# Open Source Grid Integration Model for the National Electricity Market

## openCEM Knowledge Sharing Report

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ENGINEERING | STRATEGY | ANALYTICS | CONSTRUCTION

# ABOUT ITP RENEWABLES

ITP Renewables (ITP) is a global leader in renewable energy engineering, strategy, construction, and energy sector analytics. Our technical and policy expertise spans the breadth of renewable energy, energy storage, energy efficiency and smart integration technologies. Our range of services cover the entire spectrum of the energy sector value chain, from technology assessment and market forecasting right through to project operations, maintenance and quality assurance.

We were established in 2003 and operate out of offices in Canberra (Head Office), Sydney, North Coast NSW, Adelaide and Auckland, New Zealand. We are part of the international ITPEnergised Group, one of the world's largest, most experienced and respected specialist engineering consultancies focussing on renewable energy, energy efficiency, and carbon markets. The Group has undertaken over 2,000 contracts in energy projects encompassing over 150 countries since it was formed in 1981.

Our regular clients include governments, energy utilities, financial institutions, international development donor agencies, project developers and investors, the R&D community, and private firms.

# ABOUT THIS REPORT

ITP's funding agreement with ARENA (2017/ARP013) specifies that key knowledge from the Activity since the previous milestone should be shared publicly, including key outcomes and lessons learnt to date. This report describes those lessons.

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# 1 INTRODUCTION

This report focuses on lessons ITP Analytics, as developers of openCEM, have learnt to date. These lessons are important because they will shape the way we continue to develop openCEM and its derivatives, and they also provide guidance to developers of future energy sector models.

This report will only briefly describe high-level openCEM modelling results, noting that the objective of the project not the creation of new knowledge, but rather to create an analytical tool that will allow all stakeholders to freely model scenarios relevant to their circumstances.

# 2 PROJECT BACKGROUND

This section summarises the openCEM project. More detailed information is available at www.openCEM.org.au

Collaboratively with the US Strategic Energy Analysis Center of the National Renewable Energy Laboratory (NREL), the Centre for Energy and Environmental Markets (CEEM) at the University of NSW, the Climate and Energy College at the University of Melbourne and the software development firm ThoughtWorks, ITP Analytics (ITP) developed a detailed capacity expansion model for the Australian National Electricity Market (NEM). The model is called openCEM, and the project was supported financially by the Australian Renewable Energy Agency and the Governments of NSW, Victoria and South Australia. Beyond the five-year project period, ITP will continue to maintain, develop and publish the model.

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.

Until now, energy sector analysis has largely relied on privately held models that do not fully reveal how they work or their data assumptions. But openCEM is 'open-source', so every aspect of the model, including code and assumptions are open for review, revision and critique. Consistent with the philosophy of open-source software, ITP encourages users to work collaboratively and help us update and improve our model over time.

With openCEM, Australian policy makers, energy users, energy market participants, project developers, investors, researchers and the interested public can explore the implications of changes in policy and technology costs by:

- Running multiple scenarios, testing what kind of renewable energy capacity expansion can be achieved at the least cost while maintaining energy security
- Testing their input assumptions and comparing them to reference scenarios
- Analysing when, where and what kind of energy and storage capacity should be added and when and where carbon intensive sources can be retired in order to achieve policy goals
- Repeating and update modelling at any time to account for changes, for example in policy, technology, costs or electricity demand profiles.


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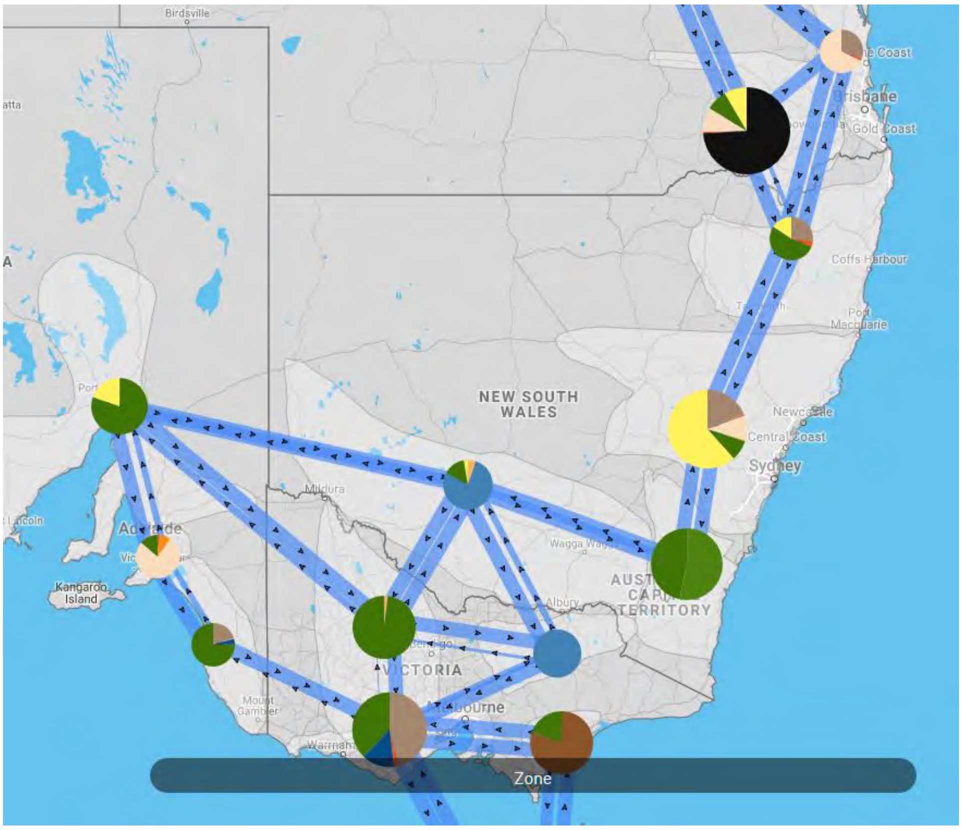
openCEM can be used in two ways. The simpler option is to explore a range of "pre-run" scenarios (based on a set of identified assumptions) on the *openCEM* website. Results such as generation capacity, dispatch and wholesale electricity cost are displayed visually using a range of graphics (such as the one illustrated below). At the outset stage ten scenarios have been selected to demonstrate the capability of the model. These are updated periodically and more may be added in response to user feedback and requests.




The more sophisticated option is for users to download and install *openCEM* on their computer. Users can then run their own scenarios, with tailored assumptions about inputs such as technologies, policies and demand profiles. A single run of the model typically takes 1.5 days on a good desktop computer, and setting up the scenario consists of filling some information in scenario input files that requires some basic understanding of how *openCEM* works. After the simulation is finished, a complete dataset of the simulation is produced that contains all input assumptions (e.g. costs, policies, traces, demand, etc.) as well as all dispatch and building decisions.

For detail on how openCEM works visit http://www.opencem.org.au/howto

# 3 OPENCEM MODELLING RESULTS

This section summarises openCEM modelling results. These are provided for interest, however, it is important to note that the objective of this project was to develop a free to use analytical tool, not a static forecast of the evolution of the energy sector. High level conclusions that can be drawn from the ten pre-run scenarios displayed on the openCEM website include that:

2. *openCEM* results reflect what other modelling studies (such as the ISP) have shown; that the least-cost replacement of the NEM fleet includes significant renewable capacity. A combination

of wind, solar, dispatchable renewable generation (hydro, biomass and solar thermal) and storage can meet increasing shares of electricity demand into the future at costs that are competitive with conventional generation.

3. Most scenarios show electricity costs that are similar. This is fundamentally because there is little difference in the forecast prices of wind, solar and storage, dispatchable renewable generation and conventional generation. What this also means is that there are many technological pathways to achieve any particular outcome.
4. *openCEM* shows that orchestration of many renewable and storage technologies, and timely transmission upgrades, is the cheapest way to achieve emission reduction or renewable target policy objectives. That is not necessarily intuitive, and some might be surprised that the model does not forecast reliance on just one or two relatively inexpensive technologies. Rather, the optimisation calls upon a wide range technology options, each with unique cost and operational characteristics, to simultaneously satisfy demand across the system.
5. The *openCEM* results indicate that, to keep pace with the energy transition, it is crucial that regional and interregional interconnectors are upgraded in a timely manner. For example, the model predicts large expansions in transmission between Northern SA, Country Victoria and South West NSW by 2025, strengthening of intra-regional transmission in NSW by 2030, and construction of the Marinus link by 2035 in most scenarios.
6. The mix of energy generation out towards 2050 depends on how we get there. Early action to transition to renewables favours wind and PV, but other technologies such as solar thermal with storage become cheaper later. Thus, more of the latter will be built if the transition is delayed.

# 4 KEY LESSONS LEARNT DURING DEVELOPMENT

At the outset of the project many questions about the modelling approach and data sources were yet to be resolved. In addition, some decisions were amended during the course of the development phase. For example:

- Modelling capacity and dispatch decisions for the entire National Electricity Market simultaneously, taking into consideration a detailed treatment of storage, was larger scale problem than ITP originally anticipated. Combined with the aim to keep the model entirely open source, led us to use Linear Programming as the method to perform the optimisation. Linear programming is relatively simplistic in its treatment of physical behaviour of the NEM, however it is well suited to tackle the scale of solving openCEM problems.
- Transmission constraints and transmission upgrades have a crucial role to play in supporting a future grid that includes renewable energy generation and storage. It became evident that without the ability to model transmission upgrades, openCEM would not produce comparable results to other publicly available modelling efforts (e.g. AEMO ISP).
- The team therefore implemented a pipeline model for transmission between NEM planning zones that computes hourly transmission flows at the intra-regional level observing capacity based thermal limits. Transmission flows observe separate forward and reverse direction limits (bidirectional), include loss factors and proportioning factors to account for transmission line efficiency and congestion at either side of interconnectors. In addition, ITP implemented continuous transmission capacity decisions that allow greater flows across transmission links at a configurable cost per link in $/MW/km. All links in the openCEM configuration can be upgraded by capacity expansion decisions in the same fashion as

generation/storage capacity expansion decisions take place, i.e. New links can be considered by adding them to a configured topology with a starting capacity of zero.

- ITP's original idea of treating coal generators with the same flexibility as other technologies resulted in impractical ramp rates for those generators. We therefore adding linearised unit commitment constraints for some fossil fuel generators in order to more realistically represent ramp rates and flexibility. This decision has been made on the recommendation from NREL based on their extensive experience of simulating fossil fuel generators in the US. Incorporated equations include ramp rates, minimum load and minimum up times to emulate unit commitment in each planning zone.
- Splitting simulations into capacity and dispatch and using time slicing to speed up the former has enabled substantial savings in computation time for the model at a very modest cost in accuracy. Finding the best balance between time slicing and full simulations is ongoing.
- Based on consultation with the Industry Reference Group it was clear that adopting the AEMO ISP data as the main source of data for the model for widely supported. AEMOs data and modelling are the most robust and reliable publicly available data source to date because of their extensive public consultation and checking process. However, there are a few shortcomings in the AEMO ISP data and assumptions which only become evident after running openCEM scenarios. For example, the experienced difficulty for a period where only the AEMO NTNDP data was available and the ISP data had not yet been released. Data records of both sources were organised in a slightly different way and the structure of openCEM data was still being defined. Once the data structure for openCEM matured this no longer was a problem and future adoption of other data sources with different structures is more straightforward.
- openCEM generates a basic report of its solution and a JSON file will all inputs and assumptions to the model as well as all decisions made by the model. Data in the JSON file can be cumbersome to access for causal users or those without advanced Python training. Based on consultation with the Industry Reference Group it was clear that it was necessary to develop a reporting tool to collate output file results and presents them in in a user friendly form.

  The reporting tool processes the JSON file into a detailed report that contains generation, capacity and hourly dispatch graphs, as well as transmission, reserve margins and other metrics. It is intended to provide some aspects of the visualisation website for users that run custom scenarios in their computers and need an easy way to access results for those scenarios.

# 5 KEY LESSONS LEARNT SINCE THE LAUNCH OF OPENCEM

Since the launch of openCEM the ITP Analytics team have provided training to our funding partners and held meeting with numerous key potential users. During these discussions and 'hands on' demonstrations we have received further feedback about user preferences. These lessons will shape the way ITP continues to develop openCEM and its derivatives. The most important lessons include:

1) There is a gap between automatic transmission upgrades computed by openCEM and the reality of transmission upgrades in the NEM. The second version of openCEM considers transmission flow limits between NEM planning zones and can make decisions to upgrade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links if it contributes to running the system at the least cost. Users view this feature positively as it aligns with the prevalent view that greater interconnection across the NEM is crucial to the integration of renewables and storage into the energy mix. However, openCEM did not observe planning and regulatory factors that impact the lead time to deliver upgrades, and this in turn may affect generator decisions. Therefore, the team has developed and released a “manual transmission upgrade” feature that allow users to disable automatic transmission upgrades for a user-defined horizon and prescribe specific transmission projects that need to be incorporated into the mix.

2) openCEM offers the most value to users when comparing a baseline scenario to changes. Given the least-cost nature of openCEM scenario solutions, variations between two scenarios can be interpreted as shadow costs between the options they represent. For example, if a given baseline scenario is re-run with additional emissions targets, the net difference between capacity and dispatch decisions can represent the shadow costs of the emissions target. openCEM allows this analysis out of the box, but initially the openCEM_analysis tool was currently limited to unpacking the results of a single scenario at a time. The team has rewritten the analysis tool to allow multiple scenario comparisons and detailed analysis of cost and operational parameters. The data footprint of the tool is also more compact and can be run in personal computers with moderate RAM and CPU requirements. A new version incorporating these and other small refinements for usability was released in the second half of 2020. This was received positively by the user community
3) There is considerable interest in the role that demand side technologies may play in the future mix of technologies. Demand response, electric vehicles and coordinated distributed resources can all play a significant role in the cost and reliability of the NEM by managing demand and shifting peak load on a daily basis and at critical times. Users are interested in extending openCEM to include optimisation decisions that model demand side technologies. With the release of the ISP 2020 data, demand side technologies and their share of operational demand are more explicitly defined. This means that it is now possible for openCEM users to alter the mix of demand side technologies that form the operational demand processed for each scenario by modifying the data query templates. For example, users are now able to run the ISP central scenario but specify 20% more electric vehicle penetration than that forecasted by AEMO.


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