Levelised cost, a general formula for calculations of unit cost in integrated resource planning

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Abstract

Levelised cost describes the unit cost of conserved water or energy. Disagreement, however exists as to the appropriate method for calculating this important metric. This paper argues that levelised cost must be applicable to both supply and conservation options and provide a fair comparison of relative cost across scales. To achieve this, levelised cost ought to be calculated by taking the present value of all costs for an option divided by the present value of the stream annual water or energy that would be saved or supplied. Unlike other formulae, levelised cost as described, is an appropriate measure for identifying least cost options in IRP as it does not systematically under represent the cost of large scale projects and is directly comparable to the marginal cost of supply.

Opposition to the levelised cost as described however exists. This opposition focuses on the conceptually problematic idea of discounting a stream of future water or energy. Opponents maintain that this is nonsensical. This paper dispels these concerns by correctly identifying the variable of the conservation/supply stream in the levelised cost equation as being demand satisfied. A quantity that should be discounted to account for a consumer's time preference for consumption.

1. Introduction

Integrated resource planning is an open, participatory, strategic planning process, emphasising the least-cost analysis of all options for meeting utility supply service needs (Vickers, 2001). Integrated resource planning was developed for the electricity industry in the United States in the 1980's (Beecher, 1995), the aim being to compare energy demand management programs with increased generation as sources of supply. In the 1990's the concepts and methods of IRP were applied to other utility supplies, such as water (Menke and Woodwell, 1990; Beecher, 1995) and gas (Greenberg and Harshbarger, 1993). Of central concern for supply utility's engaged in IRP is the potential of demand management and other conservation measures to delay or avoid the need for expensive augmentations to bulk supply.

Demand management measures are designed to promote conservation through either changes in consumer behaviour or changes to the stock of resource using equipment (Greenberg and Harshbarger, 1993). Operational conservation measures which decrease leakage or loss from distribution networks are another area of conservation commonly targeted by supply utilities (White, 1998). In urban water, bulk supplies will also be conserved through providing or encouraging secondary sources of supply which can off set particular end-uses. Examples being greywater collection system for toilet flushing and rainwater collection to supply hot water and garden watering (White and Fane, 2002). Beecher (1996) describes the concept of distributed resources to cover both small-scale local sources and demand management. Distributed resources are smaller units of supply located within the existing distribution network. By using distributed resources, it is easier to maintain supply and demand in close proximity as they can be implemented incrementally. This means that the adverse environmental and cost impacts that accompany large-scale projects will be avoided (Beecher 1996).

The key principle of IRP is that conservation measures should be treated as equivalent to supply by the utility supplier (Beecher, 1995). Further, IRP should account for the advantages of distributed resources (Beecher 1996). Despite this, inconstancies are evident in the manor in which methods used for least-cost analysis in IRP treat conservation and supply options and how sources of differing scales are handled. After a review of the existing methods, this paper outlines a methodology which is applicable to any supply or conservation option and can provide a fair comparison of relative cost across scales.

2. Methods used for evaluating conservation measures

In the water IRP literature, the evaluation of conservation measures is framed in various ways. Some authors (Skeel *et al* 1998; Howe and White, 1999) advocate the evaluation of measures based on unit cost of conserved water, known as levelised cost. Other authors frame their evaluations' in terms of the net cost or net benefit derived from a given measure (Macy and Maddaus 1987). The advantage of a levelised cost approach is that measures can then be ranked on relative unit cost and compared directly to the avoided cost of conservation. This allows an immediate comparison of the costs of conservation to the avoided cost and the price of water paid by consumers. There is also the advantage that presenting measures in a ranked order of cost effectiveness can be illustrated in the form of a conservation supply curve (Meier, 1982; Stoft, 1995).

A conservation supply curve shows a series of steps with each representing a conservation measure (Meier, 1982). The width of each step is the estimated conservation outcome and the height, the levelised cost of that measure. The levelised cost (however calculated) is compared to avoided cost of conservation. Despite general acceptance that the levelised cost of measures be compared to the avoided cost of conservation, disagreement exists as to the appropriate methods for calculating these critical parameters.

Calculating the avoided cost of water conservation

In IRP the avoided cost of conservation is the incremental or marginal cost saving associated with not producing an additional unit of supply (Beecher, 1995). Most authors use the marginal cost of supply, also know as the long run marginal cost (LRMC), as the avoided cost of conservation although some studies also account for further avoidable costs, including externalities. In theory the marginal cost of supply should account for all the predicted direct and indirect costs of future supply. Herrington, (1987) states that this would cover both quantitative and qualitative costs, in the form of externalities, operating and capital costs. In practice however, Hanke’s (1981) definition of LRMC as a metric of the cost impact of incremental use on a supply system is more commonly adhered to. This covers only those direct costs to the utility from production and bulk augmentation.

The average production cost of supply, also known as the short run marginal cost (SRMC), is relatively easy to account for with the operating costs of supply simply averaged per kiloliter produced. Calculating the fraction of future bulk augmentation cost, know as the marginal capacity cost, to assign to incremental use is, however, more difficult. Ambiguity arises due to the 'lumpiness' in costs and different methods available for spreading these costs over time. At least four methods are possible for estimating the marginal capacity cost of utility supply (Mann, *et al*, 1980). The two most commonly cited in the literature on marginal cost of water supply are Turvey's method and the average incremental cost (AIC) method.

Turvey (1969) described a method for calculating marginal capacity cost based on the cost in net present value terms of moving the next planned capacity augmentation forward by a single year. This 'cost' is then divided by the one-off volumetric increase, or increment, in current demand that would require the planned capacity augmentation to be moved forward in such a manor. With Turvey's method the LRMC is generated by adding the SRMC to the calculated marginal capacity cost.

A number of authors, have described a method of calculating the marginal cost for water supply using the term AIC (Mann, *et al*, 1980; Herrington 1987). Average incremental cost is calculated by "*discounting all incremental costs which will be incurred in the future to provide for estimated additional demand over a specified period, and dividing that by the discounted value of incremental output over the period*" (Mann, *et al*, 1980). In other words, the AIC for a supply system is the present value of the stream of capital and operating costs needed to satisfy the projected demand divided by the present value of the stream of demand itself. Average incremental cost gives an estimate of the LRMC. With either Turvey's or AIC methods, the evaluation is therefore only as precise as the demand projection.

Turvey's method or the use of AICusually are applied with reference to a subset of the possible avoidable costs due to water conservation. Maddaus (1999) identified two other capacity costs potentially avoidable when water is conserved. These are water treatment plant and treated water storage capacity costs and pumping station capacity costs, which are dependent on peak day and peak hour water demand, or fire fighting requirements respectively.

Avoidable costs to agents other than the urban water utilities can also be considered. Avoidable costs due to water conservation may be evident in wastewater systems (White, 1998). These costs are limited mostly to operational costs of wastewater treatment. Those capacity costs which can be avoidable through household sewage volumes reductions are mostly restricted to tertiary sewage treatment or land disposal capacity (Howe and White 1999). Water conservation measures can save consumers in terms of their water bills, and their energy bills for water heating. Some measures, such as washing machine rebates, may also save consumers in the cost of detergent. Savings made on water bills should not be included in avoidable costs as this represents a direct financial cost of conservation to the water supply utility and is a transfer payment (White, 1998). Other savings, on energy for example, can be included. The value of avoidable externalities, such as reduced greenhouse gas emissions due to pumping and water heating (Howe and White, 1998) or increased river flows can be estimated in monetary terms and are included in the avoided cost of conservation by some authors. tudies differ in whether these other avoidable costs are included in the avoided cost.

In practice the impact of different water conservation measures across the urban water system will vary. Differences will be evident between the avoided cost of outdoor and indoor use, measures which disproportionately impact on peak demands, and measures which provide long term and short term conservation. It can be argued that in any supply system a number of specific locational points of high avoided costs exists.

Calculating the unit cost of water conservation

The term levelised cost has been used by various authors to describe the unit cost of conserved water (Menke and Woodwell, 1990; Dziegielewski *et al* 1993; Howe and White, 1999). Other authors don't use the term but do define methodologies for calculating an estimated unit cost of 'supply' from a conservation measure. The estimate of the unit cost of conservation measures is useful in IRP as it allow immediate comparison of the relative costs of conservation to the avoided cost. The levelised costs of measures can then be presented in ranked order of cost effectiveness and represented in a supply curve of water conservation.

In his thesis on 'supply curves of conserved energy', Meier (1982) provided the original discussion of this concept, and describes the cost of conserved energy (CCE) as equal to:

$$CCE = \frac{C * r}{S[1-(1+r)^{-n}]} \qquad (1)$$

Where C is the cost of the measure, S is the annual (energy) saving r is the discount rate and n is the life time of the option. The Rocky Mountain Institute (Menke and Woodwell, 1990) describes this same formula as the 'Lawrence Berkeley Laboratory method' for calculating levelised cost for use in the evaluating water conservation measures. Menke and Woodwell (1990) define C in equation 1 as the present value of all costs associated with a conservation measure including any hardware, installation, administration and maintenance costs. The significant problem with this method is that only one single figure for annual saving can be used. Applied to both conservation measures and bulk supply this method does not account for the fact that large scale measures will produce significant over capacity in the short term. The method is systematic bias towards large scale supply options and does not account for the advantages provided by distributed resources in incrementally meeting demand (Fane *et al*., 2002).

Dziegielewski *et al* (1993), and the NSW Water Demand Management Forum (1996) independently defined the levelised cost (LC) of conserved water as:

$$LC = \frac{\sum C_t /(1+r)^t}{\sum S_t} \qquad (2)$$

Where C_t is the cost (capital and operating) of the option in the year t, S_t is the saving in year t and r is the real discount rate. The sum is taken over the life of the program or some other defined period. The California Urban Water Conservation Council (2000) advocate using this formula based on total volume of water conserved. With this method the period over which analysis is conducted will have significant impacts on the cost outcome due to the lack of discounting. If a long assessment period is taken, such as the life of a dam, then not discounting output will give an inappropriately low unit cost of supply. For shorter assessment periods as prescribed in CUWCC (2000) or WDMF (1996), large scale water supply projects would not approach their capacities.

Skeel ,*et al* (1998), and White (1998) define the levelised cost of conserved water as:

$$LC = \frac{\sum C_t /(1+r)^t}{\sum S_t /(1+r)^t} \qquad (3)$$

Where C_t is the cost (capital and operating) of the option in the year t, S_t is the saving in year t and r is the real discount rate. The sum is taken over the same length of time for numerator and denominator. This approach generates a unit cost of water which is equivalent to the 'constant price' of water from that measure (see Section 4 below).

Equation 3 is also identical to the formula given for AIC by Mann, *et al.* (1980) and Herrington (1987) except that for average incremental cost, S_t is set equal to output in year t rather than savings. The same formula (equation 3) therefore has application to both bulk supply and conservation options, and it is argued is consistent with the aims of 'equivalence between supply and conservation'. However, comparing the levelised cost of a conservation measure to the AIC marginal cost of supply needs further explanation, and this is undertaken in Section 6. Firstly the issue of ‘discounting water demand’ is addressed.

3. Discounted water demand explained

There is opposition to the levelised cost method represented by Equation 3. This opposition comes from the conceptually problematic idea of discounting a stream of future water. Opponents indicate that discounting physical quantities is nonsensical. This apparent anomaly can be explained by correctly identifying the variable S_t in equation 3. Previously this variable has been identified as water saved (White, 1998; Skeel, *et. al.*1999). Howe and White, (1999) however accurately identified the variable S_t as been "*annual reduction in demand for water resulting from that option”.* This variable, despite being measured in kiloliters or kilowatt hours, is not a physical quantity, but an estimate of the future demand satisfied by a given measure. It represents the stream of satisfied demand provided by that conservation measure and is therefore a metric of ‘utility’, in the economic sense. Discounting this quantity over time is therefore reasonable, in order to account for consumer’s time preference for consumption. The definition given by Howe and White (1999) for S_t in Equation 3 can easily be broadened to include both demand supplied and demand conserved.

4. Levelised cost as constant price

Equation 3 generates a levelised cost that equivalent to the 'constant price' of conserved or supplied demand from an option. This constant price is equal to the ‘income’ per unit that would need to be received from each unit of supply/conservation for that option to ‘break even’ in present value terms. A similar argument based on constant price has been presented by Stoft (1995) in justification for the discounting of energy conserved over time. The constant price for any option is that value of a unit price which if held constant over time and paid for each kilolitre saved or supplied, would yield the same present value for that option as it's present value cost. To demonstrate this, note that the present value cost for an option is given by the expression:

$$PV(\cos t) = \sum C_t /(1+r)^t$$

Where C_t is the cost (capital and operating) of the option in the year t, and r is the discount rate to be applied. Therefore if levelised cost is the same value of a constant unit price of water over time then:

$$PV(\cos t) = \sum LC * W_t \,/(1+r)^t$$

Where W_t is the water supplied or conserved in year t. Expanded, this equation provides:

$$PV(costs) = LC*Wyear_1/(1+r)^1 + LC*Wyear_2/(1+r)^{2\cdots\cdots\cdots} LC*Wyear_x/(1+r)^x$$

Where $Wyear_1$ $Wyear_2$ $Wyear_x$ is the demand for water supplied or conserved in year 1, year 2 and year x respectively. This can then be easily rearranged to give: *PV(costs) = LC * PV (demand for water supplied or conserved)* an equivalent expression to the formula for levelised cost given in equation 3.

5. Ranking options on levelised costs

Equation 3 with S_t defined as demand satisfied (demand supplied or demand conserved) provides a metric which allows any supply or conservation option to be compared. The formula can be applied in an equivalent manner to both demand management measures and new bulk supplies. Calculating levelised cost by Equation 3 for a given option requires both an estimated stream of costs and the estimated stream of demand conserved or supplied by that option. From these streams a unit cost equal to the 'constant price' of supply from that option (at present value) can be calculated. The levelised cost for an option including a bulk supply option is calculated as the cost of immediately implementing that option.

In a situation where there is no remaining bulk water supply capacity, then Equation 3 may then be used to rank any finite number of options in an order in which they should be implemented which will minimise the present value cost to society. In other words the least cost schedule of conservation and supply options is provided by ranking options in order of levelised costs as calculated by Equation 3. The fact that Equation 3 will generate the least cost schedule of options is illustrated through considering the following argument.

If there are only two supply or conservation options, A and B, currently available, Option A will meet increasing demand for x years and option B for y years. The present value cost of A and B, PV (cost A) and PV (cost B), cannot be compared meaningfully because they do not satisfy equivalent demand scenarios. There are then two possibilities for meeting demand over the period x + y years. The options can be scheduled either, A then B (AB) or B then A (BA).

The present value of scheduling A before B and scheduling B before A can be represented respectively by:

*PV (cost AB) = PV (D1*LCA, D2*LCA,..Dx*LCA, Dx+1*LCB,..Dx+y*LCB)*

and

*PV (cost BA) = NPV (D1*LCB, D2*LCB,..Dy*LCB, Dy+1*LCA,..Dx+y*LCA*

Where the levelised cost for options A and B are LCA and LCB respectively and D1 equals the difference between demand in year 1 and year 0, D2 equals the difference between demand in year 2 and year 1. If the levelised cost of option A is less than the levelised cost of option B then the present value cost of scheduling A before B must be less than the present value cost of scheduling B before A. This is because costs in later years are proportionally diminished in present value terms through discounting for all positive discount rates.

6 Comparing Levelised cost to Average Incremental Cost

In many IRP studies the avoided cost of conservation is taken as a given, outside the boundary of the study. Often the methods used for the cost of conservation and the avoided cost of conservation are therefore not consistent. As IRP aims to treat supply and conservation in an equivalent manner this lack of consistency is problematic.

Using Equation 3, both individual conservation and supply options can be compared and scheduled on the basis of relative unit cost. As bulk augmentation can be considered as just another option it can be argued that all options with a levelised cost that is less than that of bulk augmentation should be implemented before that augmentation occurs.

As highlighted previously, Equation 3 is the same as that used for estimating the AIC from the current system. The AIC is a representation of the marginal cost of supply from the existing supply system and the planned bulk augmentation. It has been suggested that any distributed resource with a levelised cost less than this AIC should be implemented immediately. However the AIC should represent the least cost schedule of options for meeting demand (Mann, *et al*, 1980; Herrington 1987). If distributed resources are treated as equivalent to bulk supply then the true least cost schedule should include these measures. Only for those options that have a levelised cost less than this 'true AIC' can it be argued that immediate implementation is warranted.

A methodology for generating the 'true AIC' and the least cost schedule is given below. It should be noted that only distributed resources with a fixed or long term capacity impact can be compared using this methodology. This means that the capacity of these measures in terms of supply or conservation does not decrease before bulk augmentation needs to be considered. Measures with a transient impact or the proportion of the impact of a measures that is transient should be compared to the short run marginal cost.

AIC/ levelised cost methodology outlined

The AIC/levelised cost methodology for developing the least cost scenario for conservation and supply and true AIC is outlined below:

i) Develop a detailed model of future demand for water services based on end-use analysis.

ii) Project the base case demand for bulk supply based on the assumption that there is no government or utility action to manage the bulk demand.

iii) Develop potential demand management and secondary supply measures based on the detailed end-use model and estimate conservation potential for each measure.

iv) Calculate the levelised cost for demand management measures, local secondary supply and bulk supply options using equation 3 with S_t defined as the demand met in year t.

v) Account for any other avoided costs included in the analysis to give net levelised cost for each option. These avoided cost may come from wastewater savings, peak demand savings and the avoided cost of externalities.

vi) Rank all options in terms of net levelised cost.

vii) Consulting this ranking on net levelised cost, derive a revised augmentation schedule based on implementing those options that have a lower net levelised cost and can be feasibly implemented in the future before bulk augmentation.

viii) Calculate a 'true AIC' based of the least cost conservation/supply schedule

ix) Compare the 'true AIC' to the ranked order of options on net levelised cost to identify options which should be implemented immediately.

x) Implement further options over time as the 'true AIC' increase to the point equal with their net levelised cost.

7. Conclusion

Integrated resource planning needs an evaluation methodology which is applicable to both supply or conservation options and accounts for the advantages of distributed resources. The advantage of a levelised cost approach is that measures can be ranked on relative unit cost and compared to the avoided cost of conservation. This allows immediate comparison of conservation costs to the avoided cost and to the price of water.

This paper argues that the levelised cost should be calculated by the method used previously by Skeel ,*et al* (1998), and White (1998) and that this method can be made applicable to any supply or conservation option. This method, unlike those other suggested by other authors, provides an equitable and consistent comparison of relative cost across system scales.

The water output stream variable must however be defined as the future demand which is met by the option. Discounting the water output stream in the calculation of both levelised cost and average incremental cost is then valid and appropriate to account for the time preference of consumption. It is also argued that levelised cost, so calculated, is the equivalent to the 'constant price' of a conservation or supply option. Further, it is argued that avoidable costs to agents other than the water supply utility can be included in a net levelised cost for each option. The ranking of options on net levelised cost will then provide the least cost schedule for implementation of conservation and supply options.

The AIC/levelised cost methodology outlined is similar to that utilised by previous authors but differs in the manor in which the avoided cost of conservation is determined and handled in the analysis. Further, that all options with a levelised cost less that the levelised cost of bulk augmentation should be implemented before augmentation has not previously made explicit. In AIC/levelised cost methodology, the net levelised costs of conservation measures are compared to an avoided cost of conservation identifies as the 'true AIC'. This figure represents the marginal cost of *supply or conservation* for a supply system. For only those measures that have a levelised cost less than this marginal cost can it be argued that immediate implementation is warranted.

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