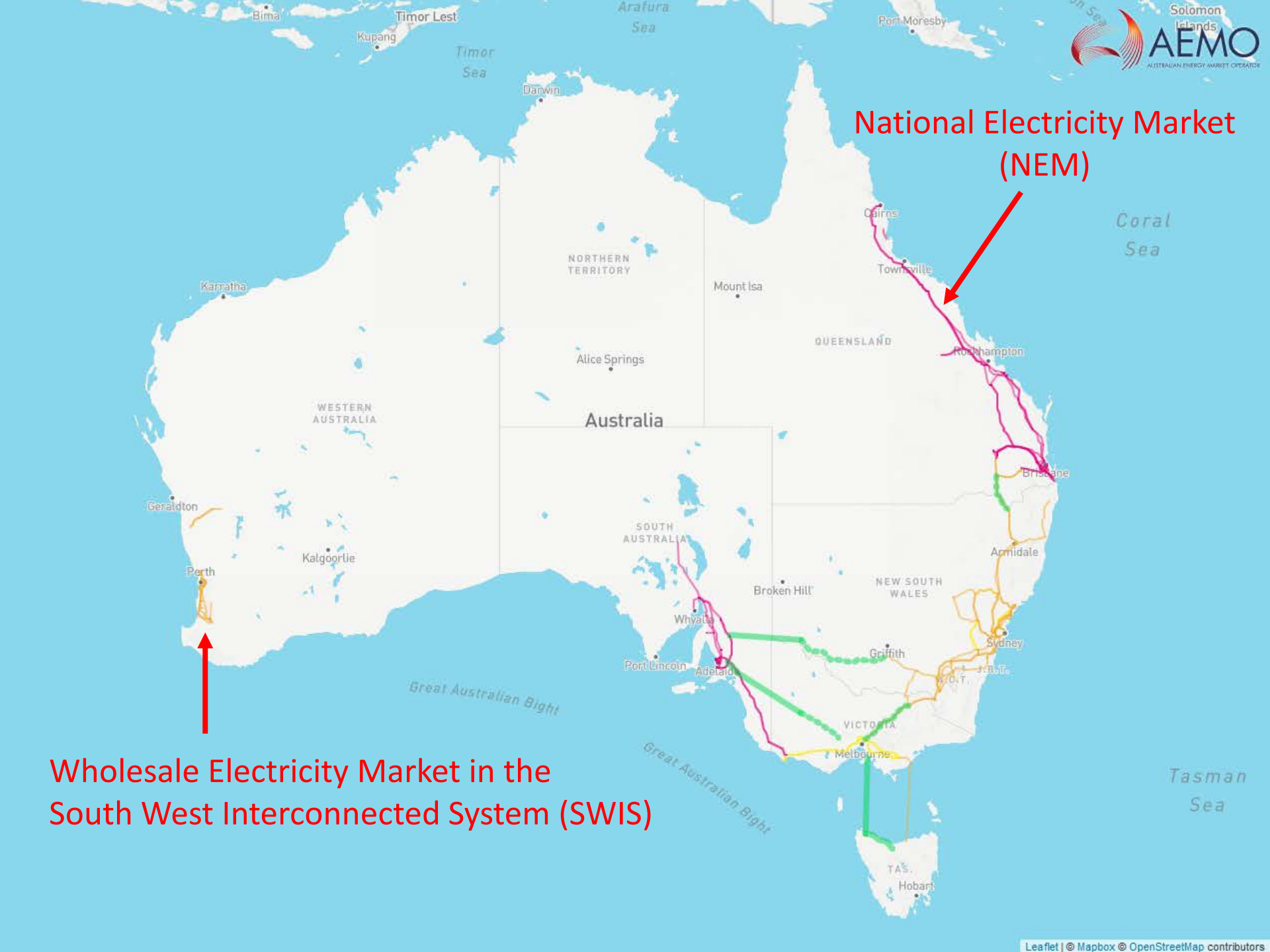
National Electricity Market (NEM)
Wholesale Electricity Market in the South West Interconnected System (SWIS)
AEMO
Australia
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TAS.
Darwin
Cairns
Townsville
Mount Isa
Rockhampton
Brisbane
Alice Springs
Karratha
Geraldton
Perth
Kalgoorlie
Broken Hill
Armidale
Sydney
Griffith
Whyalla
Port Lincoln
Adelaide
Melbourne
Hobart
Port Moresby
Solomon Islands
Timor Lest
Kupang
Bima
Timor Sea
Arafura Sea
Coral Sea
Tasman Sea
Great Australian Bight
Leaflet | © Mapbox © OpenStreetMap contributors

100% renewable electricity

- Pathways towards high variable renewable energy integration: affordability, reliability and security.


Energy 133 (2017) 471–482

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

100% renewable electricity in Australia

Andrew Blakers*, Bin Lu, Matthew Stocks

Australian National University, Australia


Energy 122 (2017) 663–674

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/energy

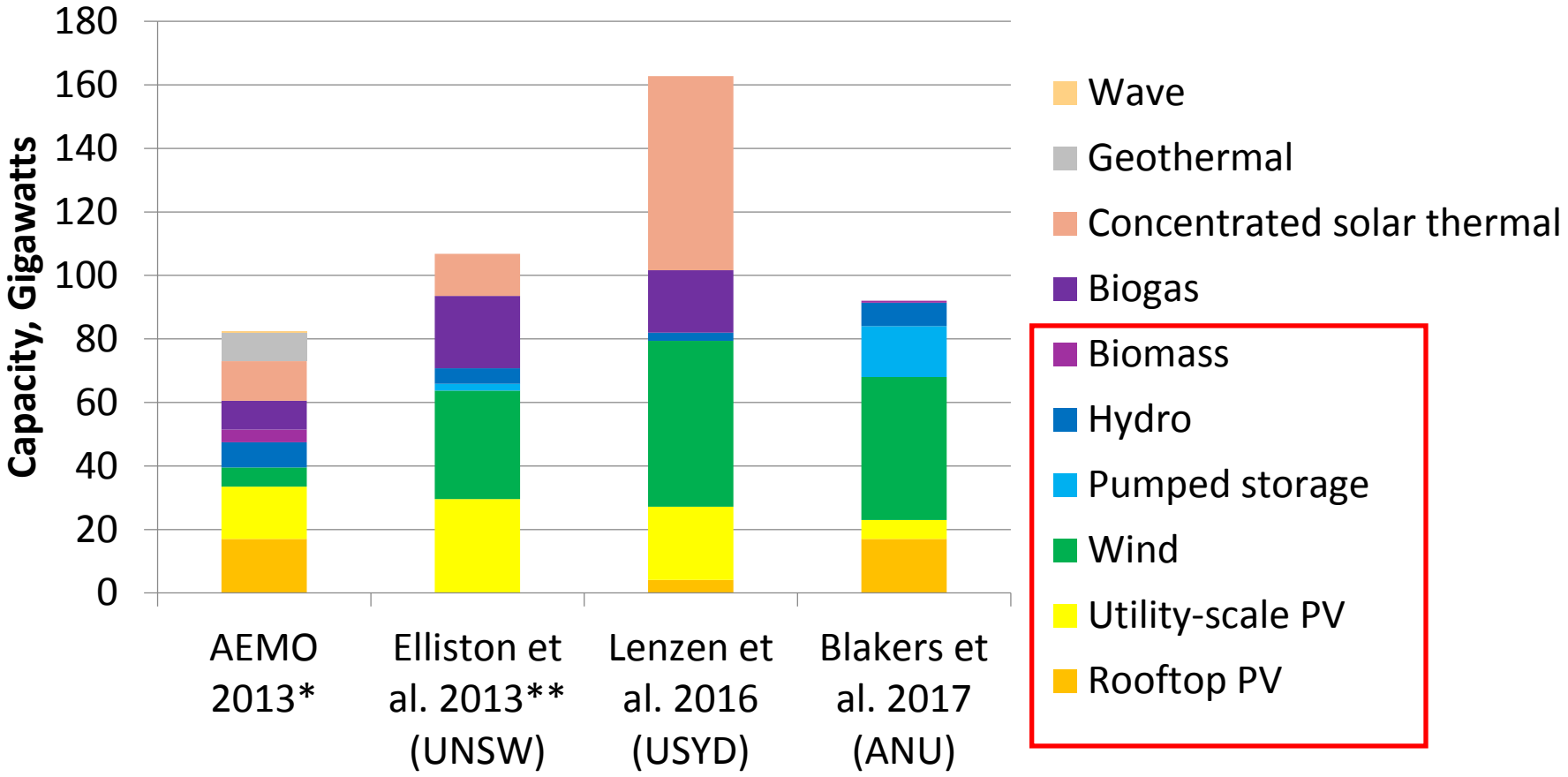
90–100% renewable electricity for the South West Interconnected System of Western Australia

Bin Lu*, Andrew Blakers, Matthew Stocks

Australian National University, Australia

Source:
Australian National University (ANU) http://www.sciencedirect.com/science/article/pii/S0360544217309568; http://www.sciencedirect.com/science/article/pii/S0360544217300774

RE100 studies in Australia



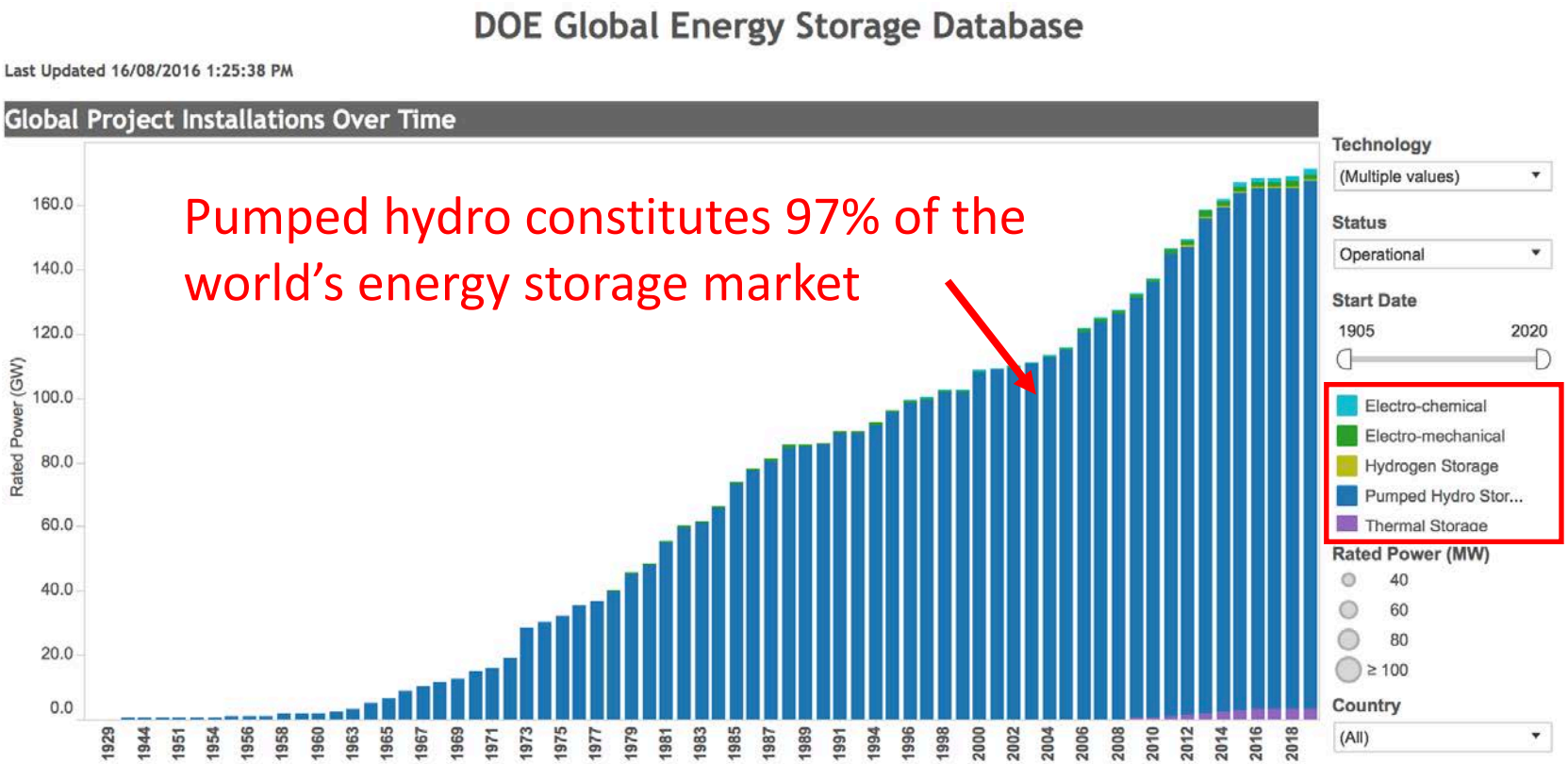
* Pumped storage included in Hydro ** Rooftop PV included in Utility-scale PV

Source:
Australian Energy Market Operator (AEMO) http://www.environment.gov.au/climate-change/publications/aemo-modelling-outcomes
University of New South Wales (UNSW) http://www.sciencedirect.com/science/article/pii/S0301421513002164
University of Sydney (USYD) http://www.sciencedirect.com/science/article/pii/S0306261916309400

Innovation

- Benchmark – Cost of 100% renewable electricity in an isolated large-scale power system using existing mature technologies
- Generation and storage technologies:
  - Greater than 100 GW of worldwide deployment
  - Unconstrained land or resource availability in Australia
  - No material supply or security issues
- Large-scale energy storage as a primary approach to achieve 100% renewable electricity in Australia's energy markets.

Large-scale energy storage



Source
U.S. Department of Energy http://www.energystorageexchange.org/projects/data_visualization

Cost assumptions

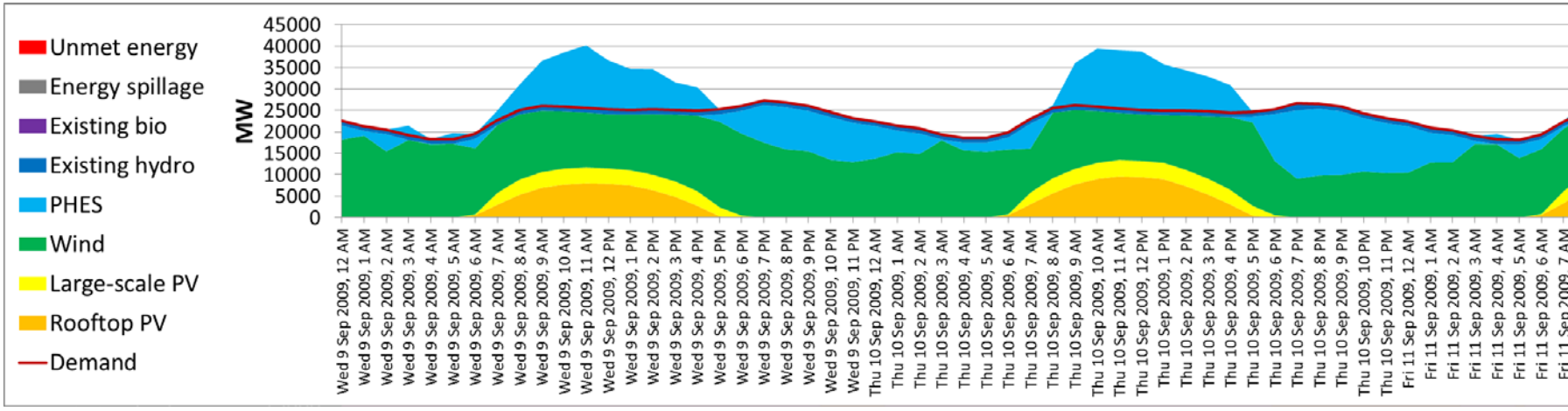
Technology	Capital cost (Australian Dollar)	Source
1-axis tracking PV	$1,700/kW-DC	ARENA Large Scale Solar program
Wind turbines	$2,300/kW	ACT reverse auctions
Pumped hydro	$800/kW plus $70/kWh	Cost models for Araluen Valley
Hydro (existing)	Purchase price $70/MWh	AEMO NEM 2016
Bio (existing)	Purchase price $70/MWh	AEMO NEM 2016
HVDC terminals *	$140,000/MW-pair	ABB
HVDC transmission lines	$400/MW-km	SGCC & ElectraNet
Submarine HVDC cables	$4,000/MW-km	Tasmanian Government
HVAC substations & lines	$1,500/MW-km	ElectraNet

* High-voltage DC/AC transmission

Source:
Australian National University (ANU) http://www.sciencedirect.com/science/article/pii/S0360544217309568

Modelling methodology

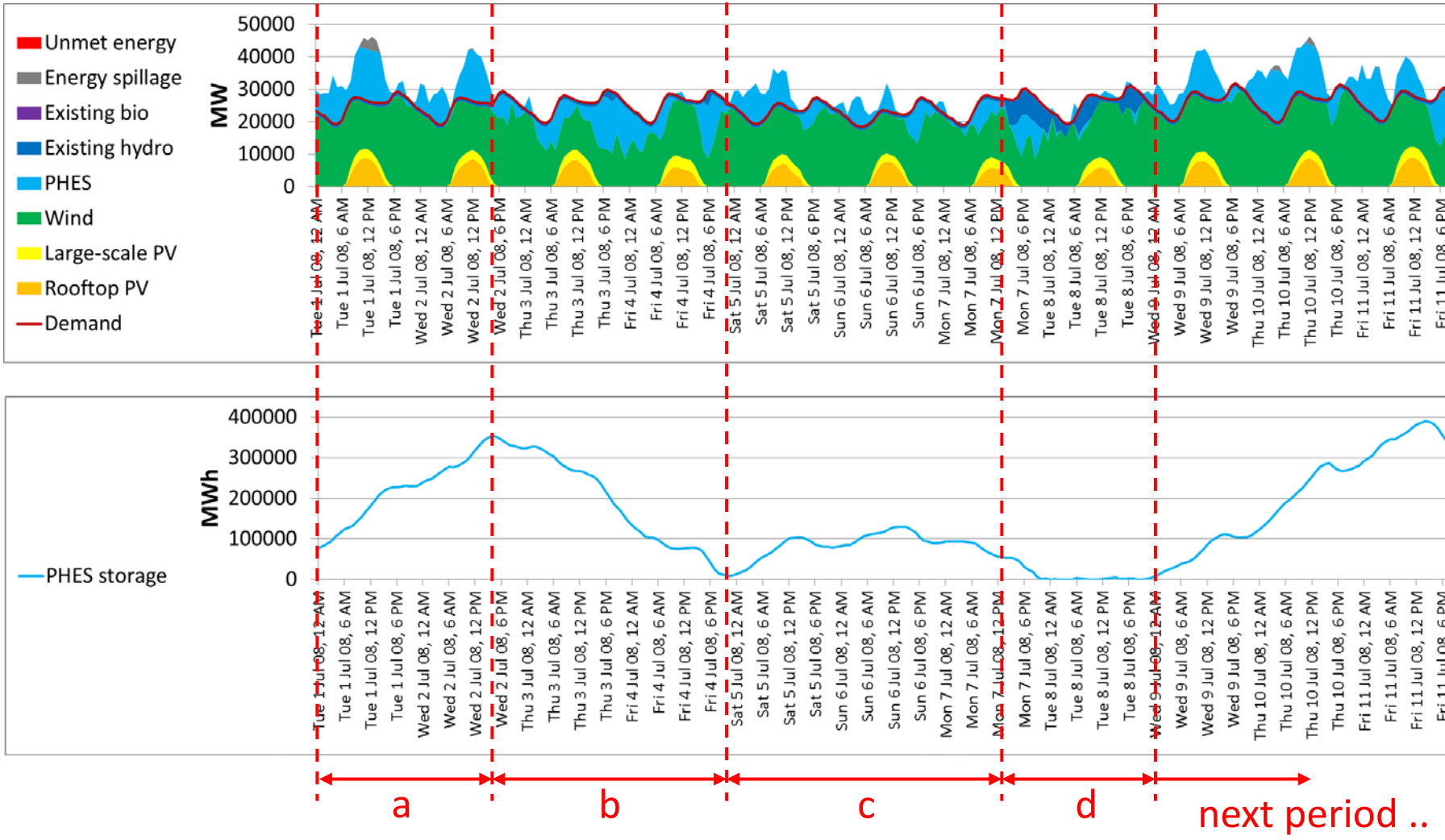
- Historical hourly demand, solar and wind data 2006–10 from AEMO
- Generating facilities: PV and wind contribute 90%, existing hydro and bio produce 10%



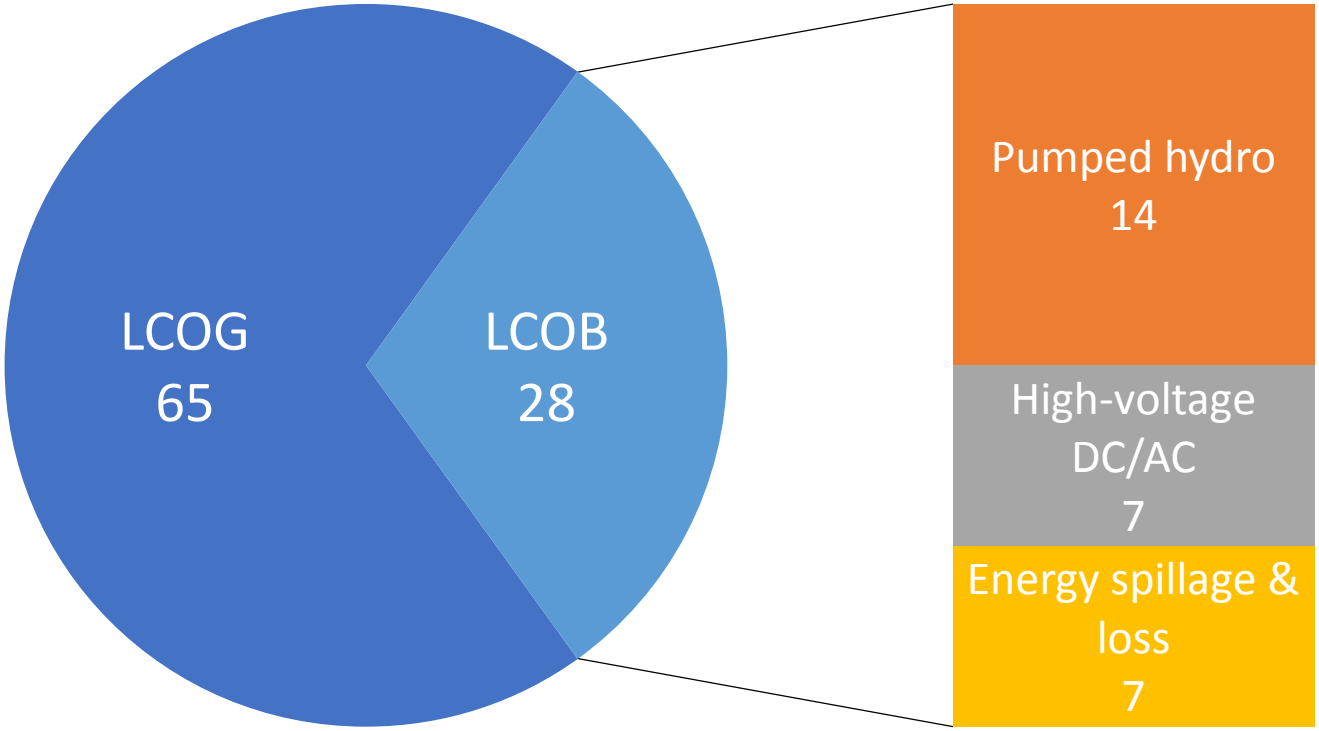
* National Electricity Market Optimiser developed by Dr Ben Elliston

Critical periods

a. Pumping surplus wind generation
b. Supporting the periods with low wind availability
c. Pumping-generation cycles
d. Co-operation with existing hydro and bio



Levelised cost of electricity

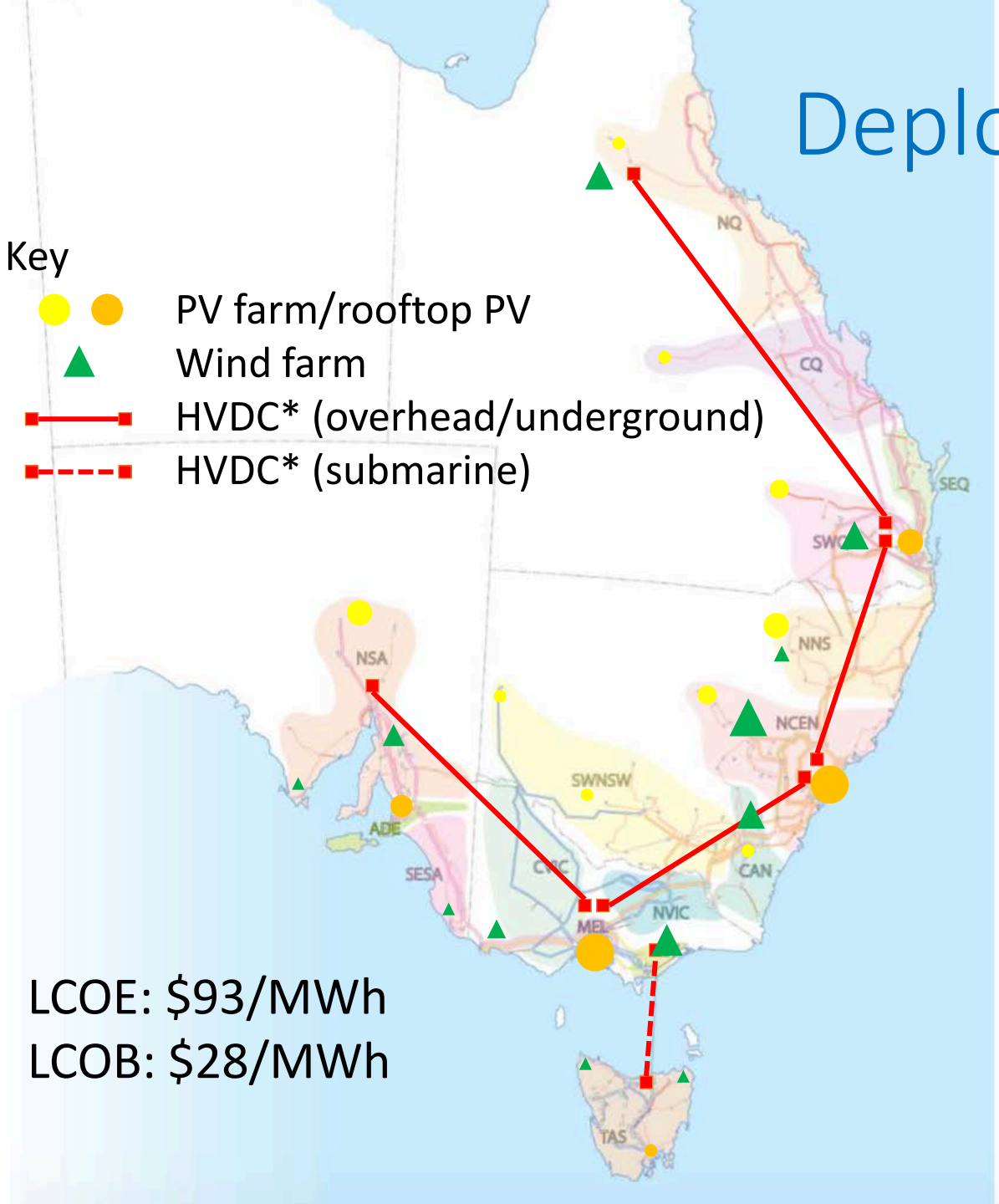


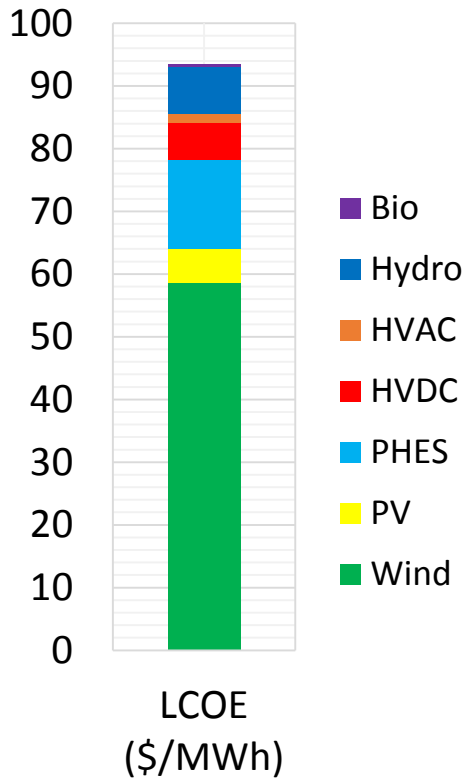
LCOE (Electricity) = LCOG (Generation) + LCOB (Balancing)

- LCOE $93/MWh (2016) = LCOG $65/MWh + LCOB $28/MWh
- LCOE $75/MWh (2030) = LCOG $50/MWh + LCOB $25/MWh

Source:
Australian National University (ANU) http://www.sciencedirect.com/science/article/pii/S0360544217309568

Deployments of PV & wind



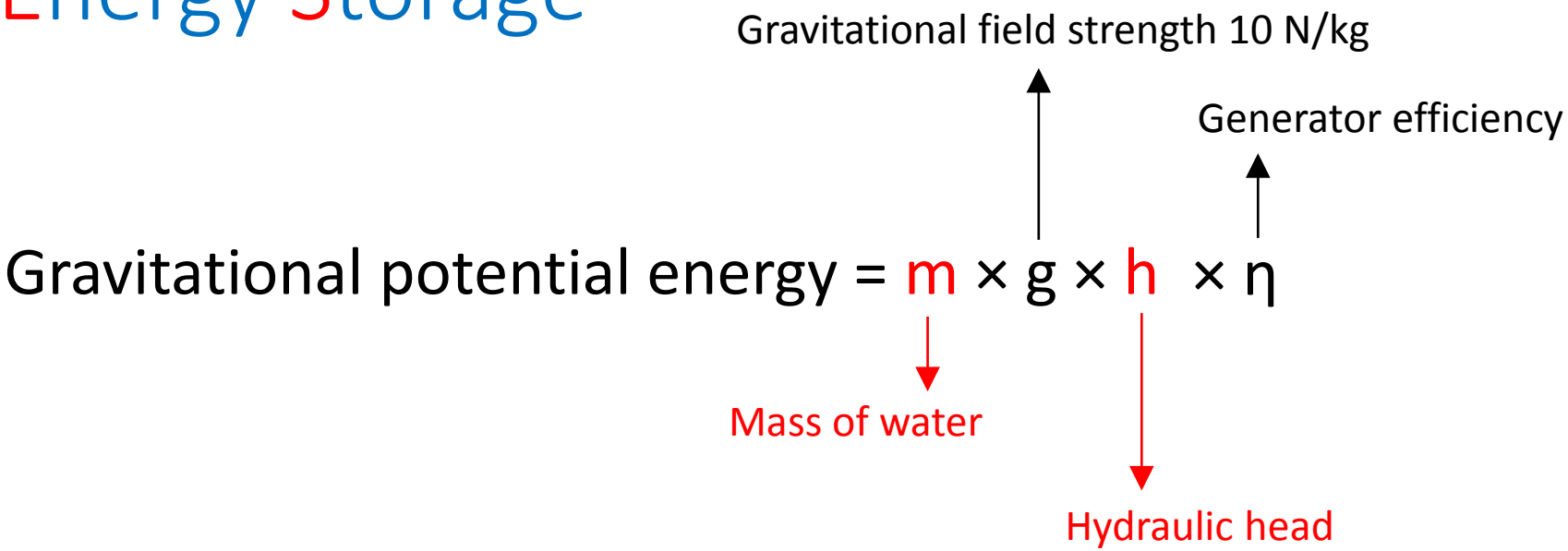


LCOE: $93/MWh

LCOB: $28/MWh

* Notional HVDC backbone

Short-Term Off-River pumped hydro Energy Storage



- Closed-loop pumped hydro systems located away from rivers
- Large altitude difference (> 300 metres)
- Facilitating renewable energy integration (day-night shifting) and grid stabilisation
- In a broad sense, it also incorporates pumped hydro systems that utilise existing reservoirs and those developed from exhausted mining pits.

Source

BBC http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_gateway/forces/themeridesrev1.shtml

2015 Asia-Pacific Solar Research Conference http://apvi.org.au/solar-research-conference/wp-content/uploads/2015/12/B-Lu_Peer-Reviewed_FINAL.pdf

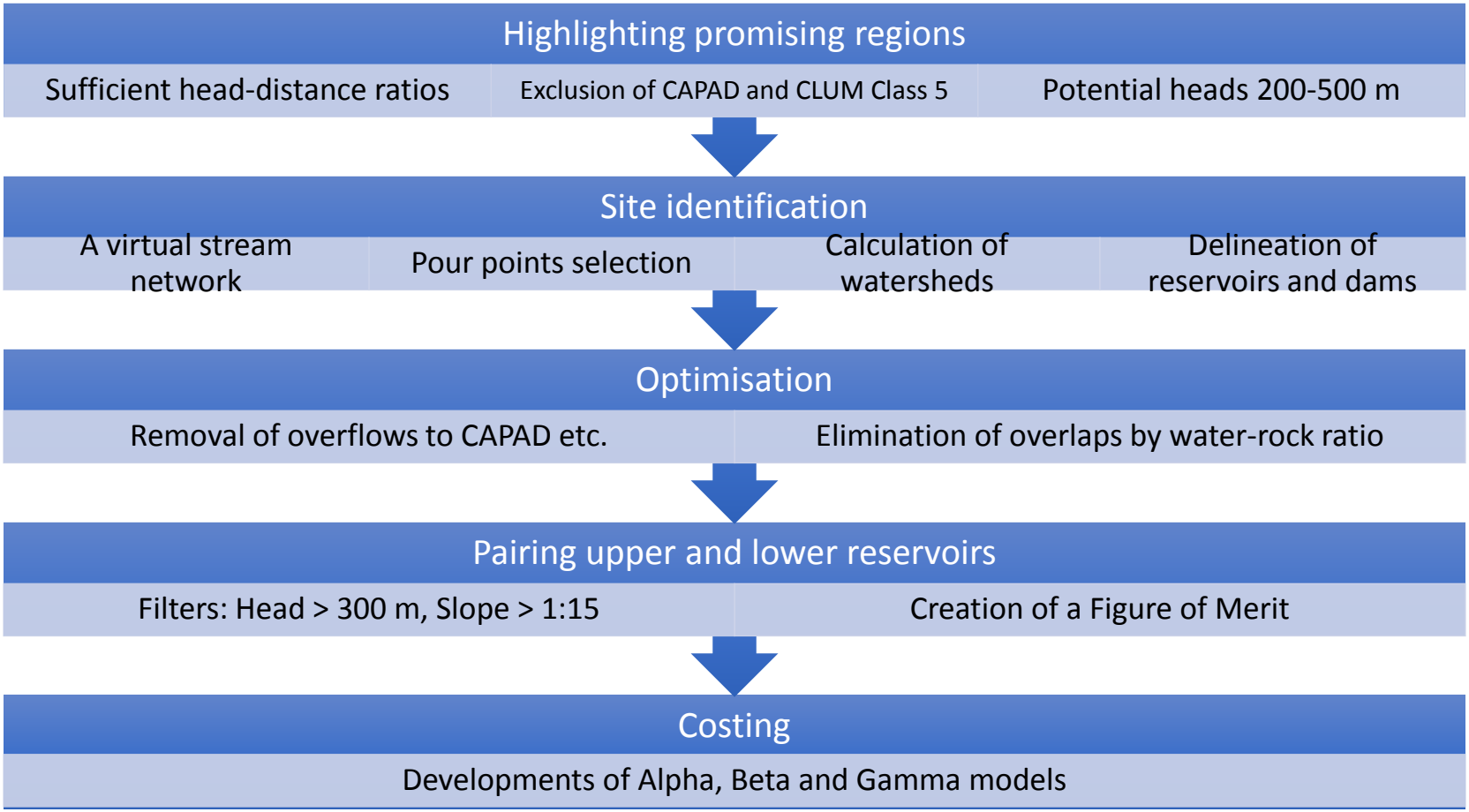
Search criteria

No.	Criterion	Value
1	Minimum head to distance ratio	1:15
2	Minimum head	300 m
3	Minimum surface area of reservoir	10 ha
4	Minimum storage capacity	1 GL
5	Maximum dam wall height	10, 20, 40, 80 m
6	Dam batter	1:1, 1:3
7	Maximum slope for dam construction	1:5
8	Protected areas	Not in CAPAD *
9	Intensive land use	Not in CLUM Class 5 **
10	Resolution (Searching interval)	10 m height

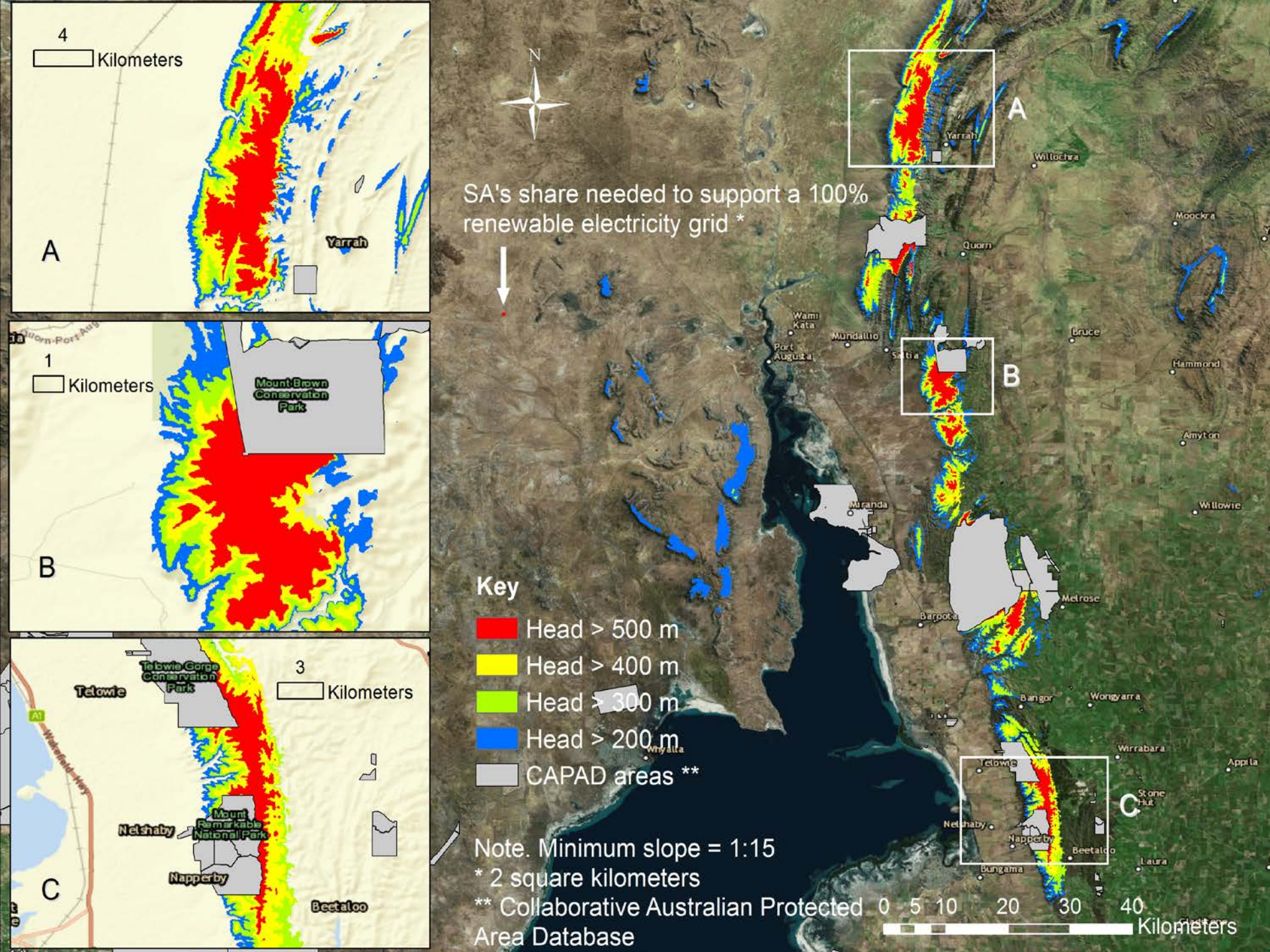
Note. Minimum head in Western Australia and the Northern Territory: 200 m
* Collaborative Australian Protected Areas Database (CAPAD)
** Catchment Scale Land Use (CLUM) datasets

Source: Australian National University (ANU)

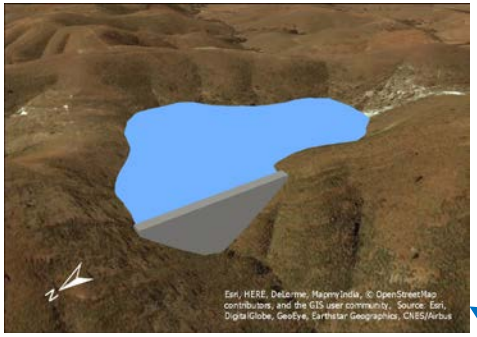
GIS-based procedures



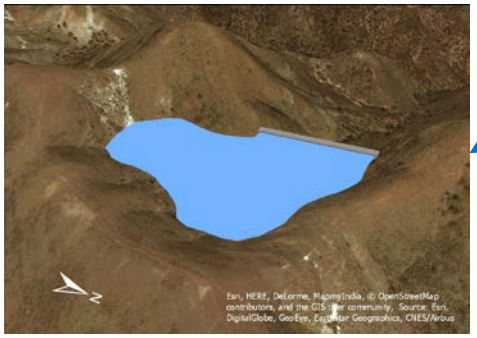
Source: Australian National University (ANU)


4
Kilometers
A
Yarrah
1
Kilometers
Mount Brown Conservation Park
B
3
Kilometers
Telowie Gorge Conservation Park
Telowie
Mount Remarkable National Park
Melshaby
Napperby
Beetaloo
C
N
SA's share needed to support a 100% renewable electricity grid *
Willochra
Moockra
Quorn
Wami Kata
Mundallio
Port Augusta
Bruce
Hammond
Amyton
Willowie
Miranda
Melrose
Barpoota
Bangor
Wongyarra
Wirrabara
Appila
Stone Hut
Laura
Bungama
Beetaloo
Key
Head > 500 m
Head > 400 m
Head > 300 m
Head > 200 m
CAPAD areas **
Note. Minimum slope = 1:15
* 2 square kilometers
** Collaborative Australian Protected Area Database
0 5 10 20 30 40
Kilometers

Delineation of reservoirs/dams

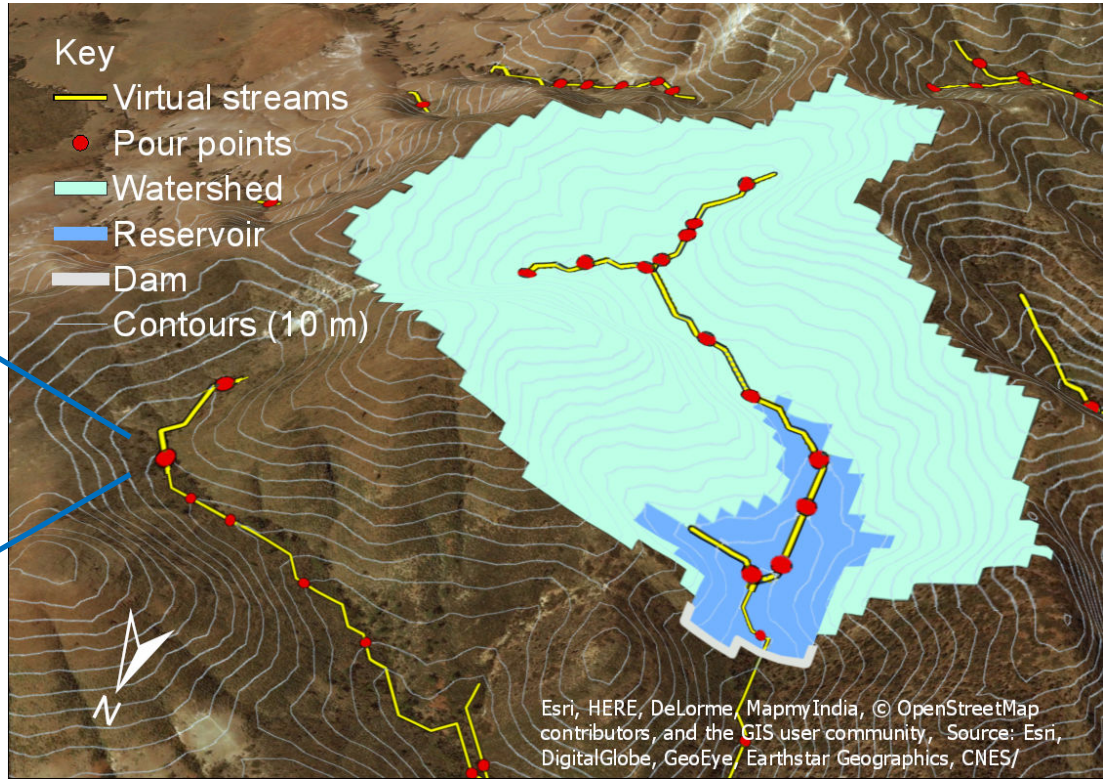


Front view



Back view

3D visualisation of a typical reservoir/dam



Delineation of the watershed, reservoir and dam of an example site (elevation exaggeration: 2)

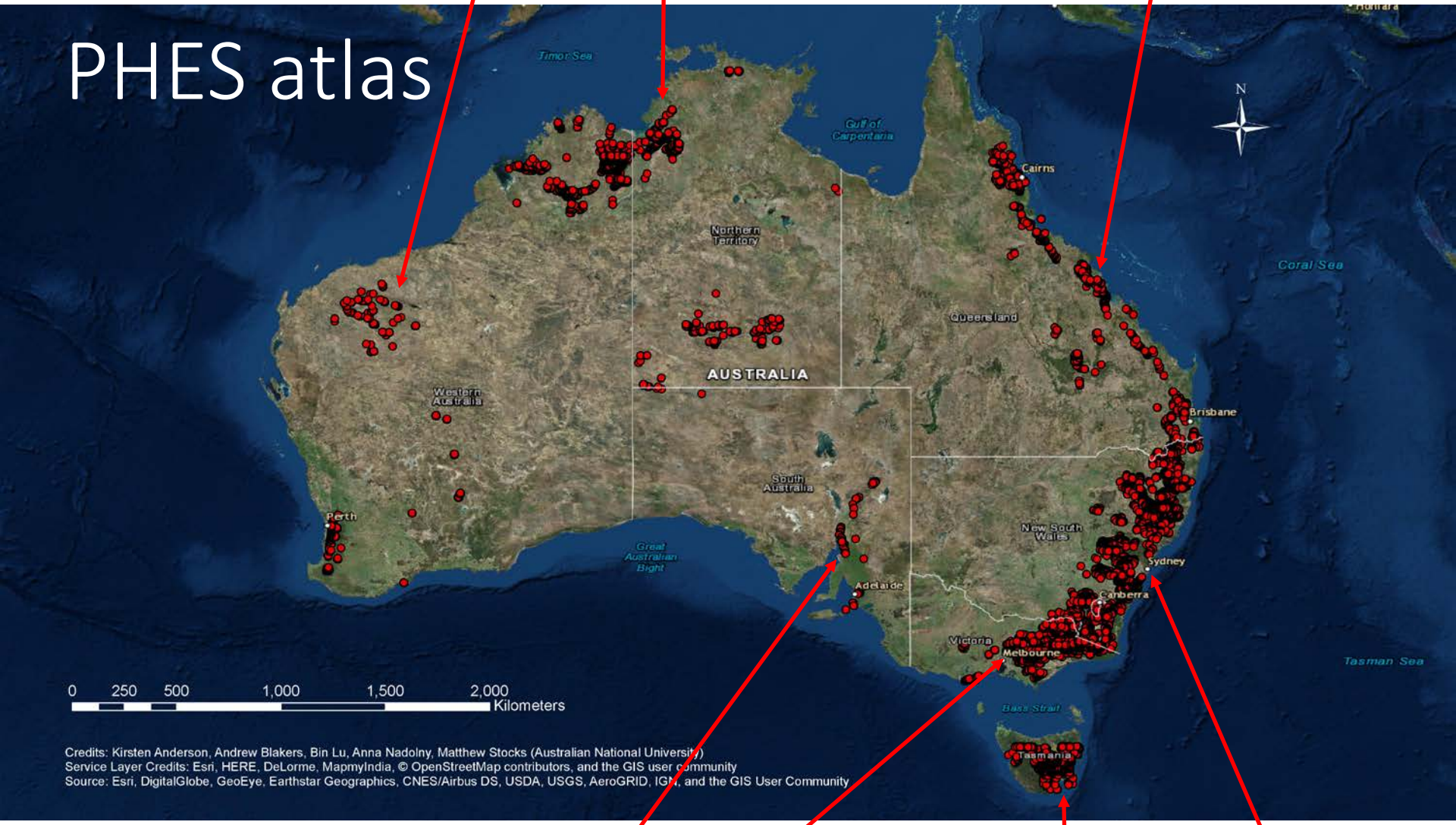
Source: Australian National University (ANU)

Northern Territory: 1,550 sites; 5,000 GWh

Western Australia: 3,800 sites; 9,000 GWh

Queensland: 1,770 sites; 7,000 GWh

PHES atlas



South Australia: 185 sites; 500 GWh

NSW (including ACT): 8,600 sites; 29,000 GWh

Victoria: 4,400 sites; 11,000 GWh

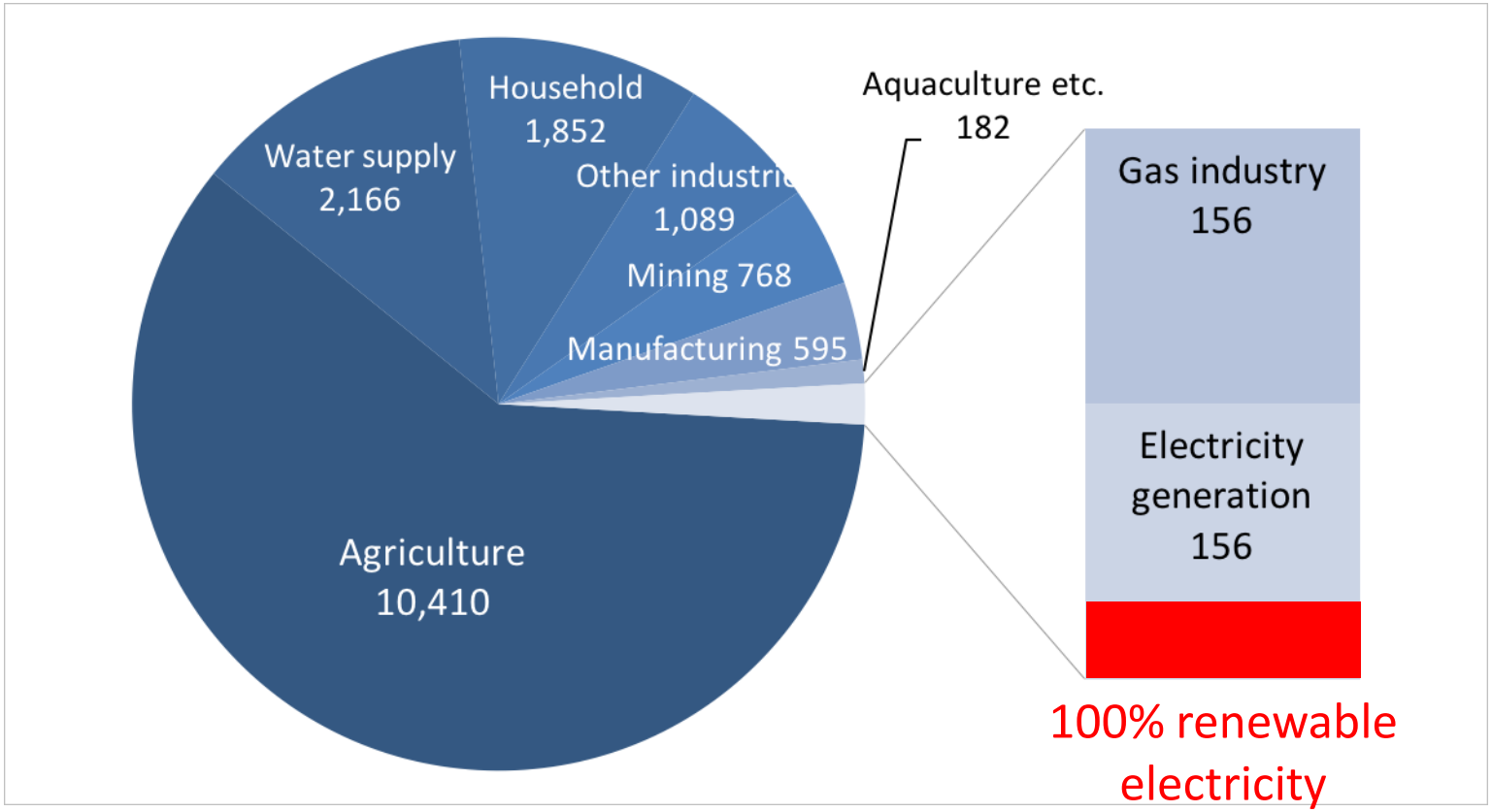
Tasmania: 2,050 sites; 6,000 GWh

Source

The Conversation https://theconversation.com/want-energy-storage-here-are-22-000-sites-for-pumped-hydro-across-australia-84275

Water consumption

- Transported from nearby water sources
- Harvested by micro-catchments
- Evaporation and leakage reductions



Note. Gigalitres in 2014-15
Assuming electricity and gas supply consume 50%: 50%

Source
Australian Bureau of Statistics http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4610.02014-15?OpenDocument
Australian National Water Commission http://www.senate.state.tx.us/cmtes/82/c510/0110BI-ANWC.pdf

Summary

- 100% renewable electricity in Australia costs,
  - $93/MWh – 2016 price
  - $75/MWh – 2020s price
- Meeting current National Electricity Market reliability standard 0.002%
- Short-term off-river pumped hydro energy storage (STORES)
  - Facilitates large-scale photovoltaics and wind integration
  - Contributes to grid stabilisation: inertial energy, spinning reserve and a range of ancillary services
- Large numbers of sites for STORES developments in Australia and elsewhere

Future work

- Meeting Australia's Paris emissions commitment at zero net cost
- 60–120% renewable electricity in South Australia
- Developing a costing model for STORES
- A global atlas of short-term off-river pumped hydro energy storage

More: Searching "ANU" & "RE100"

bin.lu@anu.edu.au