Battery of the Nation

Challenges in modelling the transforming NEM

Highlighting and discussing a range of challenges in making strategic decisions to plan for and design the future NEM

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Foreword

Australia needs valuable and relevant information to plan for the transformation of the National Electricity Market (NEM). Key strategic decisions are needed in coming years and will shape the NEM for decades to come and yet, the same factors that are prompting the critical infrastructure decisions are also the source of substantial uncertainty. This paper highlights the need for modelling as our best option to understand how the system might change, yet also cautions against too much faith in a single set of assumptions, scenarios or even a single modelling approach. Recognising the uncertainty and accommodating broader strategic conversations will be critical in identifying flexible plans that are robust to a wide range of potential futures.

There is a significant challenge ahead to plan for, and implement, a timely and orderly transition and this is amplified by the range of uncertainties and breadth of plausible future scenarios. This requires substantial effort and investment into modelling to try to understand the potential development options of the future NEM. Even with the best intentions and best efforts, there will be uncertainty in the modelling.

To successfully undertake modelling, choices and compromises must be made. The industry, including key stakeholders, need to be able to honestly and openly challenge the validity of existing assumptions, and even design, of the existing models. These technical features may have notable influence on Australia's energy future and it is vital that they are critically assessed.

Some of the uncertainty can be managed through a wide range of plausible scenarios to increase the likelihood that our decision making will be robust to unforeseen outcomes. Similarly, gathering information from a wide range of independent sources will also help expand the breadth of understanding and increase the confidence in strategic plans and market design. These plans need to consider a wide variety of drivers to design for a future that balances a range of stakeholder needs.

Steve Davy

Hydro Tasmania Chief Executive Officer

September 2019

Contents

Executive Summary

Australia's National Electricity Market (NEM) is undergoing a transformation; over coming years, the NEM is expected to be very different from today. Planning for the changing power system requires strategic decision making – and these decisions must be informed to the greatest extent possible.

There are a range of options to inform strategic planning; however, in a rapidly changing system, it is critical to understand and capture the impact of the factors that are influencing the change. 'Common sense', experience-educated guesses and extrapolated trends are all firmly based on the past. Modelling can capture the impact of new and changing drivers that might influence the future power system. Therefore, modelling has the best chance to represent the future behaviours and patterns of development for a transforming or transitioning power system. This information will be critical to strategic planning.

Modelling is the best option we have to try to understand and plan for the future power system – yet models are far from perfect. During a transformation, substantial uncertainty is unavoidable. Moreover, the fundamental characteristics of the market are expected to change, and this is likely to challenge the capabilities of our existing tools.

It is critical that decision makers understand the context and the challenges faced by modelling to be able to best use the information in their decision making processes. The days of being given a simple single answer are probably gone – we need more nuanced information to make decisions based on a wider range of inputs, patterns, projections and plausible scenarios.

The modellers also need to understand the questions that need to be answered. Since no model is perfect, there are always trade-offs to be made. If the modellers understand the decisions that need to be made, they can develop scenarios and tools that are suited to answering those specific uncertainties.

Optimising the plan for the future NEM

At present, most modelling aims to minimise cost, regardless of whether the market conditions might or might not actually encourage that outcome. The theory is that the market will be adapted to deliver such an outcome, but this requires some major presumptions that potentially conflict with each other. For example, developers need to be incentivised to build the least-cost solution, operators need to operate in such a way to achieve the lowest cost and this will occur while the system plans to minimise surplus supply. In any market scenario, minimal surplus (as planned through least-cost modelling) will effectively eliminate competition and allowing for frequent scarcity (high) pricing[1].

Least-cost modelling may help manage costs in a system with notable surplus supply and strong transmission and interconnection. However, the existing NEM is already tight on supply – and so models that were suitable in the past may no longer be appropriate. Insufficient competition is allowing for structural price increases in the market. A pure least-cost plan is unlikely to result in acceptable outcomes throughout a transformation. The theory of a least-cost model relies on sufficient competition to pass savings through to the customer and so ignores wealth transfer between participants (i.e. from customers to suppliers). The reality is that without competition pressure, customers bear the high costs and this will not be politically or socially acceptable.

In reality, there are a wide range of drivers that will influence the way that the market develops and minimising cost is arguably among the least influential. Businesses, politicians and society may all have different drivers and most projects are likely to need to satisfy all three groups of stakeholders. In fact, some of the drivers may have very different outcomes for different individuals or organisations – and maybe even the same organisation at a different point in time. For example, different businesses would likely assess the exact same project very differently depending on their existing portfolio and position in the market. This makes modelling such outcomes incredibly difficult. There are many competing priorities; decisions will be made based on multi-criteria outcomes.

Adhering to the outputs from a single model, regardless of the diligence and capability of the modellers, is likely to result in decisions that are optimised for a single future generation mix and one that is arguably unlikely to occur. This does not mean that the information provided is not useful; it is just that a richer context is needed and optimisation is unlikely to be provided from a single model run, or a single model for that matter.

[1] Note that scarcity pricing is accepted as a normal market behaviour in a well-functioning market. It signals that more capacity is required. However, in the NEM, there is little incentive for incumbents to reduce the scarcity pricing, and there are substantial barriers to entry including limited access to market through transmission and interconnection.

Arising challenges in modelling the future NEM

A large number of system changes are expected over the coming years. This will affect the choice and validity of input assumptions and the designs of the models. This necessitates continued and increased scrutiny of these factors to obtain a suitably broad view of the possible future power system.

There are a range of challenges that make modelling the future NEM more difficult than modelling the power system ten years ago. This paper addresses some of the key challenges.

Substantial uncertainty, particularly since the power system is fundamentally changing in ways which we don't yet fully understand, means that finely optimising a power system design is unlikely to deliver real benefits. In fact, allowing for safety margins is likely to result in better overall outcomes, increasing competition and being resilient to different outcomes or model inaccuracies. One example is the increasing relevance of realistic foresight for a system with increasing variable and energy constrained supply. Perfect foresight is unrealistic and will likely underestimate the total need for storage to keep the system reliable[2].

A defining characteristic of nearly all plausible future power systems is the increasing relevance of weather. Weather is already recognised as the major driver of demand. Weather is projected to be the dominant cause of supply variation (through wind and solar) and therefore also driving the requirement for 'sustained capacity'. Extreme weather may impact the operating characteristics of existing thermal generators and transmission lines – particularly in terms of bushfire risk. This all means that the power system will be driven by physical external forces that are correlated in space and time. Understanding the nature of weather variability is likely to be critical in understanding and planning the future NEM. The existing coarse temporal resolution capacity expansion models generally assume unlimited fuel and will not deliver the most valuable outcomes in a highly variable system. Understanding energy constrained storages and the benefits of diversity will be critical for efficient planning and development.

[2] Hydro Tasmania, 2019, *Operation of storages without perfect foresight*: https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state

Much of the focus for the transformation seems to be on the supply-side, yet demand is also likely to change substantially. Demand response is expected to become more widely used to help manage the super-peaks and possibly even actively manage utilisation patterns. Electric vehicles are highly likely to impact the supply-demand balance, yet the exact nature of the change is as yet unclear. Even industrial demand may change – there is a risk of old industry retiring, but also an opportunity to develop new industry on the basis of Australia's competitive renewable energy.

Even the market structure itself is uncertain. There is a process underway to review the market design and this raises substantial uncertainty when trying to plan for the future NEM. A range of notable (and plausible) changes to the market are discussed, all of which would markedly change the development of the future NEM. Trying to model all market changes would be almost futile, yet ignoring that market change may occur is creating a very large blindspot.

Making good decisions in the face of growing uncertainty

While modelling is intended to be impartial, all models are imperfect: compromises and choices must be made. There is a degree of 'art' in model design, setting assumptions and devising suitable scenarios. It is better to recognise and accept the uncertainty, looking for information to support decisions rather expecting a definitive outcome. Modellers must be given the confidence to express the shortcomings of their model outputs and the freedom to explore wide-ranging scenarios to understand plausible outcomes[3], not just those that are probable or preferred. Equally, strategic decisions makers must avoid the temptation to make a single 'bet' on a deterministic outcome from a single model. Instead, using rich information from a variety of sources will help identify robust options that could be valuable across a range of potential futures and plan for a system that is likely to support Australia's ongoing economic growth – regardless of what occurs in the future.

[3] As an example, conventional wisdom in the NEM is that demand growth has largely flattened out – yet McKinsey and Co presented a view at Australian Energy Week that through widespread electrification of transport, industry, cooking and heating Australia's electricity demand may triple by 2050 – even without notable industrial growth: https://reneweconomy.com.au/cheap-solar-and-wind-can-re-boot-australias-economic-advantage-71231/. This is unlikely to be considered a central scenario, but is plausible and should be evaluated to assess the potential impacts and responses for the system.

1. The future is uncertain and different to today

Australia's National Electricity Market (NEM) is transforming. Coal-fired generators are aging and expected to retire in coming years due to economic, safety and technical considerations. Today, coal is by far the dominant producer of energy for the NEM and as these generators retire, they will be replaced with the lowest cost forms of new energy: wind and solar. This will change some of the fundamental characteristics of the NEM. To be prepared for the change, Australia has been undertaking substantial efforts to try to better understand the future.

1.1 *"Prediction is difficult, especially about the future."* — Danish proverb

To prepare for a very different future, it is important to build an understanding of what that future may look like. Three high level approaches are presented below.

1.1.1 Judgement, experience and 'common sense'

We need to forecast future situations in almost every part of life, and most of this is based on judgement. Mostly these judgements are based on sound information gained from experience or 'common sense' derived from past events. In many cases, this is a highly effective way to manage life through fast and effective decision making.

> *XYZ Corp is a new tech company with interesting products, and new tech companies can be good investments.*

However, in reality, these forecasts are little more than 'gut feel', and quickly lose their value when circumstances are different from our past experiences.

1.1.2 Trend analysis

Explicitly analysing past data can be another way to forecast the future. Patterns may be discernible in the data that can be a useful predictor of future outcomes. Trend analysis works on the assumption that the underlying features and drivers of the future are the same as the past. In many situations this is valid, and in fact forms the basis of empirical science: observed behaviour is the best predictor of future behaviour.

> *XYZ Corp has had 10% growth for the last eight quarters and its share price has been doubling every year – it looks like a great investment!*

However, sometimes a situation may have changed and the trend is no longer valid. Trend analysis has limited value when the core drivers of a situation change.

1.1.3 Modelling drivers of change

Bottom-up modelling of behaviours and outcomes can provide valuable insight to future situations. Modelling uses expert knowledge to build up credible scenarios and does not require that the drivers and trends of future behaviour are the same as those in the past.

> *XYZ Corp has been sued for patent infringement and can no longer sell its flagship product. Without this product, the share price is expected to fall sharply.*

However, the nature of modelling means that it is complex to undertake; to produce useful outcomes the drivers of future behaviour must be sufficiently well represented. Some models can also be seen as a 'black box' with little transparency or context. Expert knowledge is often required to understand information about how models operate, and there is often some element of proprietary model design which is not public information.

A model is also limited by technical/computing constraints, and the modellers' understanding of possible drivers. To extend the example of XYZ Corp, it is possible that the share price was maintained due to an unexpected social movement that was not captured by the model.

1.2 Developing relevant information to advise future choices

The NEM is undergoing disruption, making it difficult to have confidence in understanding the future power system and market. No information source will give a flawless forecast to inform decision making. Judgement will be flawed: it is based on past experience that does not necessarily reflect the future. Trend analysis will be flawed: the characteristics of the system will change. Even modelling may be flawed because the information and behaviours used to develop and test the models in the first place may no longer hold true. Nonetheless, of the three approaches to prediction, models give us the most scope to understand the impacts and consequences of new drivers. Ironically, the rapidly changing market results in an increased need for action and thereby decision making, right at the time of greatest uncertainty.

Developing valuable insights will be critical, and yet solely relying on existing analysis configurations may produce outcomes that are not representative of all plausible futures. A broader, more strategic, view needs to be considered. The purpose of the information will influence the design of the modelling approach. While the power system is transforming, decisions need to be made about potential market structures, potential investments in supply (including potential underwriting) and potential investments in transmission.

To develop relevant and useful information, it is important to first understand the purpose of the information and how it will be used to support decision making.

Modelling of long-term developments in the NEM (e.g. regulated investment tests and integrated system planning) typically optimises on the single criterion of minimised cost. The optimisation targets the minimal total cost to provide the required power, regardless of who bears that cost. This is underpinned by an implicit assumption that market design will incentivise the least-cost solution, and that competition will prevent excessive profit margins and minimise cost to consumers. Additional criteria can be captured as constraints (e.g. a limit on the total amount of a certain type of generation which can be built or operated), or as costs (e.g. a carbon price).

The reality is that there are a variety of drivers that will affect the development and operation of the future market. It will not be built, nor operated, in a way that matches modelled least-cost outcomes. In fact, while minimising cost to the system may be a useful economic concept, it is arguably one of the least powerful drivers in decision making for future investment. The reality is that there are many competing priorities and decisions will be made based on multi-criteria outcomes, demonstrated in Figure 1. This is particularly true for supply-side options, which today are built by the private sector to meet the developer's objectives, rather than being subject to a regulatory investment test.

Decision makers run the risk of being misinformed if they are not aware of the narrow scope of the optimisation. Adhering to the outputs from a single model, without considering a broader context, is likely to result in decisions that are optimised for a single future generation mix and one that is arguably unlikely to occur. However, this does not mean that the information provided is not useful; it is just that a richer context is needed.

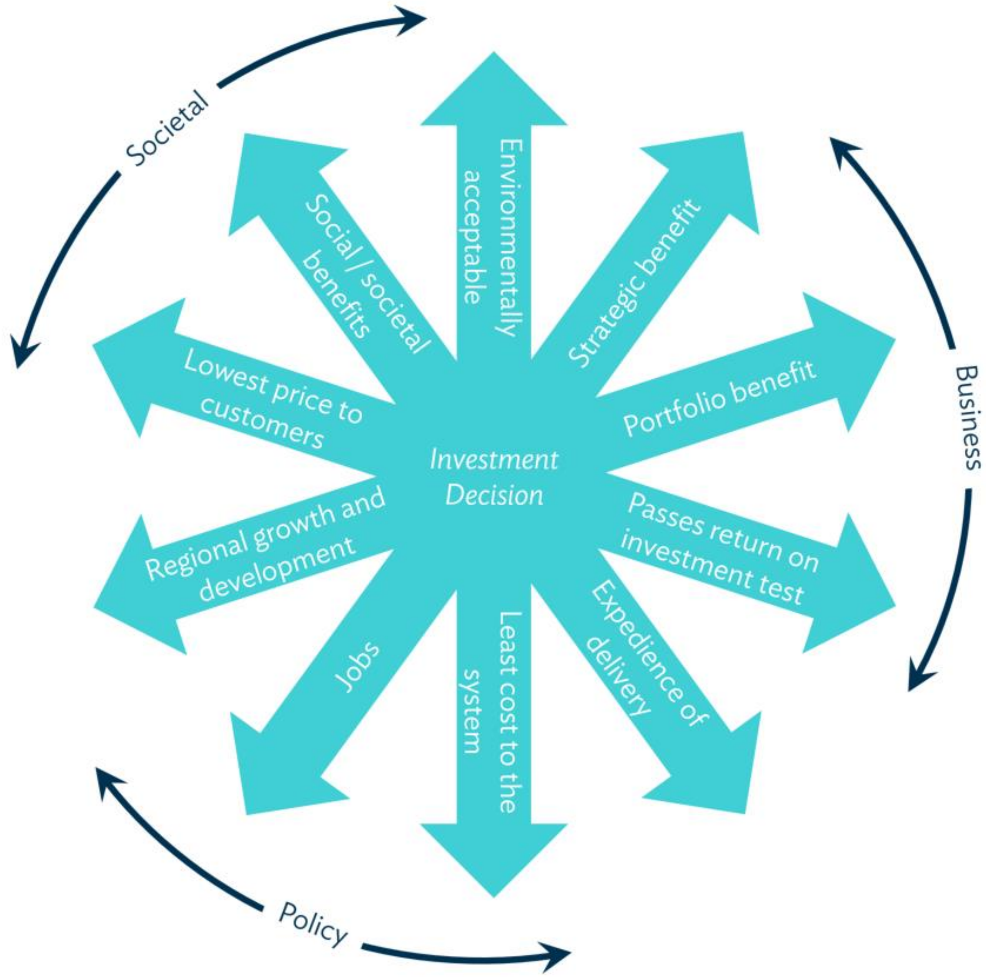

Figure 1. A demonstration of various policy, business and societal drivers that may change the relative attractiveness of an investment (or retirement) decision

2. Better understanding the modelling process

Modelling is the process of developing a simplified representation of a system to gain understanding about the features and behaviours of that system under certain conditions. A model can be used to analyse – and experiment with – the responses of a system to changes in the surrounding environment, without having to manipulate the system itself. Through modelling, we can ask 'what if' questions that would otherwise be practically impossible to answer in the real world.

Models take a variety of assumptions, input data, and knowledge about how different factors interact and turn this into a story – a view of the world that the model represents. A common adage for modelling is "garbage in equals garbage out." This is usually applied as a caution to carefully and thoughtfully select the input data and explicit assumptions. However, it is equally valid in terms of model design and operation. It is also important to continuously test validity: a model which was useful in a previous context may lose value as the environment changes.

In any real-world context, there are usually additional drivers and information that are not adequately covered by the model, and in that sense a model can rarely provide a definitive answer. Understanding this limitation should not devalue the information, but instead ensure that the information is considered in a broader context.

2.1 Modelling requires trade-offs

It's important to understand what models can and cannot do. All models are imperfect. Modelling tries to describe a situation based on the assumed conditions and simulated behaviour. To do this in a meaningful way, simplifications are necessary. A model without simplifications and assumptions isn't a model – it's called the real world.

The potential complexity of a mathematical model is only limited by the available computing power, which is getting faster and cheaper every year. Models are continually being improved; yet every improvement is a trade-off in terms of what uncertainties to resolve, weighed against the time and cost to operate the model – especially while facilitating analysis of a wide range of scenarios.

A key skill for people developing and working with models is in balancing depth versus breadth of understanding. Experts must decide which simplifications are acceptable, which features of the system may need to be represented in the future and how wide a range of situations need to be explored.

When using model output data, it is therefore important to understand that assumptions, compromises, and model designs are all choices. The development of a good model is a mixture of science and art.

Part of what makes modelling hard is that we build our knowledge based on the past, not on the future. A very good model might describe the past very well, and while this increases the likelihood that it will also represent the future, it is by no means sufficient evidence that it will.

Humans have a predilection to believe that past experience is the best predictor of the future – this well-documented feature of human thinking is known as familiarity bias. Modelling rapid change is difficult – not just technically, but also credibly and emotionally. It is much more difficult to convince ourselves and our peers that the future will be fundamentally different from today, than it is to continue to project more of the same.

2.2 Models are not good at…

The statistician George Box is often quoted as saying: "All models are wrong; some are useful." While at first it's tempting to be appalled at the idea that "All models are wrong" and to reject modelling outright, the real message is that we need to understand the limitations of models and modelling in order to benefit from their use.

All models are limited in their scope and usefulness. A model that provides very specific and detailed information about one aspect of a situation or scenario may tell us little about another aspect, even if it is seemingly related. It is appealing to take the modelled outcomes at face value, especially if those outcomes agree with our expectations. It is important to remember this when presenting and interpreting modelled results.

We must remember that (despite best efforts) models cannot be relied upon to be entirely unbiased, independent, or objective. To some degree, all models encode the inherent biases, knowledge, and ignorance (lack of knowledge) of their creators. Modellers work very hard to try to minimise the subjectivity and biases inherent in their own models, but it is impossible to completely eliminate the subjectivity of the many choices made when developing and operating a model.

One way of partially overcoming the modelling bias is by using a range of independent models, called an ensemble. If the outcomes from a range of largely independent models are in agreement, then it is reasonable to have more confidence in those outcomes. However, if models, modellers, assumptions or inputs share common biases, blind spots or history, the agreement of outcomes is likely to reinforce the shared belief: whether it is accurate or not.

The key message here is that models are not perfect, and are limited in scope. We need to be aware of this when interpreting and understanding modelled outcomes.

2.3 Models are good at…

Acknowledging that all models have limitations, it's worth noting where modelling does give us significant benefits.

Modelling helps us to validate and communicate expert opinions about plausible outcomes in a relatively transparent and repeatable way. This allows experts to challenge one another's assertions constructively based on core assumptions, rather than being constrained to difficult-to-resolve disagreements about high-level outcomes and opinions. Modelling can help us to unpack what we can agree on and be explicit about the things we still disagree on or are unsure about. Crucially, it also provides information about the implications of the areas of disagreement.

Modelling gives us the ability to explore many plausible scenarios. This allows us to build up a 'big picture' view of the system and the plausible outcomes from changes to that system. Using multiple scenarios also allows us to test the robustness of outcomes. If a particular outcome frequently occurs across a wide range of scenarios, then we could reasonably conclude that it is a likely outcome. This tends to be much more reliable than putting too much weight on any one 'answer' or scenario.

One area where models excel is in providing, often unexpected, insights into the relationships between things, including their degree of influence. For example, we might think that a particular driver of some system is very important, and therefore the assumptions we make that influence that driver are critical. A model might show us that the projected impact of that driver is actually much smaller than expected. In such a case, modelling helps focus our attention on the inputs and assumptions that really matter and pay less attention to those with little impact on the outcomes.

Modelling also allows us to discover some of our implicit assumptions and biases. If two models of the same system produce different results for the same inputs, exploring the reasons for the differences can uncover underlying divergences in the models. This can provide insight into the results, prompt improvements to the models and highlight matters of disagreement that may be useful to resolve.

Bearing all the caveats in mind, modelling allows us to explore complex systems in ways that would otherwise be difficult or impractical. The results can inform our decisions and increase our understanding of the systems they represent.

3. Modelling the future power system

The power system has been described as the most complex machine on earth. Every load, every generator and every network element interacts with all others, at sub-second speed, 24 hours a day, 365 days a year. Many components are operated by people, all with different motivations and goals. Yet the entire system has to be in near-perfect balance at all times.

Modelling this system is incredibly difficult and computationally expensive, and the simplifications and modelling compromises require deep and broad expert knowledge to produce useful outputs.

3.1 Updating models to reflect emerging drivers

The complexity of the system is also increasing as the power system transitions to include more new technologies with different characteristics. While market models of the power system have been refined over many years to give an elegant and useful representation, new drivers are becoming increasing prominent.

Significant work is underway to update model assumptions and include new drivers as relevant information is developed. For example, the Australian Energy Market Operator (AEMO) has recently been updating its assumptions about the forced outage factors. In August 2018, its annual Electricity Statement of Opportunities[4] report included marked increases in the assumed forced outages, with Victorian brown coal and NSW black coal forced outage factors rising to more than 5%. Open cycle gas and steam turbine forced outage factors also saw significant increases. In June 2019, AEMO reported on the accuracy of its forecasting in light of summer 2019 outcomes[5]. This report observed that Victorian brown coal availability had been a key cause of summer load shedding. It also observed that,

> *"… with respect to brown coal, the trend is so strong that it can no longer be considered a statistical abnormality."*

It concluded that for future forecasts,

> *"… where there is a strong trend, further consideration will be given to better capture changes attributable to equipment ageing and/or business process changes."*

Another example is the emerging importance of energy storage in the system. In December 2016, AEMO projected[6] that the NEM in coming decades would be characterised by retiring coal generation being replaced by a mixture of new wind, solar and gas. Just 19 months later, falling costs of renewables and storage, along with rising gas costs, led to a projected energy mix[7] with more than double today's wind generation, 15 times as much utility-scale solar, and 29 times as much utility-scale storage supply. In response to this change in anticipated supply mix, AEMO have been working with industry experts to better understand storage opportunities and characteristics. While significant progress has been made, this is still a work in progress. For example, analysis[8] shows that the standard assumption of perfect foresight has the potential to significantly underestimate the amount of storage needed.

While progress has been made in reflecting the changes in the power system, this has added substantial complexity to the model. There is also still significant work required to reflect other drivers and capture their impacts. Figure 2 illustrates the development of the complexity in the model over time.

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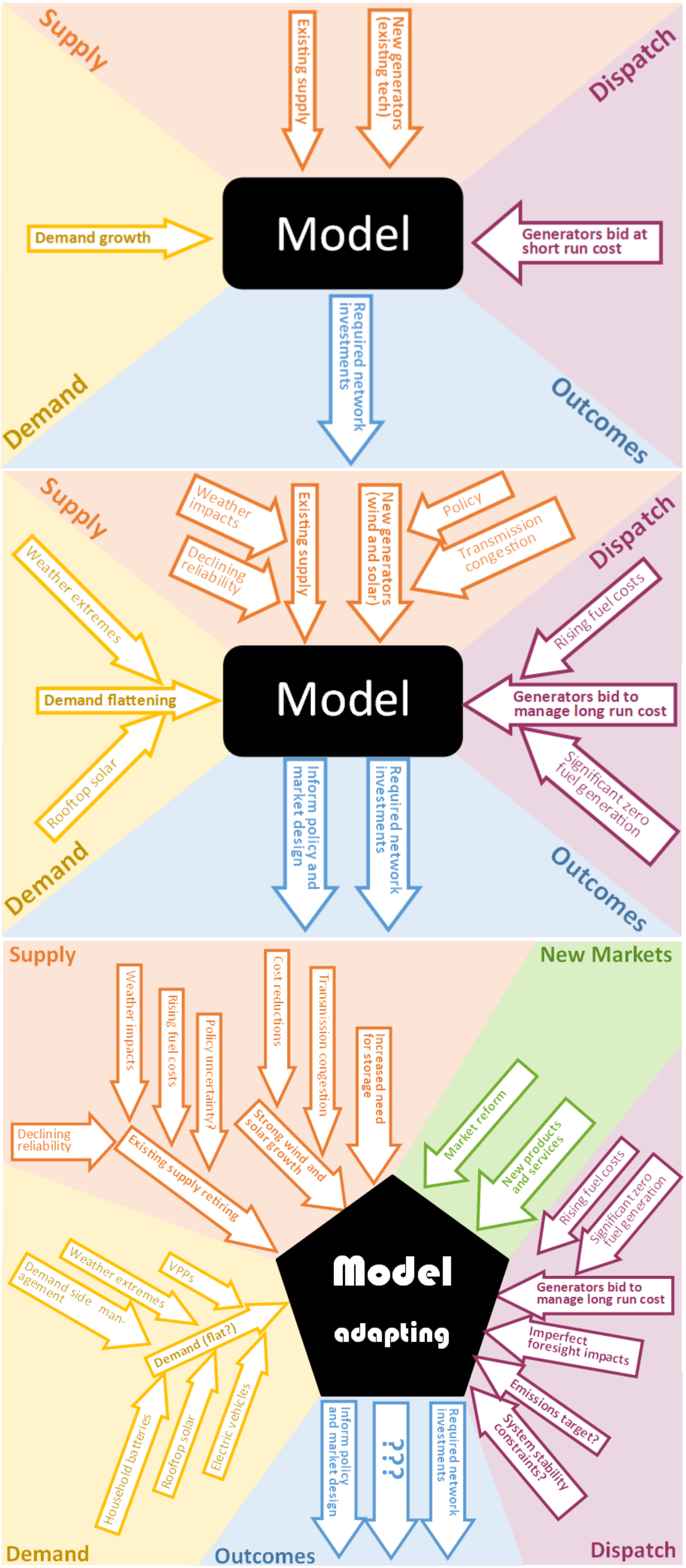
4 AEMO, *2018 Electricity Statement of Opportunities: A report for the National Electricity Market:* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf

5 AEMO, *Summer 2019 Forecast Accuracy Update: Review of the 2018 Electricity Statement of Opportunities Forecasts:* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Accuracy-Report/2019-Summer-Forecast-Accuracy-update.pdf

6 AEMO, *National Transmission Network Development Plan for the National Electricity Market, 2016:* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Report/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf

7 AEMO, *Integrated System Plan for the National Electricity Market,* 2018: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf

8 Hydro Tasmania, 2019, *Operation of storages without perfect foresight*: https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state



Past
A simple and elegant model with relatively few drivers and uncertainties

Present
A more complicated model that is still fundamentally the same at the core, but is needing to consider many new drivers and sources of uncertainty.

Future
A projected representation of a future power system model representing a wider range of drivers and uncertainties. The core of the model has also been adapted to better handle the new and changing requirements.

Figure 2. The demands on electricity market models are increasing and the models are needing to adapt

3.2 The state of rapid change we're in makes modelling harder

While the number of factors we need to capture is increasing model complexity markedly, the single biggest challenge to electricity market modelling is the rapidity of the change and the inherent uncertainty that comes with it.

The existing models were developed at a time when change was incremental, and relatively slow. We could model the impact of changes to a single transmission line or change in supply or demand in relative isolation.

We are now trying to understand the implications of significant transformation. This is not just the retirement or introduction of a single power station, but the steady exit of coal-fired generation technology – along with the characteristics around which our system was designed. This is being replaced with technologies with fundamentally different characteristics that will influence the way the market operates. In fact, the change may be sufficient to necessitate a fundamentally different market structure; one which is not represented by the existing models.

This leads to a vast array of possibilities and choices, the interactions between which are complex and difficult to predict. As such, modelling needs to move from a state of merely 'describing' the future to being seen more explicitly as a tool for helping to understand and design the future system.

Simultaneous optimisation across many interacting variables is difficult, particularly when considering a complex and uncertain context. This is true for models and it is also true for the human decision makers that need to use their outputs. The large number of moving parts in the next decades increases the impact of input assumptions and model designs. This necessitates increased scrutiny of these key factors that influence outputs. However, the degree of uncertainty also calls for increased use of parallel analyses and a strategic overlay to sense-check model outputs and identify potential blind spots.

3.3 Informing and facilitating timely and effective decisions

During the rapid transition of the power system, we can't afford to delay decision making while more or better information is obtained. We also can't afford to just rely on the experience we have developed in today's system or extrapolate the existing trends. This leaves us the option of using models to inform critical decision making.

Having recognised that no model will provide a perfect prediction of the future, but also recognised the absence of better sources to rely upon when making decisions about the future, the question becomes how to make best use of the information available to us.

We must model a range of scenarios with a range of assumptions and model designs, and then use these to identify future trends, patterns, outcomes, and decisions which may serve us well across a range of multiple plausible futures.

4. Some specific challenges driving uncertainty

As discussed, the power system is complex, and expecting to model every detail is unrealistic. However, as the power system changes, certain aspects will become crucial to represent, which until recently have been acceptable to neglect or simplify.

The following section provides a more detailed discussion, highlighting a number of aspects that will strongly affect planning for the future market, yet are not sufficiently captured by the least-cost models predominantly used today. This is not intended to be a criticism of approach or diligence of today's power system modellers – some of these aspects would be infeasible to model, others are being worked upon and the importance of some are only just emerging. Decision makers simply need to be aware of these challenges, and take them into account when considering and using the outputs from modelling.

4.1 Over-optimisation

Optimisation is used to create the least-cost system design in market modelling for regulatory investment tests, the AEMO's ISP and other such planning efforts. The nature of the cost optimisation means that all margins and surpluses are optimised towards zero (except for margins which are explicitly enforced in the model as constraints). If the modelling perfectly captured all asset/market behaviours and the scenarios were fully representative then this may be beneficial – but least-cost modelling is explicitly, and consciously, different to trying to model the actual market behaviours.

4.1.1 Optimisation determines a solution with small margins for variation

This section highlights some specific challenges associated with over-optimisation. More broadly, uncertainties tend to undermine a finely-tuned optimisation and most of the challenges raised throughout Section 4 could raise concerns about over-optimisation.

Optimisation will select a single outcome as the best, regardless of the difference in value compared with other potential solutions. For example, building an inefficient generator with a high operating cost may produce the least cost outcome in the model. However, it may be very sensitive to a wide range of assumptions and simplifications. Whereas an integrated solution that produces substantially more low cost energy may be of comparable cost and much more robust to model uncertainties – yet may not be selected because optimisation considers the simplifications and assumptions to true.

Scenarios help manage this risk, particularly if considered as a suite of related outcomes rather than a series of individual results. However, even scenarios typically only consider varying assumptions – often limited to a small range of variability. They very rarely consider different model designs that may represent future behaviour differently. It is crucial that we are careful of short-term fixes that may turn out to be expensive or inefficient in the long term.

Having some strategic oversight of the choices the model makes could encourage more robust choices, but this is relevant for all optimisation decisions. This is particularly important during an uncertain transformation. For example, the 2018 ISP[9] projected that ~2000 MW of (mostly pumped hydro) storage would need to be commissioned every year from 2035 to 2040. Over a five year period, Australia would need to construct more than double its existing (pumped and conventional) hydro capacity. This is equivalent to a Snowy 2.0, or six to seven smaller (300 MW) pumped hydro facilities every year. This build rate is likely to be extremely difficult to achieve. Strategically, it is likely preferable to bring such investments forward to reduce the risk and increase competition.

4.1.2 Limited reserves will drive scarcity pricing

It is well established that scarcity pricing is a valid market characteristic and it is necessary to send signals for additional investment. Least-cost modelling optimises to the point that the system would be constantly operating with minimal excess capacity and therefore scarcity pricing would be the norm. The system may be optimised for least cost to operate, but there would be notable wealth transfer between customers and the suppliers. The Integrated System Plan is increasingly being held to the rules for a regulatory investment test (RIT) and a RIT explicitly excludes wealth transfer (including from consumers) from the calculation[10]:

> *Funds that move between Participants count as a wealth transfer and should not affect the calculation of the final net-benefit under the RIT.*

This establishes that the RIT only considers the cost of operating the system – not the final cost to the consumer. If there was sufficient competition, this may be a reasonable outcome – yet the nature of optimisation will drive out all excess – and with it, drive out competition to try to be dispatched. This is illustrated in Figure 3 using the neutral scenario data from ISP 2018 as a starting point. Not all capacity will be available when needed – both because of outages and because of physical limits to operation. The yellow band in the figure shows the loss of a large coal station and then over time, the increasing penetration of energy constrained supply. For example, a two hour storage simply cannot supply energy for 16 hours overnight while the sun is down. That is not what short duration storage is designed to do, but it is important to recognise the changing nature of the dispatchable supply options.

[9] Australian Energy Market Operator 2018, *Integrated System Plan for the National Electricity Market,* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf

[10] AER, *Application guidelines for the regulatory investment test*, December 2018, https://www.aer.gov.au/system/files/AER%20-%20Final%20decision%20-%20RIT%20application%20guidelines%20-%2014%20December%202018.pdf

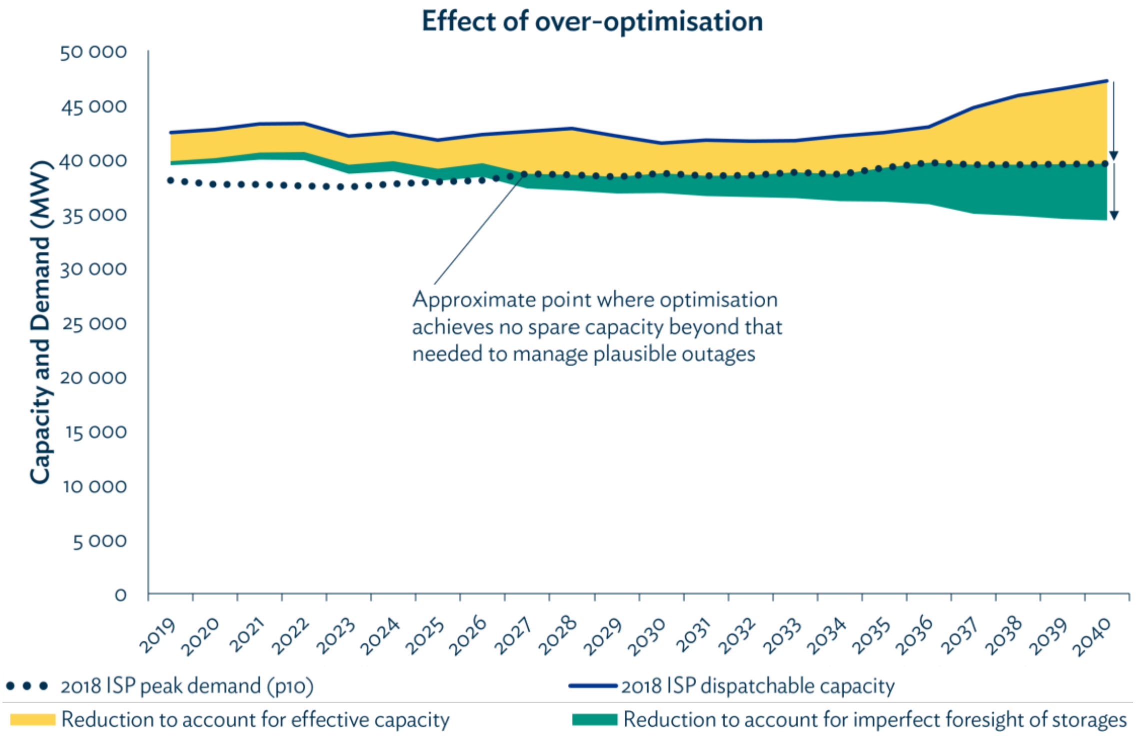


Figure 3. A demonstration of the effect of optimising to a least cost outcome

It is worth noting that interpretation of Figure 3 might indicate that there is sufficient capacity in the market[11] – yet we are experiencing high energy prices driven by relative scarcity and lack of competition. There is little surplus capacity in the market and consequently black coal operators have been able to achieve a structural price shift[12]. Over the next few years, the capacity projection rises, but then starts to reduce towards the optimised point of near-zero surplus.

4.1.3 Perfect storage optimisation

Figure 3 also shows the potential impact of reduced storage effectiveness to account for the impact of imperfect foresight. The paper *Operation of storages without perfect foresight*[13] finds that the operation of energy storages is significantly impacted when real (imperfect) forecasts are used for decision making, rather than the typical model assumption of perfect foresight. The analysis also found that storages with different durations are impacted differently by imperfect foresight. Based on these findings, Figure 3 includes a discount to the effectiveness of batteries, short duration pumped hydro and the existing longer duration pumped hydro of 30%, 20% and 10% respectively (shown in the green band). By 2040, the reduced capability of storage (including residential storage) could reduce the effective capacity in the plan by over 5000 MW. Additionally, there are reasons to believe that this is conservative – forecasts of the system will become more challenging with more variable energy sources and the forecast errors from across the system are likely to be highly correlated. Shorter duration storages may all be found empty at a time when they are needed. The highly optimised outcome is unlikely to deliver the intended benefits.

[11] It is worth noting that some of this capacity is constrained behind limited transmission and interconnection.

[12] AEMO, *Quarterly Energy Dynamics Q4 2018,* February 2019: https://www.aemo.com.au/-/media/Files/Media_Centre/2019/QED-Q4-2018.pdf

[13] Hydro Tasmania, 2019, *Operation of storages without perfect foresight*: https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state

4.1.4 Allowing partial generation, but not partial transmission, developments

Mixed integer linear programming is used to optimise the system plan. The transmission expansion and generation retirements are modelled as single units that happen all at once. Generation expansion is modelled more continuously, with partial developments being allowed. Post-processing is used to convert partial developments into more realistic outcomes, although this action also moves the plan away from the optimised outcome. This approach suits incremental changes, but does not recognise transformation, nor the benefits of synergies between options. Sometimes the most effective outcome would change if partial developments were not allowed. The optimisation doesn't make value judgements; if something is $1 cheaper, it is considered more optimal for a given scenario or suite of scenarios. This typically rewards deferring transmission investment (especially considering net present value economics) rather than building to accommodate the uncertainty of a transforming system.

4.2 Capturing the impacts of variability on different time scales

The existing market modelling software is well-designed to optimise capacity-constrained supply options with plentiful fuel[14]. However, the market projections indicate that fossil fuel-based supply will exit the market and their replacements will be variable renewable energy (wind and solar) backed-up by flexible supply. Moreover, much of the flexible supply is projected to come from stored energy (e.g. conventional hydropower, pumped hydro energy storage and electrochemical batteries). The existing models and methodologies are not designed to optimise the operations of such assets that are sensitive to variation over time. Modelling with high quality, high temporal resolution data is required to understand the likely optimisation of this supply mix. To properly represent such a system, this must be part of the long-term development planning rather than used as a final step 'sanity check'.

4.2.1 Capacity expansion (outlook) modelling with time-varying supply

AEMO's market modelling approach, outlined in their process flow diagram in Figure 4, shows a multi-step process with some feedback loops. At the heart of the modelling process is the 'capacity outlook model'. This is the engine which determines the capacity requirements in the future NEM. However, the nature of needing to optimise for a wide range of choices over many years means that this model uses coarse resolution data. The final plan is then tested with a time sequential model that simulates the operation on an hourly basis. Recent advancements have taken the output from the time-sequential model and fed that back into the gas supply model (and therefore affecting the gas metrics in the capacity outlook model), yet there is no feedback of the balancing requirements in the electricity market.

14 Fuel is available provided you are willing to pay.

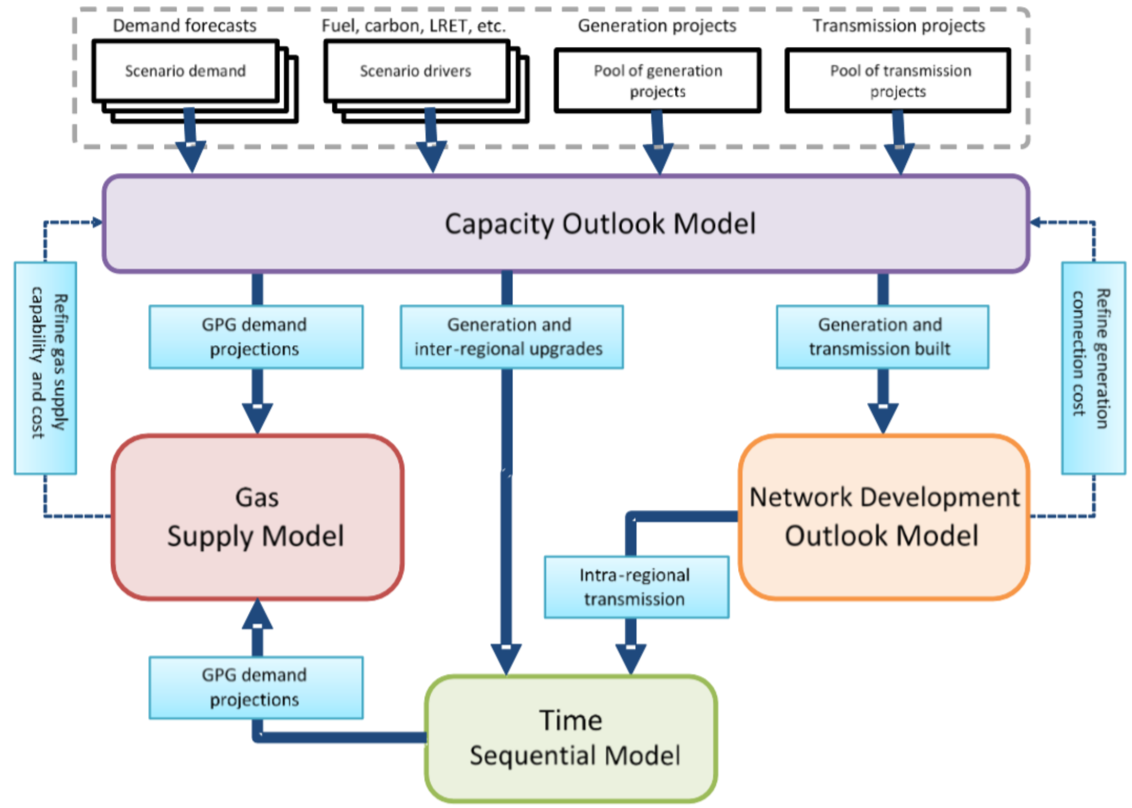


Figure 4. AEMO's market modelling process flow diagram[15]

There are a range of time-based simplifications used in the capacity outlook/expansion model compared with the time sequential model:

- The data is aggregated into a series of 'load blocks' that are typically many hours in duration[16]. Averaging out variation within these time blocks substantially underestimates the variability of some supply options and the need to balance those sources with flexible generation or storage.
- A particular challenge is understanding the value of diversity, and thereby selecting the right resources. Wind, solar and demand all vary on reasonably short timescales – supply and demand can vary greatly even over a single hour. Without inherently and directly capturing this variation, the model will not accurately represent value of diversity in moderating variability. More strongly connecting regions, particularly regions with different demand or wind generation profiles, is likely to have a substantial value in terms of diversity – but this value may not be recognised by coarse resolution data in a capacity outlook model.
- In previous modelling, monthly aggregated inflow data has been considered sufficient to represent the operation of hydropower stations. However, this is likely to overestimate the capability of hydropower stations and therefore underestimate the need for additional

15 AEMO, *Market Modelling Methodologies – For Forecasting and Planning the National Electricity Market and Eastern and South-Eastern Gas Systems*, July 2018, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Market-Modelling-Methodology-Paper.pdf

16 AEMO has recently developed the detailed long term (DLT) model, an additional capacity outlook model that operates over a shorter time horizon, but with more detail through shorter load blocks. This is an important improvement, although, even with this improvement, the load blocks are still several hours long and still cannot suitably represent the variability of wind, solar or demand.

flexible supply. In reality, most hydropower systems have substantial operational constraints that limit the ability for the assets to operate ideally. This includes environmental constraints, tunnel and energy transfer constraints between storages[17] and storages of limited size. All of these factors affect Australia's hydropower assets, with some much more affected than others. These limitations force hydropower stations to generate more at some times and less at others. At times, water inflows can be greater than can be used in the power station or stored, and water is therefore 'spilled'. Modelling monthly average inflows would produce very little spilled energy as this energy would be available uniformly across the month to be used when needed.

- During the capacity outlook stage, the power system was modelled as interconnected regions, simplifying the cost and complications of intraregional transmission – even though the majority of transmission costs are at the intraregional level. This underestimates the true cost of solutions, particularly in terms of accessing new supply options; in comparison this makes the relative cost of interconnection appear more expensive. If underestimating the cost of intraregional transmission is combined with the lack of ability to resolve the benefits of diversity, this makes interconnection substantially more difficult to value appropriately. This is particularly relevant where interconnection costing considers the cost of intraregional upgrades which may be required in the absence of that interconnection.

Linear programming is used in an attempt to create an impartial optimisation – but it is the *modelled* performance that is optimised. The simplifications in the model mean that the real power system may perform quite differently, particularly in the future where time series data is expected to be more important. The optimised model outcome may be quite different to an optimal outcome in reality.

Unfortunately, each time-based simplification underestimates the value of diversity from variable renewable sources and overestimates the smoothness of the variable supply. This also underestimates the value of both interconnection and storage. Because of this, the selected generation mix, and therefore the transmission required, is not necessarily the most valuable and cost-effective outcome.

The power system must maintain the supply-demand balance at all times. The emerging challenge will be supplying during (reasonably common) periods of wind and solar scarcity. Diversity will help manage this challenge, supported by options which can flexibly supply electricity for extended periods.

It is possible that it would be better to reject the sole use of the optimisation step and instead strategically create development scenarios and test the outcome with a time sequential model to determine value and cost effectiveness. This approach is increasingly being considered by system modellers and operators, both nationally[18] and internationally[19], on the basis that the time sequential model is fast to run and many scenarios can be developed and tested much faster than a single optimisation run – allowing a richer range of scenarios and potentially a more representative optimised outcome.

[17] The constraints, such as tunnels, connect large reservoirs to smaller headponds, yet because these conduits are limited in their ability to move water and frequently create bottlenecks, limiting continuous operation.

[18] There is work in this space being undertaken by the Australian National University as part of the Energy Transition Hub research collaboration, https://www.energy-transition-hub.org/

[19] The Western Electricity Coordinating Council (USA) explicitly use scenario planning rather than expansion modelling for their longer-term planning for the Western Interconnection – an interconnected power system with an annual demand approximately 4-5 times greater than the NEM.

4.2.2 Changing the understanding of plausible 'contingencies'

In today's power system, supply challenges are mainly associated with short-duration events caused by extreme heat and/or asset failures. To manage system security, options are needed that can rapidly respond to short-duration events while other supply options are brought online. This approach typically accounts for an 'N-1 contingency' where the system should be resilient to the loss of the single largest asset. However, with substantial variable renewable energy, it is plausible that the N-1 contingency should be overlaid with uncertainty of variable renewable generation. In fact, at times, the uncertainty of the variable renewable generation may be the largest credible change in the power system.

Climate change could also impact the credibility of large contingencies. Many power system assets experience capacity reductions in high temperatures, or even have hard temperature limits above which they cannot operate. If extreme temperatures impact many system components (including generators and transmission elements) at the same time, this could cause a significant system shortfall, in a scenario highly likely to be correlated with maximum demand. The risk of bushfires threatening critical transmission corridors is also becoming an increasingly accepted credible threat and one that may change affect multiple lines at once.

4.2.3 Changing system requirements

The International Energy Agency (IEA) is highlighting that as the penetration of variable renewable energy increases, the flexibility requirements will change. Table 1 presents a view of phases of increasing variable renewable energy penetration and the subsequent priorities for flexible supply.

Table 1. An excerpt from IEA paper *Status of Power System Transformation 2018*[20] showing the varying requirements for flexible generation changing with variable renewable energy penetration

Phase	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Becomes a main priority	Typically no system flexibility issues	Short-term flexibility	Short-term flexibility Medium-term flexibility	Ultra-short-term flexibility Medium-term flexibility Long-term flexibility	Long-term flexibility Very long-term flexibility	Very long-term flexibility

Australia is presently considered to be in Phase 2 and much of the attention is on managing short-term flexibility. Australia is rapidly moving towards Phase 3 and through the changes over the coming decade is likely to enter Phase 4. Unlike most power systems, the NEM will not be able to share these challenges through interconnection with neighbouring countries. Medium-term and long-term flexibility will be needed. The definitions from the same IEA report say that hours to days (maybe even months) of flexible supply will be needed to manage the power system in the later stages of the transition to renewables.

[20] IEA, *Status of Power System Transformation 2018*: https://webstore.iea.org/status-of-power-system-transformation-2018

4.3 Changing demand patterns

One of the significant changes to the NEM in recent years has been the nature, volume, and shape (time-variance) of electricity demand. For many years, future planning (and the modelling work underpinning it) had a fairly straightforward view of demand: total demand would increase over time, as would maximum demand; the daily profile was relatively static; and demand management was small enough to be ignored. This meant that the future needs for the NEM were likewise reasonably conventional: build a mix of new generation and network infrastructure to meet projected total and maximum demand.

Over the last decade, previous assumptions about future electricity demand have been shown to be some distance from reality. It is now expected that total (average) demand will be largely constant, or may even decline while the maximum demand may continue to increase.

The changing nature of future electricity demand also means that modelling the future has become much more difficult. Significant effort is required to produce credible projections of future demand which forms a key input into (for example) detailed dispatch modelling. If the projected demand is not credible, then the modelling outcomes are not credible either. Substantial work goes into continuous improvement of the demand models, yet the drivers of demand are changing rapidly and this makes the task challenging.

4.3.1 Demand profiles

The daily variation has already changed due to the impacts of rooftop solar, and it is expected to change even more drastically over time due to further solar penetration, batteries and electric vehicles. Customer behaviour, demand side participation and other currently unanticipated technologies may also notably influence the demand patterns.

Demand side response, from individual households to large-scale industrials, is expected to form part of the future options to help manage the supply–demand balance. However, the magnitude and availability of cost effective demand side response is unclear. Virtual power plants (VPPs) may combine behind the meter batteries and flexible demand to actively engage in the market. However, since the mechanisms for this participation are not yet clear, the responses are not yet clear either. It is likely that some of the strongest benefits would come from distribution congestion relief. However, the ability to respond rapidly and (at present) independently from the market operator also raises system security risk.

The demand patterns must also be consistent with other correlated behaviour in the model. For example, hot temperatures typically drive high demand. The same high temperatures also reduces the output rating from thermal generators, reduces the efficiency from solar panels and has a higher risk of bushfires near critical overland transmission corridors. The inter-related nature of the power system means that a single driver can affect many parts of the system and to adequately represent the system, the impacts must be reflected across the entire system and cannot be modelled separately.

A realistic representation of demand is a key requirement for useful modelling of the future NEM. Recent history tells us that demand has changed, is changing, and will continue to change over time. Modelling future demand is complicated and difficult, and must be done well in order to deliver credible outcomes.

4.3.2 Major changes in the magnitude of demand

According to the ISP assumptions, the neutral demand forecasts[21] are growing slowly – almost entirely driven by demand growth in NSW and Victoria while other states are essentially flat. However, there are some uncertainties that could influence the projections substantially – well outside the range projected by the fast and slow scenarios.

The most direct possibility is the retirement of major industrial loads. Some of these are already captured in the demand forecasts – particularly in the slow scenario. However, retirements are difficult to predict and may occur (or be deferred) for a variety of reasons outside the control, influence or even awareness of the electricity market. However, a large major industrial customer can be of a comparable scale to a coal-fired power station and the impacts of the retirement of even a single coal-fired generator can be felt around the NEM if the market is not prepared.

The impact of climate change introduces a direct uncertainty into the demand forecasts. Increased temperatures are likely to affect the demand, particularly the maximum demand. However, climate change is likely to have much broader impact on demand than just the temperature-related impacts. For example, water utilities such as Melbourne Water are treating climate change very seriously and are actively planning for alternative sources of supply[22] - one of which is increased utilisation of desalination. In a recent presentation to a workshop for the Electricity Sector Climate Information project, it was noted that most major water utilities were considering building one or more large scale desalination plant. This could potentially represent an increased demand in the thousands of MW and could be a notable proportion of the total NEM demand. The degree to which this is realised is uncertain, but such changes are not just plausible, they are actively being considered. They also project substantially increased need for pumping to manage their water supplies. These climate-related changes to demand for the water utilities are just one example of a large potential range of changes that may occur across different sectors across the NEM.

There are another large range of uncertainties that could substantially change Australia's electricity demand. Increasing liquid fuel prices, drive for decarbonisation to manage risk, climate change or to develop competitive branding could all result in substantial electrification of Australia's energy needs. At Australian Energy Week in 2019 Humayun Tai, a senior partner with McKinsey and Co., presented analysis showing that electricity presently represents approximately 20% Australia's total energy consumption, but this could rise to be as high as 60% by 2050 (against a background of increasing demand for energy)[23].

According to analysis from McKinsey and Co, electrification could potentially represent a threefold increase in demand in the NEM.

21 AEMO, ISP 2019 Assumptions, https://www.aemo.com.au/Stakeholder-Consultation/Consultations/2019-Planning-and-Forecasting-Consultation

22 Melbourne Water, 2019, https://www.melbournewater.com.au/water/securing-our-water-supply/our-water-supply-challenges

23 Renew Economy report on the Australian Energy Week presentation from McKinsey, 2019, https://reneweconomy.com.au/cheap-solar-and-wind-can-re-boot-australias-economic-advantage-71231/

This level of change is remarkable and orders of magnitude larger than the growth projection scenarios in the ISP. This projection includes substantial shifts in industrial load away from fossil fuels. While this would require substantial investment, it is not implausible in a world trying to decarbonise to manage climate change risks.

Companies are already recognising additional value for 'green' metals. Australia has strong competitive advantage in a future that needs more energy while also reducing carbon emissions. Australia has a large land space, with a comparatively smaller population, and rich renewable energy resources. In a decarbonised future energy market, Australia has all the right advantages to be able to provide cost-competitive energy and attract new energy-intensive industries. If there is notable industrialisation on top of the electrification of the existing energy demand, the growth in electricity demand across Australia could be even greater than threefold.

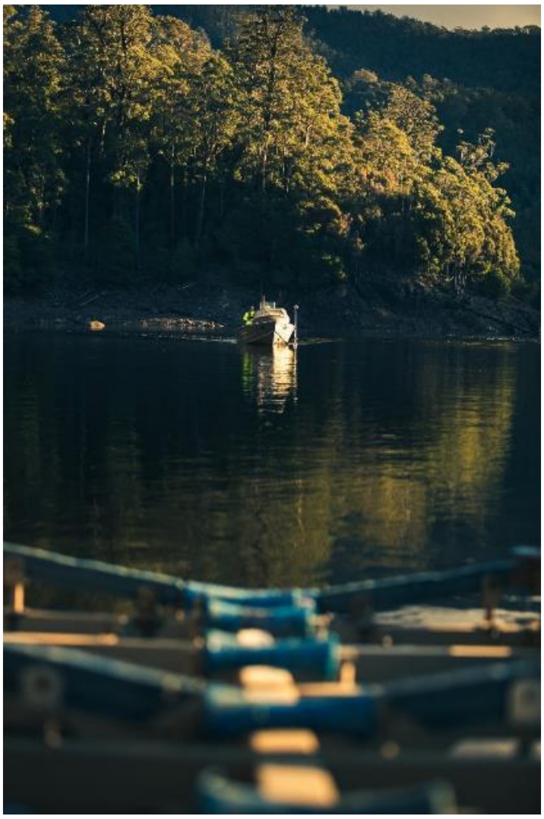
4.4 Optimising for broader outcomes

Australia's power system is an integral part of our economy. Decisions are made based on a wide range of criteria that seek to maximise various outcomes, highlighted previously in Figure 1. However, designing a model to optimise against multiple criteria is particularly challenging.

At present, the most advanced models of the medium to long-term NEM follow the principles of the RIT and optimise for least-cost outcomes. Even though, as noted above, least-cost modelling has a relatively minor role to play in investment decisions.

Most investment decisions will be made by developers and investors and will be in their best interests. This will likely be to maximise the value of their portfolio, not to minimise the cost of the system. Of course, these investments must also achieve planning approval. Increasingly, the support of the public is a key determinant of an infrastructure project's success. This may be influenced by near-term economic effects such as construction jobs, and longer-term regional development and maintenance jobs. It may also be influenced by social issues such as local impact, visual amenity, perceived benefits and broader environmental concerns such as climate change.

The optimisation to reduce cost may be a suitable approach to manage regulated investment. By contrast, least-cost modelling may be a poor indicator of actual development in supply-side options. For nearer-term[24] insights, it is important to consider broader criteria to determine what will (and won't) be built – and for that matter, what is and isn't valuable. A least-cost outcome is not necessarily the same as the maximum benefit outcome for the broader economy.



This will all mean that there is substantial uncertainty in the supply-side mix of assets and in the market more broadly. Additionally, it is also possible that the decision makers using the model outputs may have different priorities to those in the model. A politician may look to support outcomes that maximise competition and minimise price to consumers rather than achieve the least operational cost to the market (and without considering scarcity pricing, these two outcomes may be very different). Similarly, the emissions reductions in the electricity sector may be a lot easier and cheaper to achieve than similar reductions in the agricultural sector. This may also prompt different decisions in the electricity system when consideration is given to a broader context.

4.5 Zero-dollar short-run marginal cost

The existing design of the NEM is based on the assumption that generators will usually bid at their short-run marginal cost (SRMC). This allows for efficient dispatch of plant, where generators which are cheaper to run are used preferentially to those which are more expensive.

As variable renewable energy becomes more significant in the NEM, there are more generators which don't have to buy fuel and therefore have low, or zero, short-run marginal cost.

This raises questions about the most efficient dispatch of plant – both in the real world and in models. In the real world, factors that change a generator's income such as Renewable Energy Target Large-scale Generation Certificates (LGCs) and contract position lead some $0 SRMC plant to bid negative, and this along with the plant's marginal loss factor, leads to discrimination between plants. In recent years, the market has seen more deviation from SRMC bidding across the board, and the introduction of more zero SRMC energy is raising new challenges for the way the market operates.

In the model, these factors are typically not factored in to dispatch, and any marginal loss factor multiplied by zero will give the same outcome. Given that the model is only designed to give the lowest cost solution for the system, this is not inherently problematic – the dispatch of any zero SRMC plant will give the same modelled system cost outcome. However, when considering revenue sufficiency, such an outcome would be challenging.

At present, the use of power purchase agreements (PPAs) and reverse auctions, such as the Victorian Renewable Energy Target, provide a flat price for energy – similar to a regulated

[24] Beyond present planning horizons, least-cost build scenarios may still be the best information that is readily available.

return except that it is set by the market. However, as the spot market is exposed to more zero or negative prices, the ability to secure attractive PPAs will become more challenging. This may mean that overbuilds of low-cost energy sources may be the least-cost plan, but may be difficult to achieve financially in the market.

The key question raised for modellers is whether the least-cost energy solution is plausible. If the least-cost solution includes enough zero SRMC generation that the prices they receive are too low to be sustainable, the outcome may be deemed implausible. However, there is a fundamental question as to whether this indicates the need for changes to the model, or changes to the market.

4.6 Fundamental market restructure

It is likely that the NEM will have structural changes by the mid-2020s. The Council of Australian Governments (COAG) Energy Council has tasked the Energy Security Board with developing advice on a market framework that could support long-term reliability for the NEM[25]. The process of undertaking a major review of the market structure is a substantial commitment and a recognition of likely need for reform. High prices and extended supply shortfalls show that the market is failing to introduce sufficient supply options to manage the energy transition. In a market with relatively inelastic demand and a concentration of market strength in a few participants, it is possible (and arguably likely) that supply could be kept constrained to maintain high prices[26]. There are a range of barriers to entry that make electricity markets tend toward these characteristics unless managed through specific market design.

Market reform is required for an orderly transition to the future NEM, and yet nearly all models of the NEM are designed to represent (a simplified version of) today's market structures. If we are to adequately plan for the future, more consideration is needed of the likely generation mix (and potential for demand-side response) under different future markets.

4.6.1 Five-minute settlements

From 1 July 2021, the settlement period in the NEM will be changed to five minutes instead of the existing thirty minutes, to align with the five minute dispatch period. This will more directly remunerate the ability to respond to supply-demand imbalances at the time that they occur.

This change is coming, and yet is poorly represented in models to date. Five-minute settlements will mean that generators that are able to respond within a dispatch interval (five minutes) will be rewarded by being able to access market prices that slower units cannot. This is designed to alter the way the market behaves and will influence the assets that are built.

The existing models do not represent variability at the finer resolution as their finest time step is usually thirty minutes or an hour. Processing six to twelve times as much data will be a challenge, yet projecting optimal generation mixes without considering the fine resolution behaviour may result in notable inaccuracy. It is likely that more fast-response dispatchable supply (or responsive demand) will be preferred – for example, reciprocating engines are likely to be preferred over conventional open cycle gas turbines. Considering the need for flexibility while designing in the input assumptions or post-processing the output plans will be likely to be beneficial in the light of the change to five-minute settlements.

[25] COAG Energy Council, *Post 2025 Market Design for the National Electricity Market (NEM)*, March 2019: http://www.coagenergycouncil.gov.au/publications/post-2025-market-design-national-electricity-market-nem

[26] This is standard market theory and is widely researched. The following link provides a simple introduction to the concepts: https://www.economicsonline.co.uk/Market_failures/Inefficiency.html

4.6.2 Mechanisms to support capacity investment

The core of the NEM design is based on an 'energy-only' market, meaning that generators only get paid for their generation (excluding for the moment, ancillary services, which are a small portion of the market). This is contrasted against markets with explicit mechanisms to support the development of capacity – typically a payment or contractual requirement for the availability of generators, in addition to payment for the energy generated.

If the market design were to change, the drivers for investment and therefore the generation mix would change. The usual models of the NEM only represent the present market mechanisms. The change to include capacity incentives could influence the likely energy mix and it is critical to understand that when planning for the future NEM.

A study[27] of explicit capacity mechanisms in Europe and the USA found four main options:

- Strategic reserves – an explicit additional requirement for available generation beyond the amount needed for typical supply of energy.
  - It could be claimed that frequency control ancillary services (FCAS) and / or reliability emergency reserve trader (RERT) mechanism provide such a mechanism.
- Capacity obligations – an explicit requirement for load serving entities (i.e. retailers) to hold contracts for supply. Depending on the framing of the requirement, these may require varying levels of capacity, flexibility, and potentially ability to sustain output.
  - It could be claimed that the Retailer Reliability Obligation is similar to this capacity mechanism.
- Capacity markets – a centralised auction to ensure a minimum amount of capacity is available in the market[28].
- Capacity payments – a direct price-based mechanism that provides an additional set-price revenue source to some or all capacity providers in the market. This is the most direct influence in the market and could change the optimised energy/capacity mix, while the other approaches are managed outside the spot market to achieve a fixed capacity.

The introduction of any of these capacity mechanisms would affect the supply mix in the market in a way which may not be captured by the existing energy-only models. Even if these mechanisms were modelled, there are still key questions; such as:

- How much capacity would be determined to be needed?
- How long must a provider be able to sustain their capacity to be able to participate? For that matter, would multiple markets be required to manage the need for different levels of firmness?
- How would unreliability be managed? What penalty would be assessed for failure to deliver?
- How fast must the capacity be able to respond? Does 'dispatchability' imply flexibility?

Making strategic planning decisions that recognise likely support for additional capacity may be more realistic in the light of possible changes to the market. Special consideration for what kind of capacity may be needed and rewarded (i.e. longer duration capacity, flexible and responsive capacity, etc.) may also be worth bearing in mind while making strategic deliberations.

[27] MIT Center for Energy and Environmental Policy Research, *Resource Adequacy with Increasing Shares of Wind and Solar Power: A Comparison of European and U.S. Electricity Market Designs,* April 2018: http://ceepr.mit.edu/files/papers/2018-008.pdf

[28] This could be used as a mechanism to ensure sufficient capacity in the market to encourage competition, not just reliability. However, it could easily be represented in the existing models as a system constraint.

4.6.3 Dynamic nodal pricing

There is active consideration of dynamic nodal pricing by the Australian Energy Market Commission (AEMC) through the coordination of generation and transmission investment (COGATI) process to better reflect the local transmission constraints. This could potentially change the revenue sufficiency of different technologies and particularly different choices about build out.

4.6.4 Change to pay-as-bid mechanism

In the NEM, suppliers are all paid the marginal clearing price. In theory, this incentivises them to bid their short-run marginal cost. One option to try to manage the influence of large portfolios and thereby reduce the price the customer pays is to pay the suppliers their bid price rather than the marginal price. Understanding how much of the energy price that different classes of asset can capture could substantially influence the modelled supply mix.

In theory, both pay-as-bid and the existing pay-as-clear approaches achieve similar outcomes on the assumption each supplier would perfectly forecast the expected price and bid accordingly[29], as illustrated in Figure 5.

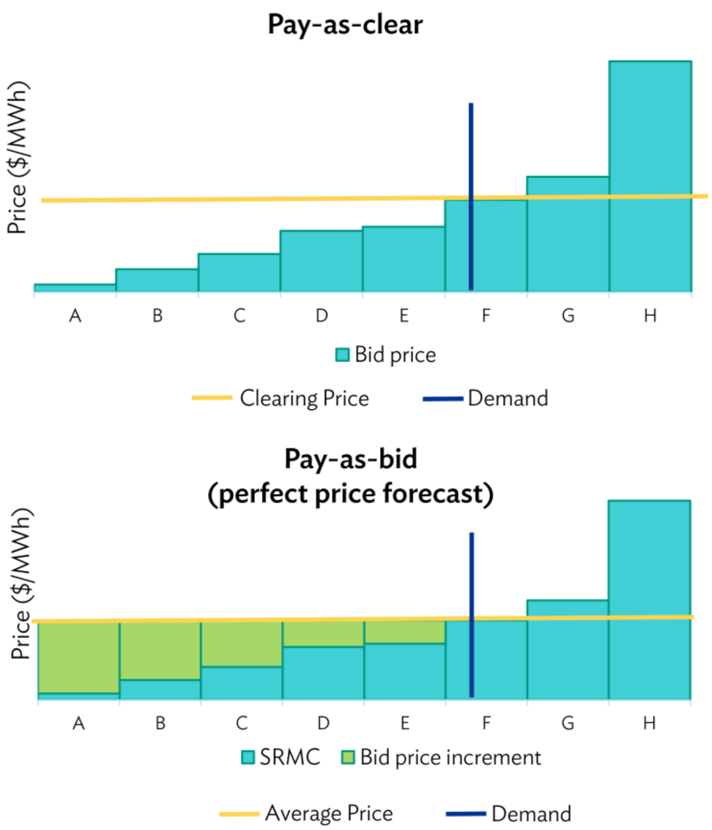


Figure 5. Under existing market structures (pay-as-clear) suppliers are all paid the marginal clearing price. Under pay-as-bid, suppliers are paid what they bid and theoretically all suppliers bid the (perfectly) forecast price.

[29] There have been a number of studies on the merits of each market design. California Independent System Operator and Office of Gas and Electricity Markets (UK) have useful presentations to explain the concepts: http://www.caiso.com/Documents/BriefingMarketPowerMitigationCapacityProcurementMechanism-MSC_Presentation-2.pdf and also https://www.ofgem.gov.uk/ofgem-publications/40790/pay-bid-or-pay-clear-presentation.pdf

Several studies have shown that pay-as-bid may also introduce merit order inefficiency. Considering Figure 5, there is no price difference with which to distinguish supplier F from supplier A. In theory, this inefficiency gets passed to the customer over the long-term.

However, the theoretical analyses all consider single snapshots in time and don't account for the physical behaviours of the generators nor their relative risk position. Inflexible generators (that can't afford to switch off) and generators with a very low short-run cost of production (that are highly exposed to opportunity cost) could both be expected to bid with price buffers to protect themselves from the loss of potential revenue. Figure 6 illustrates a potential range of pay-as-bid behaviour with more realistic price forecasts. Suppliers A, B and C bid conservatively to ensure dispatch. Suppliers E and F both bid around the forecast price and supplier D bids at a slightly higher price since it can afford to miss out on being dispatched – it is also dispatched out of merit order. Even with this inefficiency, the overall average price is notably lower than the forecast price in this illustration. A market equilibrium will be reached, but each asset class will likely behave differently and be rewarded accordingly.

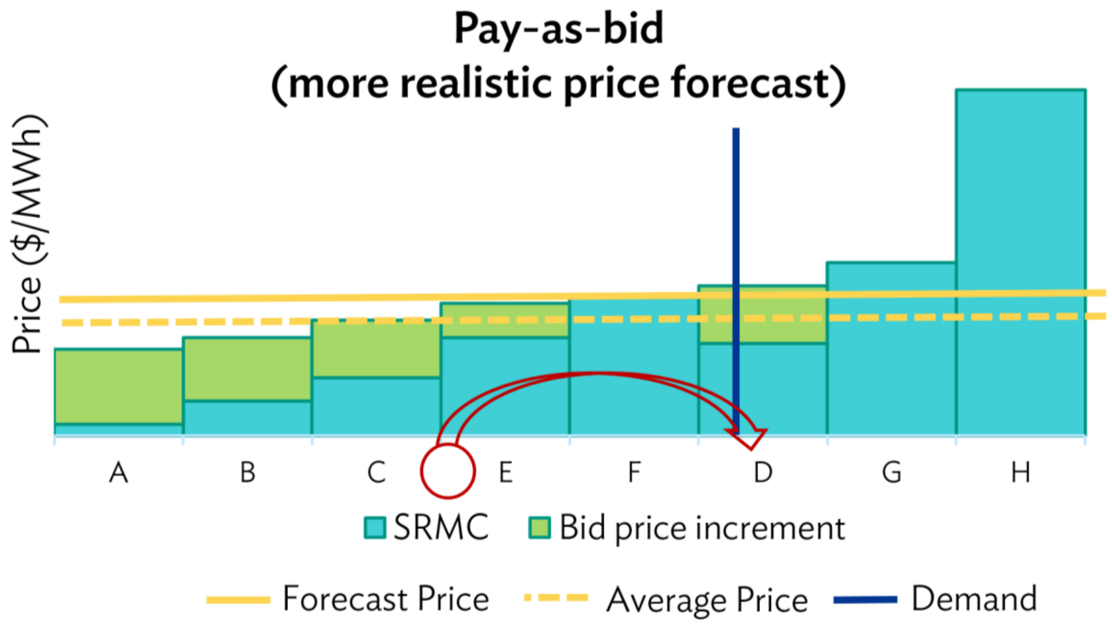


Figure 6. A demonstration of potential pay-as-bid market behaviours where price forecasts are considered less reliable

Another consideration is the impact of the price curve. At high price times, even small changes in the need for supply can result in large changes in price. A small change in supply-demand balance can result in changes from a $150/MWh price to a $1000+/MWh price (and vice versa). It is unlikely that any generators (other than pure capacity providers) would confidently forecast a price of $1000/MWh and bid accordingly. Even though the forecast was for $1000/MWh, there is a credible, possibly even likely, outcome that the price might be $150/MWh. The risk of not being dispatched is simply too high and $150/MWh is still considered a valuable opportunity not to be missed. During times of scarcity pricing (e.g. high demand), this could produce substantial savings across the market.

Insufficient competition could allow for higher prices to be bid, but this problem occurs with the marginal price setter approach as well. In fact, it would be more manageable under pay-as-bid since this mechanism would require all units to be bid competitively. Under the existing pay-as-clear market structure, an owner of a large portfolio has the option to risk a small portion of its portfolio to increase revenue for its whole portfolio.

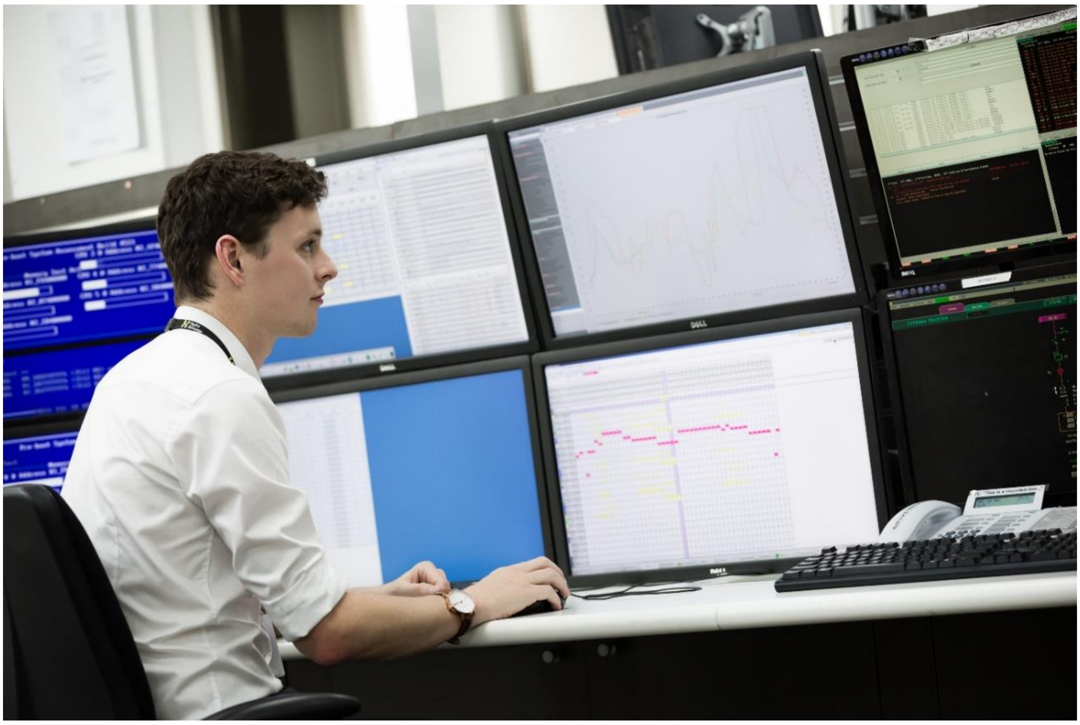
A change to pay-as-bid may favour the flexible generation sources that will be needed in the future – particularly energy constrained assets. Strategic planning decisions that favour such assets would be robust to a potential change in the price setting mechanism in the market.

4.7 Ancillary services & co-optimisation with increased variable renewable energy

Ancillary services are non-energy services that are required for the provision of electricity. For example, frequency control ancillary services (FCAS) is a suite of services relating to short-term (less than five minutes) balancing of supply and demand. However, these services are not modelled as part of the existing optimisation and tend to be added through post-processing. If the model could recognise the value of ancillary services in developing a supply, transmission and interconnection plan, it might select different mixes compared with a plan for 'energy only'. For example, the power electronics of an HVDC converter station are very similar to those of a battery and can provide valuable ancillary services that might preference its use compared with a HVAC transmission line[30].

With increased variable renewable energy, the need for ancillary services will change. The demand for some services will increase. Other new services may need to be recognised – either where they were not required in the past, or where they were available in such oversupply, they were essentially 'free'. The need for some services may even reduce, or the supply may become so abundant that costs are negligible.

It is important to assess how much of each ancillary service is needed, and what new services will be required (for example, the creation of an inertia market has been suggested). This will enable modellers to check that the energy mixes projected by their models includes adequate supply of these services. It is important to check this not just at the high level, assessing the installed capacity of capable assets, but also at the time-variant level, ensuring that projected dispatch provides for the availability of these services.



[30] Equally, the HVAC allows synchronous generators to provide inertia, while the HVDC does not.

Non-energy services may need to extend to those entirely outside our existing ancillary services markets. In addition to inertia markets, consideration should be given to other services which will be valuable in a future with high variable renewable energy penetration. For example, a key benefit of energy storage is its ability to reduce market volatility by supporting demand when excess variable renewable energy is available, and increasing supply when it is scarce. Reduced volatility provides price stability for retailers and wholesale customers, but inherently minimises arbitrage opportunity for storage providers. Therefore it may be necessary to reward this volatility reduction explicitly, to incentivise the required level of energy storage in the market.

Models could be updated to co-optimise for the full range of ancillary services. However, this would take a significant investment to improve modelling resources. It is critical to ensure that the planned generation mix is sufficient to provide the necessary services, but this could also potentially be achieved through strategic planning decisions to ensure sufficient ancillary services capability and by carefully considering the input assumptions to the model. Without co-optimisation, it is important to exercise caution when interpreting the projected generation mix since there may be cheaper ways to deliver a co-optimised outcome.

4.8 'Black swan' events

There will always be unforeseen circumstances, which could rapidly progress from seeming implausibility to reality. It is simply impossible to identify all possible 'black swan' events. However, by modelling a range of scenarios to attempt to define the bounds of plausibility, and then basing our decision making firmly on the spread of outcomes rather than on the one we deem most likely, we can develop policies and investment choices which are flexible and/or robust to a wide range of outcomes. This gives us the best chance of enabling a future power system that works, even in unforeseen circumstances.

5. Using broad (internally-consistent) scenarios

The substantial uncertainty associated with a transformation of the power system and the huge breadth of factors which are worthy of consideration serves to illustrate the futility of hoping to provide a single 'most likely' view of the future.

For this reason, modellers typically create a range of scenarios for the future, and present the outcomes of these. If the scenarios are well-formed, they should be internally consistent, meaning that the various aspects of the scenario are 'congruent': plausible, or even likely, to occur concurrently. For example, it may be deemed implausible that a significant rise in temperature would coincide with reduced frequency of bushfires.

Scenarios work best when they cover the full range of outcomes that are reasonably plausible. It can be misleading to choose a scenario which is judged most likely – or worse, most politically palatable – and focus too heavily on that. Even the seemingly most impartial modeller's view of what is likely will be strongly influenced by their past experience, and can constrict their interpretation of the range of possible outcomes.

A single answer will not be right (because models do not produce perfect predictions), so we need to look at the range of plausible outcomes and develop plans and policies that are either flexible in delivery, or robust to the full range of plausible scenarios.

In putting together these plans and policies, it is critical that those considering the model outputs understand the context of how and why a specific model was developed, and what it does, and, more importantly, what it does not capture. This will equip decision makers to capture the full value of the insights that good models can provide.

In the coming decades, the rapid retirement of coal-fired generation in the NEM presents a unique opportunity to shape our future electricity system. Australians have the opportunity to plan for a future power system that is clean, reliable and internationally cost-competitive.

To plan effectively, we need to understand the future as thoroughly as possible. Modelling provides us with a critical tool to develop insights into possible futures and their potential characteristics. However, we need to be aware that our existing models were created in the context of the past and present system behaviours. These models needed to answer different questions about how we might plan and manage the NEM.

We need to:

a) Honestly and openly challenge the validity of existing assumptions, and also the design and decisions in the existing models;

b) Ensure that we communicate, and understand in our decision making, both the strengths and limitations of our models, not only so that we can make better decisions but also so that we can ask better questions;

c) Appreciate the value of modelling a wide range of scenarios to increase the likelihood that our decision making is robust to unforeseen outcomes – and consider what might be valuable across the broad range of plausible scenarios when making strategic planning decisions; and

d) Expand our conversations and decision-making to include factors which are not viable to model, being open to going beyond a single optimisation criteria, and recognising a wider and more strategic range of drivers.

Modellers need to have the freedom to explore factors which previously were assumed to be negligible, off-limits, unrealistic, or politically unpalatable. Decision makers need to be provided with full context, including the range and sources of uncertainty, such that they can consider a range of outcomes and make strategic decisions based on the full richness of the available information.