THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

Dynamic operating envelopes Experiences from Australia ESIG Spring Workshop Tucson, AZ

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Who am I?

Prof. Fred(erik) Geth

- Bachelor of Science EE/CS, Master of Science & PhD EE-power systems, all at KU Leuven (Belgium)
- PhD 2014 “Battery storage integration in distribution networks”
- Developed an EV integration optimization software tool at Tractebel 2014-2015
- Research lab EnergyVille 2016-2018
- Moved to Newcastle Australia and worked with CSIRO in Energy Systems R&D 2018-2022
- Startup GridQube 2022 – mid 2025
- UQ Springfield City Chair of Energy
- Love cycling / bikepacking and skiing

KU LEUVEN

TRACTEBEL ENGIE

Energy Ville

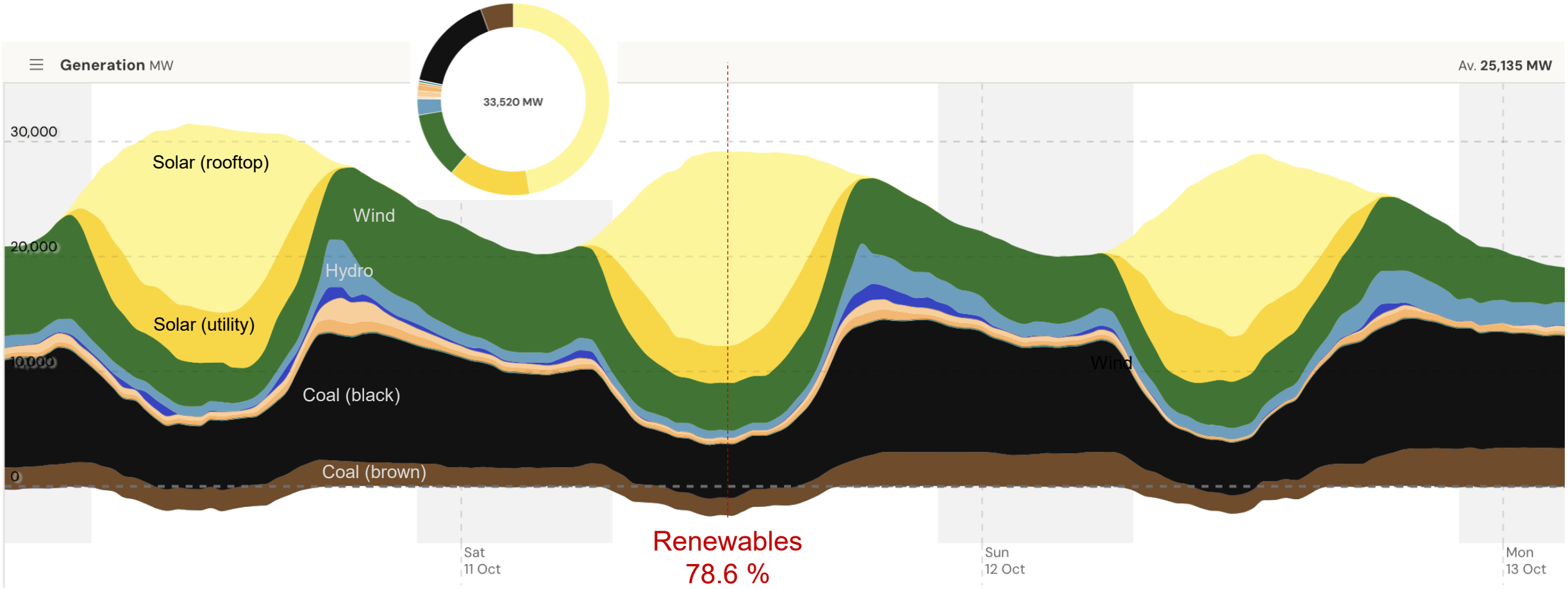
CSIRO

GridQube

Renewables are rapidly displacing coal and gas generation

About 40% of Australian homes today have rooftop PV – capable of meeting 50 % underlying energy demand across the NEM in a sunny day

Current national record highest renewables generation over a day on Saturday 11 Oct 2025



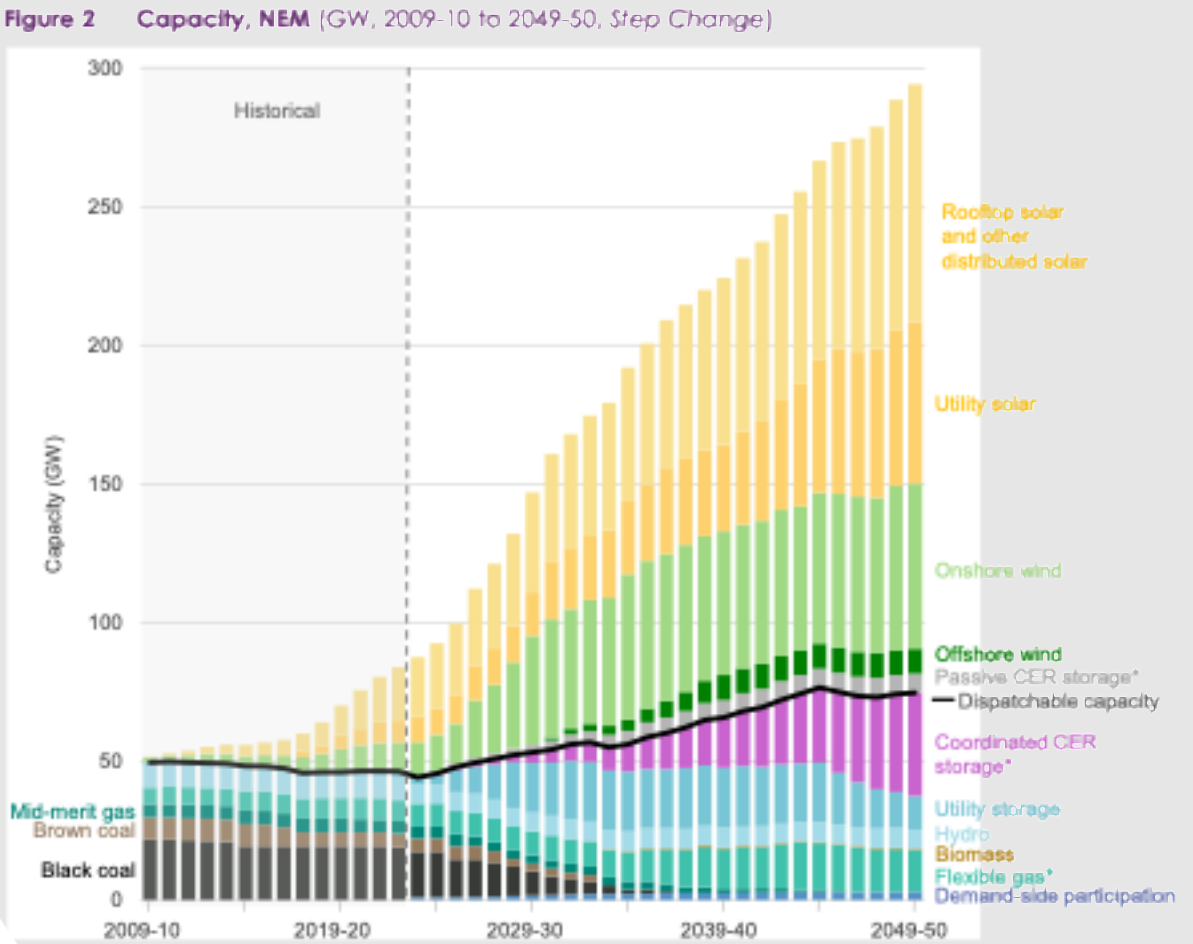
Motivation: Solar integration tomorrow

Rooftop solar expected to continue to grow

- now at approx. 1 in 3 houses throughout the country

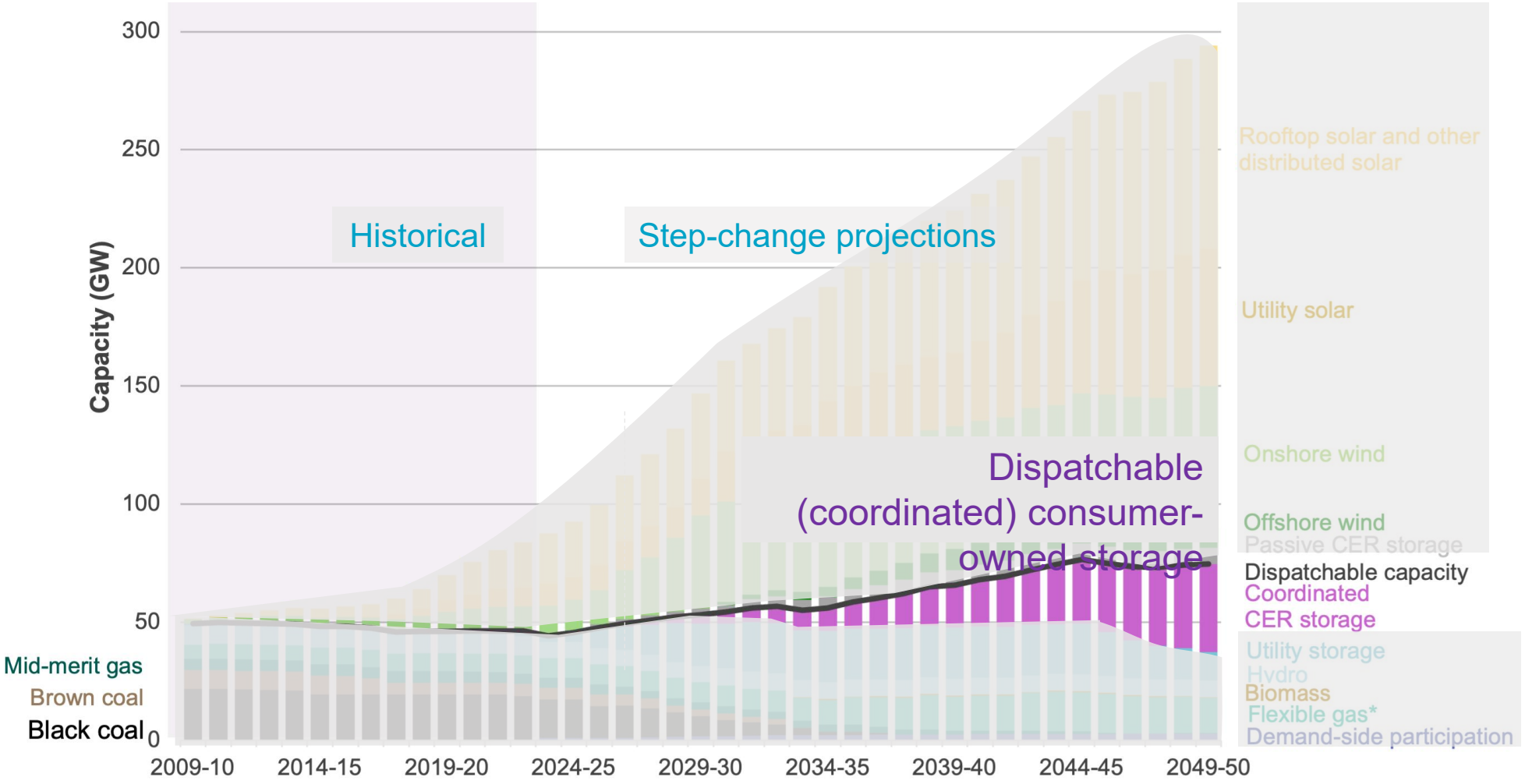
Even with Volt-var/Watt, voltage issues are significant

Compliance of inverter config/settings far from great

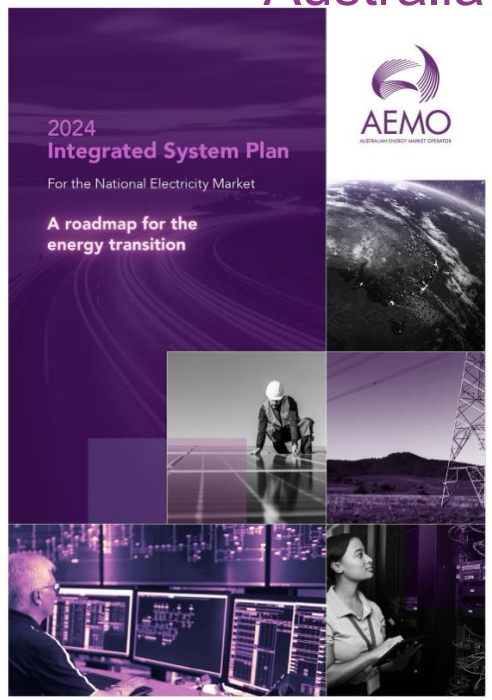


AEMO ISP 2024

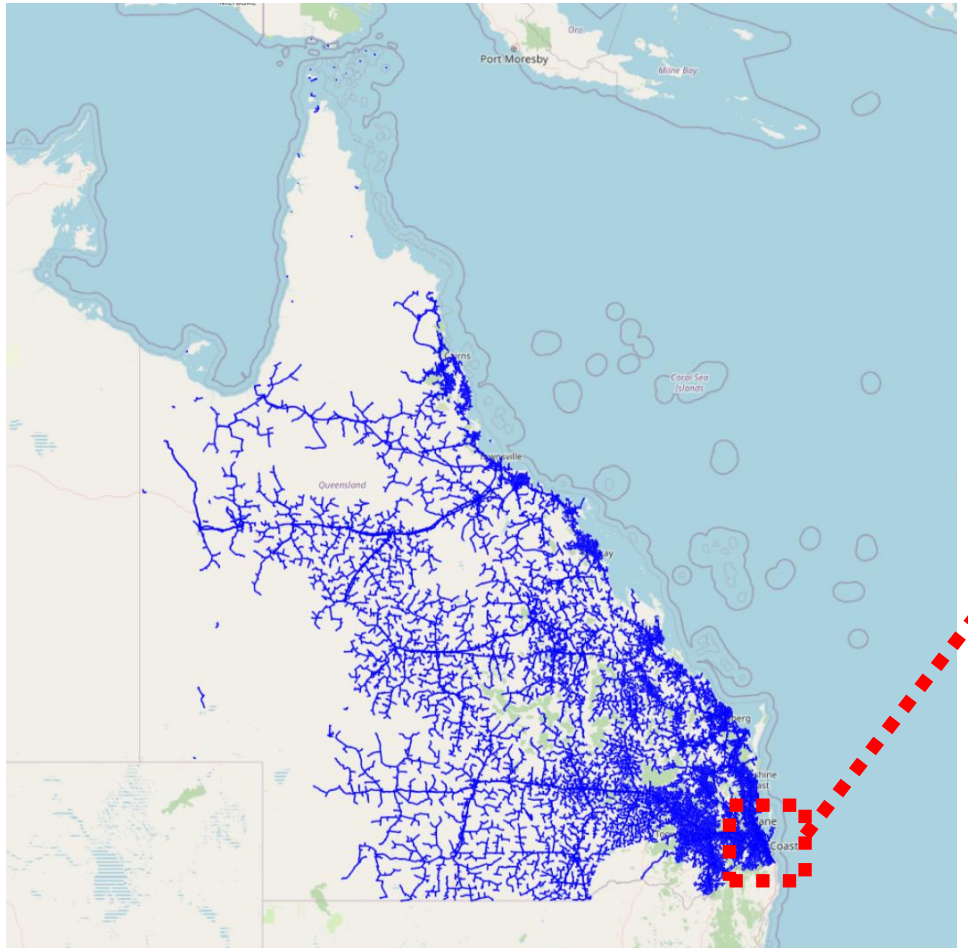
Australia's transition plans DPV 4-fold increase by 2050



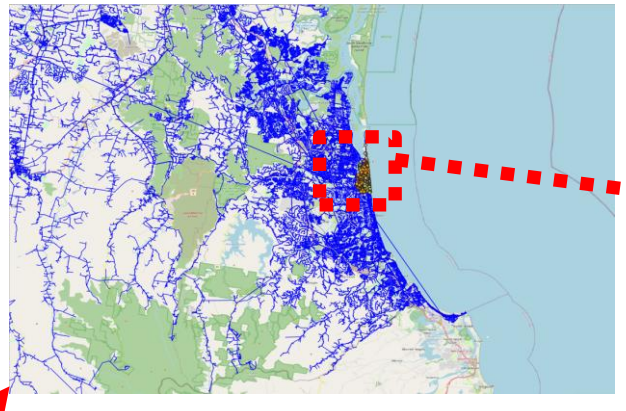
Integrated System Plan A plan for investment in the energy transition in Australia

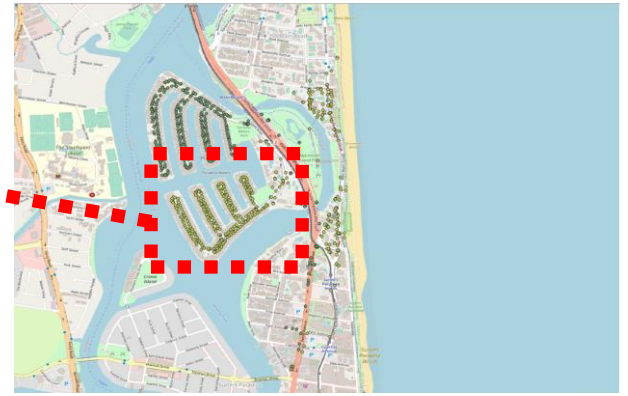


Distribution systems (& data sets) are huge



~14.5 million objects - ~30 million electrical nodes





PV deployment in Springfield (Jan 2026)

Post code 4300 = Augustine Heights, Bellbird Park, Brookwater, Camira, Carole Park, Gailes, Goodna, Springfield, Springfield Central, Springfield Lakes

Est. houses: **28 070**

PV Installations: **16 534** (approx. 56.7% of houses)

PV potential on all roof types: 2 350 093 m^2 (367 202 kW)

Est. annual energy from rooftop PV: 513.6 GWh

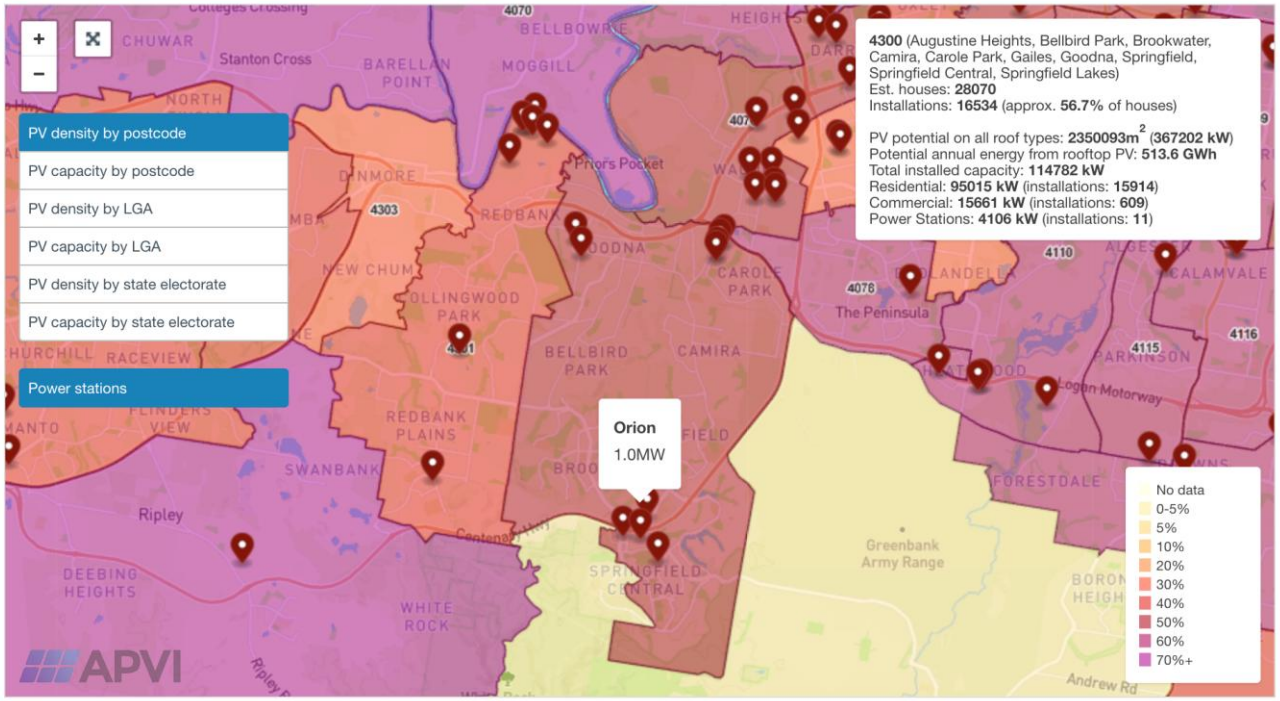
Total installed PV capacity: 114 782 kW

Residential: 95 015 kW (installations: 15 914)

Commercial: 15 661 kW (installations: 609)

Power Stations: 4 106 kW (installations: 11)

Home batteries: 13 500 kWh (installations ~ 550)



https://pv-map.apvi.org.au/

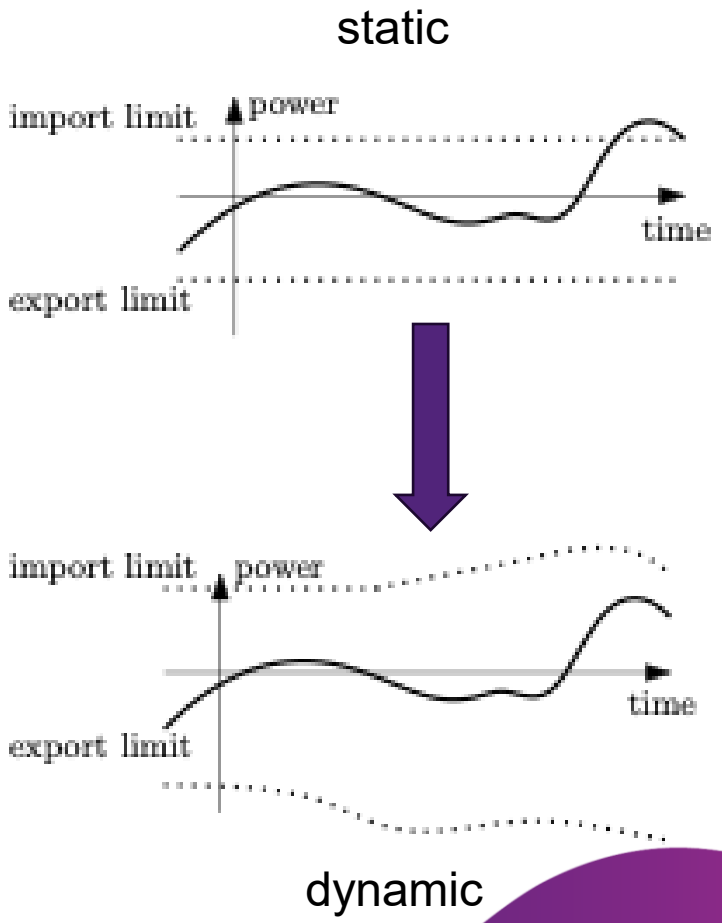
From static exports to DOEs

In Australia, you are typically allowed to *install* rooftop PV up to 5 kW per phase

- However, you may *not* be allowed to *export* power to the network, e.g. you can only inject 1.5 kW, or even 0.
- These static limits are driven by voltage-based congestion

In practice, even in congested networks, there is spare capacity a lot of the time, which is not accessible under these static export limits

… make them dynamic?



Home Batteries rollout

Volt-var/Watt also mandatory for home batteries

DOEs apply at point of connection / smart meter

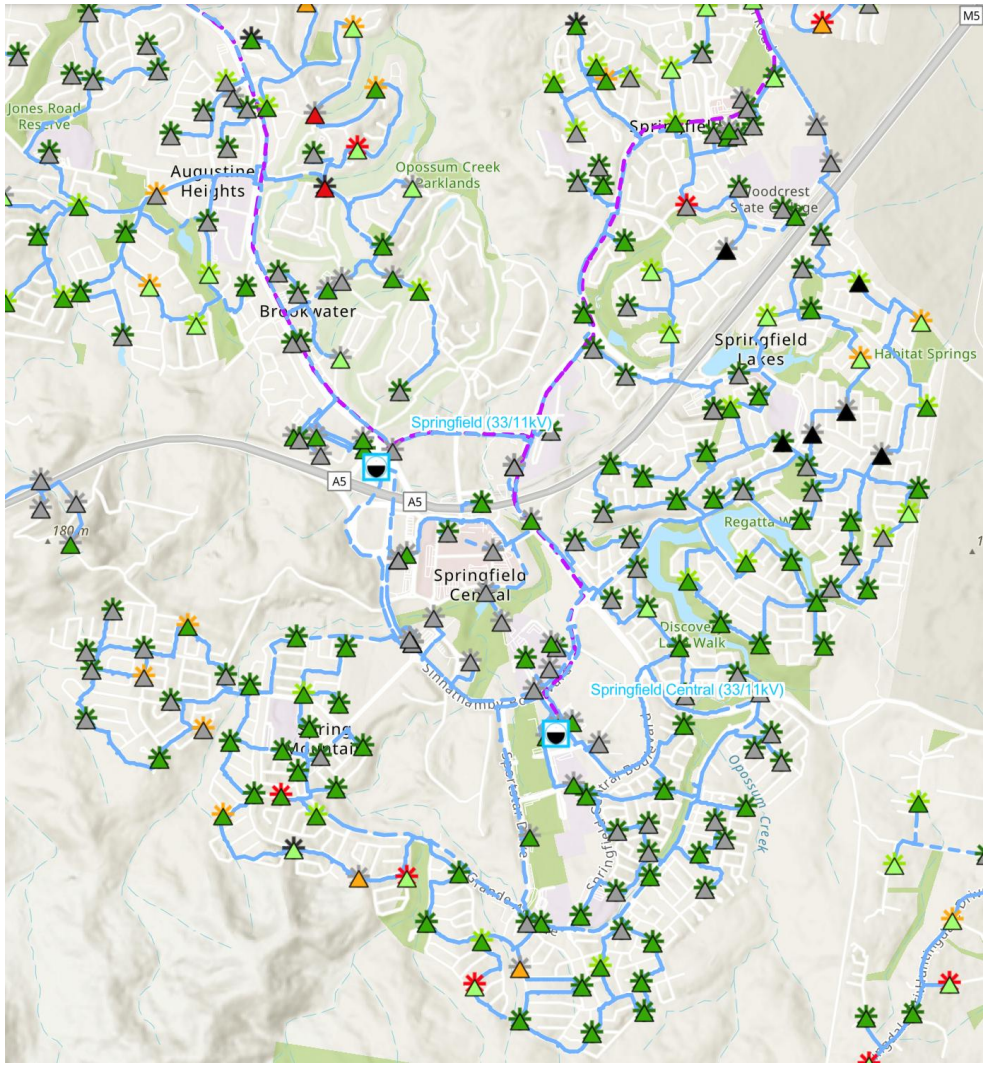
Battery system registration tied to meter identification number

DOEs become crucial

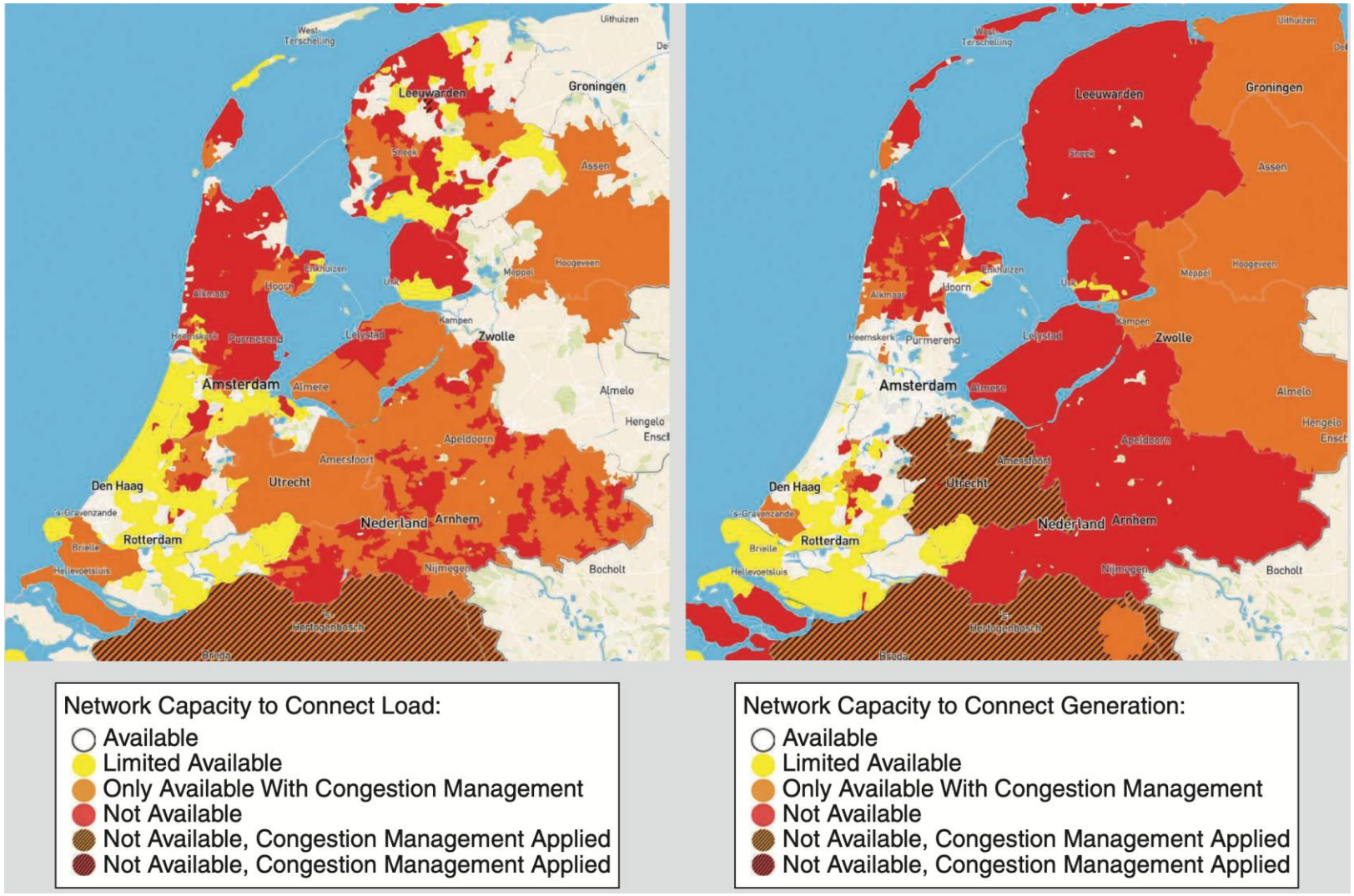
E.g. for my home, 80 A connection

10 kW ~ 43 A battery charge/discharge peak

VPP risk causing congestion through batteries



Distribution network congestion is reality



https://capaciteitskaart.netbeheernederland.nl/

What are Operating Envelopes?

Maximum export values that can be realized simultaneously without violating the network envelopes for voltage magnitude and thermal limits

- Optimisation is a natural framework for finding minima and maxima

Approach: include the distribution network physics

- Including expected inverter response
- Taking into account different objectives for equity and competitiveness

Also works for import (consumption)

Why use physics-base digital twins?

- Computationally feasible today
- Inform on what is *ultimately achieveable*
- *Unbiased*
- *Explainable, auditable, validateable,*
- *Legally defensible*
- *More than a century of knowledge and experience*

Physics does imply that customers close to substation are likely to be subject to less curtailment than those far away

Can we improve fairness?

Why not use physics-based modeling?

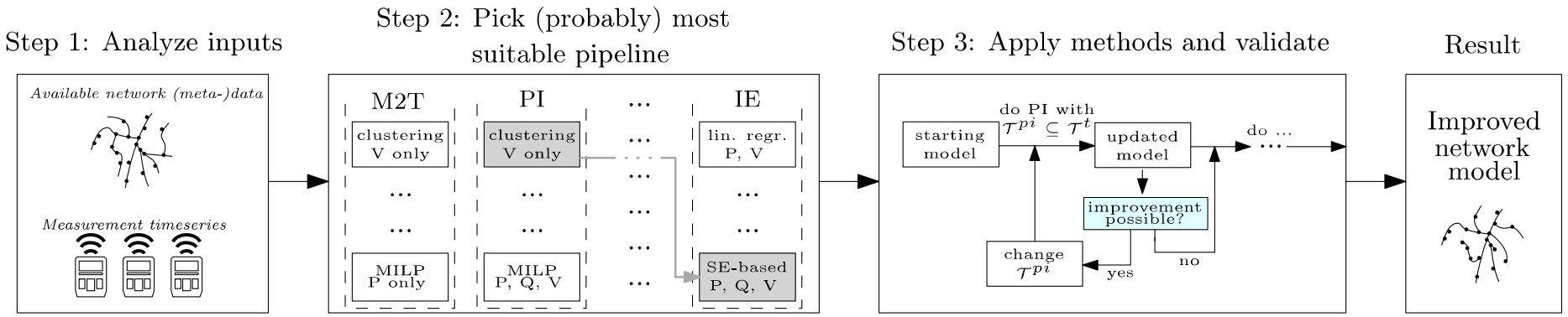
- No single source of truth today
- Building network models from GIS can be very challenging
- Validation nontrivial, though manageable
- Existing ADMS/DERMS/GIS software platforms have big gaps
- … need to invest in new scientific approaches to make network model cleanup and validation cost-effective

Real-world data quality challenges

	Issue
1	Missing phase labels (loads, transformers, etc.)
2	Switch states & user-branch connections
3*	Meter-to-transformer assignment
4*	Excessive number of buses
5	Wrong transformer tap
6	Missing tap semantics
7*	Unknown vector group usage (ansi vs euro)
8*	Unknown winding configuration
9*	Mislabeled transformer primary/secondary nominal voltage
10*	Wrong transformer rating
11*	Only Kron-reduced impedance matrices available
12*	Only sequence impedances available
13*	Meter-phase-alignment for three-phase users
14*	Missing information on neutral grounding
15	Load model (constant power, ZIP) unknown
16	Missing load (locations)
17	Measurements rms vs fundamental-only
18*	Regulators modelled as transformers
19	Missing capacitor banks (specifications)
20	Approximate cable/line impedance models
21*	Unknown (PV) inverter settings
22*	Unknown home battery dispatch strategies

Network data quality is a R&D opportunity!

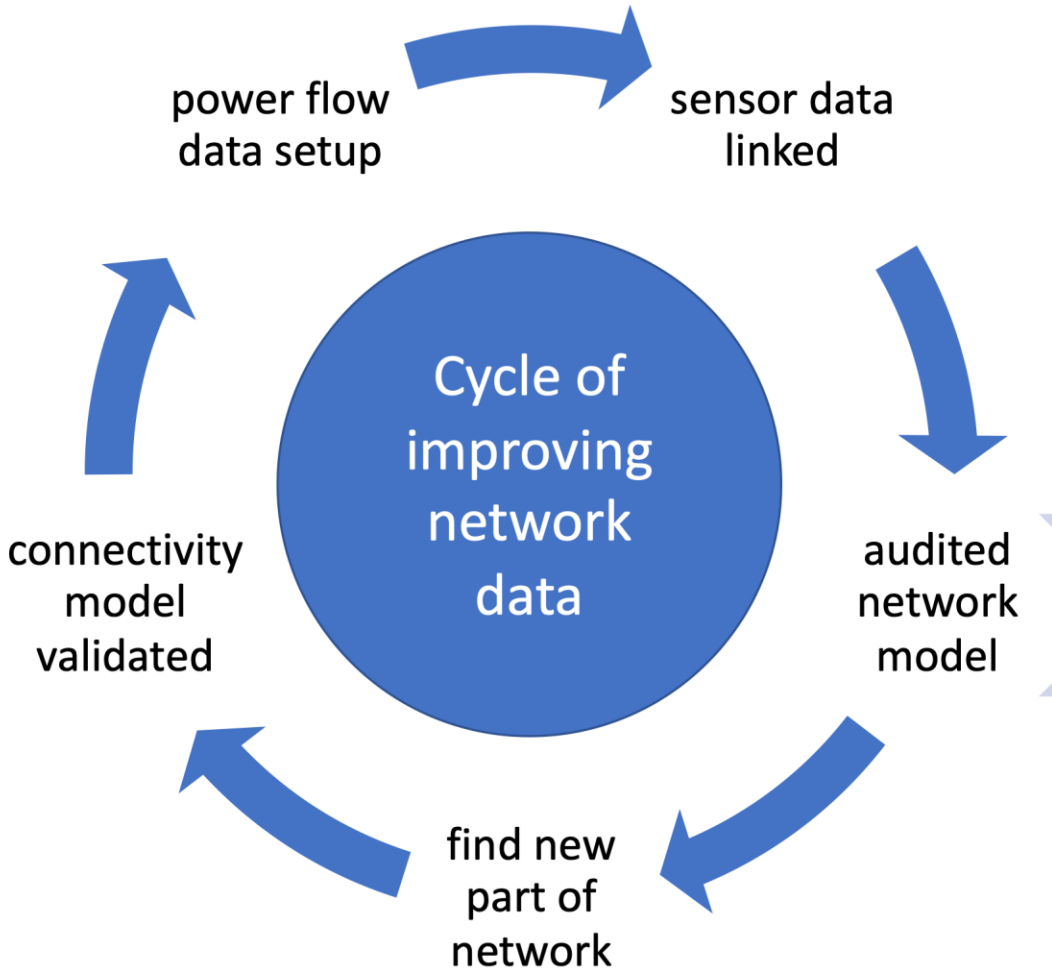
Models and algorithms for incremental cleaning of network data sets need more development [1]



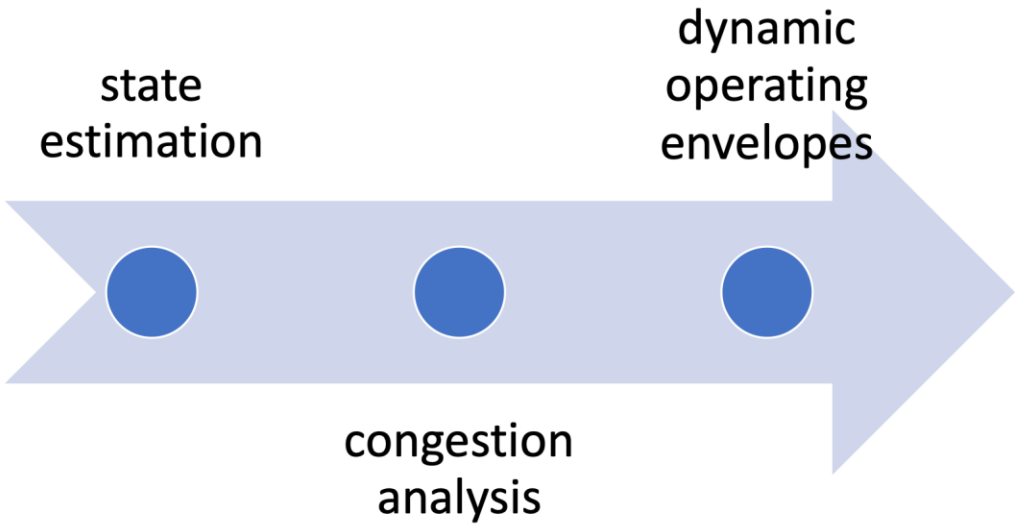
Combining state estimation and, phase connectivity and impedance estimation in math programming problems [2,3]

[1] Geth, Vanin & Van Hertem, Data quality challenges in existing distribution network datasets, CIRED 2023, Rome
[2] Vanin, Geth, D'hulst, Van Hertem, Combined unbalanced distribution system state and line impedance matrix estimation, International Journal of Electrical Power & Energy Systems, Volume 151, 2023
[3] Vanin, Van Acker, D'hulst, & Van Hertem, (2022). Phase identification of distribution system users through a milp extension of state estimation

Deploying in the real world



Scaling up state estimation roll-out



Practicalities

- Regulator has approved dynamic connections agreements for customers, including residential
- Opt-in for residential customers
- In practice, the goal is to guarantee 1.5 kW of exports per customer at all times, though more of the network state allows for it
- Various trials, different degrees of maturity
  - Fairness can be improved, but utilities struggle with justifying their decisions
- CSIP Aus / IEEE 2030.5 for communication to battery and solar inverters
  - Also send data from inverter back for compliance assessment

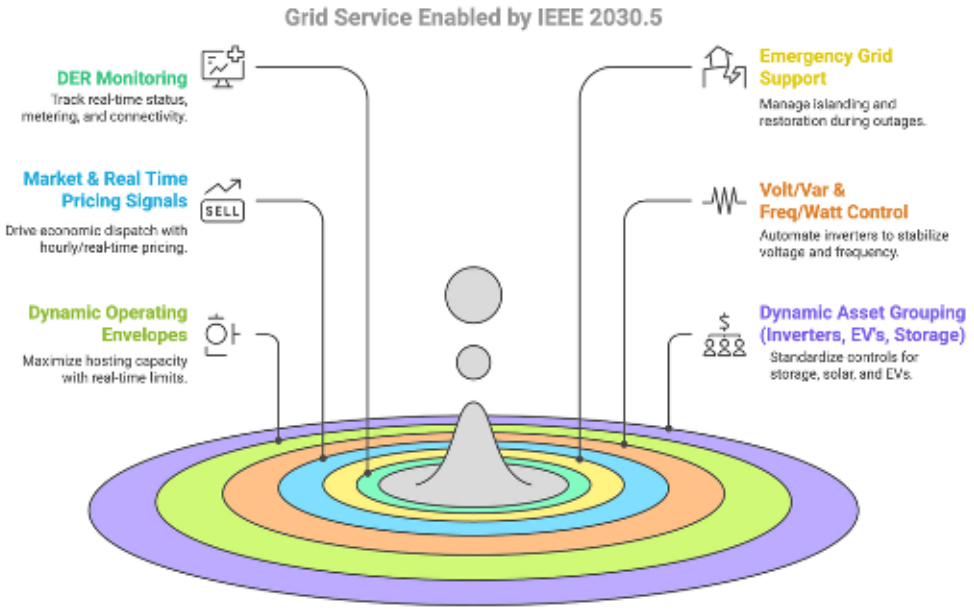


Figure 1: IEEE 2030.5 enables multiple grid services from monitoring to precision dispatch and asset aggregation

Ongoing work

- VPPs and other flexibility products to operate within the DOEs
- Home energy management systems to coordinate behind the meter resources subject to DOEs
  - E.g. including EVs

- Improving inverter volt-var/watt compliance
- DOE deployments have focused on capturing MV constraints
  - Very few with explicit LV models

- Data quality of network models may also bias export limits
  - Customer rights, auditing?

Thanks!

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