Development of Order-Independent Waterfall Graphics to Enable Comprehensive Understanding of Impact Evaluation Results

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ABSTRACT

How can impact evaluation reporting be improved to concisely show key results for multiple audiences? Because impact evaluations inform program design, regulatory policy and planning, and public understanding of energy efficiency, there are multiple audiences with varied evaluation backgrounds and needs. Impact evaluations should report both gross and net savings and illustrate drivers behind ex ante[1] and ex post[2] discrepancies whenever possible. Gross savings better aid decision making around procurement and emissions, while net savings results yield guidance on program design and impacts relative to spending. Waterfall graphics can effectively showcase savings values alongside stepwise adjustments to reported (ex ante) savings. We present both gross and net waterfall graphics that serve the needs of all evaluation stakeholders, and we develop a normalization methodology to ensure waterfall graphics show order-independent adjustments. The resulting visuals offer a concise, complete, and accurate way to highlight program achievements, provide insights for program planning, and suggest opportunities for program improvement.

Problem Statement

At the heart of any impact evaluation are two essential questions: What are the savings, and how were those savings achieved? How those questions are answered can make or break the utility of an impact evaluation report. Across measures, programs, and portfolios, savings are often shown as in Table 1, where gross savings (arbitrary units) are catalogued along with the evaluated gross realization rate (*GRR*)[3], ex post net to gross ratio (*NTG*)[4] and finally ex post net savings.

Table 1. Typical Impact Evaluation Findings Reporting

Ex Ante Gross Savings	Ex Ante Net Savings	GRR	Ex Post Gross Savings	Ex Post NTG	Ex Post Net Savings
100	80	0.5	50	0.6	30

Though documenting ex ante and ex post savings, Table 1 falls short in two key areas. First, it does not expose the reasons between ex ante and ex post gross savings discrepancies that provide insight into program performance. Second, many evaluation stakeholders (e.g. regulators, policymakers, and ratepayers) are better served by an understanding of *savings and adjustments on a net basis*. However, most impact evaluations assess ex ante vs. ex post differences at the gross level, then estimate NTG, and finally provide a net savings estimate. Yet when net savings are presented only as a bottom line, impact

[1] Ex ante savings are "before evaluation" savings estimates.
[2] Ex post savings are "after evaluation" savings estimates, informed by EM&V activities.
[3] Gross Realization Rate is defined as (Gross ex post savings) / (Gross ex ante savings)
[4] Ex post Net to Gross (NTG) is defined as (ex post Net savings) / (ex post Gross savings). Similarly, ex ante NTG is (ex ante Net savings) / (ex ante Gross savings)

evaluation results fail to serve the full audience. We will walk through possible solutions to both of these obstacles in an effort to make impact evaluation results most useful to all stakeholders.

Example #1: Exposing Ex Ante vs. Ex Post Discrepancies: The Benefit of Reporting Impact Parameters

A quality impact evaluation should report the key findings that feed into the *GRR*, whenever possible[5], since these findings provide understanding of how savings were achieved. Table 2 is an expansion of Table 1 that adds key impact parameter[6] adjustments.

Table 2. Expanded Impact Evaluation Results: Example #1

		Impact Parameters						
Ex Ante Gross Savings	**Ex Ante Net Savings**	**Hours of Use (HOU)**	**ΔWatts**	**In Service Rate (ISR)**	**GRR**	**Ex Post Gross Savings**	**NTG_{XP}**	**Ex Post Net Savings**
100	80	0.70	1.14	0.63	0.5	50	0.6	30

The *GRR* alone is not sufficient for several reasons. Consider a *GRR* comprised of Hours of Use (*HOU*), *ΔWatts* and In Service Rate (*ISR*). Ex Post adjustment factors to these parameters of 2.5, 1.0 and 0.4 would yield a *GRR* of 1.0 (2.5 x 1.0 x 0.4 = 1.0) and lead to no savings adjustment despite the fact that the ex ante *HOU* and *ISR* estimates were wildly inaccurate. With the parameter-level breakdown, program administrators are given the information to determine how ex ante savings estimates can be improved, and possibly ways to enhance program performance. In this example, further investigation into lower than expected In Service Rates could yield opportunities for increased savings.

With the impact parameters reported as in Table 2, a powerful visual can be constructed in a waterfall graph to give a concise picture of the evaluation results (Fig. 1). For stakeholders primarily interested in gross savings, this graphic compares ex ante and ex post gross savings, the effects of applying sequential impact parameters, and the relative size of each adjustment.

[5] Not all evaluation methodologies yield impact parameters or their equivalent. For example, billing analyses will often provide numeric savings estimates, without providing any insights into how the savings were achieved. In these cases we advocate for evaluators to obtain this information through other means, such as participant surveys, equipment monitoring, site visits, or other methods.

[6] Impact parameters are realization rates for physical metrics that determine savings. For example, the Hours of Use impact parameter (*HOU*) is defined as *HOU* = Ex Post HOU/ Ex Ante HOU. Realization rates are dimensionless (unitless) quantities.

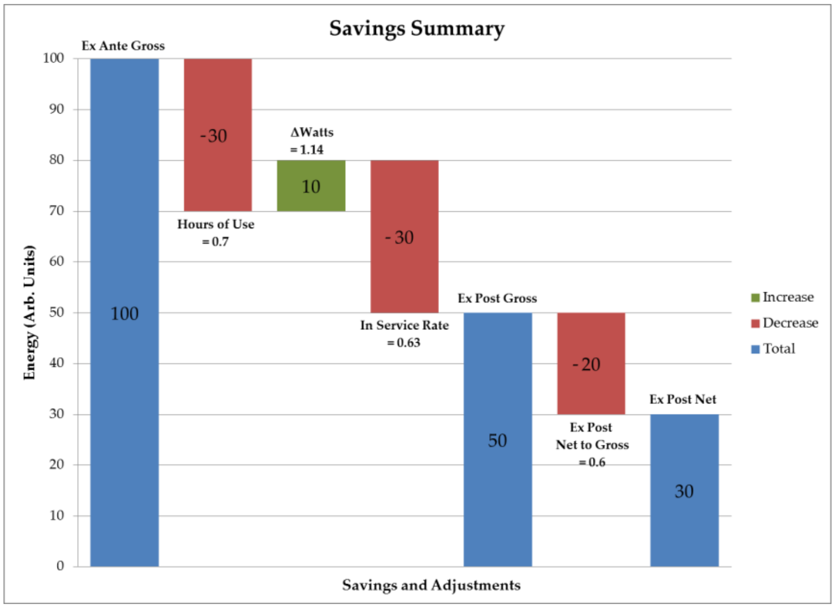


Figure 1. A waterfall graphic highlighting gross savings and adjustments from Table 2.

Although Fig. 1 gives an intuitive assessment that reflects the evaluation methodology sequence, such a display is critically lacking for stakeholders who want to compare *net savings performance*. Since a waterfall is a sequential graph, we note that ex ante NTG reductions and ex ante net savings are not included in Fig. 1, and cannot be not logically incorporated.

Net Savings and Adjustments

For stakeholders most interested in net savings, a figure comparing ex ante and ex post *net* savings would be much more useful. Again using the data of Table 2, converted to the net domain, Figure 2 can be constructed.

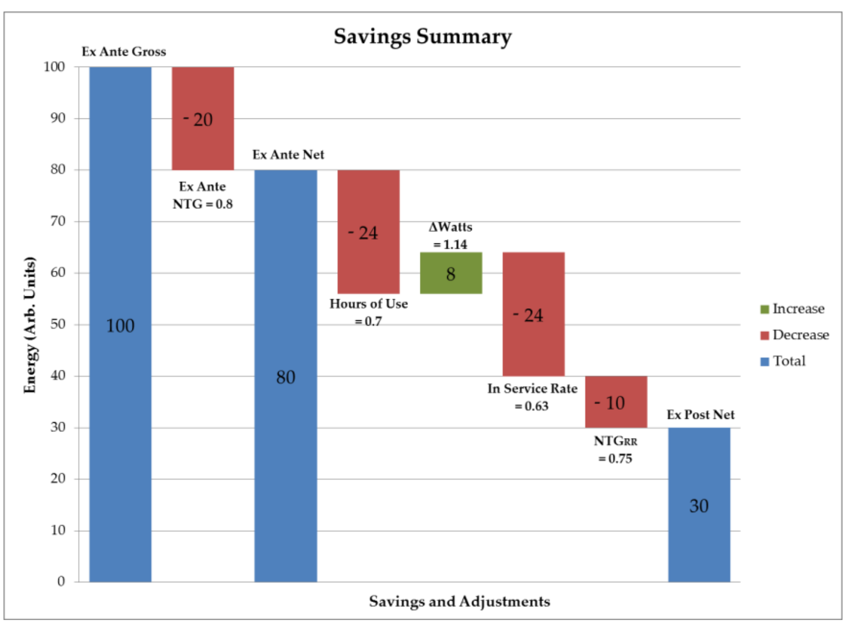
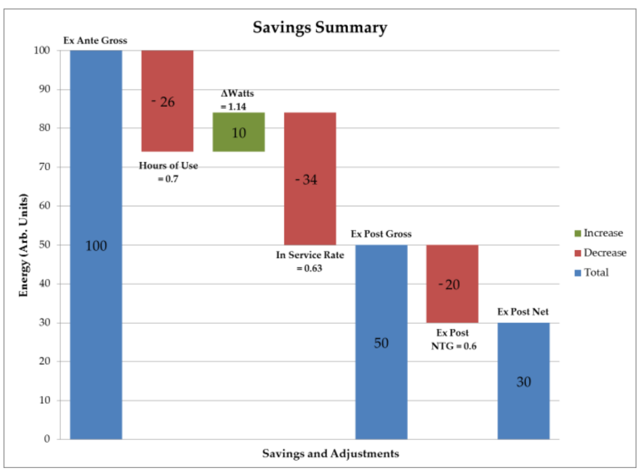


Figure 2. A waterfall graphic highlighting net savings and adjustments from Table 2.

Figure 2 allows a direct comparison of ex ante to ex post net savings, along with the reasons for any disparity. It is readily apparent that the sizes of the steps are different in the Gross and Net waterfall graphics. Furthermore, the net waterfall cannot include a step for ex post NTG because this adjustment is applied to gross savings, which are unavailable in the net savings waterfall. Therefore, a new step is needed, which we have labeled NTG_{RR}, which is the NTG realization rate. This step can be thought of as an adjustment to net savings due to the misalignment between ex ante NTG and ex post NTG. Figure 2 better serves the needs of readers focused on net energy savings, and allows a direct comparison between ex ante and ex post net savings. The conversion necessary to create the net waterfall is presented in the Methodology section along with a discussion of NTG_{RR} and the key role it plays in the net waterfall.

Developing Order-Independent Waterfall Figures

A major shortcoming of the above Figures 1 and 2 is the dependence on the order of application of savings adjustments. When presented as absolute stepwise adjustments (as in the above waterfall figures), multiplicative impact parameters are either accentuated or understated depending on the order of their application. This can be remedied by a normalization process discussed in the Methodology section. Figures 3a and 3b recast Figures 1 and 2 as order-independent waterfalls, and are the fully developed figures we propose as an option for enhanced impact evaluation reporting.



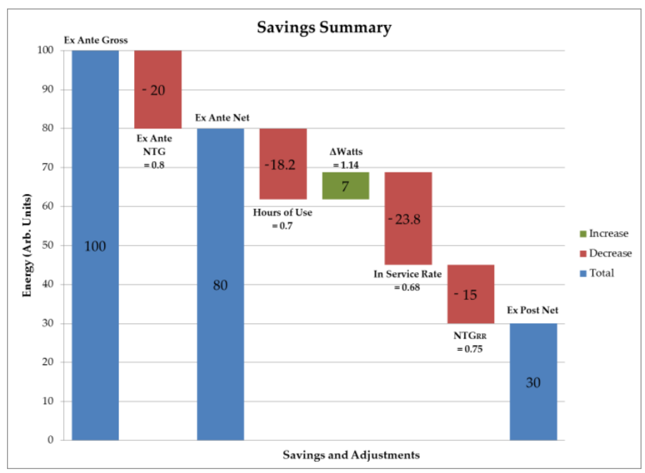


Figure 3a (left). A gross waterfall graphic displaying the savings and adjustments given in Table 2. **Figure 3b** (right). The corresponding net waterfall graphic. These figures showcase order-independent steps that result from the normalization process discussed in the Methodology section.

The steps from ex ante gross (net) to ex post gross (net) savings shown in Fig. 3 showcase *order-independent savings adjustments, which ensures their accurate relative sizes*. By comparing the stepwise adjustments of Fig. 3 to those of Figs. 1 and 2, one can see that normalization indeed yields significantly different step sizes. These graphics can be developed at the portfolio level (for a legislator or regulator), a program level (for a program administrator), or a measure level (for a program manager).

Thus far we have demonstrated the value behind the waterfall graphics and the benefit of both the gross and net waterfalls. We have also established that without careful normalization the order of application of savings adjustments can create a misleading visual. The conversion from the data of Table 2 to the order-independent waterfalls of Fig. 3 is not straightforward. In the discussion that follows, we discuss themethodology to develop the order-independent gross water fall of Fig. 3a. We then show the conversion procedure to transform Fig. 1 to Fig. 2, i.e. converting gross savings adjustments to net savings adjustments. We then discuss the approach to generate the order independent net waterfall of Figs. 3b. Finally we present a second example to showcase the need for both gross and net normalized waterfalls.

Methodology

Background

An impact evaluation of energy efficiency savings is typically conducted via two distinct and separate steps. 1. Estimate ex post gross savings ($Gross_{XP}$), which determines the gross realization rate (GRR). 2. Estimate ex post net savings (Net_{XP}), typically by determination of the ex post net-to-gross (NTG_{XP}) ratio. These metrics sequentially applied to the ex ante gross savings yield ex post gross and ex post net savings, respectively, which is expressed mathematically as:

$$Gross_{XP} = Gross_{XA} \cdot GRR \qquad (1)$$

$$Net_{XP} = Gross_{XP} \cdot NTG_{XP} \qquad (2)$$

where the XA and XP subscripts indicate ex ante and ex post values, respectively.

From an evaluator's perspective, measuring gross savings impacts is most practical because gross savings show up at the meter, appear on a customer's bill, and are directly correlated to fuel consumption, emissions, and peak loads. The *GRR* is often comprised of several impact parameters specific to the measure, program or portfolio being evaluated. In the example above and in the remainder of the text we take Hours of Use (*HOU*), change in equipment wattage ($\Delta Watts$) and In Service Rate (*ISR*) as the impact parameters such that

$$GRR = HOU \cdot \Delta Watts \cdot ISR \qquad (3)$$

where each of the individual impact parameters are defined as the ratio of an ex post determination to the corresponding ex ante estimate. For example,

$$HOU = \frac{HOU_{XP}}{HOU_{XA}} \qquad (4)$$

with subscripts again indicating ex ante and ex post.

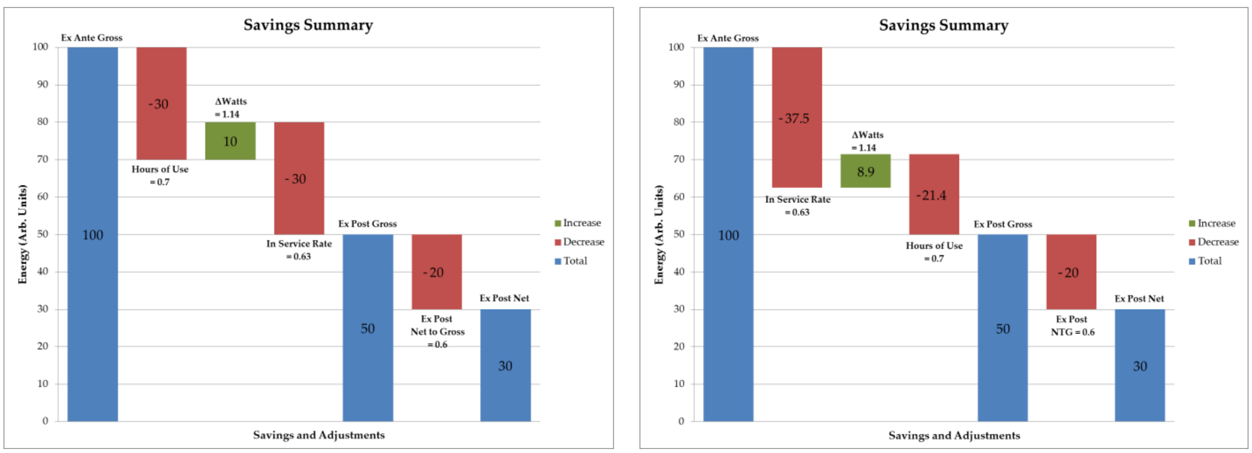
Order of Evaluation Adjustments Matters

When the impact parameters are broken out as shown in Table 2, the waterfall graphic of Fig. 1 can be constructed by a sequential multiplication to determine the absolute adjustments due to each impact parameter as shown in Table 3.

Table 3. Impact Parameter Adjustments

Ex Ante Gross = 100			Resulting Savings	Change
Impact Parameters	**HOU**	0.7	70.0	-30.0
	ΔWatts	1.14	80.0	10.0
	ISR	0.63	50.0	-30.0
	Ex Post Gross		**50.0**	
	NTG_{XP}	0.6	30.0	-20.0
	Ex Post Net		**30.0**	

However, we draw attention to a major caveat of this utilization of a waterfall graphic – *the order of application of individual impact parameters matters*. Note that in Fig. 1 and Table 3, despite the fact that *ISR* (0.63) imposes a greater fractional adjustment to the gross savings than *HOU* (0.7), because the *ISR* is applied to the full 100 units while the *HOU* adjustment is only applied to 80, the two appear to make an identical contribution to the overall *GRR* reduction. Figure 4 illustrates how the individual savings adjustments change by reversing the order of application. We emphasize that the relative importance of each adjustment has not changed from Fig. 4a to Fig. 4b, but the step sizes that compel a visual perception of importance are significantly altered. While in Fig. 4a, *HOU* and *ISR* adjustments appear to be equal, in Fig. 4b, the *ISR* adjustment appears nearly twice as important as the *HOU* adjustment.



Figures 4a and 4b. An example to demonstrate that the order of the steps (order of application of evaluation parameters) affects their size. **Figure 4a** (left). A waterfall graphic displaying the savings and adjustments given in Table 2. **Figure 4b** (right). The waterfall graphic that results from reversing the order of application of impact parameter adjustments.

Normalization by Permutation

Consider the example of three impact parameters used thus far (*HOU*, *ΔWatts*, and *ISR*). Those three parameters can be applied in a total of six different orders. In other words, six equally valid tables analogous to Table 3 could be generated and each would yield a waterfall graph that paints a different picture of the evaluation results. Similarly, four parameters can be applied in a total of 24 different orders. In general, a number N parameters can be applied in N factorial (N!) different orders.

Normalized, order-independent impact parameter adjustments can be obtained with the following three step procedure:

1. Perform all possible permutations of the sequential application of multiplicative impact parameter adjustments.
2. Sum the changes due to each individual impact parameter.
3. Divide the results of Step 2 by the total number of permutations.

Though calculating many permutations may be an imposing task when several impact parameters are in question, the problem only needs to be solved once if automated in a workbook program such as Microsoft Excel. Figure 3a above shows the result of this permutation normalization procedure for Example 1.. In that graph the gross impact parameters are order-independent and give an accurately proportioned visual indication of the corresponding savings adjustments.

Converting Gross Evaluation Parameters to Net Evaluation Parameters

Here we describe the methodology to convert the Table 2 data (gross evaluation parameters) into net evaluation parameters to construct the net waterfall format of Fig. 2 and then the order-independent Fig. 3b. First, we recall standard evaluation equations. In Equations 1 and 2 we showed the pathway to ex post net savings via the *GRR*. However, a second pathway is equally appropriate: Application of ex ante *NTG* followed by the Net Realization Rate (*NRR*) (Equations 5 – 6).

$$Net_{XA} = Gross_{XA} \cdot NTG_{XA} \qquad (5)$$

$$Net_{XP} = Net_{XA} \cdot NRR \qquad (6)$$

Equations 1 – 2 and 5 – 6 can be combined to give,

$$Net_{XP} = Gross_{XA} \cdot GRR \cdot NTG_{XP} = Gross_{XA} \cdot NTG_{XA} \cdot NRR \qquad (7)$$

By equating the middle and right hand elements of this equation, $Gross_{XA}$ cancels and we are left with,

$$NTG_{XP} \cdot GRR = NTG_{XA} \cdot NRR \qquad (8)$$

which, upon rearrangement gives,

$$NRR = GRR \cdot \frac{NTG_{XP}}{NTG_{XA}} = GRR \cdot NTG_{RR} \qquad (9)$$

where NTG_{RR} is identified as the net to gross realization rate as defined in Equation 10.

$$NTG_{RR} = \frac{NTG_{XP}}{NTG_{XA}} \qquad (10),$$

Substitution of Equation (9) into Equation (6) yields,

$$Net_{XP} = Net_{XA} \cdot GRR \cdot \ NTG_{RR} \qquad (11)$$

Equation 11 is a key result. It shows that ex post net savings are determined with two adjustment factors to ex ante net savings: GRR[7] and NTG_{RR}. Application of the NTG_{RR} factor in Equation 11 can be thought of as a net to gross adjustment for the misalignment between ex ante NTG and ex post NTG. With Equations 5 and 11, the construction of a net-to-net waterfall as in Fig. 2 is straightforward. However there is still the issue of order independence to be considered.

Creating the Order-Independent Net Waterfall

Maintaining the ex post net to gross adjustment separate from the impact parameters in the gross waterfall of Fig. 4 is sensible because it allows a determination and display of ex post gross savings, a quantity of utmost importance to procurement planning. However, in principle there is no reason adjustments due to the gross impact parameters should take precedent over the net to gross factor. Because there is no such rational ‘stopping point’ in the waterfall from ex ante net to ex post net savings, including the NTG_{RR} in a permutation with the impact parameters removes the compulsory prioritization of the impact parameters that distorts the importance of adjustments.

A choice could be made to treat the NTG_{RR} as another impact parameter and fully permute the set. Yet the elementary difference between the GRR parameters, which reflect fundamental discrepancies in engineering assumptions, and net to gross, which addresses possible influence and behavior metrics (free ridership, spillover and take back), leads us to recommend a simpler conversion approach:

1. Establish the permutation of *GRR* impact parameters via the three step procedure detailed above.

2. Permute the *GRR* and NTG_{RR} adjustments using the following two equations:

$$grr_N = {}^{1}\!/_{2} \cdot Net_{XA}(GRR - 1) \cdot (1 + NTG_{RR}) \qquad (12)$$

$$ntg_{rr} = {}^{1}\!/_{2} \cdot Net_{XA}(NTG_{RR} - 1) \cdot (1 + GRR) \qquad (13)$$

where grr_N and ntg_{rr} are the absolute (dimensioned) *permuted* adjustments to ex ante net savings due to application of the *GRR* and the NTG_{RR} as in Equation 9.

3. Re-calculate the impact parameter adjustments maintaining their relative ratios from step 1 such that summing the impact parameter adjustments equals grr_N.

Equations 12 and 13 are the permutation formulas to recast the order-dependent *GRR* and NTG_{RR} into order-independent quantities. Step 3 then breaks out and renormalizes the *GRR* impact parameter steps for use in the net to net waterfall.

[7] As previously shown, the GRR can be the product of separate impact parameters, such as Hours of Use, Delta Watts, ISR, etc.

Summary: Illustrative Example

Example #2: Gross and Net Waterfalls Together Illustrate a Complete Picture

We end with a second example to tie key concepts together and illustrate the utility of the order-independent waterfall graphics. Table 4 provides data for a new example in the same format as Table 2.

Table 4. Impact Evaluation Results: Example #2

			Impact Parameters					
Ex Ante Gross Savings	Ex Ante Net Savings	Hours of Use (HOU)	ΔWatts	In Service Rate (ISR)	GRR	Ex Post Gross Savings	NTG_{XP}	Ex Post Net Savings
100	90	0.50	2.00	0.90	0.9	90	0.2	18

These data are used to generate the gross waterfall graphic of Fig. 5a on the left and the net waterfall graphic of Fig. 5b on the right. The impact parameters in both waterfalls are normalized (order-independent) via the permutation procedures discussed above.

Figure 5a shows that the ex post *HOU* varied significantly from the ex ante assumption, constraining gross savings. Similarly, the *ΔWatts* adjustment significantly enhanced savings. Despite major discrepancies in the ex ante/ex post impact parameters, the *GRR* of 0.9 yields a relatively small adjustment to ex post savings. In contrast, the very low ex post *NTG* leaves only a small portion of savings (ex post net) attributable to program influence.

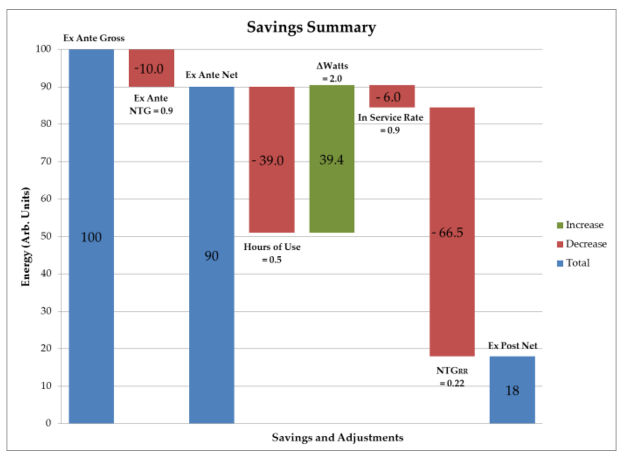


Figure 5a (left). An order independent gross waterfall graphic displaying the savings and adjustments given in Table 4. **Figure 5b** (right). The corresponding net waterfall graphic. These figures result from the conversion and normalization via permutation procedures discussed in the text.

For such a measure or program, questions arise around if and where to devote additional resources and further efforts. The gross waterfall visual of Fig. 5a suggests that the size of adjustments due to the *HOU* and *ΔWatts* impact parameters are of nearly the same relative importance as the ex post *NTG* adjustment. However, because the *GRR* adjustment is geared to developing ex post gross savings, it is not permuted with the ex post *NTG* adjustment. In contrast, these adjustments are permuted in the net waterfall of Fig. 5b, which paints a very different picture for a policy maker or program planner. The net waterfall clearly shows that the cut in net savings due to the ex ante/ex post *NTG* discrepancy far outweighs the impact parameter adjustments. This observation allows proper prioritization for future program planning. This example shows the importance of reporting methodology to decision making and the care that must be exercised in the use of waterfall graphics.

Conclusions

How impact evaluation results are presented has a major influence on the usability of the results depending on audiences' needs. Order independent waterfall graphics of gross and net savings concisely convey reported savings, evaluated results, and the reasons for misalignment that satisfies multiple and diverse audiences. Though a focus on gross savings is appropriate for procurement and emissions savings assessments, it fails to deliver the net adjustment parameters essential to inform clear-cut program decisions on resource allocation. In contrast, a pure focus on net savings fails to inform readers interested in overall impacts on the energy system and emissions. We have shown that the ex ante Gross to ex post Gross waterfall is straightforward to construct, while the ex ante Net to ex post Net waterfall required the equation: $Net_{XP} = Net_{XA} \cdot GRR \cdot NTG_{RR}$. Finally, to make the waterfall graphics into accurate visuals, we have developed a permutation procedure to normalize savings adjustments, which results in order-independent impact parameters. We encourage the adoption of the waterfall graphics detailed here and the methods used in their elaboration in future impact evaluations to enable quick reviews of impact results and comparisons across energy efficiency efforts.

References

TecMarket Works. 2004 California Evaluation Framework, prepared for the California Public Utilities Commission and the Project Advisory Group, September 2004.