10.04

LRMC methodology report

Ausgrid

Deloitte.
Access Economics

Long run marginal cost in theory and practice

Report for Ausgrid

December 2017

Contents

Glossary

AEMC	Australian Energy Market Commission
AER	Australian Energy Regulator
AIC	Average incremental cost
CDCM	Common Distribution Charging Methodology
ESC	Essential Services Commission
LRAC	Long run average cost
LRMC	Long run marginal cost
MC	Marginal cost
MW	Megawatt
MVA	Megavolt-amps
NER	National Electricity Rules
NPV	Net present value
PIP	Portfolio Investment Plan
SRAC	Short run average cost
SRMC	Short run marginal cost
TSS	Tariff structure statement

Executive summary

Background to the report

The pricing principles in the National Electricity Rules (NER) require network tariffs to be based on the long run marginal cost (LRMC) of providing the service.

We have been engaged by Ausgrid to assist it with the preparation of the Tariff Structure Statement (TSS) applying to the regulatory control period commencing on 1 July 2019. This report provides our independent evaluation of LRMC estimation methodologies and recommendations on which of these methodologies is appropriate for Ausgrid.

Approaches to estimating LRMC

In this paper we consider three approaches to estimating LRMC:

- The perturbation (Turvey) approach – considers the change in an optimised capital expenditure forecast required to meet a permanent, material increase or decrease in forecast demand.
- Average Incremental Cost (AIC) approach – uses average incremental expenditure required to meet forecast demand compared to current demand over a period of time.
- A simplified version of the Turvey approach – LRMC is estimated by bringing forward, or pushing back a defined expenditure plan, rather than re-optimising the capital program, in response to a perturbation in forecast demand.

The following table provides a summary of the nature of the LRMC estimate produced and data and implementation issues for each approach.

Table i : Comparison of LRMC estimation approaches

Approach	LRMC estimate	Data and implementation
Perturbation / Turvey	Closely aligned with theoretical concept of LRMC as it measures cost of changed investment as a result of a permanent change in an individual cost driver (e.g. demand or consumption).	Costly to implement as it requires a minimum of two demand forecasts to estimate LRMC (and ideally three), with a fully re-optimised expenditure forecast required for each demand forecast.
AIC	An average of incremental expenditures, rather than a true marginal cost. Averaging approach places more emphasis on costs in the near-term. As such, it may result in very low estimates in the presence of excess capacity, and may also exhibit more variation over time than Turvey, particularly where capital expenditure is lumpy.	Simple to implement, requires only a single demand forecast and capital expenditure forecast. As such the information required can typically be taken from forward capital and operational plans – and subject to demand forecasts and capital planning covering a sufficient timeframe, no additional information is required for its calculation.
Simplified Turvey	Aligned with the concept of LRMC, and will provide similar results to a full Turvey estimation where shifts in demand affect the timing but not the nature of investment plans (i.e. a change in demand would not be expected to result in a significant re-optimisation).	Avoids the need to re-optimise capital expenditure plans, and therefore addresses the main administrative cost of Turvey, but may require a number of alternative demand forecasts and a thorough understanding of how alternative forecasts would affect the nature and timing of expenditure.

Which costs should be included in LRMC?

Expenditure relevant to marginal cost pricing must be related to future changes in use of the network. In relation to the forecast in Ausgrid's Portfolio Investment Plan (PIP) – its whole of business capital expenditure planning tool – this should include:

- Growth or augmentation expenditure, which is driven by changes in peak demand, and forms the basis of most LRMC estimates for electricity distribution
- Connections expenditure, driven by customer numbers growth and intrinsically linked to demand and energy use
- Probabilistic replacement expenditure, which is based on an assessment of energy at risk if an asset were to fail, and is therefore driven by energy consumption.

Other capital expenditure, such as general replacement expenditure (i.e. not probabilistic), reliability, non-network, overheads and capital contributions would appear to have minimal relevance to LMRC, because changes in the use of the network have limited impact on these expenditures.

Summary of findings

As part of this project, we also reviewed Ausgrid's LRMC modelling for consistency with the concepts outlined in this report. We consider that Ausgrid's inputs and LRMC modelling are consistent with the theoretical concepts in the literature and the practical application of AIC and perturbation approaches to calculating LRMC observed in various infrastructure sectors. We believe Ausgrid's modelling applies a methodology that appropriately estimates marginal costs and can be used to inform Ausgrid's tariff structure reforms.

Given Ausgrid's current demand and capacity outlook, we consider that the AIC approach remains an appropriate methodology for estimating LRMC for demand-driven capital expenditure (augmentation and connections). The AIC approach is well-understood, relatively simple to apply and likely to provide a reasonable estimate of LRMC in these circumstances. We have reviewed Ausgrid's approach to modelling LRMC using the AIC approach, and consider that the approach adopted by Ausgrid is consistent with best practice application of this method, and that the results obtained are reasonable estimates of LRMC.

Ausgrid has also identified a component of replacement expenditure that is driven by changes in consumption. The timing of probabilistic replacement expenditure depends (among other things) on the asset condition and the amount of unserved energy that would occur if the asset were to fail. We have reviewed the modelling undertaken by Ausgrid to produce its LRMC estimates using the perturbation approach. Ausgrid has applied several alternative consumption forecasts (perturbations) and produced re-optimised capital expenditure profiles associated with each forecast. We consider that Ausgrid's application of a perturbation approach to estimating the LRMC for its replacement expenditure is consistent with the underlying principles of the Turvey approach.

Ausgrid's use of the AIC and perturbation approaches allow it to calculate LRMC for both growth related capital expenditure (including connections) and replacement capital expenditure, providing a more complete picture of LRMC than estimates based on growth capital expenditure alone. We consider that the LRMC estimates produced by Ausgrid using this approach are reasonable estimates of LRMC. Integration of these estimates into pricing will allow Ausgrid improve signals to customers about the costs of using the network.

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1 Background

1.1 Network pricing objective under the National Electricity Rules

In 2014, the Australian Energy Market Commission (AEMC) introduced new obligations into Chapter 6 of the National Electricity Rules (NER) that require network businesses to set network prices that signal to individual customers the cost of providing services. The objective of these changes was to provide customers with the information they need to make informed choices in relation to how they use electricity and the costs they incur in doing so. Where network prices signal the costs of providing services at particular times, and customers respond to these signals, investment in network infrastructure may be able to be deferred resulting in lower network costs for all customers.

To guide network businesses in setting networking pricing, the AEMC introduced a network pricing objective and a number of new pricing principles.

The network pricing objective, under clause 6.18.5(a) states that:

> *…the tariffs that a Distribution Network Service Provider charges in respect of its provision of direct control services to a retail customer should reflect the Distribution Network Service Provider's efficient costs of providing those services to the retail customer.*

The pricing objective is designed to guide network businesses in how they set prices and is supported by a number of pricing principles that require, inter alia, each network tariff to be based on the long run marginal cost (LRMC) of providing the service (clause 6.18.5(f)).

The NER do not mandate the methodology for calculation of LRMC, and provide distribution businesses with discretion to select a methodology taking into account factors such as the costs and benefits of the approach, differences between tariff classes, and locational factors ((Clause 6.18.5(f)(1),(2),(3)).

1.2 Tariff Structure Statement

The pricing objective and the pricing principles are supported through the requirement for network businesses to develop, and seek the AER's approval of, a Tariff Structure Statement (TSS). The TSS is a document that outlines the network business's proposed tariff classes and tariff structures. In addition to demonstrating compliance with the pricing objective and pricing principles, network businesses are required to consult on their proposed TSS and demonstrate to the AER how they have addressed the views of their customers.

1.3 This report

Ausgrid has engaged Deloitte Access Economics to assist it with the preparation of the TSS applying to the regulatory control period commencing on 1 July 2019. This report that provides our independent evaluation of the available LRMC estimation methodologies and recommendations on which of these methodologies is appropriate for Ausgrid.

The remainder of this report is structured as follows:

- Section 2 sets out the theoretical basis for LRMC pricing
- Section 3 describes and compares alternative approaches to estimating LRMC
- Section 4 covers the types of costs that should be included in LRMC (with particular consideration, replacement costs) and applies the concepts to Ausgrid's costs
- Section 5 provides a summary of findings and recommendations.

2 Long run marginal cost

2.1 Marginal cost pricing in theory

Setting prices based on marginal cost provides efficient price signals that reflect the economic cost of providing services. When prices are based on marginal costs, consumers can take into account the future cost of meeting demand when making consumption and investment decisions. Marginal cost pricing also provides incentives for cost efficient investment in the provision of services by producers.

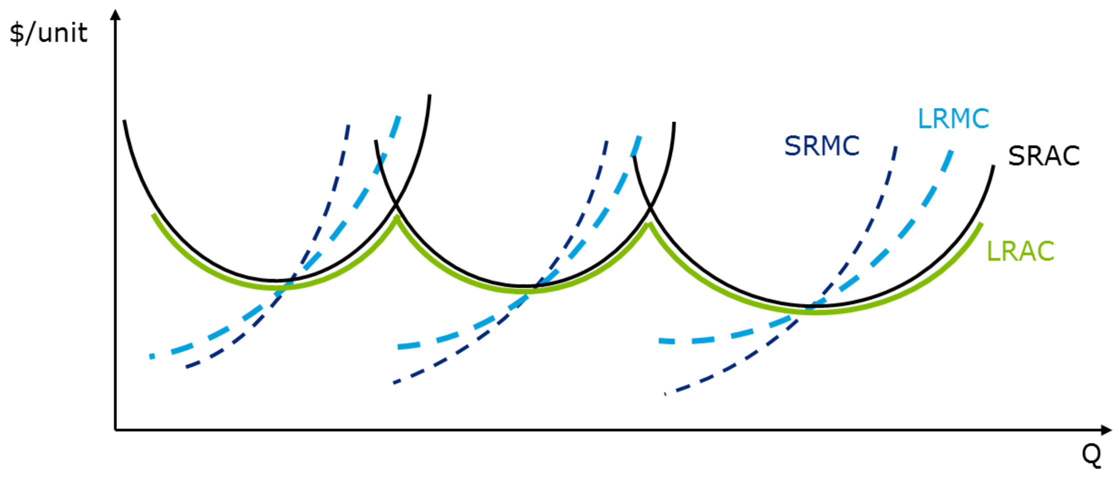
Short run marginal cost (SRMC) relates marginal cost and output holding some input (typically capacity) constant. Prices based on SRMC reflect the costs of service provision for a feasible level of output given a fixed amount of productive capacity, and therefore will tend to increase as supply reaches its limits (i.e. reflect congestion costs). SRMC pricing can be highly variable – very low when there is excess capacity and very high when capacity constrained. Mann et al. (1980) highlight how only focusing on the short run will generate socially unacceptable instability in tariffs and charges over time. SRMC pricing has also been perceived as inadequate to incentivise long term efficient investments in productive capacity, creating further instability in prices (Turvey, 1969; Mann et. al, 1980), potentially resulting in a sub-optimal level of consumption for welfare maximisation.

LRMC is the change in cost incurred for one additional unit of output in the long run – that is, the period where all factors of production (i.e., operating and capital expenditure requirements) are variable. Including potential changes in capital inputs as well as operating costs in the estimate tends to smooth, or flatten the marginal cost curve, smoothing prices over time (i.e. minimising long run average costs).

The distinction between the long run and the short run in this context is purely conceptual. In practice, there is no set time period where all costs are variable, and the long run is typically defined as covering a period where at least one major change in capacity is planned to occur. A pragmatic approach to measure the long run is to use other timeframes such as the average life of assets, time for future plant additions or retirements to be made or the planning horizon (Turvey, 2000; Tooth, 2014).

The following figure illustrates the theoretical relationship between cost curves in the short and long run with lumpy investments.

Figure 2.1: Relationship between average cost and marginal cost



Source: Deloitte Access Economics, adapted from Tooth (2014)

Each SRAC curve represents a feasible range of output and cost per unit of production with a fixed allocation of capital (i.e. in the short run). Capacity augmentations shift the SRAC curve to the right, tracing the LRAC curve which is the lowest point of SRAC at any given time.

If capital investments were infinitely divisible, the SRAC curve could be shifted to the right equivalent to a single unit, and the LRAC curve would be a relatively smooth line tracing the minimum point of each SRAC curve. However, when capital investments are lumpy (i.e. large enough to create some excess capacity), LRAC forms a wave-like pattern and LRMC a saw-tooth pattern.[1] The saw-tooth pattern of LRMC indicates that marginal cost will be low immediately after a capacity addition (when there is excess capacity) and then increase as spare capacity is added and then increasingly constrained.

There are several implications for LRMC-based prices in the presence of lumpy capital investment that can be drawn from the figure:

- Immediately after an investment, price is likely to be greater than SRMC (leading to underutilisation of assets which have spare capacity)
- Leading up to a new investment (i.e. where marginal costs are higher than average costs), price is likely to be less than SRMC (assets may be over-utilised)
- Signals to invest are provided when SRMC is greater than LRMC (i.e. immediately after the point at which the firm is producing at the bottom of the LRAC curve for a given capital stock), because the marginal cost of producing another unit is higher than the price received per unit.

Despite these factors, pricing at LRMC is used because, as previously highlighted, it gives accurate price signals that reflect capacity constraints in the system (including providing suppliers with signals of when to invest), whilst maintaining more price stability than would occur under SRMC. It also provides distributors with accurate signals of when they need to invest.

[1] Note this is a stylised representation to illustrate the implications of non-divisible (i.e. lumpy) capacity additions, and a more accurate representation would most likely exhibit a less pronounced rise and fall with capacity additions.

3 Approaches for estimating LRMC

3.1 Alternative approaches for estimating LRMC

There are a range of approaches that can be used to produce estimates of LRMC. In this paper we consider three well-known approaches:

- The perturbation (Turvey) approach – considers the change in an optimised capital expenditure forecast required to meet a permanent, material increase or decrease in forecast demand.
- Average Incremental Cost (AIC) approach– uses average expenditure required to meet forecast demand compared to current demand over a period of time
- A simplified Turvey approach – LRMC is estimated by bringing forward, or pushing back a defined expenditure plan, rather than re-optimising the capital program.

The following sections provide a summary of each approach, and its application in utility regulation.

3.1.1 Perturbation (full Turvey)

The Perturbation, or Turvey, approach is based on an approach developed by Professor Ralph Turvey in a seminal paper on the topic nearly 50 years ago (Turvey, 1969). Turvey's approach is based on consideration of how changes in demand affect the nature and timing of investments. Specifically, the perturbation approach involves estimating the change in expected costs arising from a permanent change in demand (increase or decrease).

The following steps are required to estimate LRMC under the perturbation approach:

1. Forecast unconstrained demand over the long run (e.g. 15 years), assuming that demand is not affected by any capacity (or other resource) constraints
2. Develop an optimal expenditure pathway (capital and operating expenditure, plus efficient demand management) to meet demand
3. Modify demand forecasts by a (small) hypothetical, permanent increase or decrease
4. Develop a re-optimised expenditure pathway based on the revised demand forecast
5. LRMC is then Estimate present value of change in (capital and operating) costs as the present value change of costs in meeting demand, divided by the present value of the permanent change in demand

$$LRMC = \frac{NPV\ (revised\ optimal\ capex\ and\ opex - optimal\ capex\ and\ opex)}{NPV\ (revised\ demand - base\ demand)}$$

While a number of Australian regulators have recognised the perturbation approach as being conceptually strong (in that it is most closely linked to the theoretical concept of LMRC), we note that examples of its application are rare.[2]

3.1.2 Average Incremental Cost

Average Incremental Cost (AIC) was proposed by Mann et al (1980).[3] AIC involves estimating the LRMC by considering additional expenditure required to meet forecast incremental demand, then averaging these costs over the estimation period.

The following steps are required to estimate LRMC under the AIC approach:

1. Forecast unconstrained demand over the long run (e.g. 15 years), assuming that demand is not affected by any capacity (or other resource) constraints

[2] A number of state-based regulators have investigated the use of the perturbation method for estimating LRMC (typically for the purpose of urban water tariff structures), but to our knowledge it has not been broadly applied to pricing decisions.

[3] Mann et al. (1980) source their definition of AIC from Saunders (1976)

2. Starting from the existing endowment of resources, define the lowest cost investment path to meet incremental demand (capital and operating expenditure, plus efficient demand management)
3. AIC is then the present value of the additional costs expected under the optimal strategy divided by the present value of incremental demand.

$$AIC = \frac{NPV\ (additional\ capex\ and\ opex\ to\ meet\ incremental\ demand)}{NPV\ (incremental\ demand)}$$

Given its conceptual simplicity and relative ease of calculation (it can typically be calculated using existing expenditure and demand forecasts), the AIC approach is the most commonly applied approach for estimating LRMC by regulators and regulated infrastructure providers in Australia.

3.1.3 A simplified Turvey approach

Recognising the administrative costs of applying the Turvey approach, an alternative procedure in practice is to start with a change in capacity costs and solve for an increments or decrements in capacity that would be associated with this change (Turvey, 2000). This procedure involves:

1. Postulating a change in the timing of future capital expenditure
2. Estimate the costs of bringing forward or postponing the next proposed capacity related capital project
3. Divide by the increment or decrement in future outputs that would then be possible with this change in capacity.

The result is an estimation of marginal cost based on an increment of decrement that lasts for one or a few years. The above calculation would be the same as a full Turvey estimation if the underlying investments undertaken do not change between step 3 and step 4 in the full Turvey approach (i.e. rather than re-optimising the capital program, it is simply brought forward or deferred to reflect optimal timing of the change in capacity for the change in demand). Therefore the main benefit of the simplified Turvey approach is the avoidance of costs and complexity required to undertake multiple optimisations of the forward capex program. Turvey (2000) has noted that the estimates from this approach may be justified because:

- There may be no alternative in the absence of explicit re-optimised long-term planning
- It may yield an answer that is consistent with the full Turvey approach when such planning is done (i.e. the re-optimised capital plan may be sufficiently similar to the original plan, with the main difference being timing).

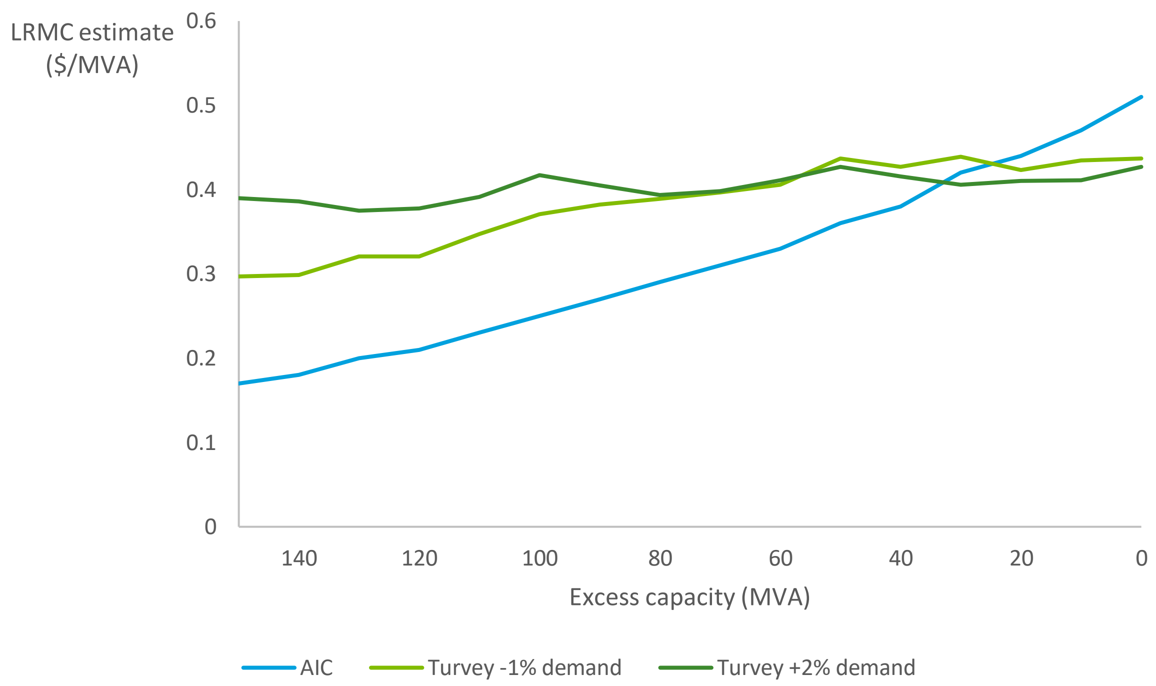
A similar methodology to the simplified Turvey approach has previously been applied by Melbourne Water, which followed a methodology set out by Hanker and Wentworth (1981). Melbourne water estimated both peak and off-peak LRMC for bulk water by calculating the difference in costs of bringing forward investments by one year, over a forecast period of 20 years (ESC, 2015).

3.2 Illustrative example of LRMC estimation using Turvey and AIC

We have undertaken simple quantitative scenario analysis to assess the implications of applying different methods of estimation of LRMC by Ausgrid, using a simplified model of Turvey perturbation and AIC. Our Turvey perturbation approach is based on the simplified approach outlined above – whereby rather than re-optimising the entire capital expenditure forecast under a change in demand, we simply bring forward, or push back, the same program of capital expenditure in response to an incremental or decremental change in demand.

The following diagram represents an estimation of LRMC under each approach across various levels of current excess capacity. The amount of excess capacity can be viewed as a proxy for the timeframe until the next capacity augmentation – the more excess capacity, the further away the next augmentation.

Figure 3.1: Illustrative comparison of Turvey and AIC under differing levels of spare capacity



Source: Deloitte Access Economics

As can be seen in the figure:

- **When the network is close to capacity (and the next capacity augmentation), the AIC will tend to give higher results than Turvey.** This can be understood through the relevant weighting each approach gives to costs – the Turvey method gives equal weight to the marginal cost of meeting additional demand over the planning period, while the AIC method gives greater weight to the marginal costs of meeting additional demand in the near term. Hence AIC will deliver different results from Turvey in circumstances where there is significant excess capacity, or very lumpy capital expenditure. Conversely, a smooth capex profile (with similar sized, evenly spaced investments and limited spare capacity) would result in both approaches delivering similar results.
- **AIC is a more volatile measure, in that it results in a larger spread of LRMC estimations across different levels of excess capacity.** While Turvey is relatively stable across a range of excess capacities (i.e. investment horizons and profiles), AIC can change quite dramatically – in circumstances where there is significant excess capacity, and limited demand growth, AIC would be expected to approach zero.
- **Turvey estimates for a decrement in demand are different from estimates from an increment in demand.** Under our simplified approach, Turvey estimation of LRMC essentially pushes forward or back an investment profile. A decrement in demand pushes the timing of investment back and therefore tends to reduce the LRMC estimate (which is a weighted average of an NPV).

3.3 Summary comparison of Turvey and AIC

The AIC approach and Turvey approaches are similar in that they produce an estimate of LRMC based on averaging of future costs using a notion of future demand.

In terms of the estimates achieved from each approach, we note the following characteristics have been observed by a number of commentators:

- Turvey approach more accurately aligns with the theoretical concept of LRMC in that it measures the marginal cost of changes in demand over the long term, and is relatively stable over time. However, this characteristic can result in significant departures from SRMC, which will tend to be low where there is excess capacity and high when capacity is constrained

- The AIC approach is simpler and places more emphasis on costs in the near-term. As such, it may result in very low estimates in the presence of excess capacity, and may also exhibit more variation over time than Turvey, particularly where capital expenditure is lumpy
- The simplified Turvey approach aligns with the concept of LRMC, and will provide similar results to a full Turvey estimation where shifts in demand affect the timing but not the nature of investment plans (i.e. a change in demand would not be expected to result in a significant re-optimisation).

A further benefit of the Turvey approach is that it can relatively easily estimate LRMCs associated with different or multiple drivers. By re-optimising the capital expenditure forecast under a permanent change in an individual cost driver (for example, energy consumption, demand, or energy/demand at a specific location) the Turvey approach will provide a relatively precise estimate of LRMC associated with that individual driver.

The other main source of difference between methodologies is level of data and analysis required for implementation:

- AIC requires only a single demand forecast and capital expenditure forecast. As such the information required can typically be taken from forward capital and operational plans – subject to demand forecasts and capital planning covering a sufficient timeframe, no additional information is required for its calculation.
- However, the full Turvey approach requires a minimum of two capital expenditure forecasts to estimate LRMC (and ideally three, in order to calculate the impact of both an incremental and detrimental change in demand). Furthermore, as the size of a permanent change in demand is a somewhat arbitrary assumption, estimation using perturbation may need to include a variety of sensitivity tests. With each alternative demand scenario requiring a re-optimisation of capital and operational plans, the Turvey approach has the potential to be costly when applied to complex capital expenditure scenarios.
- The simplified Turvey approach avoids the need to re-optimise capital expenditure plans, and therefore addresses the main administrative cost of Turvey, but may require a number of alternative demand forecasts and a good understanding of how alternative forecasts would affect the timing of expenditure.

The table below summarises the differences between the two main approaches.

Table 3.1 Summary of theoretical properties of perturbation and AIC

Property	Perturbation/Turvey	Average Incremental Cost
Strengths	+ Closely aligned with theoretical concept of LRMC + More accurately measures cost of changed investment as a result of a permanent change in an individual cost driver (e.g. demand or consumption) + Can dampen variability of SRMC-based prices when there are large capital investments	+ Easier to implement, data requirements not as onerous (requires only a single demand forecast) + Still accounts for complex interactions between supply and demand + Places a greater weight on costs incurred in the near term, thus may be more reflective when long term costs are highly uncertain
Weaknesses	- Accentuates issues of using LRMC, such as inefficient short-term price signals - Data and time intensive, requires plans to be developed for a range of scenarios - Results can be sensitive to permanent change in demand chosen	- Average, rather than a direct marginal approach - Tends to overestimate when network is constrained in the short term, and underestimate if the network has a lot of spare capacity

Source: Deloitte Access Economics

4 Application to Ausgrid

4.1 Which costs should be included in LRMC?

When calculating LMRC, it is necessary to make a judgement on which costs should be included in the calculation. The method chosen to calculate LRMC has implications for how this decision affects the estimates:

- When using the AIC approach, it is important to ensure that only incremental costs of meeting incremental demand are included in the calculation
- Under the Turvey approach, the question of which costs should be included when calculating LRMC is of less concern – even if all costs are included, costs that do not change in response to the perturbation are netted out of the calculation and only those costs that respond to the perturbation will remain
- Under the simplified Turvey approach set out above, there may need to be some judgement made about the relevant costs – ultimately this will depend on the sophistication of demand forecasts and specifically, how closely they are linked to capital expenditure.

In reviewing methodologies used by distributors to estimating LRMC in their 2017 TSS proposals, the AER noted that in applying the AIC approach the businesses had used only augmentation costs, and proposed that the calculation of LRMC should include replacement capital expenditure and associated operating expenditure. The AER considered both augmentation costs and replacement cost should be included as they relate to forward costs influenced by forecast demand levels. In the AER's view, replacement costs are relevant as changes in demand can influence a distributor's decision on the size and timing of any replacement decision and as such, including replacement costs in LRMC estimates helps promote efficient network design in the long-run (AER, 2016). The AER also noted that not all costs are relevant for LRMC, and separated replacement costs into:

- Demand driven: Replacement of assets with increased capacity (to deliver a higher service level)
- Non-demand driven: Replacement of assets with modern equivalent (to deliver similar service level).

4.2 Electricity distribution network cost structure

The distribution network connects customers to supply from the transmission system via substations and feeders, and associated infrastructure (e.g. switchgear and transformers). The following excerpt from Ausgrid's submission to the Finkel review provides a summary of the major assets and cost drivers of a typical distribution network business:

> *Broadly speaking, in mature urban networks, network assets serve one of two functions. Zone Substation and Sub transmission assets serve to provide capacity, while LV and HV mains serve to connect end use customers to that capacity. The quantum of LV mains is determined by customer spacing, while the quantum of HV mains is predominantly determined by distribution centre spacing. The ratings of such mains is standardised and largely set by physical (mechanical) constraints, rather than load. Load growth is achieved by injecting more frequently into the virtually static LV network, by the provision of additional distribution centres, and into the largely static HV network, by the provision of additional zones (and to a limited extent by adding additional cable connections back to existing zones).*[4]

In summary, the following cost drivers apply to distribution network capital investments:

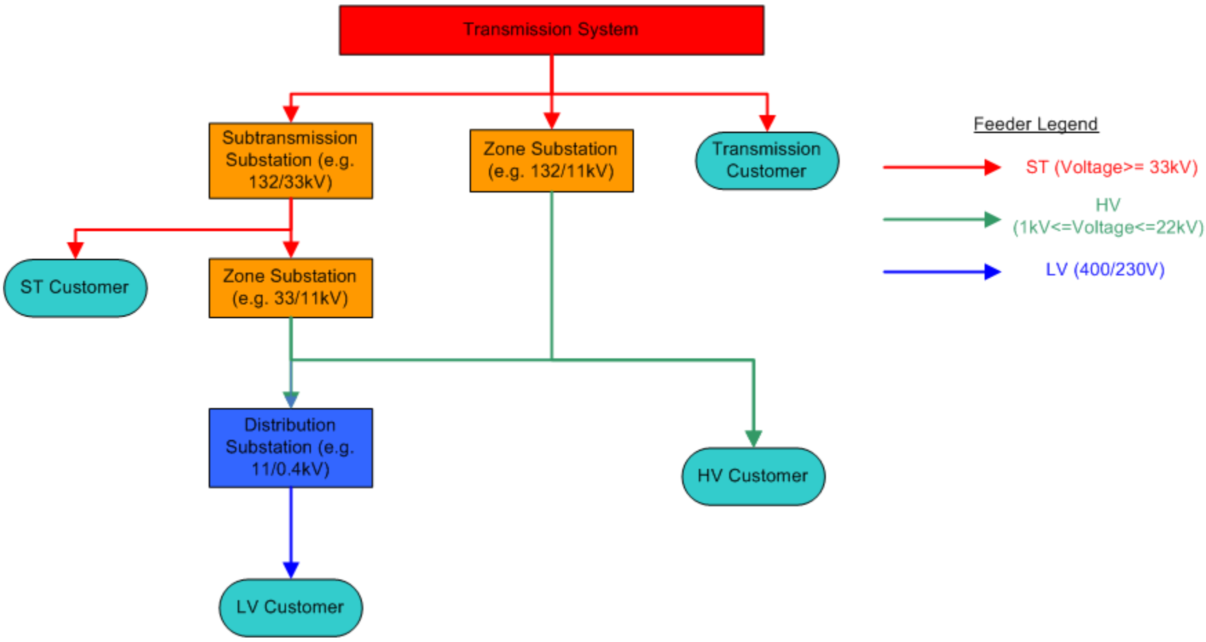
- Substations: expenditure on substation capacity is driven by peak demand. Network topology (network area) drives substation numbers, with some trade-off between the number of

[4] Ausgrid (2017) *Submission to the Finkel Review*

substations and the capacity of individual substations (although this is really a matter for individual networks in terms of how they optimise these variables)
- Feeders: feeders are designed to connect load and designed capacity will generally depend on customer density. Sub transmission feeders, which connect substations to the transmission network, are sized dependent on the sizing of the substation they connect to.

The figure below illustrates the typical network structure for an electricity distribution network such as Ausgrid.

Figure 4.1 Electricity network structure



Source: Ausgrid

4.3 Ausgrid's capital expenditure and cost drivers

Ausgrid's Portfolio Investment Plan (PIP) provides a capital expenditure outlook for FY19 to FY29, with distribution capital expenditure broadly grouped into the following categories:

- Replacement
- Non-system
- Growth
- Duty of care
- Customer connections
- Reliability standards.

Non-system, duty of care and reliability, appear to have minimal relationship with customers' demand and use of the network, and hence limited relevance to LMRC. As such, this section focusses mainly on growth, connections and replacement expenditure.

In this section, we comment on the types of capital expenditure reflected in the PIP, and relationship with LRMC. Note that some of the figures here, such as the percentage splits between different types of capital expenditure, reflect the current figures at the time of writing, and may change as Ausgrid's capital expenditure forecasts are further developed and refined.

4.3.1 Growth

Growth accounts for around 12% of total capital expenditure over the ten year forecast period in the PIP. Growth capital expenditure mainly comprises of substations, switchgear, feeders and transformers.

The principal drivers of growth capital expenditure for a network business are new customers connecting to the network and increases in peak, or maximum, demand at each network node. Augmentations to capacity are lumpy and often matched to standardized discrete sizes (such as in the case of feeders, outlined above. Typically augmentations take place in increments of capacity of the order of 30% to 50%, and once undertaken provide ongoing capacity for many years or even decades to come. Even under moderate growth scenarios, areas that have recently been augmented will generally have low LRMC values, while areas that are in imminent need of augmentation have high LRMC values. The current industry approach to LRMC calculation is to smooth the calculation across a whole service territory, somewhat negating the 'see-saw' pattern implied by a lumpy capital expenditure profile for smaller areas.

4.3.2 Connections

Connections make up around 1% of the capital expenditure forecast in the PIP. The majority of connections expenditure is on feeders, with a small component on switchgear and transformers.

As new customers connecting to the network will typically have an impact on maximum demand (in that location), we consider that it is appropriate to include connections expenditure in LRMC calculations.

4.3.3 Replacement costs

Replacement costs make up around 58% of Ausgrid's capital expenditure in the PIP. Replacement expenditure is divided into two types in the PIP:

- Project, or probabilistic replacement expenditure (comprising 28% of replacement expenditure in the PIP) – asset replacements based on detailed assessments of the likelihood and cost of failure, generally applied to major assets such as substations, sub-transmission feeders and switchgear.
- General, or program, replacement expenditure (72% of replacement expenditure) – asset replacements that are not suitable for a probabilistic model, based on either estimation conditions or data requirements. General replacement expenditure can be further broken into: supervisory control and data acquisition (SCADA); network control and protection; pole top structures; and other replacement expenditure (Ausgrid, 2015).

Probabilistic replacement costs and their relationship with peak demand and energy consumption are detailed in Box 1, below.

Box 1: Probabilistic replacement expenditure

Ausgrid's replacement program for significant assets is based on probabilistic forecasts of energy use and asset failure. The expected costs of asset failure (based on probability of failure and the costs of unserved energy in the event of failure) are compared to the costs of replacement to determine prioritisation and timing of replacement expenditure. Replacement of an asset will occur where:

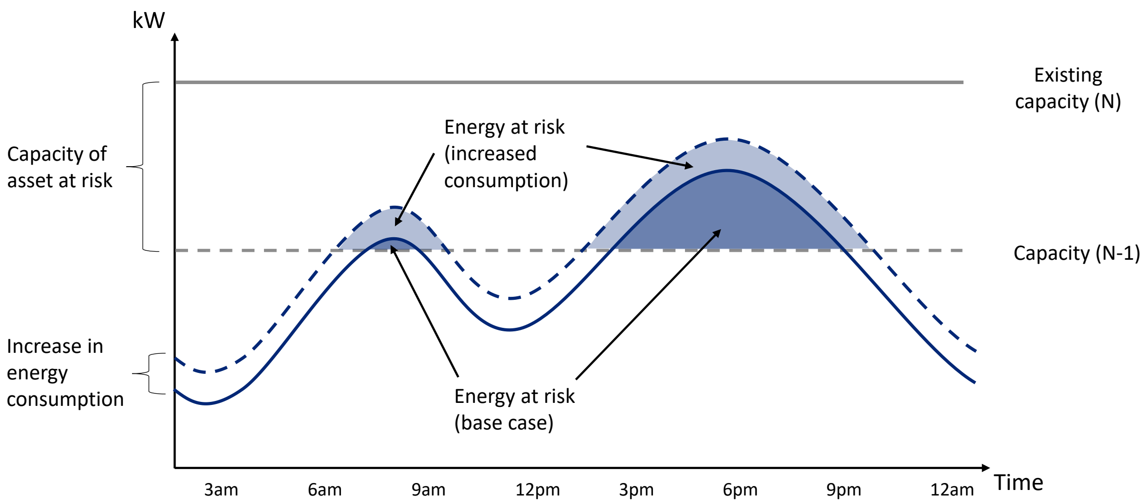
Expected cost of asset failure (p x USE x VCR) > Cost of replacement (annuitised)

Where:

p = probability of failure of a given asset
USE = unserved energy, or energy at risk should the asset fail
VCR = value of customer reliability

As such, probabilistic asset replacement is determined with reference to energy consumption rather than peak demand, as shown in figure 4.1. An increase in energy consumption will increase energy at risk (USE) and increase the expected cost of asset failure. This could bring forward asset replacement when the expected cost of asset failure increases above the cost of replacement.

Figure 4.1 Unserved energy risk under increased energy consumption



Source: Deloitte Access Economics

4.4 Ausgrid's LRMC modelling and results

As part of this project, we also reviewed Ausgrid's LRMC modelling for consistency with the concepts outlined in this report. The comments in this section relate specifically to the excel spreadsheet titled, *Ausgrid – Long Run Marginal Cost Model* of 21 November 2017. We note that the final LRMC estimates reflected in Ausgrid's TSS may differ due to changes in inputs (in particular, capital expenditure and demand forecasts), however to the extent that Ausgrid's approach to estimating LRMC remains the same, our findings will be applicable to Ausgrid's LRMC modelling and estimates.

4.4.1 Inputs and translation to pricing

We note that Ausgrid does not have the data to hand required to implement the full Turvey approach, as the PIP produces a single optimised capital expenditure plan over a 10 year forecasting horizon. As such, we consider that continuation of the AIC approach is appropriate for growth and connections expenditure. The probabilistic planning approach used for replacement expenditure allows a simplified Turvey approach (with several perturbations) to be applied.

When using the full Turvey approach, there is no need to specify which types of expenditure should be included. However, when using AIC or a simplified Turvey approach, it is important that only costs related to marginal changes in network use are included.

Based on the drivers of expenditure discussed above, we consider that Ausgrid's estimates of LRMC should include:

- Growth or augmentation expenditure, which is driven by changes in peak demand, and forms the basis of most LRMC estimates for electricity distribution
- Connections expenditure, driven by customer numbers growth and intrinsically linked to demand and energy use
- Probabilistic replacement expenditure, which is based on an assessment of energy at risk if an asset were to fail, and is therefore driven by energy consumption.

Growth and connections expenditure yield a demand-based LRMC estimate (i.e. $/kW or $/kVA), while probabilistic expenditure yields a consumption-based LRMC estimate (i.e. $/kWh). LRMC estimates formed in this manner could then feed into charges targeted at demand and energy consumption, respectively. However, in the absence of a demand-based tariff for Ausgrid, it may be necessary to convert the LRMC derived from growth and connections expenditure into a $/kWh charge.[5]

Ausgrid has three tariff periods to send more accurate price signals to consumers about system capacity. These three tariff periods are: off-peak period (non-ToU), shoulder period (ToU) and peak period (ToU). Ausgrid's ToU tariffs vary by:

- Time of day – higher tariffs are charged during hours of high demand through peak period charges and, to a lesser extent, shoulder charges.
- Time of year – the duration of ToU charges varies across seasons, reflecting seasonal network constraints. During summer and winter, Ausgrid apply both a peak and shoulder charge. The summer peak is longer (2pm-8pm) than the winter peak (5pm-9pm). Autumn and spring do not have a peak period charge.

To calculate both non-ToU and ToU tariffs, the LRMC estimate in $/kVA is first converted into $/kW by applying a power factor adjustment (reflecting how effectively electric power is consumed). Following this conversion, each tariff can then be calculated as follows:

Non-ToU:

$$(\$/kWh) = \frac{LRMC}{hours\ per\ annum}$$

ToU tariffs:

$$(\$/kWh) = \frac{LRMC}{peak/shoulder\ hours\ per\ annum\ in\ the\ relevant\ season} * p(MD)$$

where *LRMC* is expressed in *$/kW* and *p(MD)* is the probability of maximum demand occurring during the time relevant time period.

4.4.2 AIC approach

Ausgrid's AIC model estimates LRMC by voltage level (sub-transmission, high-voltage and low voltage). LRMC estimates at the voltage level are then used to calculate charges for each tariff class. In addition to the capital expenditure data described above, the following inputs are used in the LRMC model:

- Demand forecasts – annual total peak demand by voltage, for each of the four regions (Sydney South, Sydney North, Central Coast, and Newcastle and Hunter).

[5] We note that Ofgem's common distribution charging methodology (CDCM) separately calculates charges for demand and energy consumption related costs. The CDCM aims to calculate the incremental cost of an additional 500MW increment in capacity. The estimation is used to determine two prices: a charge that represents the costs associated with demand and a charge related to energy (Ofgem, 2011).

- Asset lives – capital expenditure is annuitized over a weighted average asset life of 40 years.
- Financing costs – a real WACC of 4.2% is used.
- Operating expenditure forecasts – Assumed to be 2% of capital expenditure.

The calculation methodology is consistent with the formula set out in section 3.1.2, and results in estimates that we consider reasonably reflect the LRMC or providing the service.

4.4.3 Perturbation (simplified Turvey) approach

Ausgrid has determined that the timing of probabilistic replacement expenditure depends on both asset condition and also the amount of unserved energy that would occur if the asset were to fail. To apply a perturbation-based approach to estimate the LRMC for this expenditure, Ausgrid has used capital expenditure on 11kV switchgear (which makes up around a third of total probabilistic, or project, replacement capital expenditure), and extrapolated the results to the other major categories of probabilistic replacement capital expenditure (sub-transmission feeders and substations). Key steps and inputs used in the LRMC model include:

- Renewals expenditure primarily driven by USE identified and included in forecasts, with large project expenditure not primarily driven by USE (for example, where environmental factors are the key driver of expenditure) is excluded
- Capital expenditure forecasts for 11kV switchgear, optimised for alternative consumption forecasts (base forecast, ±10%, and ±20%).
- Demand and expenditure are forecast for 20 years
- Financing costs: a real WACC of 4.2% is used.
- Operating expenditure: not included as difference between demand scenarios assumed to be immaterial
- LRMC estimates extrapolated out to other expenditure categories (sub-transmission and zone substations, and sub-transmission feeders) using relative expenditure levels
- LRMC estimates are then translated to the charging periods (peak, off-peak and shoulder), using weightings reflecting the proportion of energy use at each time and relationship with USE

We consider that Ausgrid’s inputs and LRMC modelling are consistent with the theoretical concepts in the literature and the practical application of AIC and perturbation approaches to calculating LRMC observed in various infrastructure sectors. We believe the model applies a methodology that appropriately estimates marginal costs and can be used to inform Ausgrid’s tariff structure reforms. The LRMC estimates produced by Ausgrid using this approach are likely to contribute to improved signals to customers about the link between use of the network and costs. We also note that given that USE is just one driver of replacement expenditure (with other drivers, such as environmental factors, often driving expenditure), the estimates derived using this approach are likely to be towards the upper range of LRMC for this component of capital expenditure.

Ausgrid’s use of the AIC and perturbation approaches allow it to calculate LRMC for both growth related capital expenditure (including connections) and replacement capital expenditure, providing a more complete picture of LRMC than estimates based on growth capital expenditure alone. Integration of these estimates into pricing will allow Ausgrid improve signals to customers about the costs of using the network.

5 Summary of findings

5.1 LMRC methodology

Our analysis is consistent with the academic literature and previous studies on LRMC, finding that the Turvey approach will typically provide a more accurate estimate of LRMC than the AIC approach. Turvey estimates will also be more stable over time and more robust to changing circumstances (e.g. significant levels of excess capacity, lumpy capital expenditure program). However, we also recognise that application of the Turvey approach is likely to be prohibitively costly due to the requirement to optimise a long-term capital expenditure plan at least twice (and ideally several times) to calculate robust Turvey estimates.

With increasing demand and a relatively smooth capital expenditure profile, AIC will provide similar results to Turvey. However, when the capital expenditure forecast is very lumpy (for example, where there is significant excess capacity) AIC can diverge significantly from the Turvey estimates and may also vary significantly over time. The AIC approach can also be difficult to reconcile when there is declining demand.

5.2 Ausgrid's approach to estimating LRMC

Given Ausgrid's current demand and capacity outlook, we consider that the AIC approach remains an appropriate methodology for estimating LRMC for demand-driven capital expenditure (augmentation and connections). The AIC approach is well-understood, relatively simple to apply and likely to provide a reasonable estimate of LRMC in these circumstances. We have reviewed Ausgrid's approach to modelling LRMC using the AIC approach, and consider that the approach adopted by Ausgrid is consistent with best practice application of this method, and that the results obtained are reasonable estimates of LRMC.

Ausgrid has also identified a component of replacement expenditure that is driven by changes in consumption. The timing of probabilistic replacement expenditure depends (among other things) on the asset condition and the amount of unserved energy that would occur if the asset were to fail. We have reviewed the modelling undertaken by Ausgrid to produce its LRMC estimates using the perturbation approach. Ausgrid has applied several alternative consumption forecasts (perturbations) and produced re-optimised capital expenditure profiles associated with each forecast. We consider that Ausgrid's application of a perturbation approach to estimating the LRMC for its replacement expenditure is consistent with the underlying principles of the Turvey approach. We also consider that the LRMC estimates produced by Ausgrid using this approach are reasonable estimates of LRMC and are likely to contribute to improved signals to customers about the link between use of the network and costs.

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