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NEMOSIS – NEM Open Source Information Service; open-source access to Australian National Electricity Market Data.

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Abstract

The Australian National Electricity Market (NEM) is undergoing rapid change as utility-scale wind, solar and now battery storage technologies enter the market. The impact of these changes on the operation of the NEM is of interest to a potentially wide range of stakeholders including researchers, market participants, consultants and energy NGOs. Detailed operational data is essential in assisting these stakeholders to understand these impacts and possible future outcomes in the NEM. Open data and open-source software for energy are increasingly seen as key to improving transparency and reproducibility, and therefore productive discussion on energy policy and market reform amongst a wide range of stakeholders.

There is an excellent opportunity to further these aims in the NEM, due to high levels of transparency around market data, with the Australian Energy Market Operator (AEMO) releasing nearly all the data used in the central dispatch process. However, a significant processing and interpretation overhead exists when analysing the large and often complex datasets made available to the public. This paper reports on a new open-source software tool, NEMOSIS *NEM Open Source Information Service, NEMOSIS*, which aims to lower this overhead and improve the accessibility of data sourced from AEMO.

While a number of similar proprietary tools exist and are widely used by industry stakeholders, NEMOSIS offers additional benefits. It is completely open to modification and extension with the source code available on GitHub, while also being highly portable with the ability to package the tool as an executable file and operate it via a graphical user interface. It complements some other open source data tools for the NEM by providing access to a wide selection of data without the need for the user to have any coding knowledge.

To demonstrate the use of NEMOSIS, this paper presents two examples of how it can be used to assess utility-scale renewable generator performance; firstly, with a simple example that outlines how to access 5 minute dispatch data for all scheduled generators in the NEM, and then, a second more complex example explains the implementation of a custom data table of plant performance statistics.

1. Introduction

The Australian National Electricity Market (NEM) plays a key role in societal welfare, yet also contributes over a third of Australian Greenhouse Gas emissions. We are, therefore all stakeholders in its transformation to a low carbon future whilst maintaining affordability and security objectives. The complex coordination required for electricity industry dispatch within market oriented arrangements requires high levels of data transparency for market participants. Such data has wider value for stakeholders interested to better understand technical and commercial electricity industry performance. The Australian Energy Market Operator (AEMO) makes a large portion of the data from the Market Management System (MMS) available to the public (AEMO, 2017a) in order to facilitate decision making and also to ensure transparency around market operation given its significant financial and economic implications. The availability of this data also allows researchers and policymakers to investigate the implications of aspects of the NEM such as technology mix and market design, as well as other endogenous factors. However, this data is not provided in a particularly easy to use format for interested stakeholders.

The interest in data from the NEM, as well as the difficulty processing it is evidenced by the number of commercial tools available for accessing the data. These include NemSight, by Creative Analytics (Creative Analytics, 2013), NEO by Intelligent Systems (Intelligent Energy Systems, 2018), NEM Review 6 (Global Roam, 2016) and NEM Watch (Global Roam, 2018) by Global Roam and Energy Edge MMS Batcher by Energy Edge (Energy Edge, 2018). In this paper we present NEMOSIS as an open-source alternative to these tools and argue its open-source nature offers several benefits, including transparency of the codes and methodologies and better opportunities for validation and customisation.

NEMOSIS provides a software interface for accessing AEMO data and compiling, merging and filtering it to create datasets that are easier to analyse. Optionally, custom tables can provide access to pre-analysed data. Figure 1 gives an overview of the work flow carried out by the program when accessing AEMO data tables. NEMOSIS is written in Python which is a programming language, popular for engineering and data science and an open-source alternative to Matlab. The interface can be utilised by running the source code on computers with Python installed, but for many users, running the graphical user interface as a windows executable file will be the most convenient way to use the tool, as it does not require any installation or additional packages. Links are provided below so the reader can familiarise themselves with the tool.
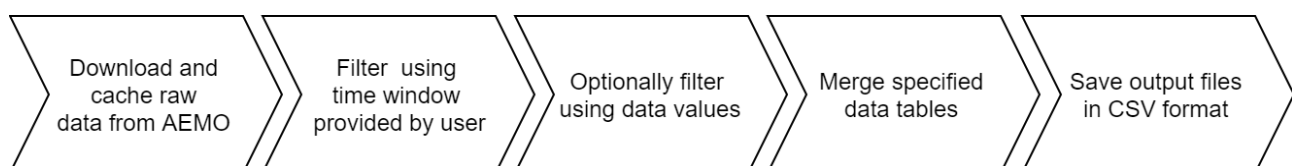

Figure 1 Overview of the NEMOSIS workflow when accessing AEMO data tables through the graphical user interface.

NEMOSIS is available on GitHub, source code: https://github.com/UNSW-CEEM/NEMOSIS and the latest executable version: https://github.com/UNSW-CEEM/NEMOSIS/releases.

1.1. The role of data in assessing NEM performance

The focus of NEMOSIS is to provide better access to publicly available operational data from AEMO. While the NEM has been recognised as operating with a high degree of transparency and with much greater public availability of data than many other electricity markets (Wolak, 2005), at the time of NEMOSIS first release, a broad discussion regarding data accessibility in the NEM is taking place. In at least part, this discussion is being driven by rapid technology developments including wind and solar as well as distributed resources, changing policy drivers and growing

security and reliability concerns. Recent years have also seen high wholesale market prices and questions regarding the level of market competition. A growing number of stake holders have expressed concerns about NEM performance and the potential need for major reform (Global Access Partners, 2017; Grattan, 2018; Ludlow, 2017; Pears, 2017; Wood and Blowers, 2017). Among the suggestions for reform are further increases to the levels of data transparency and accessibility, including from the Finkel Review, the Energy Security Board (Finkel, 2017; Schott et al., 2018) and from academia (Ghahremanlou and Dungey, 2017).

We would certainly agree that data access will be critical to allowing stakeholders to engage in the reform process, including policy discussions, which have lately tended to be dominated by consultant modelling with a lack of transparency that has become increasingly problematic for building consensus around evidence-based decision making. Increasing complexity of market operation due to an increase in generation technology types, the increasing importance of ancillary services markets and high resolution data as security challenges emerge, and the availability of new technologies for more detailed monitoring highlights the opportunities for increased data transparency.

While this paper does not seek to engage with broader reform or transparency questions, we believe the open-source tool presented here is valuable in this context, as it allows for completely transparent analyses that can be critiqued, and for modellers to engage and improve the quality of analysis and build consensus around methods and results.

1.2. Open-source NEM data processing

The development of NEMOSIS is occurring in parallel with another open-source tool with similar goals - OpenNEM (McConnell et al., 2018). So far, OpenNEM is focused on current weekly datasets and a web-based graphical user interface. This interface provides access to dispatch data on technological and regional basis, as well as access to price and temperature data. OpenNEM also provides visualisation of this data. In contrast, NEMOSIS is based around a desktop application that provides access to a number of historical data tables, with an emphasis on dataset merging and filtering, but without any data visualisation. While development across the two projects is currently divergent, the open-source nature of both projects leaves open the possibility for cross-pollination of ideas and collaboration.

1.3. Data sources

Currently all data available in NEMOSIS is sourced from AEMO. A large portion of AEMO's publicly available data is provided in the Market Management System Data Model (AEMO, 2017a). Data conforming to this format is available through the NEMWEB portal (AEMO, 2018a), which contains historical data starting from July 2009 and is provided on a monthly basis. From the MMS Data Model there are 19 tables currently available in NEMOSIS. These include tables that contain details relevant to operational outcomes, including dispatch, FCAS enablement levels, demand, prices, interconnector flows, constraints, bids, ramp rates and loss factors. Also available in NEMOSIS from the NEMWEB portal is the FCAS Causer Pays data, which provides 4 s interval SCADA data for dispatch units and interconnectors (AEMO, 2017b). NEMOSIS additionally sources a limited number of data tables from links on AEMO's web page, including the Generators and Scheduled Loads list (AEMO, 2018b) and the FCAS Causer pays Elements Index file and Variables List file (AEMO, 2018c). Sourcing data from these tables is less stable then through the NEMWEB portal as it could be affected by changes in the format of the AMEO website, however while providing a comparatively small amount of data compared to other sources these tables are key to the analysis of other data sources. This is particularly true of the Generators and Scheduled Loads list, as it provides information on dispatch unit technology types, which is critical to all analyses of renewable generation.

1.4. Paper structure

In the remainder of this paper, we describe the general attributes of NEMOSIS and demonstrate the use of NEMOSIS to obtain and analyse data on renewable energy generator dispatch. The general approach to data processing is discussed in Section 2. A simple example of accessing renewable generator dispatch data is given in Section 3. The implementation of a custom table to provide plant performance statistics is outlined in Section 4. The discussions and examples aim to illustrate the usage of the tool, but also the benefits of open source data for better understanding the NEM.

2. Data processing method

2.1. Table categories

NEMOSIS separates data tables into two categories, AEMO tables and custom tables. There are currently 22 AEMO data tables available through the graphical user interface. NEMOSIS performs minimal processing steps on these tables, and the data is provided largely as presented by AEMO. The main exception to this is the removal of some table columns by NEMOSIS. Columns are removed where they are no longer in use by AEMO but still exist in the table, or on a subjective basis where the table would otherwise be overly large and the main data columns obscured. Any additional exceptions are detailed as part of the table summary in the NEMOSIS Wiki (Gorman, 2018a). AEMO tables with no filtering are available using the underlying Python functions.

Custom tables are a space within the tool for contributors to host tables derived from the AEMO datasets, this can be done locally by users or on the original GitHub page upon review by the code base maintainers. These custom tables can include any level of data manipulation to produce novel or useful higher-level information. As custom tables each use a unique methodology, they are not discussed further in this section. The descriptions here are reserved for methodologies generalisable across the tool, and where applicable in the examples, information on custom table methodologies will be given.

2.2. Datetime filtering

The AEMO data tables can be further broken down into dynamic and static tables. The dynamic tables contain timeseries data and include a datetime column that allows NEMOSIS to filter and extract data based on a start and end time. The static tables are data sets that do not include a datetime column and cannot be filtered by start and end time.

To facilitate datetime filtering, within NEMOSIS a primary datetime column is defined for each dynamic table, which contains the column used to determine the times a record applies to. This is needed as tables may contain many datetime columns, including secondary datetime columns such as the 'last changed' column, that do not affect when a record applies.

Dynamic tables are filtered on their primary datetime column to return records that are applicable between the start and end time provided. However, there are multiple primary datetime column types that dynamic tables can contain, and these in turn affect the processing methodology applied. The two most important column types are 'settlement date' that has a direct relationship to when a record applies and 'effective date' that has different applicability depending on when a more recent record supersedes an older record. Settlement date records apply only to the interval specified in the settlement date column. The filtering for this column selects records where the settlement date is greater than the start time and equal to or less than the end time. Effective date records can apply to any time after their specified datetime. Filtering for this column returns any records where the effective datetime is greater than the start time and less than the end time, and also returns the most recent effective date record less than or equal to the start time. Other primary datetime columns may also be used for filtering, these are filtered on the same principles as either the settlement date or effective date, with minor adjustments as described in the Wiki.

2.3. Value filtering

Filtering of tables by value is also possible for a subset of table columns. It is restricted to columns that contain text strings or integer values that can be filtered for exact matches. This simple filtering option is not intended to support complex analysis but ensures output datasets can be reduced to a manageable size or filtered by important categories where needed.

2.4. Table merging

NEMOSIS also allows the merging of data tables, which can be done when two tables contain columns of the same type. The columns to be merged from each table are specified as key columns, with their order determining which columns are matched against each other. Rows from the two specified tables are joined when all key column values match exactly. The type of join can also be specified as either left, inner or right, where a left join preserves all rows from the first table specified, a right join preserves all rows from the second table specified and an inner join only preserves rows where matches are found. Merging data sets combines information needed for analysis from different tables into a single data set. This makes the outputs more convenient for rapid analysis using charts or element-wise calculations.

2.5. Methodological completeness

Despite the relatively simple data processing methodologies employed by NEMOSIS, within the constraints of this paper, it is not possible to describe all of the details of how NEMOSIS builds tables. However, the open-source nature NEMOSIS ensures the transparency of the methodology, with the complete version available via GitHub (Gorman, 2018b).

3. Usage example 1: accessing renewable generator dispatch data

Accessing renewable generator dispatch data provides a simple example of how NEMOSIS can be used. It also highlights some of the complexities of working with the datasets provided by AEMO.
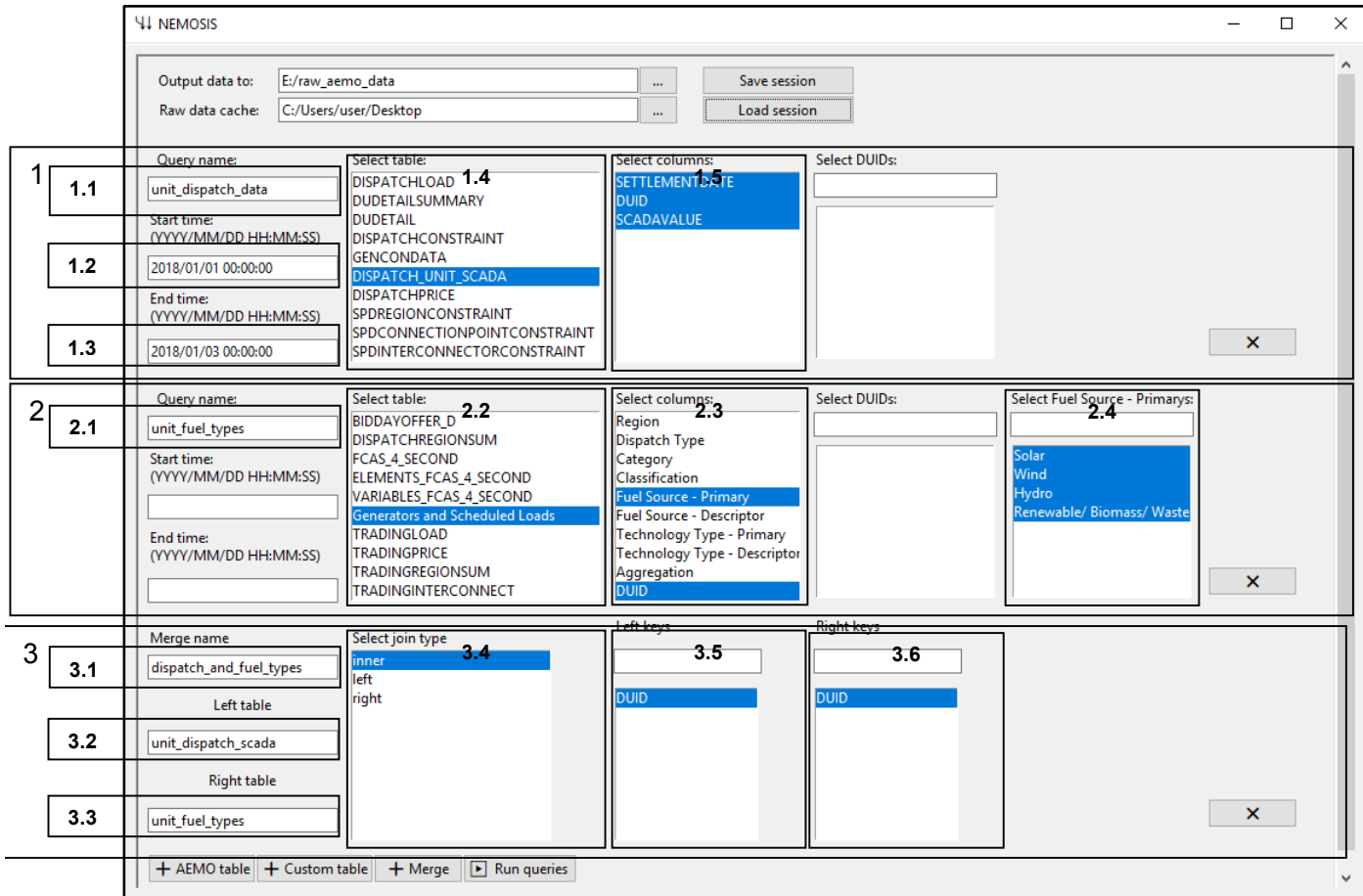
Before any data can be gathered, the type of dispatch data must be chosen. There are three potential tables when looking for "dispatch data": (1) DISPATCH_UNIT_SCADA provides a SCADA value which measures the output of each registered dispatch unit at the beginning of the dispatch interval (in MW); (2) DISPATCH_LOAD provides the total cleared value, which is the target dispatch for each plant at the end of the interval (in MW) as determined by the central dispatch process; and (3) TRADING_LOAD provides the average total cleared value over a given trading period (in MW). It is clear that the AEMO datasets are highly detailed resources, but also that care must be taken in selecting the data required, as there are many subtly different data tables. In this example we used the DISPATCH_UNIT_SCADA table, however data can be sourced from the other tables similarly.

3.1. Extracting the dispatch dataset

To extract dispatch data by technology type, it is necessary to access AEMO's list of Generators and Scheduled Loads. This information is sourced from the NEM Registration and Exemption List excel file (AEMO, 2018b) which details the technology and fuel types of registered dispatch units in the NEM. The version available in NEMOSIS is modified to provide the data on a per Dispatch Unit ID (DUID) basis, as MMS data tables report most generator data on this basis. The original table reports data on a *physical unit* level, but this additional level of information is not needed for most analyses (down to the dispatch unit level), and cannot be used when working across datasets that do not report this level of detail.

The renewable generator dispatch dataset is created in three steps, as shown in Figure 2. (1) Firstly, a query is set up to retrieve the DISPATCH_UNIT_SCADA table; (1.1) a name is given for the resultant csv of the query, (1.2) a start time is provided, (1.3) an end time is provided, (1.4) the table is selected, and (1.5) the table columns required are selected, in this case no additional filters

are applied. (2) Secondly, a query to retrieve the table Generators and Scheduled Loads is set up; (2.1) a name is given for the resultant csv of the query (as this is a static table no start and end times are provided), (2.2) the table is selected, (2.3) the columns required are selected and (2.4) a filter for renewable generators is added. (3) Lastly, a merge is set up to combine the results of the first two queries; (3.1) a name is given for the resultant csv of the merge, (3.2) the left table in the merge is defined using the name given to the first query, (3.3) the right table in the merge is defined using the name given to the second query, (3.4) the merge type is defined as inner, which will filter out any SCADA values without the specified fuel types, (3.5) the left join key is defined as the DUID column, (3.6) the right join key is defined as the DUID column. Once set up, the three steps can be executed sequentially using the run queries button.

Figure 2 Creation of the renewable generator dispatch data set using the NEMOSIS graphical user interface.

3.2.   Results

The results can be viewed on a Fuel Source or DUID basis as shown in Figure 2. This is can be done by manipulating the results in an excel pivot chart or similar application. The results for the time between 1/01/2018 0:00 and 3/01/2018 0:00 show that three renewable generator types were operating during this time, Solar, Wind and Hydro. Solar generation is the only technology of the three that drops to zero output on aggregate. Wind drops to a minimum level of 260 MW and Hydro drops to a minimum level of 280 MW. For the example of the single DUID given, we see a greater level of output variability with ARWF1 (Ararat Wind Farm) dropping to nearly 0 MW on consecutive days.

3.3. Discussion

This example of accessing renewable generation data demonstrates a simple example of using NEMOSIS to prepare datasets for analysis. A more detailed breakdown of the renewable generators' output can be obtained by including additional information from the Generators and Scheduled Loads table. For example, the inclusion of the Fuel Source – Descriptor field would enable solar to be broken down into tracking and non-tracking systems, or the generator Region could be included to give a regional breakdown.

It is also worth comparing the creation of the dataset in NEMOSIS to performing the same work using excel. Historical SCADA data is available from AEMO in monthly files that each contains data for all dispatch units. Each file is around 100 MB and too large to open completely in excel. This means each file needs to be processed separately to extract the
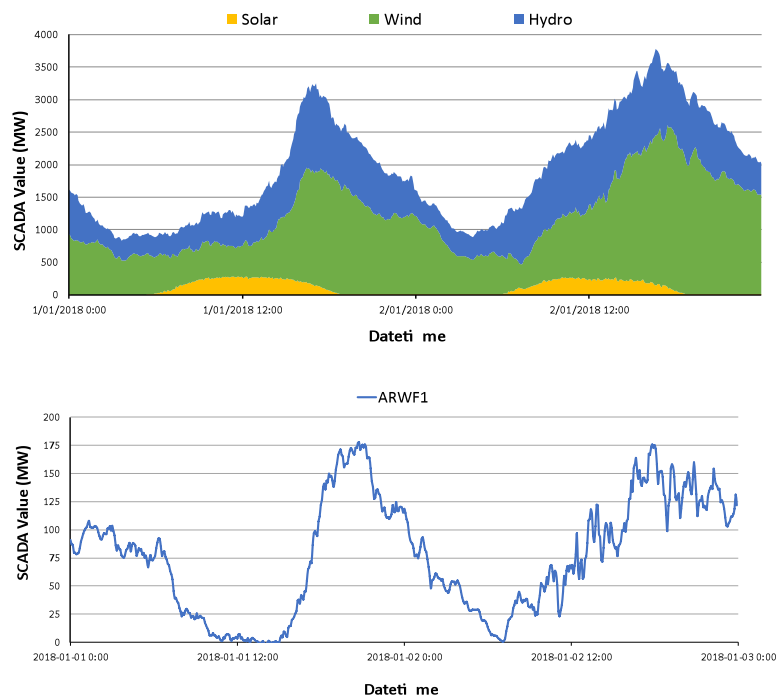

Figure 3 The renewable generator dataset results. The first chart shows the aggregate results on a fuel type basis. The second chart shows the results for a single dispatch unit ARWF1 (Ararat Wind Farm).

renewable generators, using an excel data model or similar (Barreto, 2017). Then, the 12 resulting files need to be concatenated to create a single dataset. NEMOSIS and similar tools are useful largely because they avoid the manual work involved in examples such as this.

4. Usage example 2: Plant performance statistics

The table PLANTSTATS is an example of a custom table implemented to produce a high-level summary of the AEMO data tables, the computation to produce this summary is done locally on the user's machine when a query is made The table analyses DUID-level dispatch to produce the following monthly performance measures: volume, trading volume weighted average price (VWAP), dispatch VWAP, capacity factor (CF), nodal peak CF and nodal 90th percentile CF. They aim to track the level of renewable contribution in the NEM, the price received by units for their generation, the value of the energy units are contributing to the spot market, the performance of individual renewable units and the contribution renewables are making to meeting peak demand. The inclusion of dispatch VWAP as measure of plant performance could be considered superfluous as it does not measure the actual compensation of dispatch units. However, the design of the NEM to include five minute dispatch intervals indicates that there is value placed on the sub thirty minute operational decisions of dispatch units in the ongoing process of balancing of supply and demand. This view and the importance of measuring dispatch VWAP is further supported by the decision to transition the NEM to a full five minute pricing (AEMC, 2017). A brief description of the methodology for calculating the statistics is given below and the full methodology can be viewed in the NEMOSIS source code.

4.1. Methodology

The method for the calculation of each performance statistic is as follows:

- The volume is calculated by summing the dispatch SCADA values across the month and dividing by 12 to convert from MW to MWh values.
- The trading VWAP is calculated to approximate the average effective price that a dispatch unit is paid for a trading interval. The average price for each trading interval is taken from the table TRADING_PRICE. The average unit dispatch for each trading interval is calculated from the DISPATCH_UNIT_SCADA table. The price and dispatch data are then used in the following formula to calculate the VWAP:

$$VWAP = \frac{\sum P \times D}{\sum D}$$

Where P is the regional price in $/MWh and D is the unit dispatch in MW.

- The dispatch VWAP is calculated to approximate the spot market value of the unit's operation. It follows the same method as the trading VWAP but uses the 5 minute dispatch values rather than 30 minute trading interval values.
- The capacity factor (CF) is calculated by dividing the unit dispatch SCADA value by the dispatch unit's max capacity in each timestamp. The resulting array of fractions is then averaged across the month.
- The nodal peak CF is the CF for the unit only considering the dispatch interval in which the unit's region was at its monthly maximum demand level.
- The nodal 90th percentile CF is the CF for the unit only considering dispatch intervals where the regional demand was above the 90th percentile level.

The table can be accessed as shown in Figure 2, replacing the DISPATCH_UNIT_SCADA table with the PLANT_STATS table. To produce the results shown in in Figure 5, Figure 4 and Figure 6 data was extracted for the financial year between 30/06/2017 and 1/07/2018. The merging of the PLANTSTATS table and the Generators and Scheduled Loads table allow the results to be aggregated by fuel source in an excel pivot chart or similar application. This simple aggregation does not normalise by volume or capacity on a DUID or monthly basis, meaning small plants or low volume months have a disproportionately high weighting when the statistics are averaged. A more complex analysis could include proportional weighting, however the results shown serve to demonstrate the potential applications of the tool.

4.2. Results

The results in Figure 5 report the monthly energy generation of utility scale solar, wind and hydro in the NEM. Solar generation's energy contribution remains modest, averaging 67 GWh/month over the last financial year. Wind and hydro generation are similar, averaging 1.0 TWh/month and 1.3 TWh/month respectively. It is also possible to observe significant monthly variation in renewable generation, with the combined peak to trough variation equalling 1.3 TWh. The average VWAP results are reported for renewable
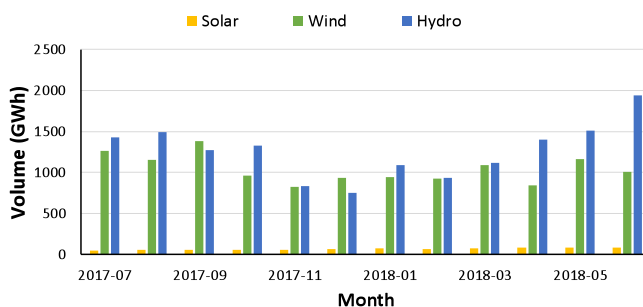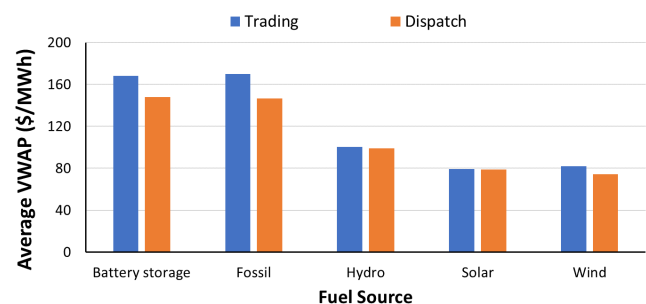
**Figure 5 Renewable energy volumes in the NEM.**

Figure 4 Average Fuel Source VWAP.

generators by fuel source in Figure 4, and battery and fossil fuel generation are also reported as

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the renewable results are more relevant in this context. Solar and wind generators experience similar average VWAP trading prices of 79 $/MWh and 82 $MWh respectively, hydro generators experiences a higher VWAP of 100 $/MWh on average and battery storage and fossil generators experience the highest VWAP of 168 $/MWh and 170 $/MWh on average, respectively. The comparison of trading to dispatch VWAP indicates that on average solar, wind and hydro generators receive a trading VWAP in line with their value on the spot market. It also indicates that some battery storage and fossil generators receive a trading VWAP above their value as measured by the five minute dispatch VWAP. This is an interesting issue as the NEM looks to transition to full five minute pricing. However, care must be taken in interpreting this result, due to the simple aggregation used.

The average CF results for solar and wind generators are reported in Figure 6. The monthly average CF of solar generators varies between 12% and 25%. However, it is likely that the solar CFs are low due to the lag between unit registration and the start of operation, as well as the hydro unit RUBICON, which was not operational over the year, erroneously being recorded as a solar
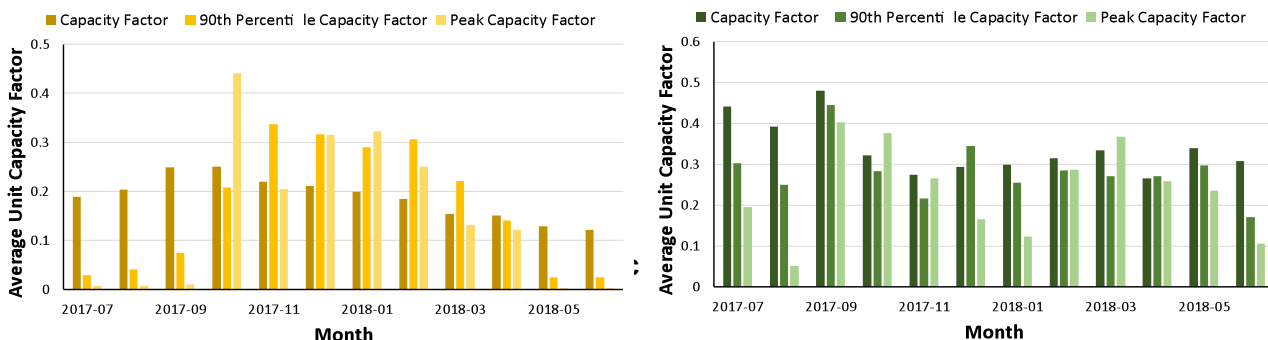
farm. The monthly average CF of wind generators varies between 27% and 48%. The average 90th percentile CF and average peak capacity for solar generators shows a strong seasonal bias, with a variation between a maximum of 44% and minimum of 0% in peak CF. Wind generation also shows a significant variation between a maximum of 40% and minimum 5% in the average peak CF, although seasonality is less apparent.

4.3. Discussion

The case study of the PLANTSTATS table highlights the flexibility of data access and analysis using NEMOSIS custom tables. It also demonstrates how assumptions about data structure, such as the definition of nameplate capacity, and integrity can impact results. Importantly, the open-source nature of NEMOSIS allows these issues to be recognised and methodologies to be improved. Appropriate assumptions and methods may vary depending on the work being conducted, and analysis in custom tables allows for the use and adaption of analysis methods by other researches within the NEMOSIS framework.

5. Conclusion

NEMOSIS provides transparent access and analysis for publicly available AEMO data tables. To provide this requires the implementation of non-trivial processing methods that cannot be fully and concisely described in a short paper such as this. However, provision of the tool in an open-source format maintains transparency of the data processing methodology. Section 4.2 raised issues of erroneous underlying data and the structure of data impacting results. These are difficult issues to overcome, but access to the source code improves the chances of such issues being noticed and addressed. We believe NEMOSIS currently contains enough data tables for it to be broadly applicable to the analysis of renewable energy in the NEM. The data and analysis presented in sections 3.2 and 4.2 use only part of the data available, with additional tables covering

interconnector flows, bids, FCAS, loss factors, network constraints and 4 second SCADA. There is significant opportunity to further to develop and enhance the tool, particularly if ongoing use by the research community provides feedback on possible future development pathways or contributes by building new features directly.

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