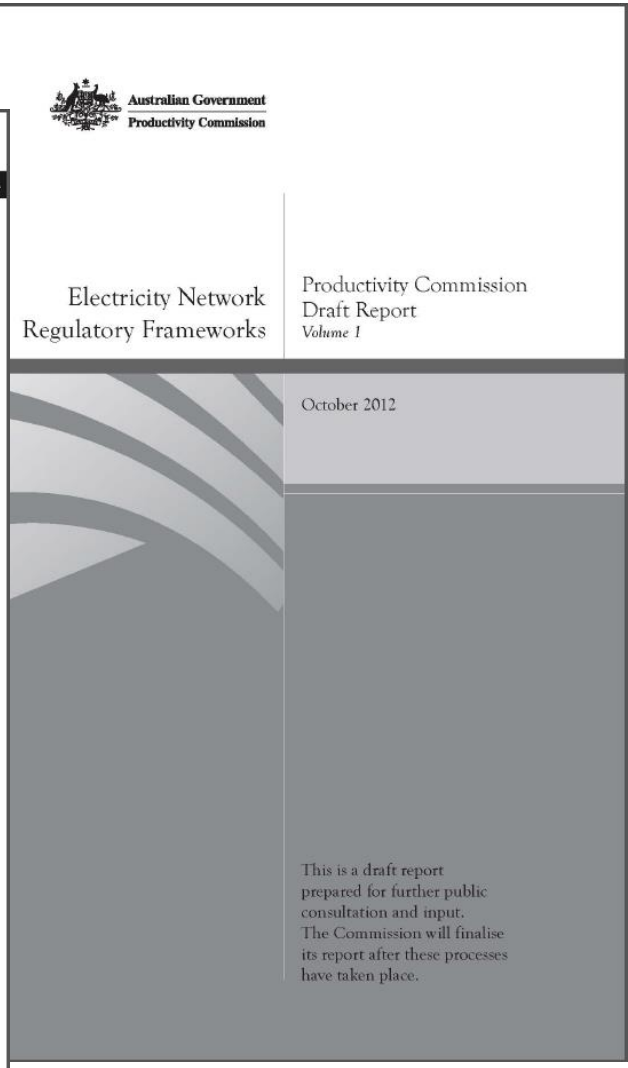



**Figure 16:** Interaction between different constraints in the 'application constraint space'.

# Questions


ENERGY TRANSFORMED FLAGSHIP
www.csiro.au
Solar intermittency:
Australia's clean
energy challenge
Characterising the effect of high penetrati
intermittency on Australian electricity net
June 2012


Institute for Sustainable Futures
UNIVERSITY OF TECHNOLOGY SYDNEY
THINK SMALL
The Australian Decentralised
Energy Roadmap
1st Issue:
December 2011
National Research FLAGSHIPS
Energy Transformed
CSIRO
iGrid
intelligent grid


Australian Government
Productivity Commission
Electricity Network
Regulatory Frameworks
Productivity Commission
Draft Report
Volume 1
October 2012
This is a draft report
prepared for further public
consultation and input.
The Commission will finalise
its report after these processes
have taken place.