RACE for 2030

RELIABLE AFFORDABLE CLEAN ENERGY

Energy Trends Visualisation Tools

Final Report

Australian Government

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Energy Trends Visualisation Tools

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Project partners

Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

What is RACE for 2030?

RACE for 2030 CRC is a 10-year co-operative research program with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future. https://www.racefor2030.com.au

Table of Contents

1 Project Background and Acknowledgements

1.1 Project Background

The Energy Trends Visualisation (ETV) project was established to explore and develop prototypes of at least two online tools that assist energy stakeholders access data to navigate the challenges and opportunities presented by the energy sector transformation.

By making crucial energy trends more visible and comprehensible, the visualisation tools aim to inform decision-making, build consumer trust, and drive innovation. If successful, these prototypes could be expanded into a larger project to develop an integrated platform for data visualisation tools and applications potentially across a wide range of RACE projects.

Seven initial tool concepts were shortlisted in collaboration with the Stakeholder Reference Group for consideration to be taken to a prototype stage:

1. Minimum demand
2. Electric Vehicles (uptake, charging infrastructure and impact on load profiles)
3. Curtailment (large scale and small scale)
4. Large energy users and purchasers, touching on tariff structures and load flexibility
5. Industry trust building (consumer sentiment and unlocking reporting data)
6. Making use of voltage data and opportunities for voltage management
7. Energy workforce jobs (project future workforce and market size from energy scenarios)

Ultimately, four tools were selected to progress to the prototype stage: minimum demand (#1, by UNSW), electric mobility (based on #2, by UNSW) and large-scale curtailment (#3, by UNSW) and small scale (distribution level PV) curtailment (#3, by UTS).

1.2 Acknowledgements

The UNSW and UTS project teams wish to wholeheartedly thank the Stakeholder Reference Group (SRG) members, who are presented in Table 1. Meetings took place between December 2022 and March 2024.

Table 1: Members of the Stakeholder Reference Group (SRG)

Name	Organisation
Research Team	
Iain MacGill (Overall Project Lead)	UNSW
Anna Bruce	UNSW
Dylan McConnell	UNSW
Nargess Nourbakhsh	UNSW
Ed Langham (UTS Project Lead)	UTS-ISF
Jaysson Guerrero (Project Manager)	UTS-ISF
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SRG members	
Jonathan Dennis	Powerlink
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Barton Hellyer & James Hazelton	Endeavour Energy
Oli Morgan-Williams	Ausgrid
Martin de Groot	EnergyOS
Adriano da Costa & Anders Vandenberg	Department of Environment, Land, Water and Planning - Victoria
Melissa McAuliffe	Energy Consumers Australia

Name	Organisation
Bridgette Carter	Energy Users Association of Australia
Chris Briggs	Business Renewables Centre Australia
Sarea Coates	Energy Security Board

The UTS team also wish to thank Riza Tolentino from Endeavour Energy and Ausgrid team members Lianne Moller, Navid Haghdadi, Evan Riddell and Jaysson Guerrero Orbe for additional data supply.

The UNSW team would particularly like to thank Jonathan Dennis of Powerlink for his early contributions to the curtailment and minimum demand tool, and Katelyn Purnell for her e-mobility modelling datasets that were incorporated into the EV scenarios tool.

2 Project Outcomes Media Release

Visualisation tools help customers understand emerging trends in the renewable energy transition

Researchers from UNSW and UTS have released a suite of four prototype data visualisation tools to help stakeholders understand emerging trends with the rapid adoption of renewable and customer energy sources.

“By making crucial energy trends more visible and comprehensible, the visualisation tools aim to inform decision making, to build consumer trust and to drive innovation,” said joint project leader, Professor Iain MacGill.

The tools focus on understanding the magnitude of the curtailment of surplus rooftop solar and utility scale solar and wind generation, the impacts of electric vehicles on the grid, and the emerging phenomenon of ‘minimum demand’, where large volumes of solar generation are changing the shape of grid energy demand. Joint project leader Dr Ed Langham noted, “These tools have revealed parts of the grid where we could develop productive uses for this ‘free’ surplus power, and that some households – such as those further away from the local zone substation – could experience six to seven times more curtailment than the average customer. So, equity is a key consideration in how we respond.”

Supported by the RACE for 2030 Cooperative Research Centre, the Energy Trends Visualisation (ETV) project was launched to help energy stakeholders access data to navigate the challenges and opportunities presented by the energy sector transformation.

The project was supported by industry partners Powerlink, Endeavour Energy, Ausgrid and EnergyOS. “We have been grappling with forecasting how much curtailment of rooftop solar will occur over the coming decade, and wanted to help customers and decision makers understand this critical issue, and what we can do about it,” said Barton Hellyer, Senior Future Grid Engineer at Endeavour Energy.

If successful in engaging users and securing ongoing data access agreements, these prototypes may be expanded into an integrated platform for data visualisation tools and applications. To view the tools and lodge your interest in seeing these prototypes further developed.

Media enquiries: Ha Thi Bui

Project enquiries: Professor Iain MacGill; Dr Ed Langham

3 Tool Summaries

3.1 Rooftop Solar Curtailment Explorer (UTS)

The UTS team developed an interactive explorer to help users understand the current and forecast magnitude of rooftop PV curtailment on distribution networks, and what can be done to address the issue.

3.1.1 Data inputs and source data access

The primary data used is modelled curtailment forecasts produced by DNSPs (specifically Endeavour Energy and Ausgrid) for the five-year 'regulatory reset' investment approval process, run by the Australian Energy Regulator (AER). This was supplemented with contextual background data to aid user understanding of the underlying concepts. While this data is not yet routinely updated, over the coming two years after having gone through their regulatory reset periods, similar data should be produced by all DNSPs.

Curtailment forecasts are not currently publicly available and were supplied to the research teams under agreements for research purposes. Endeavour Energy found the process of producing the data informative and is pursuing the production of this data for annual strategic planning (and potentially stakeholder communication) purposes. Endeavour Energy has approved the final visualisations for public release as part of the prototype tool.

3.1.2 Audience and messages

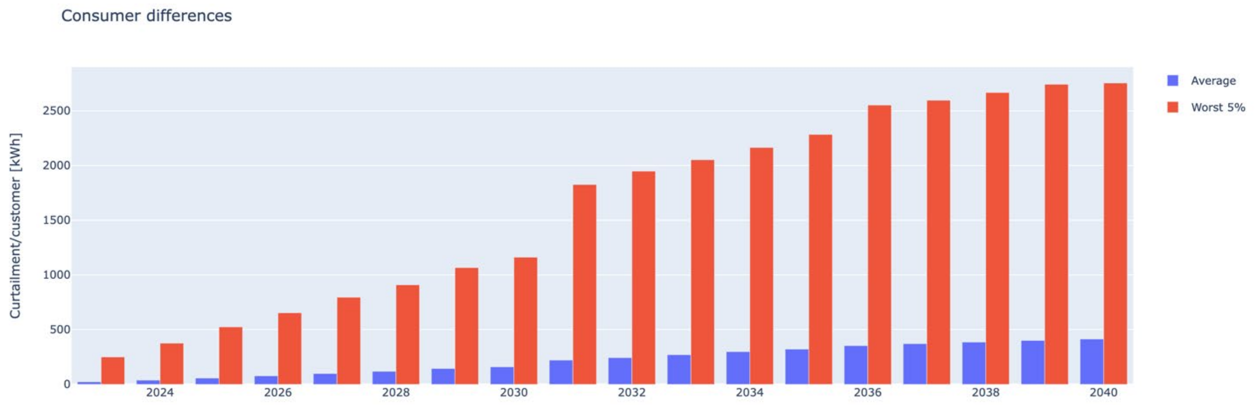
The key audiences are those working in the energy transition but who may not be highly technically oriented regarding the electrical engineering concepts of curtailment. Target users are DER developers/agents, regulators, customer advocates and the broader industry participants.

The key messages are:

- Curtailment is currently limited but is forecast to accelerate across the network.
- Not all customers are equally affected, so equity is an important consideration.
- Both networks and customers can act to reduce curtailment substantially.

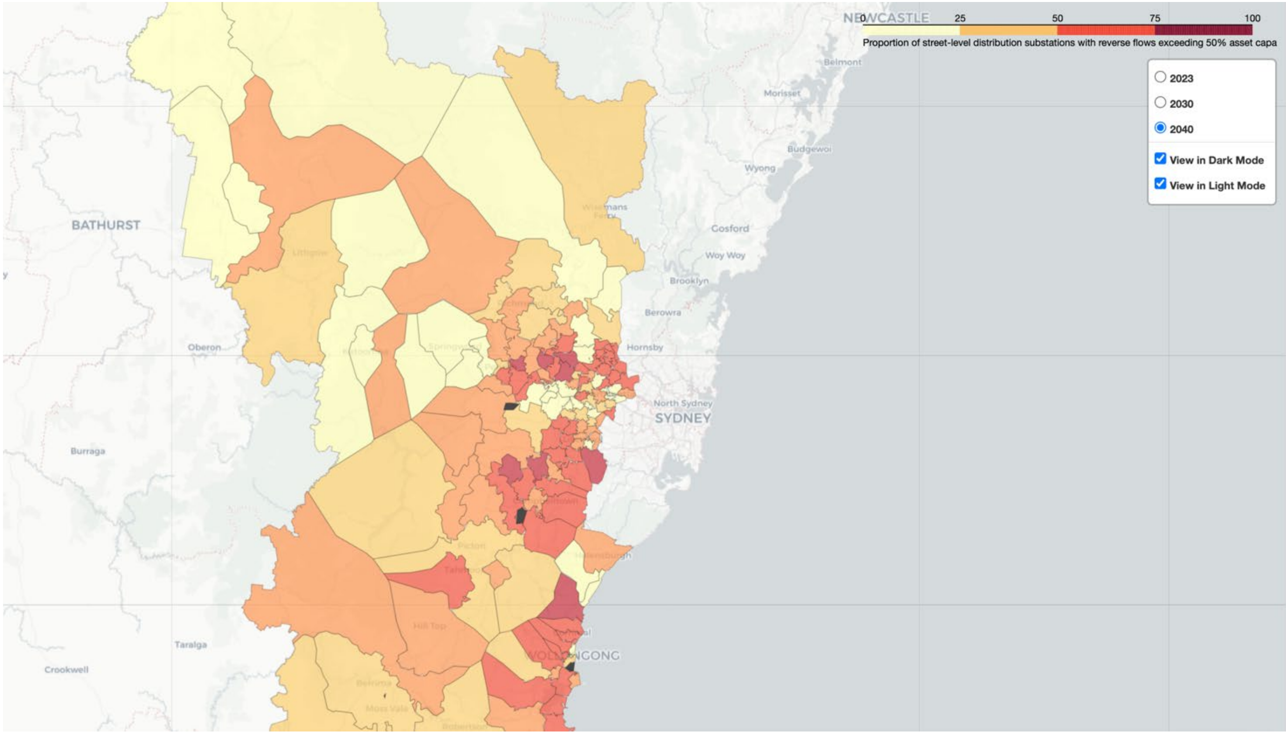
3.1.3 Selected visualisation approach and analysis

To make the tool more accessible for less highly technical users, a narrative based structure was employed, incorporating video-based explanation and interactive graphs that contextualise and lead the user into the data, or pick out specific messages – such as comparing the average and worst affected 5% of curtailed customers – as shown in the graph below.



The main data explorers are time-series maps illustrating the spatial and temporal variability in the data, as shown in the map below. This incorporates both a 'straight' normalised representations of data, with hotspots represented as % of distribution substations forecast to experience reverse flows, and contextualised representations, such as the number of hot water systems that would be required to shift load to soak up excess solar generation.

Time series maps of reverse flows by Zone Substation (Endeavour Energy 2040)



3.1.4 Key findings from the tool

- Curtailment will affect customers unequally, both in terms of some zones being more affected than others, and in terms of a specific customer's distance from the nearest zone substation, where more distant customers incur proportionally greater curtailment (in the absence of active management).
- Different networks are forecasting quite different curtailment trends. This either indicates the need for greater consistency of modelling approaches, or genuinely different network characteristics having a material effect on the magnitude of the curtailment issue.

- Curtailment outcomes can be heavily influenced by active management by DNSPs (at some cost) or by load shifting activities of customers.

3.1.5 User feedback

Numerous changes were made to the tool based on user feedback, including the following:

- Compressing narrative structure into video content.
- Concealing data detail in info pop-up boxes to limit complexity while providing clarity to more technical users.
- Adjust numerous data representations to more clearly contextualise the magnitude of curtailment relative to concepts people commonly understand (such as % of total generation, or $ per year).

3.2 Utility renewable energy curtailment (UNSW)

This tool presents curtailment data through facility-level and regional visualisations.

3.2.1 Data inputs and source data access

These visualisations use a range of datasets from AEMO's "Market Management System" (MMS) to estimate the total renewable energy curtailment occurring in the Australian NEM. This specifically includes data from:

- "BIDS" data package ("BIDDAYOFFER_D", "BIDPEROFFER_D" tables)

- "DISPATCH" data package ("UNIT_SOLUTION", "LOCAL_PRICE", "PRICE" tables)

The unit solution file provided a direct estimation of total curtailment through comparison of the "available generation", and "dispatch target" fields. This dataset also allows the determination of the contribution of curtailment resulting from interventions from the market operator, by comparing results with the "intervention flag" activated.

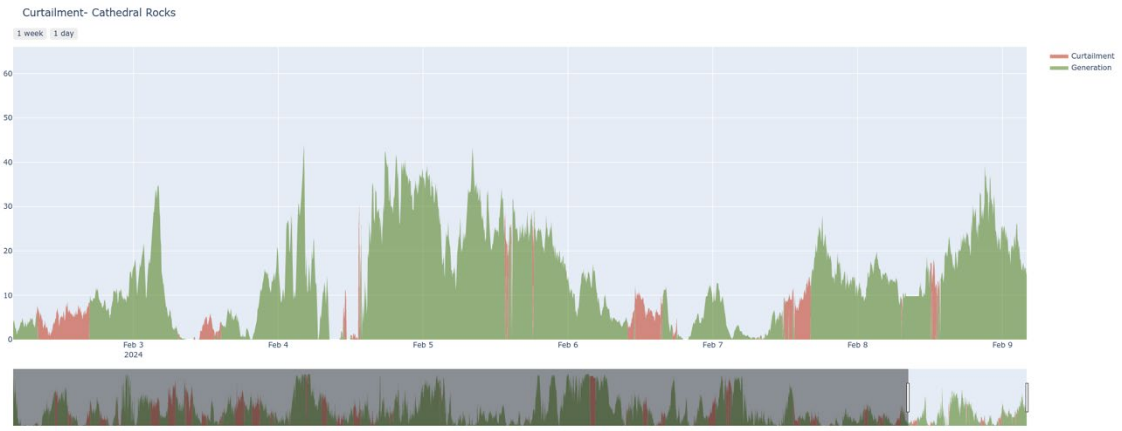
3.2.2 Audience and messages

The increasing prevalence of curtailment presents risks and challenges to the development of new renewable projects in the Australian national electricity market. This tool aims to enable stakeholders to understand renewables curtailment characteristics and dynamics, and its potential implications for the timely and efficient delivery of zero emissions generation. Key audiences include policymakers, regulators and advocates, as well as industry associations (including renewable energy representatives and advocates).

3.2.3 Selected visualisation approach and analysis

Facility Level Data:

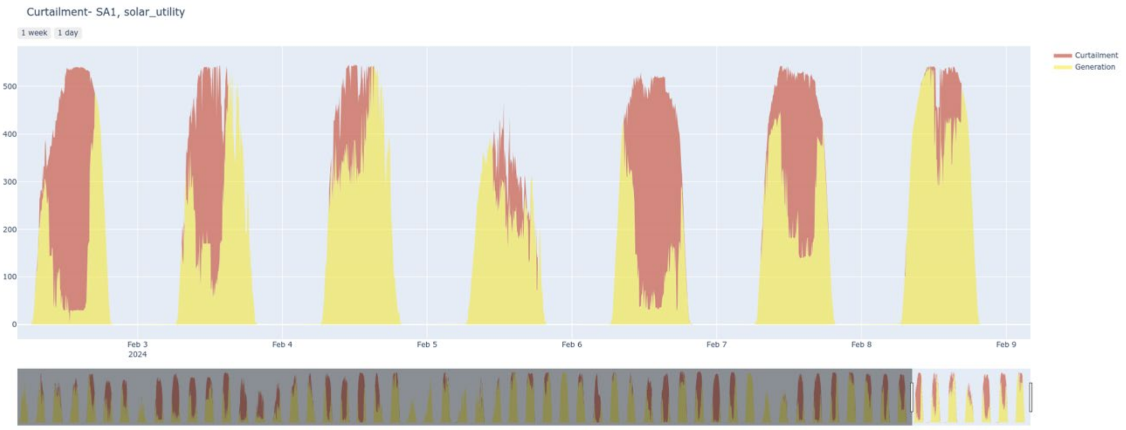
- The first visualisation allows selection of individual renewable energy generators in the National Electricity Market (NEM) by region, resource type, and identifier, displaying the last week of generation and curtailment at a 5-minute resolution, with a slider to explore up to the last 60 days. A selected example of this visualisation is illustrated below.



- The second visualisation facilitates geographical exploration of curtailment at individual generators, showing relative curtailment as a fraction of potential generation, with tools to adjust the time frame examined.

Regional Aggregated Data:

- The first set of visualisations explores curtailment at a regional level within the NEM, allowing selection by region and resource type, and showing data with similar detail and flexibility as the facility level visualisation. A selected example of this visualisation is illustrated below.
- The second visualisation provides a mean profile of generation and curtailment over the last 60 days, illustrating the patterns of curtailment.



3.2.4 Key findings from the tool

- Significant geographic diversity in the prevalence of curtailment, at both facility level and regional scales.
- Temporal patterns illustrate the strong correlation between occurrence of curtailment and solar generation.
- The drivers of curtailment vary across regions, though it can be difficult to robustly and objectively estimate the relative scale of these drivers given complex interactions between pricing and technical

dispatch constraints, and incomplete datasets.

3.2.5 User feedback

Several additions and modifications were made to the tool, based on feedback from the SRG. This included, but is not limited to:

- Consolidating and grouping visualisations by theme
- Providing more context and explanatory text to each of the visualisations
- Adjusting the visualisations themselves for clarity, or to provide a more useful range of data (and options to select the data).

3.3 Future e-mobility scenarios and their potential impact on electricity demand (UNSW)

This tool aims to illustrate the potential impact of electrification of different transport sectors on the future electricity system, and particularly hourly demand profiles.

3.3.1 Data inputs and source data access

These visualisations utilise a dataset of yearly electric vehicle traces developed by Purnell et al (2022)[1]. This dataset contains yearly demand traces for the following modes of transport on a fleetwide, per vehicle basis: passenger vehicles (cars and motorcycles), commercial vehicles (a blended trace containing light commercial vehicles), bicycles, taxis/on-demand ride share vehicles, municipal buses, municipal ferries, and articulated trucks. For each of these categories, the dataset also includes the impact of four different possible charging regimes on electricity demand: End of Service, During Service, Sunshine, Non-peak.

This trace data is upscaled with state-level vehicle data to estimate state-level impacts on demand. National vehicle numbers from the Australian Bureau of Statistics and pro-rated by each state's population. Public transport and taxi numbers were based on ABS data, Transport NSW data, and Purnell et al (2022). The impact on the demand profile was estimated using underlying demand traces from the 2022 ISP.

3.3.2 Audience and messages

The potential impact of EV load on the electricity system is expected to be significant, and the interaction with both peak demand and minimum demand presents both risks and opportunities that need to be better understood. This tool aims to illustrate the dynamic nature of electricity demand with the electrification of transport, providing insights into how varying charging times and vehicle electrification rates could influence future electricity demand patterns. Key audiences include policymakers, regulators and advocates, as well as electricity industry participants (e.g. network planners) and electric vehicle advocates.

[1] Purnell, K., Bruce, A.G., MacGill, I., 2022, 'Impacts of electrifying public transit on the electricity grid, from regional to state level analysis', Applied Energy, 307, https://doi.org/10.1016/j.apenergy.2021.118272.

3.3.3 Selected visualisation and scenario development approach and analysis

Demand Forecast and the Impact of EV Charge Profiles

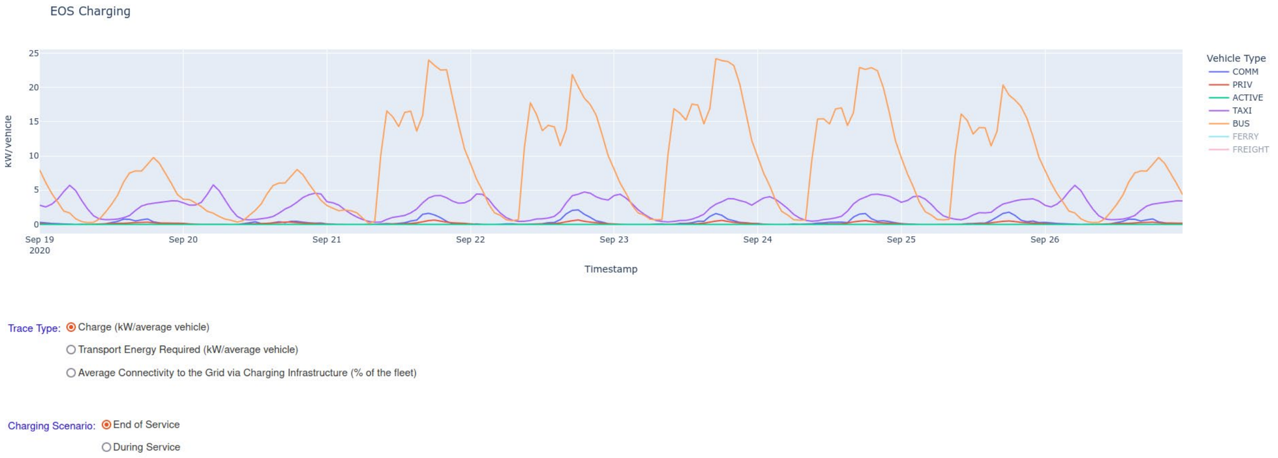
This visualisation and interactive scenario explorer showcases the potential impact of electric mobility on projected electricity demand in the National Electricity Market (NEM) regions from 2023 to 2051.

The tool can be used to investigate how the different charging regimes (End of Service, During Service, Sunshine, Non-peak) and the electrification rate of different vehicle types might affect future regional electricity demand. By selecting a region, time span, charging regime, and electrification percentage for each vehicle type, the tool calculates and displays the additional demand generated by EVs. The image below illustrates this visualisation (with the hypothetical impact of end-of service charging for passenger vehicles in NSW selected).

EV Traces for a Typical Year

This visualisation illustrates different characteristics of electric mobility throughout the year. This includes charge rate (kW/average vehicle), transport energy requirements (kW/average vehicle), and percentage of a given fleet connected to the grid via charging infrastructure at a particular time.

These characteristics can be under different charging scenarios (End of Service, During Service, Sunshine, Non-peak) to understand how each affects EV interaction with the grid. Interactivity includes selecting trace types or charging scenarios to visualise relevant data, zooming in for detailed analysis, toggling visibility of vehicle types, and hovering over traces to view precise values. A selected example of this visualisation is illustrated below.



3.3.4 Key findings from the tool

- The charging regime and charging behaviour can have significant impacts on both timing and extent of peak demands on the grid.
- Simply avoiding current existing peak periods may only move the timing of the peak, not substantially lower overall peak.
- There is potentially significant overlap in the demands from different transport types.

3.3.5 User feedback

Based on feedback from the SRG, a number of modifications were made to the visualisation:

- Text was included to provide more context and explanation of both the data and methods used to create the visualisations.
- A small subset was pre-configured to be selected in order reduce lag and improve user experience.
- Optimisation of the back end to further improve load times and user experience.

3.4 Minimum NEM demand visualisations (UNSW)

This tool is intended to help stakeholders better understand the now emerging issue of minimum demand in the Australian NEM. Historically, the focus has been on the challenges of managing periods of peak demand given the risks it poses for the secure and reliable provision of electricity. This is easily appreciated as a challenge of having sufficient generation to meet demand. Stakeholders have less appreciation of the challenges that low minimum demand poses for secure power system operation, and demand trends over the past decade that are making this ever more challenging.

3.4.1 Data inputs and source data access

This tool uses publicly available historical NEM dispatch and scheduled demand data from AEMO, as well as forward looking demand profiles developed by AEMO as part of their Integrated System Plan process.

3.4.2 Audience and messages

The intended audiences for the tool are those working on energy transition challenges but who may not appreciate the growing challenges of minimum demand. Better understanding these challenges can also motivate key stakeholders to consider options to address the resulting system challenges. Target users are regulators, customer advocates, larger energy users and broader industry participants looking for opportunities to deploy renewables and, critically, flexible options for taking advantage of these regular renewables surpluses.

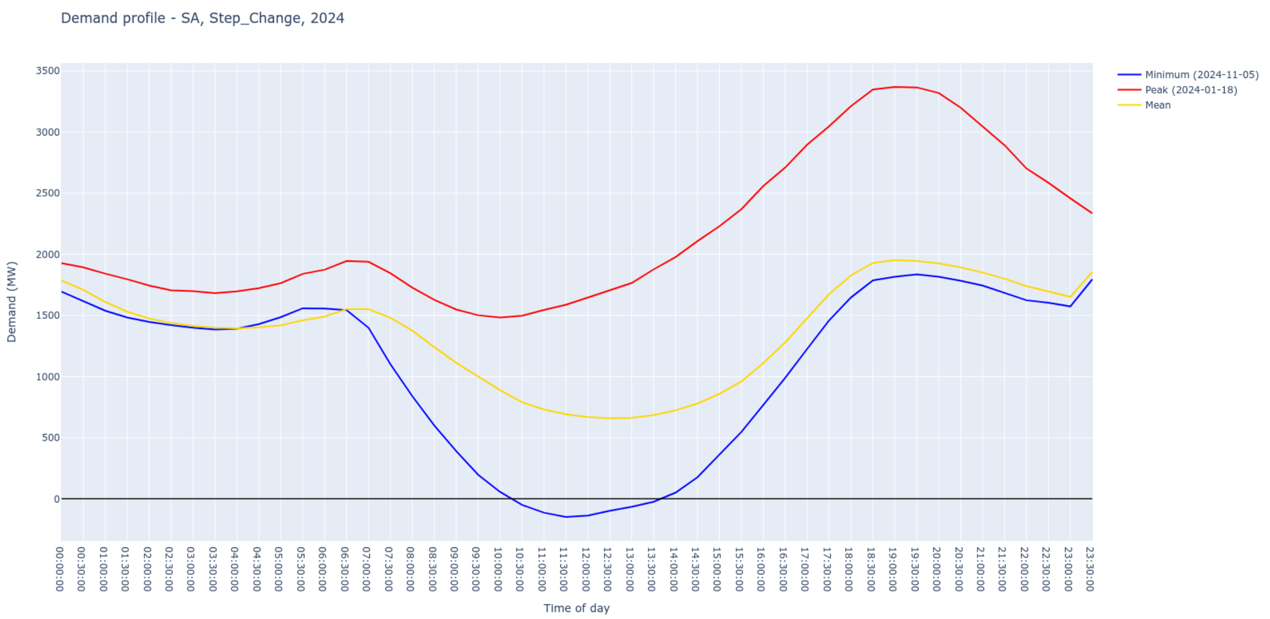
3.4.3 Selected visualisation approach and analysis

Historical and projected regional demand

The first of visualisation explores the evolution of operational demand at a regional level within the NEM, allowing selection by region and forward looking scenario. The visualisation illustrates the evolution of the minimum, maximum and mean operational demand for the region selected. Both historical realised values are shown alongside the projected values from the selected ISP scenario. A selected example of this visualisation is illustrated below.

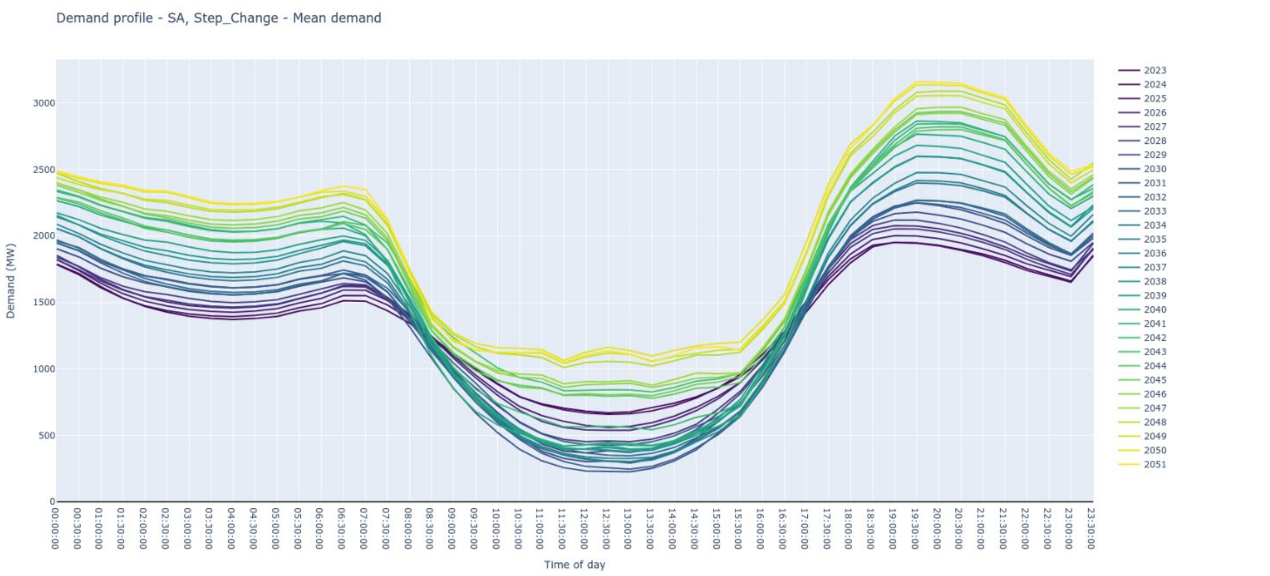
Regional demand profiles by year

The second visualisation illustrates profiles of operational demand for a particular year and region in the NEM. The tool shows the demand profile for minimum demand day, the peak demand day and the mean by time of day, and allows a particular year, region and scenario to be explored. As with the first visualisation, historical realised values are shown as well as projected values from the selected ISP scenario. A selected example of this visualisation is illustrated below.



Regional Demand Profiles over time

The final visualisation also illustrates profiles of operational demand for a particular region in the NEM. This tool, however, allows the user to select a single demand metric (e.g. minimum demand) and visualise how that evolves over time. Similar to the previous visualisations, this also allows the region and demand project to be selected. A selected example of this visualisation is illustrated below.



3.4.4 Key findings from the tool

- Minimum demand has been falling in almost all regions of the NEM, although to differing extents
- The operational demand peak is expected to continue to slowly grow, and the minimum operational demand to slowly fall, representing an increased range of operational demand
- The profile of operational demand is strongly correlated with solar production hours.
- AEMO projections suggest that these challenges may abate somewhat in future years, with the decline in demand slowing or reversing in the middle of the 2030s.

3.4.5 User feedback

A number of modifications were made to the tool based on feedback from the SRG.

- Providing more context and explanatory text to each of the visualisations.
- Adjusting the visualisations for clarity, as well us user interface options to select the different datasets.
- Additional visualisation was added to better illustrate dynamics over time.

4 Future Data Access and Tool Development Strategy

4.1 Tool specific insights

4.1.1 Rooftop solar curtailment explorer

The rooftop solar curtailment explorer is likely to achieve its greatest value if a large number of DNSPs supply data to the tool, as the comparison of magnitudes and trends adds valuable context for the user. Establishing a simplified data supply could be achieved with a published data structure circulated to DNSPs, to facilitate greater participation.

This is likely to reveal inconsistency in data production methods between DNSPs. In and of itself, this is an important finding that would help the AER in its role in assessing curtailment forecasts and appropriate DNSP investment to tackle the issue, as well as ongoing improvement and standardisation of curtailment forecasting methods. It is therefore recommended that the prototype be socialised broadly with the AER to float the challenge of supplying data from existing regulatory reset submissions.

For ongoing updates of the data – which would be required annually to give the tool the currency required to drive return users – this would require DNSPs to be deriving operational value from the data for strategic purposes. This is outside the control of the research team, but the likelihood of this could be ascertained by engagement with key contacts channelled via Energy Networks Australia.

4.1.2 Utility renewables curtailment

Stakeholders beyond the project partners, including AEMO and the NSW Government have already expressed an interest in this tool. The data is all publicly available and the tool could be formally implemented and deployed with only modest resources (cloud hosting).

Maintaining and extending the tool to provide greater details, including the particular drivers of curtailment at different times (network constraints, system security and reliability interventions, economic due to negative prices) could potentially be undertaken with further resources. Other options for deployment could include integration with other well-established tools such as openNEM.

The tool could also be better integrated with the UTS and other UNSW tools to highlight the linkages between renewables curtailment – utility and rooftop – with minimum demand, and opportunities to reduce both curtailment and minimum demand challenges through the deployment of flexible electrical loads such as EVs. Again, there appear to be opportunities for further RACE projects to develop such tools, building on the lessons from this project.

4.1.3 Future e-mobility scenarios and their potential impact on electricity demand

This project utilised public demand data from the Australian NEM as well as published e-mobility data traces of hourly demand for different transport modes under different charging assumptions. Again, it would not be too challenging to formally release the tool. A particular feature of this tool was that it went beyond offering users different visualisations to allowing them to create different scenarios of e-mobility uptake and charging scenarios.

The construction of these traces involved complex analysis and design from a wide range of datasets. The key limitation at present is the quality and broader relevance of these mobility traces given the significant assumptions required and the specific context from which they were derived (e.g. Australian state transport survey, analysis of bus schedules in a particular region).

Future development of the tool could look to enhance these e-mobility traces across more jurisdictions, and develop more sophisticated charging regimes. We could also look to add details on typical renewable energy traces so that the implications of different e-mobility deployments and charging regimes on renewable, particularly solar, integration. Again, there are links to the renewables curtailment and minimum demand tools.

4.1.4 Minimum NEM demand visualisations

The importance of minimum demand for secure power system operation is increasingly recognised by stakeholders but the rapidity of demand decline in the middle of the day due to distributed rooftop solar (that is seen by AEMO as a demand reduction) is still not fully appreciated. There are implications for remote control of rooftop solar by AEMO under extreme circumstances, as now seen in South Australia, that have raised some concerns from energy users with PV systems. There are also stakeholders with potential opportunities to move demand into the middle of the day, and efforts underway to encourage such scheduling such as 'solar soak' tariffs.

This prototype uses publicly available historical data on a 5/30 minute basis, as well as demand projections within the ISP that are also publicly available and updated every two years. The visualisations do require manual intervention at this time so formally implementing the tool would require some level of ongoing support. It is particularly closely linked to the curtailment tools (both utility and rooftop) and e-mobility tools in terms of drivers of minimum demand and its potential implications, as well as opportunities to address the challenges.

4.2 Shared insights for Future Data Access and Tool Development Strategy

Across the four prototype tools, shared issues for tool development and deployment include:

Skills

- Subject matter expert(s) – in order to accurately understand and validate the data
- Web visualisation specialists – to efficiently develop visualisations and simulations for web environments.
- Infrastructure/software engineers – to maintain and deploy the data pipelines (and potentially websites)

There is some overlap of these skills with personnel within the current project team, however, there are also weaknesses, particularly with respect to software engineering. For individual projects or visualisation developments, this may not be an issue, but across multiple teams and visualisations, this becomes more challenging.

Visualisation environment

The tools were prototyped in the Python package 'plotly' as a common plotting library across the project. Depending on the desired look and interactions for further tool development, that may need to be rethought for a more accessible and functional implementation. Many visualisation tools move beyond plotly (and similar libraries) for production environments, in order to have more bespoke visualisations, tailored user experiences and efficient loading of large, dynamic datasets. This would likely require web visualisation specialists.

Data

Timely access to data was an issue for some of the visualisations, particularly with the UTS tool. Ensuring appropriate data access agreements will be important if and as these tools are expanded to utilise data from other providers.

The updating of data over time will be important for ongoing tools development. Across multiple visualisations, this requires robust infrastructure and ongoing resources to do this and is likely one of the more challenging parts of sustaining tools over time. These tools are not 'set and forget' and need appropriate resourcing, by any stretch of the imagination.

Also, the project has focussed on the visualisation options, rather than the data management arrangements. Providing better access to the underlying data could be an area to develop the project (e.g. development of an API) but would be a significant undertaking (and may have some data availability or licensing restrictions).

Data vs narrative

There is an interesting and as yet unresolved issue on the boundary between the underlying data, and analysis, or narratives that may be supported by that data. There are generally multiple possible interpretations of the data. Some stakeholders involved in tools development may have narratives or "problems" that they want to highlight or showcase. Linked to tool development, therefore, are questions of how such narratives might be shaped, by whom and with what degree of certitude.

User feedback

User feedback was critical in shaping the tool development.

Possible business models for data provision and tools

Business models for data provision and analysis is a challenge for many data domains beyond energy. Our growing capabilities to collect, store and analyse data at falling per-unit costs is competing against the growing value that can potentially be derived from such data. Data might want to be free, but its also a potential source of competitive advantage.

Some of the tools have utilised publicly available data from AEMO. This data is provided on the basis that the operation of the Australian NEM is enhanced by providing all interested stakeholders with information that supports their participation on a somewhat equal basis. Note however that a number of commercial providers have created successful businesses using this data but providing better graphing, analytics and insights.

One clear gap at present, however, is the public availability of high temporal and spatial energy user demand data. Issues of data management but particularly privacy have been factors in this data gap. One of our tools utilised DNSP data which is not public, while still being potentially highly relevant to diverse electricity industry stakeholders. There are other potential providers of energy user consumption data including a number of SMEs within RACE. Putting a value on these data sets is extremely challenging – there are real costs in its collection, storage and collation, and a wide range of potential value propositions. Research such as that undertaken by RACE can help establish the potential value of such data. There is a clear opportunity for RACE to undertake further work on the interface between the use of data for research and the development of business models for commercial deployment.

Other tools

Early concept work was undertaken on other tools that were ultimately not developed into prototypes, but which have good potential. These were an energy jobs tool, which was considered both viable and to have a high impact potential. It is recommended that this be pursued as a bolt-on to other RACE employment modelling and supply chain projects.

A Power Purchase Agreement (PPA) explainer for large energy users was considered a plausible concept, but the available data was deemed too immature. It is recommended that this be reviewed as a concept after the UNSW 24/7 Renewables project is completed.

The exploration of natural language processing models to aid stakeholder engagement with energy regulatory processes or to understand consumer sentiment about energy was considered novel, albeit more speculative. This could be pursued as a stand-alone concept after some early-stage viability testing.

5 Next Steps

The Energy Trends Visualisation (ETV) project developed and demonstrated four visualisation and simulation tool prototypes that could assist a wide range of stakeholders in better understanding and communicating the challenges and opportunities of clean energy transition. Lessons from the development of these tools and possible implementation pathways forward were outlined in the previous section.

For RACE more generally, the project provided a means to explore opportunities to enhance the CRC's impact through the use of energy data visualisations and simulation tools. A survey of RACE projects early in the ETV project highlighted the range of RACE projects already featuring data and tools in their desired outcomes. The ETV project outcomes certainly support the potential value of such outputs in CRC projects.

A range of potential opportunities for RACE include:

- Most immediately, supporting the integration of the prototypes within a publicly hosted web domain, with a degree of integration.
- Supporting the formal, commercial deployment of one or more of the prototype tools from the ETV project.
- Explicitly encouraging the development of datasets and tools as project outputs, with a focus on supporting and facilitating stakeholder engagement and assisting future projects to build on previous RACE work.
- Working with a range of potential energy data providers – RACE industry partners and beyond – to better understand the costs and potential value of different data sets, and possible business models for their provision
- Providing funding support for such tools development and their ongoing maintenance and enhancement.
- Helping RACE research partners publicise and build engagement with data and tools that they develop.
- Supporting the release of public datasets and tools deployment arising from RACE projects through RACE IT infrastructure and support, including specialised IT and visualisation expertise.
- Looking to make RACE a 'go to' destination for energy industry stakeholders to find data sets and tools from a range of sources above and beyond specific RACE project outcomes.

The development of a wider RACE strategy on research data and tools lies beyond the ETV project but there are certainly lessons from the project that can input into a RACE or broader Cooperative Research Centre (CRC) process for developing such a strategy.

6 Appendix 1: Summary of Knowledge Sharing Activities

Engagement occurred through two primary channels:

1. Three Stakeholder Reference Group (SRG) meetings (15 Dec 2022, 10 Mar 2023; 5 Mar 2024)
2. User feedback, both from SRG members and from specific, targeted broader industry stakeholders considered relevant to each tool. UTS ran a centralised user feedback process through an online workshop, while UNSW ran 1-on-1 targeted sessions with high-priority users, and a remote feedback process to broader users.

Key takeaways from the SRG meetings are shown in Table 2, below. User feedback is touched upon in the description of each tool.

Table 2: Takeaways from SRG Meetings

SRG Meeting # & Topic	
#1: Project overview and directions	General principles encouraged by the SRG included covering a variety of target audiences (including large energy users), accessibility guidelines, storytelling, creating interactivity, data segmentation according to specific user types, and incorporating customer cost representations as well as geospatial elements.
#2: Proposed prototype concepts	Levels of interest of each SRG member in the proposed tools were captured in a poll, to aid in the selection of tools, ultimately guiding the final selection. Those not selected to take forward were based on the following SRG feedback and team reflection: • Energy jobs tool: While this was deemed both useful and viable, with was less core to funding partner goals for the project. • PPA explainer for large energy users: Available data Deemed too immature data to develop into a tool now, but to be reviewed after the UNSW 24/7 Renewables project is completed. • Community Pulse: Hard to do well within the budget and not core to initial project objectives, so potentially targeted as a separate RACE for 2030 project.
#3: Final showcase & feedback	Feedback from the SRG on prototype tools was generally positive, with some productive minor suggestions that were integrated, and major substantive opportunities for future consideration. An interesting suggestion was that the framing of ‘curtailment’ is an inherently negative construct, and perhaps could be flipped to promote a positive message regarding the opportunity available for ‘free’ services from surplus solar. Flexible demand opportunities for customers on. This has been considered in the final naming and framing of the tools. • Rooftop Solar Curtailment Explorer (retitle ‘Rooftop Solar Surplus Explorer’):

	- Add the potential retail value of 'free solar' and in future consider linking to wholesale market liability reduction. - Increase technical detail and provide a link to network business forecasting methodologies underpinning data. - Integrate proportionality figure for final map explorer (where data is readily available for this). - Ask Endeavour Energy whether the network solutions data should be included. - Round numbers to two decimal places. - Potentially tweak video description of Step Change to describe what is included in this scenario (relates to UNSW tools also). • Utility Curtailment: - The future addition of a live API would add value and keep users engaged. - Add unit units of measurements to timeseries visualisations. - As data becomes available, the evolution of curtailment over time would be useful. - Mapping of curtailment could be linked with transmission network overlay. • Minimum Demand: - More details on the creation on AEMO's creation of the forward-looking demand traces would be useful. • EV Grid Impacts: - Potentially add more details on the charging regimes considered. - A simplified version of this visualisation might be useful for future editions. Plan for RACE engagement event to include broader research and industry partners and A2EP, with their focus on flexible demand. Could also include AER and internal network audiences or run separate event/s for this.

7 Appendix 2: Review of Comparable Tools and Visualisations

An environmental scan of the current landscape for visualisation tools was conducted as inspiration and to kickstart the development of a novel Energy Trends Visualisation Tool. The list of 24 identified tools and their main characteristics can be found in **Table 3**, below. In compiling this list, the focus was on free access energy tool applications in the Australian context with a small number of international additions. The following figures summarise the high-level trends identified in the reviewed energy tools, including the topic of the tool (**Figure 1**), type of visualisation (**Figure 2**), live or non-live data (**Figure 3**) and software used to produce the tool (**Figure 4**).[2]

Figure 1: Topics of Energy Trend visualisation tool

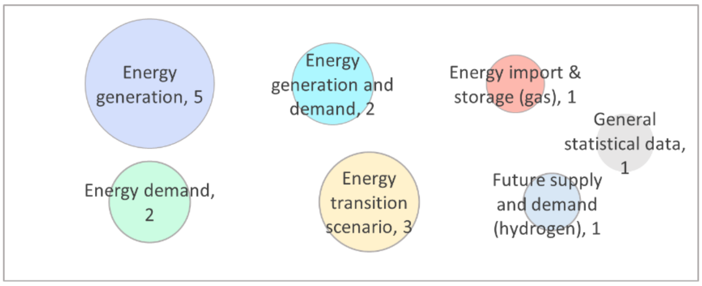


Figure 2: General types identified in the analysed energy visualisation tools

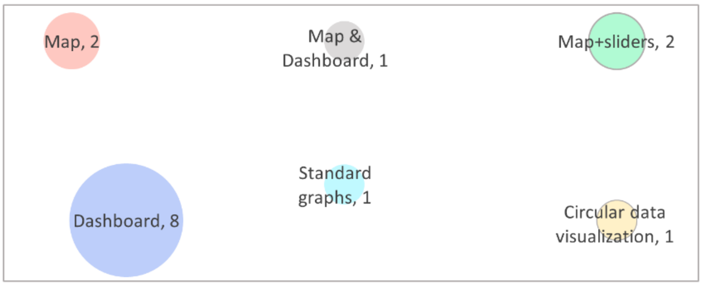


Figure 3: Live and non-live data

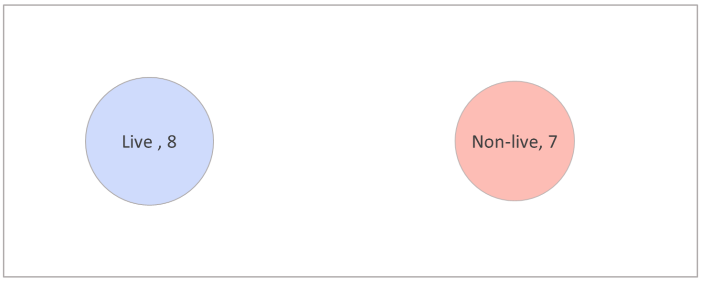


Figure 4: Software used in the list of identified energy tools.

[2] This analysis was compiled based on 15 tools; an additional 9 tools were added retrospectively.

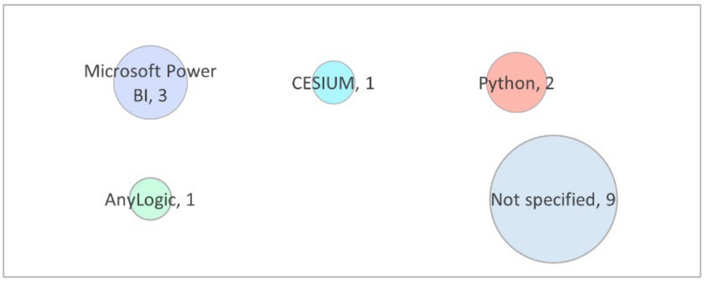

Microsoft Power BI, 3
CESIUM, 1
Python, 2
AnyLogic, 1
Not specified, 9

Table 3: Analysed visualisation tools

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
1	Solar PV status maps https://pv-map.apvi.org.au/	APVI	Understand the Australian solar PV market with live generation data, historical maps and animations, and tools to explore rooftop PV potential and per-postcode market penetration.	AU	Not specified	Live	Not specified	Map & Dashboard	Energy generation
2	National Map https://nationalmap.gov.au/	Australian Government	NationalMap is an online map-based tool to allow easy access to spatial data from Australian government agencies and is based on a fully open architecture. When you access data through it, you are typically accessing the data directly from the government department or agency who are the custodian of that data.	AU	Not specified	Non-live	CESIUM	Map	General statistical data

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
3	OpenNEM https://opennem.org.au/	Energy Transitions Hub	The OpenNEM project aims to make the wealth of public National Electricity Market (NEM) data more accessible to a wider audience	AU	Not specified	Live	Javascript (web frontend) - Python data	Dashboard	Energy generation
4	NEM AEMO's dashboards https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem	AEMO	An at-a-glance view of the NEM's key data points, including price and demand, dispatch, and short and medium-term outlooks.	AU	Not specified	Live	Not specified	Dashboard	National Electricity Market
5	DER data dashboard https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/metering-data/nem-der-and-interval-metering-dashboard	AEMO	An interactive display of publicly available information from the DER register. This tool shows the number of DER units, their rated capacity, and storage capacity for each jurisdiction.	AU	Not specified	Live	Not specified	Dashboard	Energy generation
7	Carbon-neutral European Energy systems https://explore.callio.pe/	Delft university of technology & ETH Zurich	Visualise different ways in which Europe's energy system can become green and self-sufficient by 2050.	EU	Researchers and decision makers	Non-live	Plotly Dash	Map + sliders	Energy transition scenario

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
8	Energy transition https://zenmo.com/en/virtual-labs-en/	Virtual labs (ZEnMo simulations)	Show hundreds of ways of how Europe's energy system can become green and self-sufficient.	NL	Grid operators, Researchers and decision makers	Non-live	AnyLogic	Map + sliders	Energy transition scenario
9	Energy demand flexibility and the rhythms of everyday life https://energy-demand-flexibility.co.uk/	University of Reading, UK	The aim of this project was to provide you with accessible, user-friendly visualisations that show the ways in which our activities impact our energy demands.	UK	Not specified	Non-live	Not specified	Circular data visualisation	Energy demand
10	EU gas dashboard https://gasdashboard.entsog.eu/	European Network of Transmission System Operators for Gas (ENTSOG)	Support stakeholders and policy makers to better understand and use data in relation to European gas flows, LNG, and storages.	EU	Stakeholders and policy makers	Live	Microsoft Power BI	Dashboard	Energy import & storage (gas)

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
11	Hydrogen visualisation platform https://h2-project-visualisation-platform.entsog.eu/	European Network of Transmission System Operators for Gas (ENTSOG)	It shows the location of hydrogen valleys, and how they can be connected to transport hydrogen from areas with large production potential to demand centres located possibly in other Member States via an EU-wide logistical infrastructure.	EU	Stakeholders and policy makers	Non-live	Microsoft Power BI	Dashboard	Future supply and demand (hydrogen)
12	SmartD: Smart Meter Data analytics Dashboard	Polytechnical University Lausanne	Show how customer characteristics define energy consumption	EU	Not specified	Not specified	Standard graphs	Energy demand	
13	NEMWatch : Supply-and-Demand Widget https://www.nem-watch.info/widgets/reneweconomy/	Openroam	Presents what is currently happening with energy supply and demand. AEMO is publishing a lot of data every day. NEM-watch helps to analyse that data and shows what is most important in a market overview.	AU		Live	Not specified	Dashboard	

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
15		NEAR Program - AEMO	provides a rich dataset and visualisations that can used to identify and target opportunities to enhance smart meter rollout or programs that could leverage an existing high penetration of interval meters or DER.	AU	DNSP, Governments, (Smart meters Roll out programs) DER developers, Researchers	Live	Microsoft Power BI	Dashboard	Energy generation
16	OpenCEM http://www.opencem.org.au/	itp analytics, CEEM-UNSW, energy transition hub, ThoughtWorks, NREL, ARENA, NSW Gov, VIC Gov, SA Gov	openCEM is a free electricity sector modelling tool that aims to support transparent and well informed analysis of technology and policy options for future planning of Australia's electricity system. With openCEM, Australian policy makers, energy users, energy market participants, project developers,	AU	Australian policy makers, energy users, energy market participants, project developers, investors, researchers and the interested public	Non-live	Python	Map	Energy transition scenario

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
			investors, researchers and the interested public can explore the implications of changes in policy and technology costs.						
17	NetworkMap https://networkmap.energy/	Rosetta Analytics	NetworkMap brings together existing network Infrastructure locations and other planning and capacity data to aid new project development. Main user type is renewable energy developers.	AU	Renewable Energy Developers	Non-live (mostly annual planning data)	Python	Map	Infrastructure location and project planning

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
18	Energy Charts https://www.energy-charts.info	Fraunhofer Institute for Solar Energy Systems ISE	A site for interactive graphics displaying energy production and spot market prices in Germany. By making the data available, the website intends to promote transparent and objective discussions relating to all factors regarding the energy transformation.	DE	Not specified	Live	Javascript. (highcharts)	Series of dashboards(Maps, timeseries, heatmaps)	Energy generation, energy transition
19	GridStatus.io https://www.gridstatus.io/	GridStatus	Grid Status is a "one-stop shop for everything happening on the electrical grid". This includes dashboards, analytical tools, and API's	USA	Not specified	Live	Python	Series of dashboards(Maps, timeseries,)	Electricity market data, electricity
20	Electricity Maps https://app.electricitymaps.com	Electricity Maps (Danish company)	Provides actionable electricity data for more than 160 regions. Aims to help businesses more effectively reduce their emissions, and enable products and services to differentiate their	Global	Not specified	Live	Python (backend), javascript (visualisation)	Mainly maps (with some time series)	Electricity market data, with focus on generation and emissions

No	Tool	Developer (s)	Aim	Region	Audience	Frequency of updating	Software	Type of analysis	Topic
			offerings by empowering end-users to be more carbon-aware.						
21	Electricity Data Explorer https://ember-climate.org/data/data-tools/data-explorer/	Ember	The latest electricity demand, generation, capacity and CO_2 data by country, available freely and easily to help others speed up the electricity transition.	Global	Not Specified	Live	Python backend	Data dashboard, some timeseries visualisations	Aggregated (annual) electricity system data.
22	Hourly Electric Grid Monitor https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48	US Energy Info	Hourly operating data about the high-voltage bulk electric power grid in the Lower 48 states. Draws on data from the electricity balancing authorities (BAs) that operate the grid.	USA	Not Specified	Live	Not Specified	Dashboards – featuring maps and timeseries visualisations	Hourly and aggregated electricity system data

No	Tool	Developer (s)	Aim	Regi on	Audience	Freque ncy of updati ng	Software	Type of analysis	Topic
23	Open Energy Tracker https://openenergytracker.org/en/	DIW Berlin	Open data platform for monitoring and visualising energy policy goals. Graphically depict governmental targets, most of which are specified for the year 2030, and compare them with the current status.	DE, FR, AU	Not specified	Non-live (mostly annual data)	Python (plotly)	Series of interactive (plotly) timeseries charts	Focus on renewable energy expansion, electric mobility and electrolysi s, but cover also other indicators.
24	Axle Energy https://wind.axle.energy/	Axle Energy	Small app for explore the wind power that the UK is discarding due to transmission constraints.	UK	Not specified	Live	Streamlit (Python)	Dashboards and timeseries charts	Sole focus on wind curtailme nt in the UK

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