Unbundled: Maximizing CHP Value by Accounting for Energy, Capacity, and Carbon Dioxide Emissions Separately

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ABSTRACT

Combined heat and power (CHP) systems have not reached their full market potential, despite being a proven technology, due to several market barriers. Additionally, several barriers have prevented widespread adoption of utility and government programs which promote CHP, notably, the disagreement on methods to quantify benefits to the electric grid. A root cause of the disagreement in methods is how to discount claimed electricity savings by accounting for the increased fuel use at the CHP host site.

This adjustment, however, is unnecessary. CHP may result in increased fuel use at a single site, but they also result in a net decrease in societal fuel use. Thus, while many accounting methods show the increased site fuel use as a cost to society, it isn't.

CHP produces benefits to the electric system by reducing load, benefits the fuel system by reducing net societal fuel consumption, and reduces net societal carbon dioxide emissions. Unbundling the accounting of CHP's reduction attributes could thus maximize their value by recognizing each of these value streams. For example, the benefit to the electric grid of CHP is its full generation output. Consider that price suppression in wholesale electricity markets would be the full generation output of a CHP plant. Thus, discounting the claimed electricity savings of CHP because of the increased fuel use on-site results in severely undervaluing its societal contribution as an electricity resource. Similarly, CHP results in net societal fuel and carbon dioxide savings, each with a value separate and distinct from that which accrues to the electric grid.

In this paper we illustrate that the value of CHP to the electric grid is underestimated by various published savings accounting methods. We propose unbundling the savings accounting, allowing the use of much simpler accounting methods for electrical energy (kWh), capacity (kW), fuel (mmBtu), and carbon dioxide emissions savings based on standard thermodynamic equations.

Introduction

It is generally understood that combined heat and power (CHP) technologies can provide societal benefits in the form of fossil fuel use reductions, CO_2 emissions reductions and alleviation of the electric grid's capacity constraints. For example, the American Council for an Energy Efficient Economy (ACEEE) shows that under the emissions constraints of EPA's proposed Clean Power Plan, CHP could contribute about 20 GW of electric generation capacity. (Hayes 2014).

Realizing this level of CHP adoption will require private investment, since many of the ideal implementers of CHP systems are not in the utility or government sector, but instead are large industrial facilities, hospitals, universities, etc. Though CHP is cost effective when compared to others forms of increasing electric grid capacity, from a regulated cost testing perspective, it can still often have a simple payback beyond the threshold of most industrial facilities. For example, a typical good candidate for installing a CHP system can achieve a simple payback between four to ten years. Though this simple payback presents a high rate of return (10% to 25%), most industrial facilities have payback thresholds of fewer than three years. Thus, without a public policy or regulatory framework that encourages CHP, most manufacturers will not likely implement CHP. Generally, an important component of a successful CHP policy is the proper accounting of all the benefits of CHP.

One barrier to achieving successful policies for CHP is disagreement in how to properly account for and incentivize the societal benefits of a CHP system. This paper addresses four key societal benefits of CHP, critiques several previously published methodologies, and proposes unbundling and evaluating the four key societal benefits of CHP separately. We refer throughout the paper to previously proposed methods by Elliott et. al., Kelway, the State of Massachusetts, and Sullivan and Demeter as "the Published Methods".

Separating these four benefits will allow all accounting and incentivizing to be performed with simple widely accepted thermodynamic equations, which will help ensure accuracy and eliminate potential confusion among policy implementers and regulators.

CHP Accounting Methods

The primary societal benefits achieved by CHP implementation are listed below. Each of these benefits is described in detail later.

- Electric Energy - There is a reduction in electricity generated by the electric utility and transmitted through the grid to the end user. This reduction is measured in kilowatt-hours (kWH) and have a recognized benefit in electricity markets.
- Electric Capacity - There is an increase in the overall electric grid's capacity, due to the installation of new a generation unit. This capacity improvement, which could be valued in electric capacity markets, is measured in kilowatts (kW).
- Fuel - There is a net reduction in overall fuel resource consumption, due to the efficiency gain of generating both the heat and electricity simultaneously from a single fuel source. This fuel resource reduction is measured in million British Thermal Units (mmBtu).
- Emissions - There is a net reduction in overall CO_2 emissions, which is a direct effect of reduced fuel resource consumption. This emissions reduction is measured in pounds of CO_2 (lbs CO_2).

As explained below, proper accounting of each of these four benefits, individually, is simple and well established with basic thermodynamic equations. However, most of the popular energy savings accounting methods being published and debated by government and utility programs do not account for these benefits separately. Instead they attempt to bundle at least electricity and fuel system benefits into a representative electricity savings value, which mimics the familiar savings values found in energy efficiency resource standards (EERS) programs specifically for electric utilities. While CHP creates separate benefits to the electric, fuel, and emissions systems, the published methods generally treat electric and fuel benefits as unable to co-exist, requiring benefits to be counted either on the electric system, or the fuel system, but not both as to prevent “double counting”[1].

As explained in the next section, this is an inaccurate approach. The published methods attempt to quantify electricity savings. However, CHP systems do not reduce electrical energy consumption at the end-use, like other traditional efficiency technologies. The load a CHP system serves, presumably, is unchanged and as efficient or inefficient as before the CHP system was installed. But, CHP systems do reduce fuel use, reduce emissions, and remove electric load from the grid.

Thus, instead of asking “how much electricity does a CHP system save?” we recommend the relevant question is “how does the electric grid benefit from CHP?”, “how does the fuel network benefit from CHP?”, and “how do emissions reductions benefit from CHP?”.

General Concept of CHP Fuel and CO_2 Emissions Savings

It is important to note that **CHP systems do not reduce the end-use consumption of electricity**. However, they do reduce the overall fuel needed to provide an end user’s thermal and electric needs. This is an important distinction since many of the published methods have the goal of converting the overall fuel savings into a representative electricity consumption savings, measured in kWh. This is understandable, as many CHP incentive programs are operated through electric system efficiency programs.

The Basic Savings Equations

The method of estimating fuel savings from CHP systems is well understood and widely accepted. Hedman and Hampson (ASHRAE, 2011) provided an excellent explanation of the method of calculating fuel savings. In their paper, a sample scenario is provided to demonstrate fuel consumption and CO_2 emissions reduction of a CHP system versus a conventional system, reproduced in the figure below. This example shows that through combining the generation of both electricity and process heat, there is an efficiency gain, realized in fuel savings.

[1] See Elliott, et. al. (2009) at 4-42, “ACEEE recommends that credit for the energy savings from a CHP system be allowed to apply to only one market – either electric of thermal.” And Kelway (2012) at page 4, “…the two utilities would allocate percentages of the total savings to either fuel or electricity in a way that avoids double counting”.

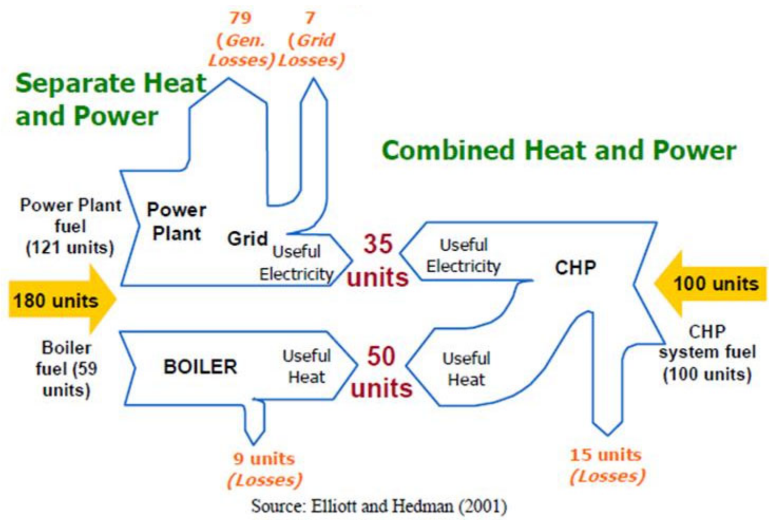

Figure 1: CHP Schematic (Source: Elliott and Hedman, 2001)

Directly from the Headman 2011 paper, the fundamental fuel and CO_2 emissions savings equations, based on a basic thermodynamic energy balance of a CHP system versus a traditional system are:

[1] FS = (FT + FG) – FCHP,

Where,

FS = total fuel savings,
FT = fuel use from avoided on-site thermal production,
FG = fuel use from avoided purchased grid electricity, and
FCHP = fuel use by the CHP system.

The equation for CO_2 emissions savings is

[2] CS = (CT + CG) – CCHP,

Where,

CS = total CO_2 savings,
CT = CO_2 emissions from avoided on-site thermal production,
CG = CO_2 emissions from avoided purchased grid electricity, and
CCHP = CO_2 emissions from the CHP system.

It should be noted that once fuel savings are quantified, the CO_2 emissions savings can be quantified through looking up associated CO_2 emissions values tied to the applicable resource fuels. Also, as described by Headman, typical electric utility grid heat rates and CO_2 emissions factors can be looked up for applicable regions and utilities.

These basic thermodynamic equations and the concepts of referencing typical CO_2 emissions values for fuel sources and regional electric grid heat rates are acknowledged by all four of the accounting methods we evaluate in this paper. These four example methods also agree with equation [1] to determine fuel savings.

Published Accounting Methods

This section provides a description of four published CHP accounting methods, which attempt to quantify electric energy efficiency savings from a CHP system.

1) Massachusetts Method: Fuel savings, as quantified in equation [1], are converted to representative electricity savings units (kWh) directly. This method simply counts all fuel savings as electricity savings. Though this method correctly accounts for all net energy savings achieved through reduced fuel consumption, this method is flawed because it does not accurately account for how electrical savings benefit the grid. Accounting of CO_2 emissions savings and peak generation capacity benefits are not explicitly addressed in this methodology's publication (Massachusetts 2007).

Thus, electricity savings are calculated as:

[3] Selec = FS / 3.412 mmBtu/MWh

Where,

Selec = calculated electricity savings in MWh/year,
FS = fuel savings from equation [1] in mmBtu/year, and
3.412 is simply a conversion factor of mmBtu/MWh.

2) ACEEE Method: Elliott, et. al, (2009) described an alternate method for quantifying electricity savings from CHP. The first step to this method is to evaluate fuel savings, as quantified in equation [1]. Electric savings are then estimated from dividing these fuel savings by the heat rate of the grid, determined from the regional grid's average efficiency. This method calculates the electricity savings as what could have been supplied by the grid with the fuel savings. This accounting method evaluates how much electricity would have been delivered to the end-user if all of the fuel saved were fed back through the power grid. This method is also flawed because it incorrectly accounts for how electricity savings benefit the grid. Elliott, et. al., also proposed an accounting method for net CO_2 emissions savings from CHP systems. In that paper, emissions savings are accurately calculated with equation [2].

Thus, electricity savings are calculated as:

[4] Selec =FS / HGrid

Where,

Selec = calculated electricity savings in MWh/year,
FS = fuel savings from equation [1] in mmBtu/year, and
HGrid = heat rate of the grid in mmBtu/MWh. This value is published and can be referenced for the CHP plant's region.

3) SWEEP Method: Kolwey (2013) provides yet another method to calculate electricity savings from CHP systems. The first step to this method is to evaluate fuel savings, as quantified in equation [1]. Electric savings are then estimated from dividing these fuel savings by the heat rate of the CHP system. This often results in electricity savings greater than the generation output of the CHP plant. To mitigate that effect, Kolwey recommends capping electricity savings at 100% of the actual electrical output of the CHP system. Thus, electricity savings are calculated as the electricity that could be

generated by the CHP system from the fuel savings, as long as this does not exceed the CHP system's actual electrical output. Kolwey's method differs from the Elliott's only in that fuel savings are converted to electricity savings using the CHP heat-rate instead of the grid, and are capped by the electrical output of the CHP unit.

Accounting of CO_2 emissions savings and peak generation capacity benefits are not explicitly addressed in this methodology's publication (Kolwey 2013).

Thus, electricity savings are calculated as:

[4] Selec =FS / HChp

Where,

Selec = calculated electricity savings in MWh/year,

FS = fuel savings from equation [1] in mmBtu/year, and

HChp = heat rate of the CHP plant mmBtu/MWh. This calculated as:

[5] HChp = (Fchp – Fboiler) / Echp

Where,

Fchp = total fuel input into the CHP system in mmBtu/year,

Echp = electrical output of the CHP system in kWh/year, and

Fboiler = fuel to boiler prior to CHP system (thermal load / boiler efficient≈80%) in mmBtu/year.

4) NRDC / OEC Method: Sullivan and Demeter (2013) put forward a white-paper in consultation with Hedman and Cuttica providing yet another method for quantifying electricity savings. Here, electricity savings are determined by multiplying the actual electrical output by a tiered savings factor, as shown in Table 1, which is based on the calculated CHP efficiency. This method does not require a calculation of the fuel savings directly, but does require a calculation of the system's overall lower heating value (LHV) efficiency. We suspect this method is not necessarily focused on quantifying the accurate value of energy savings to the electric grid, but rather provide proper incentive structures that favor the highest efficiency CHP technologies. This method does indirectly capture a CHP system's ability to save fuel through applying a system efficiency calculation. However, like the other methods, it inaccurately quantifies how reduced electrical load benefits the electrical system. Accounting of CO_2 emissions savings and peak generation capacity benefits are not explicitly addressed in this methodology's publication.

The LHV efficiency is calculated as:

[6] LHVeff = (ECHPther + ECHPelec) / (Fchp x LHV/HHV)

Where,

ECHPthe = useful thermoal output of CHP system in mmBtu/year,

ECHPelec = electrical output of the CHP system in mmBtu/year,

Fchp = total fuel input into the CHP system in mmBtu/year, and

LHV/HHV = the lower heating value over the high heating value of the CHP system's fuel type.

Next the tiered table is used to determine what percentage of the CHP system's electric output can be counted. The tiers are:

Table 1. Multiplier tiers

Tier Level	Overall CHP System efficiency – Lower Heating Value (LHV)	Portion of MWh output considered savings
	< 60%	0%
Tier 1	60% - 65%	60%
Tier 2	65% - 70%	70%
Tier 3	70% - 74%	80%
Tier 4	74% - 77.5%	90%
Tier 5	> 77.5%	100%

The electric savings are then:

[7] Selec = Echp x multiplier from table

Where,

Echp = electrical output of the CHP system in kWh/year.

Proposed Accounting Method

We propose an accounting method utilizing the simple and widely accepted thermodynamic equations used to calculate CHP fuel and CO_2 savings. To do this we propose unbundling and separately accounting for each; electrical energy generation (kWh), reduction to the grid, net grid capacity increase (kW), net fuel savings (mmBtu), and net carbon dioxide emissions reductions (lbs CO_2). Each of these four benefits can be individually quantified, accurately, with basic methodologies widely accepted in the scientific community. Calculating these four benefits separately should end debate over the accuracy of CHP accounting, but does not necessarily address how best to incent each of the benefits.

We propose the following accounting methods for each benefit:

1) <u>Electrical Energy Load Reduction Which Benefits the Electric System</u>: We propose that the electrical energy reduction which benefits the electrical system is that which should be counted within an energy-efficiency resource standard. In the case of CHP, it is simply the electrical energy generated by the CHP plant, measured in kWh. We illustrate this concept by considering Demand Reduction Induced Price Suppression (DRIPE) in wholesale electricity markets. DRIPE has been proposed as a system benefit by NE ISO (2012) and Chernick and Plunkett (2014) among others. We acknowledge that DRIPE is but one of the many system cost savings benefits that can be captured in regulatory cost testing. We reference DRIPE here principally because of its usefulness in illustrating how electrical energy savings from any single energy-efficiency project creates societal benefits. DRIPE shows that energy savings from a single efficiency project creates a universal benefit for all consumers on the electrical system by suppressing wholesale electricity prices. For example, Figure 1 below shows electricity price as a function of system load for the western Pennsylvania-Jersey-Maryland (PJM) Regional Transmission Organization (RTO). There is a clear relationship between

electrical load and energy price. Thus, a reduction in electrical load results in a reduction in energy price. The societal benefit is easily quantified from this relationship.

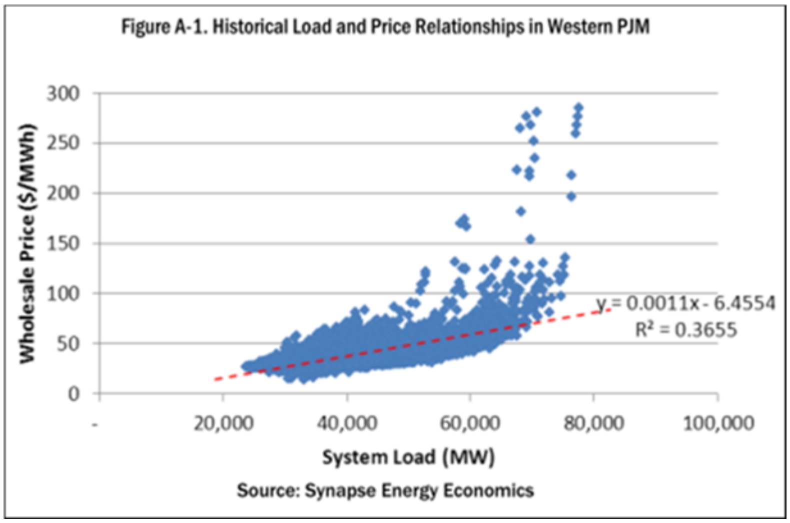

Figure 1: Historical Load and Price Relationship in Western PJM (Source: Synapse Energy Economics)

In the case of a CHP project, the average reduction in load would clearly be the average generation output of the CHP unit. Thus, total annual kWh energy reduction from the electric grid (Egrid reduction) would be quantified as:

[8] Egrid reduction = Echp

Where,

Echp = electrical output of the CHP system in kWh/year.

2) Electrical Capacity: A big benefit to implementing CHP is the ability to increase net generation capacity of the grid, diversify generation sources, and suppress price in wholesale electric capacity markets. To account for this, it is necessary to determine the CHP plant's generation capacity during peak periods, measured in kW. Determining this value is straightforward, based on the rated and tested characteristics of the CHP plant. Whatever the CHP plant owner and operator are capable of generating during peak events is what the CHP plant capacity is. This is the value that could be utilized and accepted within electrical capacity markets.

Thus, total generation capacity of the CHP would be valued in the electric market as either a load resource or a supply resource and this realized resource value (EResVal) would be quantified as:

[9] EResVal = EchpCap

Where,

EchpCap = CHP system's achievable electric output capacity in kW.

3) Net Fuel Savings: The quantification of the net fuel savings is the true representation of the energy efficiency gains from a CHP system. That is, the energy-efficiency gain is in efficiency of fuel energy use. It is important to note that these fuel

resource savings are not easily relatable to the typical energy efficiency savings achieved through utility incentive programs, which usually focus only on electric or natural gas consumption reductions at the end-use. The accurate way to account for fuel energy savings from a CHP plant is to trace the system back to the process heating and electricity generation fuel sources. These savings are captured with the basic fundamental equation [1], already explained above. Typically this is accounted for in units of mmBtu/year.

In the previous scenarios, we used DRIPE to illustrate that the universal benefits on the electrical system from a CHP system are directly related to the output of the CHP unit. However, we've recognized that there is increased fuel use on site. Traditionally, energy-efficiency programs have discounted electrical benefits by any increased fuel use, as it is generally recognized that the electrical benefits are partly *caused* by a switch from electricity to fuel. This is generally referred to as "fuel switching". Electrical system benefits that are created wholly by fuel switching are usually banned from receiving incentives. This is because fuel switching creates costs on the fuel system, most often the natural gas network. Efficiency programs are right to ban incentives for fuel switching, as it can result in electric ratepayers subsidizing the transfer of load to natural gas ratepayers. An example of fuel switching would be incenting the replacement of residential air-source heat pumps to natural-gas fired furnaces. Replacement of heat pumps with furnaces clearly creates electrical system benefits by shifting load to the natural gas network, and thus creating natural gas system costs.

CHP, however, does not create net system costs for the natural gas network, or the overall fuel infrastructure (natural gas, oil, coal). In fact, as we showed in our previous calculations, CHP results in an overall net reduction in fuel use. Therefore, CHP should not be treated as out-right fuel switching, where increased gas use by the host site is treated as a cost to society.

Specifically, the reduction in costs to the natural gas network are likely to be pronounced in the coming years, and similar to the universal benefits realized on the electrical grid. As the electrical system shifts from predominately coal-based to a greater mix of natural gas generation, CHP will likely reduce load in natural gas markets. And, as Hoffman et. al. (2013) showed, DRIPE does exist in natural gas markets as well. Thus, the universal benefit CHP creates to the natural gas market should be unbundled, and quantified and monetized separately. Treating the increased gas use by the CHP host site as a societal cost is clearly improper.

4) Net CO_2 Reductions: The quantification of net CO_2 emissions savings is determined similarly to the net fuel savings. The accurate method to account for these savings is to trace the systems back to the baseline process heating and electric generation fuel sources. These savings are captured with the basic fundamental equation [2], already explained above. Typically this is accounted for in lbs-CO_2/year.

Quantifying the value of emissions reductions reinforces the concept that there are net societal fuel savings. While the CHP host-site will have higher direct CO2 emissions, the net CO2 emissions from society will decrease. This is fairly obvious. Thus, the net emissions reduction should be treated separately and monetized separately. If it were not, the CHP host-site would be responsible for paying for the cost of their increase in emissions. If that were to happen, it would be a severe barrier to adoption of CHP. More likely, CHP will be recognized for creating net societal emissions reductions. A CHP unit owner will likely be able to monetize the net reduction in emissions as the difference between reduced indirect emissions from the electrical grid, and increased direct emissions at their host site.

Comparison of Bundled to Unbundled Incentives

We consider a real, anonymous example savings calculations for an 10.3 MW CHP unit to compare bundled incentives under the Massachusetts, SWEEP, and ACEEE methods versus unbundled incentives. To illustrate the difference in total incentive amounts, we assume set incentives for electrical energy, fuel, and emissions. We are not recommending these incentive rates as the proper incentives, but instead using them to demonstrate the magnitude of difference the various accounting methods produce. We use the following incentive amounts:

- Electrical energy - \$0.03 /kWh_{saved} annually. While this is a lower incentive amount per kWh than is offered in many custom and prescriptive energy-efficiency programs, it is in line with the total per kWh incentive offered for CHP projects in Illinois, Maryland, New York, and New Jersey. Typically, this incentive does include a capacity (kW) incentive blended in.
- Fuel - \$10 /mmBtu. This reflects typical incentives from commercial natural gas energy-efficiency programs in Ohio. (Note that this is not fuel cost, but a potential incentive for fuel saved).
- Emissions - \$10 /ton-CO2-year, assuming a 15-year lifetime

Our case study is of a 10.3 MW CHP project that that produces 84,165,758 kWh/year, saves 405,040 mmBtu/year in fuel, and reduces emissions by 45,769,520 lbs CO2/year. The total of the unbundled incentives would be about:

Electricity: \$0.03 /kWh x 84,165,758 kWh/year x 1 year incentive = \$2,524,973

Fuel: 405,040 mmBtu/year x \$10 /mmBtu x 1 year incentive = \$4,050,400

Emissions: 45,769,520 lbs CO2/years / 2,000 lbs/tonne x \$10 /ton CO2 x 15 years = \$3,432,714

Total: \$10,008,087

Comparatively, the Published Methods result in the following total project incentives, assuming the same unit incentives for electricity, capacity, natural gas, and emissions. We illustrate using the Massachusetts method, and present results for all Published Methods in Table 2.

Energy: \$0.03 /kWh x 118,710,329 kWh/year x 1 year incentive = \$3,561,310

Fuel: \$0

Emissions: 45,769,520 lbs CO2 / 2,000 lbs/tonne x \$10 /ton CO2 x 15 years = \$3,432,714

Total: $6,994,024

Table 2. Estimate of Bundled Incentives from Published Methods

Method	Electricity Incentive	Total Incentive
Massachusetts	$3,561,310	$6,994,024
SWEEP	$2,163,017	$5,595,731
ACEEE	$1,165,011	$4,597,725
NRDC	$2,524,973	$5,957,687
Go Sustainable Energy	$2,524,973	$10,008,087

We can make several observations from this comparison. First, even with the same unit incentives, the value to the electrical system is treated significantly differently by the different Published Methods, the ACEEE method resulting in significantly lower incentives while the Massachusetts method results in significantly higher incentives. Second, because the Published Methods attempt to incorporate some measure of societal fuel savings within the electric incentive, the Published Methods dramatically undervalue the total societal value of CHP. Treating fuel savings as a separate value stream could create another source of incentive revenue for CHP projects. Additionally, treating emissions savings separately, as opposed to basing emissions savings off of electrical system savings, creates more accurate valuation of the emission reduction.

Conclusions

Several methods have been proposed in the literature to estimate electrical energy savings from CHP for incorporation in energy-efficiency resource standards. All of the Published Methods agree on the amount of fuel energy savings, but then disagree when converting these fuel energy savings to claimable electrical energy savings. The previously Published Methods' modifications create complicated ways to value CHP as an electric energy-efficiency resource. We have shown that the electrical system benefits CHP produces are directly related to the full electrical generation output of the CHP unit. Thus, to accurately value CHP, electricity savings should be treated in a simple, straightforward way by counting the CHP electricity generation output without modification. Importantly, when CHP electricity savings are treated this way, the societal benefits of fuel savings and emissions savings can be separately quantified. Unbundling electricity, fuel, and emissions savings into separate value streams allows for the value of the CHP system to be more accurately and simply accounted for and incented. As a result, the monetary incentive value for CHP units increases significantly.

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