ELECTRIC POWER RESEARCH INSTITUTE

THE TOTAL VALUE TEST: A FRAMEWORK FOR EVALUATING THE COST-EFFECTIVENESS OF EFFICIENT ELECTRIFICATION

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Abstract

This report presents the Total Value Test (TVT) as a metric for the cost-effectiveness of energy efficiency measures and programs, inclusive of electrification. The TVT represents an amalgam of the best attributes of the standard practice tests for energy efficiency that have been implemented by utilities and state regulatory bodies for decades, adapted and refined to include a more comprehensive set of benefits and costs characteristic of electrification considerations, including environmental impacts. The TVT can be applied to objectively compare the cost-effectiveness of electric, natural gas, or other options, and is not disposed to favor any particular technology based on how it is powered or fueled. The report provides a review and critique of the energy efficiency standard practice tests, presents the rationale and methodology of the TVT, and illustrates the use of the TVT in three case studies.

Keywords

Benefit-cost analysis
Carbon reduction
Demand-side management
Energy efficiency
Electrification
Standard practice manual
Total resource cost

Overview

Energy efficiency encompasses all forms of end-use energy, including electricity, natural gas, and other fuels. Efficient electrification represents an extension of energy efficiency that may be defined as follows:

> The application of electric powered end-use technology as a substitute for direct-use fossil-fueled or non-energized processes for customer homes, buildings, industries, or transportation that results in net economic benefit to the customer and net environmental benefits to society.

Efficient electrification can yield considerable benefits not only to customers who undertake this activity—in the form of lower overall energy costs and enhanced productivity, comfort, convenience, and so on—but also more broadly to electricity customers and society-at-large. One of the impediments to greater utility engagement in efficient electrification programs is determining their cost-effectiveness. Utilities and their regulators typically require a favorable estimation of cost-effectiveness to justify investment in programmatic activities with customers.

However, there is not yet an industry accepted cost-effectiveness framework with sufficient depth and breadth to appropriately quantify the value of electrification. The objective of this paper is to present a suitable cost-effectiveness framework for evaluating prospective efficient electrification programs.

To establish the cost-effectiveness framework proposed in this report, we first reviewed of existing frameworks for evaluating the cost-effectiveness of demand-side programs. This review includes the well-known cost-effectiveness "tests" originally established in the

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California Standard Practice Manual (SPM), subsequently published literature on the topic, and recent utility regulatory filings introducing new electrification programs. The literature review was supplemented with the findings of in-depth interviews with 15 experts on electrification and cost-effectiveness analysis.

Based on this review, we have concluded that the SPM tests are useful for assessing electrification cost-effectiveness at a conceptual level, although they are rarely applied for this purpose. Contrary to common perceptions, the tests account for considerations that are critical when evaluating efficient electrification programs. These considerations include, for instance, the cross-sector impacts of fuel switching, non-energy benefits, environmental impacts, grid management benefits, employment impacts, and productivity enhancements.

Among the various cost-effectiveness test perspectives defined in the SPM, the Societal Cost Test is the most aligned with our recommended framework for evaluating efficient electrification programs. Broadly, the Societal Cost Test determines whether costs to society at-large will be reduced with the introduction of a new program.

At the same time, the Societal Cost Test has developed a reputation among critics for being too "open ended" and allowing for a subjective interpretation of which benefits and costs to quantify and include in the assessment. The Societal Cost Test also uses a low "societal discount rate" which, by putting significant weight on longer term benefits, tends to be very generous to new demand-side programs.

To mitigate these concerns about the Societal Cost Test, we propose a revised test known as the **Total Value Test,** particularly for regulators who view their role as implementing social policy. The Total Value Test uses the utility's weighted average cost of capital as the discount rate (which is typically higher than a societal discount rate) but also includes the non-energy benefits and costs included in the Societal Cost Test as well as core customer cost savings.

Although the overarching California SPM framework is valid for evaluating efficient electrification, *implementation* of the SPM tests often falls short. The following are critical considerations when applying the Total Value Test:

1. **Identifying costs and benefits.** The Total Value Test takes the broadest possible perspective on the costs and benefits of efficient electrification programs. Although the aforementioned environmental impacts and non-energy benefits are important considerations, the Total Value Test weighs them against similarly important changes in energy resource costs and other benefits that may accrue directly to participants and/or non-participants. An advantage of the Total Value Test is that it comprehensively accounts for all of these possible sources of value rather than taking a narrow perspective that may exclude important considerations. Costs and benefits of efficient electrification programs included in the Total Value Test are summarized in Table 1.
2. **Including "non-energy" costs and benefits.** The inclusion of non-energy benefits and "market barrier costs" will take on increasing importance in an electrification context. New electric end uses will likely include a range of features with significant non-monetary benefits and costs to consumers. New research is needed to quantify these costs and benefits. Where they are not quantifiable, they should be given careful qualitative consideration—particularly when evaluating measures that are marginally failing the relevant cost-effectiveness tests. A useful approach adopted by states such as Vermont and Massachusetts is to apply qualitative "adders" to value non-energy benefits that cannot be quantified to a reasonable level of confidence yet are understood to have non-zero value.
3. **Accounting for policy goals.** Cost-effectiveness analysis that is conducted without consideration for policy goals will not yield conclusions that are useful for decision making. Therefore, the impacts of established policies should be accounted for in the baseline scenarios against which the electrification program is being compared. In other words, the baseline scenario should reflect the costs and market dynamics associated with the achievement of policy goals. The proposed electrification program can then be evaluated on the basis for which it increases or decreases costs and benefits under these conditions.
4. **Defining the Total Value Test "boundary."** Some existing cost-effectiveness tests, such as the Societal Cost Test, do not allow available subsidies to count as a net reduction in costs associated with an electrification program. The reason is that from a net societal perspective, subsidies to program participants are a cost to non-participants (for example, through tax payments). The two cancel one another out. However, utilities and state regulators may wish to define the boundaries of the Total Value Test at the state level. As a practical consideration, doing so would allow federal subsidies to be included as a benefit (that is, cost reduction) in the program.

Table 1. Costs and Benefits of Efficient Electrification in the Total Value Test

Category	Example	Quantifiability
Program costs		
Administration costs	Marketing, measurement & verification	●
Incentive payments	Rebates for equipment purchases	●
Participant contribution to costs	Cost to consumer of equipment, net or rebate	●
Third-party contribution to costs	Trade ally contribution to marketing costs	●
System impacts		
Production capacity costs	New electricity generation peaking capacity	●
Production energy costs	Reduced need for gasoline to power vehicles	●
Cost of environmental regulations	Reduced gas utility compliance fees due to lower demand	●
Fuel transmission capacity costs	Reduced need for natural gas pipeline expansion	●
Fuel distribution capacity costs	Increased need for electric distribution capacity	●
Line losses	Higher electricity line losses due to higher volume of sales	●
Ancillary services	Provision of frequency regulation from new sources of flexible load	●
Risk to the utility	Increased risk of stranded natural gas assets	◑
Renewable resource obligation	Higher RPS requirement due to higher electricity sales	●
Energy market price effect	Increased wholesale electricity price due to peak demand growth	◑
Participant impacts		
Other resource costs	Increased water demand for hydroelectric power	◑
O&M costs	Elimination of need for regular oil changes for a gasoline vehicle	◑
Health impacts	Reduced medical costs	○
Productivity	Reduced product spoilage/defects	◑
Asset value	Improved property values	○
Economic well-being	Reduced foreclosures	○
Comfort	Vehicle noise reduction	○
Societal impacts		
Air quality	Reduced tailpipe emissions from gasoline vehicles	◑
Employment	Vendor/contractor staffing changes	◑
Economic development	Changes in gross domestic product	◑
Energy security	Reduced dependence on fuels from unstable regions	○
Public health	Reduced health insurance costs due to cleaner air	○

Key

● Well established methodology, easily obtainable data
◑ Less established methodology or difficult/costly to obtain data
○ Speculative, subject to high degree of uncertainty

"Quantifiability" represents the extent to which there is a well-established methodology for quantifying the impact, data is readily obtainable at a low cost, and there is limited uncertainty in the results

5. **Near-term versus long-term costs and benefits.** It is important to evaluate the cost-effectiveness of efficient electrification programs over a long-term study horizon. The benefits of electrification programs may extend well beyond the life of the equipment directly associated with the program (for example, charging infrastructure deployment that allows transportation electrification to overcome the chicken-and-egg problem of range anxiety). Electrification programs may also drive down technology costs over time. Alternatively, there is also the possibility of stranded costs associated with the fuel that was replaced by electricity. Ultimately, the time horizon over which the analysis is conducted and the use of a consistent discount rate are available tools for addressing these issues in the Total Value Test framework.

Introduction

Replacing fossil-fueled end-use and non-energized processes with electric technologies, a conversion known as *electrification*, can yield considerable benefits not only to customers who undertake this activity but more broadly to electricity billpayers and society-at-large. This holds true for the buildings sector and especially for the transportation sector. Recent EPRI analysis found that electrification could feasibly lead to an increase in U.S. electric load of anywhere between 24% and 52% between now and 2050, while economy-wide emissions would decrease by 19% to 67% as a result.[1] Similarly, research by The Brattle Group found that achieving the technical potential for electrification of transport and buildings in the U.S. could more than triple the rate of total electricity sales growth by 2050, while nearly achieving an 80% reduction in energy-related CO_2 emissions if coupled with decarbonization of the power supply.[2]

One of the impediments to greater utility engagement in customer electrification programs is determining their cost-effectiveness relative to alternatives. Utilities and their regulators typically require a favorable estimation of cost-effectiveness to justify investment in programmatic activities with customers.

However, there is not yet an industry accepted cost-effectiveness framework with sufficient depth and breadth to appropriately quantify the value of electrification. The objective of this paper is to present a suitable cost-effectiveness framework and associated test for any type of energy efficiency measure or program *inclusive of efficient electrification*. The framework includes a comprehensive inventory of benefit and cost streams associated with electrification.

Efficient electrification may be defined as follows:

> The application of electric powered end-use technology as a substitute for direct-use fossil-fueled or non-energized processes for customer homes, buildings, industries, or transportation that results in net economic benefit to the customer and net environmental benefits to society.

Our approach begins with a review and assessment of existing frameworks for evaluating the cost-effectiveness of demand-side programs. This review includes the well-known frameworks established in the California Standard Practice Manual as well as subsequently published literature on the topic. Our review of the cost-effectiveness literature is intended to identify any gaps in the application of these tests to efficient electrification programs. *A Review of Current Practices* summarizes the literature review.

The literature review is followed by the findings of interviews with fifteen experts on electrification and cost-effectiveness frameworks. These findings are summarized in *Expert Perspectives*.

A Framework for Evaluating Electrification Cost-Effectiveness presents our recommended framework for evaluating the cost-effectiveness of efficient electrification programs. The cost-effectiveness framework is called the Total Value Test (TVT). Our specification of the TVT is derived from the literature review and interviews described in the preceding sections.

Case Studies illustrates the application of the TVT with three case studies. The case studies illustrate how the proposed TVT framework can be applied to electrification technologies in practice. The three case studies are (1) a municipal fleet of battery electric buses, (2) indoor agriculture, and (3) water heating.

The report concludes with a summary in *Conclusion*, with an appendix, *Assessing the Grid Flexibility Value of Electrification*, discussing treatment of the grid flexibility value of electrification.

A Review of Current Practices

Introduction

Cost-effectiveness analysis has been utilized in utility investment decisions for decades. Methods specifically for evaluating demand-side initiatives were developed following the introduction of billpayer-

[1] EPRI, "U.S. National Electrification Assessment," April 2018.

[2] Jurgen Weiss, Ryan Hledik, Michael Hagerty, and Will Gorman, "Electrification: Emerging Opportunities for Utility Growth," The Brattle Group, January 2017.

funded conservation programs in the 1970s. The California Standard Practice Manual (SPM), published by the California Public Utilities Commission (CPUC) in 1983, has largely served as the authoritative manual for analyzing the cost-effectiveness of demand-side management (DSM) programs since its introduction.[3]

DSM cost-benefit analysis serves as a useful starting point when considering applicable approaches for evaluating the cost-effectiveness of billpayer-funded efficient electrification programs. Both DSM and efficient electrification involve changes in end-use energy consumption. These changes in consumption patterns and levels in turn drive the displacement or increase in use of resources such as power systems infrastructure, fossil fuels, and renewable energy.

This section summarizes the literature on demand-side cost-effectiveness, beginning with a review of the SPM. The SPM discussion is followed by a survey of subsequently published critiques of the SPM, with a focus on insights that are relevant to electrification initiatives. The section concludes with a brief review of recent utility efforts to evaluate the cost-effectiveness of new electrification programs.

The California Standard Practice Manual

History

The SPM was first developed by the CPUC in 1983. Subsequent revisions to the document were published in 1988 and 2001, through with no major conceptual changes to the framework described in the original version. The cost-effectiveness tests defined in the SPM have been adopted to varying degrees by most state regulatory commissions, often with nuanced modifications that are designed to address specific state objectives. The SPM is most commonly used to determine if utility investment in demand-side initiatives is in the public interest and, consequently, if the costs associated with these initiatives should be recovered from all consumers through retail rates.

The SPM has typically been used to evaluate utility-funded energy efficiency (EE) and demand response (DR) programs. However, the SPM tests were explicitly designed to also account for, using the terminology of its day, "fuel switching" and "load building" programs.[4] Electrification falls under these two categories.

The SPM Framework

The SPM defines five cost-effectiveness tests that embody different perspectives on the cost and benefit categories to be considered when evaluating demand-side programs. The SPM provides commentary on the advantages, disadvantages, and appropriate uses of each of the five tests.

The SPM does not provide specific instructions for how to calculate each cost and benefit. For example, the SPM does not provide guidelines for establishing marginal energy costs or the load impact profile of a specific demand-side program. In California, these nuanced issues are addressed in much longer and more detailed "cost-effectiveness protocols" documents.[5] Other states have a range of established methodological precedents which can vary significantly.

The SPM touches on each of the following elements of a cost-effectiveness valuation framework:

- Cost-effectiveness perspective (participant, non-participant, administrator, utility system, or broader society)
- Relevant categories of benefits
- Relevant categories of costs
- Time horizon over which costs and benefits are appropriately calculated
- "Baseline" conditions for cost and benefits
- Impacts on baseline conditions attributable to the demand-side program
- Appropriate discount rate
- Appropriate treatment of tax-related incentives
- Appropriate cost-effectiveness metric(s) (i.e., net present value, benefit-cost ratio, levelized cost, etc.)

The Five Tests

The SPM includes five cost-benefit tests, as described below.

- **The Participant Test** provides an assessment of cost-effectiveness from the perspective of participating customers. Benefits are the sum of bill decreases and customer incentives paid by the utility. Costs are incurred by the participant to gain the benefits of the program and include any applicable participation fees.

[3] California Public Utilities Commission, "California Standard Practice Manual," October 2001.

[4] The terms are used in the SPM.

[5] For instance, the demand response protocols can be found on the CPUC website: http://www.cpuc.ca.gov/General.aspx?id=7023.

- **The Ratepayer Impact Measure (RIM) test** provides an assessment of cost-effectiveness from the perspective of non-participants. Benefits are the reduction in avoided supply-side costs plus participant fees. Costs are the sum of revenue losses, incentives paid to customers, and utility administrative costs.
- **The Total Resource Cost (TRC) test p**rovides an assessment of cost-effectiveness from the perspective of customers and the utility. Benefits are the reduction in avoided supply-side costs. Costs are the program costs of the administering the program and incremental costs incurred by customers in joining the program.
- **The Utility Cost Test, also known as the Program Administrator Cost (PAC) test,** provides an assessment of cost-effectiveness from the perspective of the utility or the third-party program administrator. Benefits are the reduction in avoided supply-side costs. Costs are the sum of customer incentives and program administration costs.
- **The Societal Cost Test (SCT)** provides an assessment of cost-effectiveness from the perspective of society at-large. Benefits are the avoided societal costs, including all measurable externalities. The costs are usually the same as in the TRC test.

A summary of the five cost-effectiveness tests is provided in Table 2.

Table 2. Summary of the Five SPM Cost-Effectiveness Tests

Test	Key Question	Benefits	Costs
Participant Test	• Is the participant better off?	• Bill Decrease • Customer Incentives	• Program Costs (Participant) • Participation Fees
Total Resource Cost (TRC) Test	• Is resource efficiency improved?	• Avoided Supply-side Costs	• Program Costs (Total)
Ratepayer Impact Measure (RIM) Test	• Are rates lowered?	• Avoided Supply-side Costs • Participant Fees	• Revenue Loss • Customer Incentives • Program Costs (Utility)
Utility Cost Test (UCT) or Program Administrator Cost (PAC) Test	• Are revenue requirements lowered?	• Avoided Supply-side Costs • Participant Fees	• Customer Incentives • Program Costs (Utility)
Societal Cost Test (SCT)	• Are societal costs lower?	• Avoided Societal Costs, inclusive of Supply-side Costs and Social Externalities	• Program Costs (Total)

Critiques of the SPM

Overview

Since its introduction, the SPM has spawned a breadth of literature on cost-effectiveness evaluation methodology. To identify the most relevant publications, we conducted an internet search and drew upon Brattle's existing library of DSM cost-effectiveness resources. Expert interviews were used to further identify relevant resources (see *Expert Perspectives* for further details).

The purpose of our review was to identify gaps in the existing SPM methodologies, as well as alternative approaches. As such, we focused specifically on those publications that provide a critique of the SPM methodologies, or propose new frameworks for estimating cost-effectiveness. We gave less consideration to publications summarizing cost-effectiveness evaluations of specific utility DSM measures. Those studies focus mostly on implementation of the cost-effectiveness methodology and typically do not offer recommendations for improving the methodology.

The relevant studies are discussed below. They are presented in chronological order. We provide a brief summary of each study, followed by a discussion of the relevance of its conclusions in the context of electrification

SPM Critiques

Hobbs (1991): The "Most-Value" Test: Economic Evaluation of Electricity Demand-Side Management Considering Customer Value[6]

Hobbs (1991) highlights several shortcomings of the TRC test: (1) the test assumes customers do not react to program-induced retail rate change, (2) it assumes all market barriers preventing customers from installing the DSM measure on their own are reduced to zero, (3) it assumes customers use the same amount of energy service before and after the DSM program's introduction, and (4) it assumes customers receive the same quality of service after the program's

[6] Benjamin F. Hobbs, "The 'Most Value' Test: Economic Evaluation of Electricity Demand-Side Management," *The Energy Journal* 12 No. 2 (1991): 67-91, http://www.jstor.org/stable/41322416.

introduction. To address these shortcomings, the study proposes the "Most Value Test" (also known as the Value Test or Net Economic Benefits Test), which quantifies the change in "consumer surplus."

Efficient Electrification Insights:

Electrification involves switching fuels and, as a result, changing the mix of fixed versus variable costs that faces a consumer. For example, a customer may pay an up-front premium for a heat pump to reduce variable heating costs. The lower marginal cost of heating could lead to an increase in consumption.[7] The Value Test presents a framework that allows for this potentially important dynamic to be captured. As discussed later in this section, it is challenging to quantify the costs and benefits that are included in the Most Value Test. However, subsequent studies have presented methodologies for performing the calculations.

Fulmer and Biewald (1994): Misconceptions, Mistakes and Misnomers in DSM Cost-Effectiveness Analysis[8]

Fulmer and Biewald (1994) summarizes and critiques each of the five SPM cost-effectiveness tests, plus the subsequent "Value Test." The study uses an "envelope" framework for determining which costs and benefits should and shouldn't be included in each test. It concludes that there are shortcomings of each SPM test.

Efficient Electrification Insights:

The authors find that implementation of all tests fails to fully account for "non-energy benefits." Non-energy benefits include those benefits that are not related to the avoided costs of the utility, such as improved comfort or health benefits from cleaner air. Non-energy benefits are particularly important in an electrification context, where new electric end-uses are likely to include additional non-energy benefits (e.g., quieter operation of electric vehicles) as well as potential inconveniences (e.g., customer anxiety about electric vehicle range).

Impacts on tax exposure for participants (e.g., exposure to increased property taxes due to increase in property value) are currently overlooked in most applications of the tests. Such tax impacts could be particularly significant when considering implications of retrofitting a building with alternative electric end-uses.

The authors also conclude that the RIM test does not provide enough detail to fully address issues related to cross-subsidies that may exist between participants and non-participants. For instance, the RIM test does not give a sense of the magnitude by which rates will go up (i.e., it does not account for differences in expenses versus rate base, and it does not account for whether rate increases will be contained within the customer class or spread across all customers). Given current equity concerns related to electrification (such as perceptions that certain electrification opportunities are only accessible by higher-income households), it would be prudent to develop a more rigorous method for understanding the distributional impacts of electrification programs.

To establish avoided costs, the authors suggest that detailed models of the power system be run with and without inclusion of the proposed demand-side initiative. While this is more of an implementation issue than a cost-effectiveness framework issue, it could be particularly important in the current environment of rapid renewables growth, where marginal costs are generally decreasing but the value of flexibility is rising (and is difficult to quantify in the absence of simulation modeling).

Finally, the authors indicate that standard application of the TRC test values avoided fuel cost at the cost of supply, whereas a literal interpretation of the definition of the test calls for the avoided fuel to be valued at the "retail" price (tariff or market price). Given that electrification programs hinge on fuel switching, the appropriate treatment of fuel cost is particularly important and should be evaluated carefully.

Herman and Hicks (1995): From Theory Into Practice: One Utility's Experience with Applying the Value Test[9]

Herman and Hicks (1995) addresses criticism that the Value Test is useful in theory but impractical to implement. In doing so, the study presents an example of how the Value Test was implemented for one New England utility.

Efficient Electrification Insights:

The study points out that the challenge with the Value Test – as well as other tests – is its difficulty to quantify non-energy benefits (e.g. improved comfort) and market barrier costs (e.g. technology risk

[7] This so-called "rebound effect" is discussed conceptually in the energy efficiency literature, but there is little evidence to substantiate this claim.
Data on efficiency improvements in lighting suggests a minor rebound effect (https://www.nrdc.org/onearth/rebound-effect-real).

[8] Mark Fulmer and Bruce Biewald, "Misconceptions, Mistakes and Misnomers in DSM Cost-Effectiveness Analysis," *ACEEE Summer Study Proceedings* Volume 7 (1994): 73-83.

[9] Patricia Herman and Elizabeth G. Hicks, "From Theory into Practice: One Utility's Experience with Applying the Value Test," *ACEEE Summer Study Proceedings* Volume 8 (1994): 77-87.

aversion). The authors provide several practical approaches to quantifying these costs and benefits. Given the potentially high degree of importance of both non-energy benefits and market barrier costs in electrification efforts, it will be important to explore such approaches. *A Framework for Evaluating Electrification Cost-Effectiveness* provides a review of such techniques.

Earle and Faruqui (2006): Toward a New Paradigm for Valuing Demand Response[10]

Earle and Faruqui (2006) discusses the application of the SPM tests specifically to demand response (DR) programs. The study provides several recommendations for how the SPM tests can be improved to better account for the cost and benefits of DR, though the recommendations are largely more generally applicable to demand-side initiatives

Efficient Electrification Insights:

The authors' focus on DR is relevant in the sense that the electrification of various end-uses will introduce the potential for more load flexibility. It is important to recognize this flexibility value in cost-effectiveness evaluation of electrification programs. Further, the authors indicate that the DR of its day typically does not provide a reliability benefit beyond the avoided cost of capacity. This is often misunderstood by those who wish to assign both an avoided capacity cost and an additional reliability benefit to demand-side resources such as the flexible EV charging or electric heating.

The authors indicate that the TRC test penalizes measures that increase energy use, even though the customer may derive positive value from that incremental use. This is similar to the treatment of non-energy benefits discussed in prior studies and is an important consideration in load-building electrification initiatives.

It is recommended that uncertainty be incorporated into cost-effectiveness assessments through probabilistic analysis. Given the nascent state of some forward-looking electrification programs (relative to conventional EE and DR programs), this may have significant merit in an electrification context.

Demand-side initiatives can have an impact on market prices, particularly for high-priced hours with a steep demand curve and/or ancillary services products such as frequency regulation for which there is a limited need. This effect is sometimes referred to as the demand response induced price effect (DRIPE). While neither a cost nor a benefit in the TRC test, the marginal price impact is an important consideration from a policymaking standpoint. With respect to electrification, if this impact is considered it will be important to look outside of electricity markets and include market price effects for natural gas and other impacted fuels.

EPRI (2010): A Framework for Evaluating the Benefits and Costs of Investments in Electric Vehicle Infrastructure[11]

While not a direct critique of the SPM, the authors provide an alternative detailed framework specifically for evaluating the costs and benefits of electric vehicles.

Efficient Electrification Insights:

The proposed framework in its entirety represents a societal view of costs and benefits of electrification, but it highlights the many different industries and stakeholders that could be impacted positively or negatively by transportation electrification. This demonstrates that there may be additional perspectives beyond those presented in the five SPM tests that are worth policymaking consideration. For instance, a state energy regulator may want to consider the specific impact of electrification initiatives on natural gas utilities, including the possibility of stranded gas assets. Such considerations will be important in establishing policies and programs that transition to electrification in a cost-effective manner.

Neme and Kushler (2010): Is it Time to Ditch the TRC? Examining Concerns with Current Practice in Benefit-Cost Analysis[12]

Neme and Kushler (2010) highlight two main concerns with the TRC and its widespread adoption by state commissions. First, as discussed above, application of the TRC test commonly ignores non-energy benefits (NEBs). The authors cite several studies indicating that NEBs can be even larger than the energy benefits of demand-side programs. Second, the TRC test does not treat demand-side and supply-side resources equally. For instance, the authors point out that utility decisions to purchase generation do not penalize the generation based on any subsidies it is receiving, whereas tax incentives for demand-side initiatives are a consideration in some cost-effectiveness tests. Similarly, utility decisions to

10 Robert Earle and Ahmad Faruqui, "Toward a New Paradigm for Valuing Demand Response," *The Electricity Journal* 19(4) (May 2006): 21-31.

11 Electric Power Research Institute, "A Framework for Evaluating the Benefits and Costs of Investments in Electric Vehicle Infrastructure," December 2010.

12 Chris Neme and Marty Kushler, "Is it Time to Ditch the TRC? Examining Concerns with Current Practice in Benefit-Cost Analysis," *ACEEE Summer Study on Energy Efficiency in Buildings* Volume 5 (2010): 299-310.

contract for output from behind-the-meter generation do not account for the customer's costs of installing the unit, while the TRC includes demand-side installation costs.

The authors feel that the best solution is to rely on the PAC test, as this does not require the calculation of difficult-to-quantify non-energy benefits and puts demand-side initiatives on a level playing field with supply-side resources.

Efficient Electrification Insights:

The authors raise the point that energy efficiency is often packaged with other premium features (i.e., typically the low cost, basic appliance model will not be energy-efficient, and buying efficiency also requires buying other features). A modern electrification analog is EVs, which are not typically entry-level models – although the EV market is evolving with new vehicles at lower price points.

The authors make an interesting case for putting more emphasis on the PAC test in cost-effectiveness evaluations. This highlights the point made in the SPM that it is necessary to consider multiple perspectives when evaluating electrification programs. Utilities, regulators, and stakeholders too often rely on a literal interpretation of one test as the basis for their conclusions about a program's cost effectiveness.

Lazar and Colburn (2013): Recognizing the Full Value of Energy Efficiency[13]

Lazar and Colburn (2013) discusses a broad range of issues related to demand-side cost-effectiveness evaluation, including a critique of the SPM and the Value Test. The report presents a comprehensive list of costs and benefits for consideration in the evaluation of DSM programs, as well as several instructive examples of misapplications of the SPM tests in practice.

Efficient Electrification Insights:

The authors present the Societal Cost Test (SCT) as the recommended standard for evaluating demand-side programs. While this tends to be a less-utilized test in many states, in part due to challenges quantifying the value of externalities, it is a particularly important test to consider for electrification programs, which are now commonly driven by decarbonization efforts. Further, electrification initiatives may have significant costs and benefits that extend beyond the utility service territory, which is the focus of the TRC.

National Efficiency Screening Project (2017): National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources[14]

National Efficiency Screening Project (2017) proposes a "principles based" cost-effectiveness Resource Value Framework rather than the more prescriptive tests presented in the SPM. The authors cite the regulator's core mission of determining what is in the "public interest" as the overarching driver of determining how to approve demand-side initiatives. In doing so, the authors emphasize that consistency with public policy goals should be a key consideration when determining approval of demand-side programs.

Efficient Electrification Insights:

The authors' focus on the importance of consistency with public policy objectives is relevant, as electrification initiatives are often presented, at least in part, as efforts to promote the policy objective of decarbonization. As such, the authors suggest that there is a significant subjective aspect of demand-side cost-effectiveness evaluation. Some regulatory subjectivity is required when it comes to weighing the non-quantified benefits of marginally failing measures. It is important to consider a variety of test perspectives rather than relying on a single benefit-cost ratio. Conversely, it is important to maintain a consistent economic basis for establishing cost-effectiveness, and to allow economics rather than politics to dictate technology choice.

Current Utility Practices

Overview

As a complement to the theoretical focus of the literature on cost-effectiveness, we reviewed actual utility reports or regulatory filings that included quantitative information about costs and/or benefits of electrification programs. We identified and reviewed eight such studies.

In several cases, the electrification proposals were not subject to comprehensive cost-effectiveness analysis, because they were only being proposed as pilot programs. Otherwise, the analyses generally followed established cost-effectiveness protocols in their respective states, relying on RIM, TRC, and SCT frameworks. Thus far, the

[13] Jim Lazar and Ken Colburn, "Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits)," Regulatory Assistance Project, September 2013.

[14] Tim Woolf et al., "National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources, Edition 1," National Efficiency Screening Project, May 18, 2017.

SCT seems to have been used more commonly for electrification than in standard DSM contexts, presumably due to the societal impact of electrification programs (including decarbonization). A summary of the utility studies is provided in Table 3 and source documents are listed in the *References* section of this report.

Table 3. Utility Assessments of Costs and Benefits of Electrification Programs

Utility	State	Description	Tests Used
AEP	Ohio	EV charging load control program	"Regional Test" [1], RIM
Ameren	Missouri	EV charging infrastructure and C&I electrification	Modified TRC
Avista	Washington	Deployment of EV supply equipment (mostly chargers)	None [2]
City of Palo Alto	California	Residential heat pump program	SCT, RIM
Kansas City Power & Light	Kansas	Deployment of non-residential EV supply equipment	None [2]
National Grid	Rhode Island	Portfolio of transportation and heating electrification programs	SCT, RIM
Pepco	Maryland	EV charging demand management	None [2]
Portland General Electric	Oregon	Portfolio of transportation electrification programs	RIM, TRC, SCT
Southern California Edison	California	Deployment of EV supply equipment	None [2]

Notes:
[1] The regional test perspective appears to be a hybrid of the TRC and SCT.
[2] The pilot program was not subjected to cost-effectiveness screening, but filings include a detailed list of cost, typically split between utility costs and billpayer costs.

Conclusions

The literature review has led us to "Top 10 List" of considerations for assessing the cost effectiveness of energy efficiency inclusive of efficient electrification:

1. **Broadly, the SPM appears relevant and applicable.** The SPM is not broken. In fact, it directly includes considerations appropriate for electrification-type programs. However, several refinements and additions to the SPM methodologies can improve its application to electrification projects. We explore this theme in later sections of this report.

2. **Carbon reduction is a key environmental policy driver in some jurisdictions.** Energy efficiency and electrification programs in some states are driven by the policy objective of decarbonization, which can have impacts that extend significantly beyond the electric utility system.

3. **Non-energy benefits and costs merit further research, such that they can be quantified where possible or qualified as warranted.** The inclusion of non-energy benefits and "market barrier costs" will also take on increasing importance in an electrification context. New electric end-uses, particularly in transportation, will likely include a range of features with significant non-monetary benefits and costs to consumers. New research is needed to quantify these costs and benefits. Non-quantifiable benefits and costs should still be carefully considered, particularly when evaluating measures that are marginally failing the relevant cost-effectiveness tests. A useful approach adopted by states such as Vermont and Massachusetts is to apply qualitative "adders" to value non-energy benefits that cannot be quantified to a reasonable level of confidence yet are understood to have non-zero value.

4. **It is important to evaluate program impacts from multiple perspectives — societal, customer, and utility.** It is critical to consider a range of perspectives when evaluating the cost-effectiveness of electrification programs. While this is generally true of cost-effectiveness evaluations, it is particularly important in an electrification context where multiple stakeholder groups can be significantly impacted.

5. **Pilots should not need to demonstrate cost-effectiveness.** Consistent with observed practices around the U.S., any type of pilot, electrification or otherwise, should not be required to demonstrate cost-effectiveness. Rather, these pilots are implemented, at least in part, to determine whether large-scale electrification programs could be cost-effective.

6. **Additional detail on the distribution of bill impacts is needed.** While the RIM test can provide an initial assessment of the impact of electrification programs on the rates and bills of non-participants, further analysis is needed to better reflect these impacts, with a focus on program eligibility and impacts across income segments. The RIM does not account for other types of benefits from energy efficiency that may accrue to non-participating customers, such as non-energy benefits or demand reduction induced price effects (DRIPE) in RTO and ISO markets.

7. **Uncertainty analysis should be included in cost-effectiveness evaluations.** The nascent nature of electrification programs, compared to conventional DSM programs, calls for better accounting for uncertainty in projections of future impacts, costs and benefits. Uncertainty can be addressed through probabilistic analysis and advanced data analytics, rather than developing point-estimates of cost-effectiveness.

8. **Consideration should be given to the flexibility value of electrification.** Even if a proposed electrification program does not include a specific provision for demand management, assessment of benefits should recognize that the new electric load may have future flexibility value for the grid, as a function of its end-use characteristics and market mechanisms for monetizing flexibility. This consideration of grid flexibility benefits should apply to any form of demand-side program, including energy efficiency and demand response programs that target peak demand hours.

9. **Power simulation modeling will be increasingly important for valuing electrification programs.** Rather than simply relying on static estimates of marginal costs when estimating the impacts of electrification programs, it may be necessary to perform more detailed simulations of the power system. This will capture important issues related to the depth of the need for certain valuable resources and will better capture new issues being introduced in an increasingly decarbonized power supply mix.

10. **Programs should be cost-effective, not just satisfy policy objectives.** Just because an electrification program may be consistent with certain policy goals, that alone does not necessarily justify its development. There may be alternative, cheaper means for achieving the same goal. Thus, cost-effectiveness analysis should always be a key consideration when evaluating new electrification opportunities.

Expert Perspectives

Background

As a complement to our review of the literature on cost-effectiveness, we interviewed fifteen experts about the economics of efficient electricity. They were selected to provide us a sampling of views from energy efficiency organizations, state commissions, utility trade associations, and national research laboratories.

These phone interviews were designed to help us understand diverse perspectives on efficient electrification, with written questions submitted in advance.

Each conversation began with a proffered definition of efficient electrification, followed by asking for general comments on efficient electrification and the role of utilities in promoting it. Interviewees were then asked to answer one or more of the following seven questions:

1. Do you think it is a good idea for utilities to pursue efficient electrification?

2. Should utilities be allowed to recover expenditures for efficient electrification from all customers, just as they are recovered today for energy efficiency expenditures?

3. Should utilities be allowed to put expenditures for efficient electrification in the rate base? For example, could assets like electric vehicle charging stations and related infrastructure be rate-based in a similar manner as investments in transmission or distribution assets? If not, what are the key differences? Is there a way to reconcile these distinctions?

4. Should utilities be allowed to earn incentives for attaining efficient electrification goals, just as they are allowed (in some states) to earn incentives for attaining their energy efficiency goals?

5. Are there particular economic tests that should be applied to efficient electrification expenditures before determining their eligibility for cost recovery, and possible rate-basing, from customers?
6. Should California's Standard Practice Manual (SPM), which has been applied nationwide to assess energy efficiency programs, be expanded to include a sixth test for efficient electrification?
7. Do you have any materials that you can share with us as we proceed with our study?

Some experts provided an overall response to the questions, some answered a few of the questions, and some answered them all. As expected, there were both areas of agreement and disagreement among the experts.

Themes

In their initial comments, some of the experts expressed multiple definitions of efficient electrification. Some equated it with "fuel switching" between electricity and fossil fuels (e.g. natural gas) for space heating, water heating, and process heating. Others equated it with new uses of electricity, such as in transportation. A couple of interviewees suggested that "decarbonization" is a preferable term. Further, some felt that the definition of efficient electrification should also refer to its potential to enhance the flexibility of the power system.

In general, there was a broad base of support among the interviewees for pursuing efficient electrification that reduces emissions of carbon and other criteria pollutants and lowers customer costs of energy by reducing total energy consumption and/or increasing productivity. Some experts said that efficient electrification would be driven by state legislation, such as SB 350 in California, acknowledging that policy drivers would vary by state.[15]

Experts emphasized the importance of recognizing the distinction between efficient electrification versus traditional utility "load building" activities, as pursued in the 1950s and 1960s. The distinction is that efficient electrification must contribute to societal objectives, such as lowering carbon emissions, while also reducing customer costs or improving power system flexibility, with additional utility load as a byproduct.

In terms of evaluating the cost-effectiveness of utility-funded efficient electrification programs, it was stated that the SPM was originally developed for evaluating energy conservation and load management programs.

Some experts articulated that the TRC, the most widely used test in the country, has the following limitations:

1. Only considers non-energy benefits that can be monetized. Those are included in the Societal Cost Test but they are hard to measure;
2. Ignores the response of customers to the change in rates that might follow the implementation of demand-side programs, i.e., price elasticity;
3. Overlooks the value consumers gain from consuming electricity, i.e., consumer surplus;
4. Assumes that avoided costs are constant regardless of the amount of demand-side programmatic activity – a limitation that can be overcome through production cost simulation models.

Other experts noted that new types of demand-side programs introduced since 2001 do not necessarily fit within the confines of the SPM methodology. For example, advanced demand response programs that emphasize load flexibility and efficient electrification may require the introduction of a new test that goes beyond the five in the SPM repertoire.

While some interviewees asserted that utilities have a natural role to promote and lead efficient electrification efforts, others argued that this is not self-evident. One expert noted that electrification of the Port of Oakland, California was implemented by the Port without any utility involvement simply because it made economic sense for the Port Authority and for shippers.

Some experts said that efficient electrification should not be presumed the exclusive purview of utilities, but rather as an opportunity for end-use customers and market-driven actors to pursue. This point is punctuated by the assertion that efficient electrification can be enabled solely by having appropriate market incentives. As a counterpoint, one expert noted that having the right codes and standards is more important than providing incentives to utilities or other market actors, since the former had been more impactful than the latter in attaining energy efficiency goals.

[15] California Senate Bill 350, "Clean Energy and Pollution Reduction Act" (SB 350).

Others noted that the objective of efficient electrification – market transformation to promote decarbonization – should be pursued though all channels including, but not exclusively, utilities.

On the issue of providing incentives to utilities to pursue efficient electrification, some experts stated that utilities will naturally benefit from increased electricity sales and improved load factors, yielding better earnings. The argument continues that as “natural beneficiaries” of electrification, utilities do not need special incentives for undertaking activities in their self-interest. Most such electrification programs would pass the Ratepayer Impact Measure (RIM) test, insofar as it would lower rates for all customers.

Experts pointed out the need for utility incentives for energy conservation, which lowers electricity sales, decreases recovery of fixed costs, and lowers earnings. By that reasoning, some posit that utilities may *not* need similar incentives to pursue efficient electrification, which has the effect of increasing electricity sales, increasing recovery of fixed costs, and raising earnings.

However, in states that have decoupled electric utility revenues from sales to align incentives and reduce barriers for energy efficiency programs, the natural utility incentive for efficient electrification is diminished. Hence, utilities in such states may require some earnings opportunities to undertake efficient electrification initiatives, whether in the form of rate basing infrastructure or incentive payments or performance incentives.

An additional point made was that market barriers for energy efficiency programs, which have existed over the past four decades, may not exist for efficient electrification programs. It was also suggested that in the future, cost-of-service regulation may give way to performance-based regulation and that change in regulatory paradigm would have to be considered when designing incentives for utilities to promote efficiency electrification.

A couple of experts suggested using the “Three-Prong Test” for evaluating efficient electrification programs, which has been applied for many years by the California Public Utilities Commission (CPUC) as a screening tool for energy efficiency programs in the state. In this test, a program must simultaneously pass the TRC test, lower carbon emissions, and lower total BTUs of energy consumed. While the Three-Prong Test appealed to some interviewees for going beyond the traditional Total Resource Cost (TRC) test, it did not appeal to others who find it too stringent for evaluating efficient electrification programs. Experts generally acknowledged that very few efficient electrification programs would pass the Three-Prong Test, leading to a sub-optimal social outcome. These experts particularly questioned why reducing source energy consumption should be a requirement of decarbonization initiatives when, in fact, a net increase electricity consumption (replacing fossil-fueled end use) could have environmentally beneficial results in regions with a less carbon-intensive power supply mix.

Moreover, some experts opined that a demand-side management program should be deemed appropriate for pursuit if it advances any one of the following three policy goals without adversely impacting the other two:

- Lowers carbon emissions
- Lowers energy costs
- Improves grid flexibility

In evaluating the cost-effectiveness of efficient electrification, some parties suggested a modified TRC test, such as put forward by Ameren in its “Charge Ahead” electrification program filing in Missouri.[16] This test focuses on the benefits that would accrue from electrification in the form of reduced use of other fuels. One expert stated that fuel substitution is considered in the TRC test but only in the context of electricity and natural gas. The modified TRC includes other fossil fuels in the computations, such as gasoline, diesel and propane.

There was widespread agreement among the interviewees that carbon reduction benefits must be factored into any new cost-benefit calculus. Thus, some experts suggested using the “Resource Value Test” in the National Standard Practice Manual (NSPM), a cost-effectiveness framework that can apply to demand-side or supply-side options.[17] The Resource Value Test does not propose a specific formula for quantifying costs and benefits, but rather presents a set of principles for assessing cost-effectiveness. For instance, the Resource Value test asserts that analyzed costs and benefits should account for state policy objectives and that all assessments should be forward-looking. But there was disagreement among interviewees on how to quantify non-utility costs and benefits with this test, with some arguing that any answer could be derived depending on what

[16] Direct Testimony of David K. Pickles, on behalf of Union Electric Company, Missouri Public Service Commission, File No. ET-2018-0132, February 22, 2018.
[17] Tim Woolf, et al., “National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources, Edition 1,” National Efficiency Screening Project, May 18, 2017.

values are assumed. Concern was also expressed that the general nature of this test may favor policy objectives over economics as the chief determinant of cost-effectiveness.

Implications for Electrification Cost-Effectiveness Analysis

The expert interviews identified important considerations for conducting cost-effectiveness analysis of efficient electrification programs. The following key takeaways emerged from the interviews as points of near consensus agreement.

1. Challenges and controversies of evaluating cost-effectiveness are driven more by decisions of how to implement the tests than by the conceptual design of the tests themselves. Implementation of the tests must ensure that costs and benefits are given equal treatment (e.g., include non-energy benefits if including non-utility costs, and vice versa).
2. The principles defined in the National Standard Practice Manual (NSPM) are important to consider, as the Resource Value Test is gaining visibility in several jurisdictions. The implication is to establish an evaluation framework that allows for consideration of state policy objectives. However, on a closer examination, the NSPM does not differ conceptually from the California SPM broadly defined.
3. Improved power system flexibility is an important and often overlooked benefit of electrification that should be included in cost-effectiveness analysis.
4. Non-energy benefits and costs are likely to play a significant role in the evaluation of electrification programs. This was also a conclusion of the literature survey in *A Review of Current Practices*.
5. Efficient electrification is an important element of decarbonization efforts. Environmental impacts – at a minimum those that can be monetized – should be included in the evaluation of electrification programs.

A Framework for Evaluating Electrification Cost-Effectiveness

Introduction

This study set out to determine if there are gaps in existing cost-effectiveness frameworks when applied to efficient electrification programs. The basis for this assessment included a review of the literature, a close examination of the California Standard Practice Manual (SPM), and interviews with industry experts, as discussed in *A Review of Current Practices* and *Expert Perspectives*.

Based on this review, we have concluded that the SPM tests, as originally conceived, are appropriate for assessing electrification cost-effectiveness. The SPM tests account for considerations that are critical when evaluating efficient electrification programs, such as the cross-sector impacts of fuel switching, non-energy benefits, grid management benefits, environmental impacts, employment impacts, and productivity enhancements.

However, while the overarching California SPM framework is valid for evaluating efficient electrification, *implementation* of the SPM tests often falls short. This is true even for the most common use of the SPM framework, which is its application to energy efficiency programs. Further deficiencies have been observed in alternative applications of the test, such as for demand response and electrification.

Considering that efficient electrification programs present unique characteristics not found in conventional DSM programs, correct implementation of the California SPM is imperative. Therefore, this section presents recommendations for effectively applying the California SPM tests in the context of efficient electrification, and more broadly to energy efficiency in general. While it is beyond the scope of this paper to comprehensively cover all implementation details, we provide critical guidelines and considerations.

The California SPM and Efficient Electrification

Debunking myths about the SPM

Despite the SPM's long history of use to evaluate DSM programs, the SPM's nuances are often misunderstood by industry practitioners. Our interviews with industry experts – and close re-examination of our own understanding of the SPM – identified several commonly held misperceptions about the California SPM tests. We discuss myths directly relevant to the assessment of efficient electrification programs below.

Myth #1: The SPM does not account for fuel switching

The SPM explicitly accounts for fuel switching. Contrary to some perceptions, the SPM's focus extends beyond programs that reduce electricity consumption. Categories of programs that are specifi-

cally described in the SPM include "fuel substitution" and "load building."[18]

In discussing the nuances of "fuel substitution" programs, the SPM uses residential heat pumps – a common efficient electrification program – as an example:

> "Categorizing programs is important because in many cases the same specific device can be and should be evaluated in more than one category. For example, the promotion of an electric heat pump can and should be treated as part of a conservation program if the device is installed in lieu of a less efficient electric resistance heater. If the incentive induces the installation of an electric heat pump instead of gas space heating, however, the program needs to be considered and evaluated as a fuel substitution program."[19]

The SPM also emphasizes the "total energy supply system" perspective that is taken in the TRC and Societal Cost tests. This perspective is critical to efficient electrification assessment:

> "For fuel substitution programs, the test measures the net effect of the impacts from the fuel not chosen versus the impacts from the fuel that is chosen as a result of the program. TRC test results for fuel substitution programs should be viewed as a measure of the economic efficiency implications of the total energy supply system (gas and electric)."[20]

Thus, the California SPM was designed with electrification-like programs in mind. It should be noted, however, that the SPM tends to emphasize switching between electricity and natural gas in its discussion of fuel substitution programs. The SPM concepts are similarly applicable to switching between other fuels, such as switching from gasoline to electricity in the transportation sector.

Myth #2: The SPM only considers electricity bill impacts

Consistent with its accounting for multiple fuels as described above, the SPM considers impacts on total energy bills from a customer standpoint. The SPM does not just focus narrowly on electricity bill impacts.

The Participant Test, for example, includes a measure of the "avoided bill for the alternative fuel" in its quantification of the participant benefits of an efficient electrification program.[21] The description of the TRC and Societal Cost tests explicitly acknowledges that "the costs also include the increase in supply costs for the utility providing the fuel that is chosen as a result of the program."[22]

Myth #3: The SPM prescribes a specific methodology for quantifying avoided costs

The SPM defines a useful set of cost-effectiveness test perspectives and establishes the appropriate costs and benefits to be included to accurately capture each perspective. The SPM does not, however, dictate a precise methodology for calculating the benefits of a demand-side program.

Some in the industry have expressed frustration with the way costs and benefits are calculated in DSM proceedings, and have assigned this frustration to perceived flaws in the SPM. It is important to recognize that the SPM is not the source of these methodological decisions. The precise method for calculating benefits and costs is typically determined between utilities, regulators, and stakeholders on a state-by-state basis. For instance, the CPUC has developed multiple supplemental reports laying out protocols for quantifying costs and benefits of DSM programs.[23]

Myth #4: The SPM's results are driven by a focus on environmental externalities

The Societal Cost Test (SCT) is the only SPM test that includes all environmental externalities. And in the SCT, environmental impacts are weighed against a broad list of other costs and benefits. As discussed later in this section, the SCT accounts for avoided resource cost across the energy supply chain, employment impacts, and changes in quality of service, among many other factors. Environmental impacts are not given higher or lower priority than these other factors – all are considered on a level playing field.

Myth #5: The SPM requires that demand-side programs reduce source energy BTUs

The SPM provides a framework for determining if the benefits of a given program outweigh the costs. It does not include an explicit requirement related to energy consumption. The impact of a pro-

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[18] "California Standard Practice Manual," California Public Utilities Commission, October 2001, 2-3.
[19] Ibid., page 3.
[20] Ibid., page 18.
[21] Ibid, p. 11.
[22] Ibid, p. 18.
[23] California Public Utilities Commission. "Energy Efficiency Portfolio Report." May 2018.

gram on net energy use only affects the benefit-cost equation to the extent that changes in net energy use increase or decrease costs and benefits. None of the SPM tests require that a program provide a prescribed change in energy use to pass.

There have been policies, such as California's "Three-Prong Test," which do include this requirement. However, those policies were developed outside of the SPM and exist independently of it (see the sidebar at the end of this section for further discussion).

What Makes Efficient Electrification Unique from a Cost-Effectiveness Standpoint?

Our conclusion that the SPM is relevant and applicable to efficient electrification may be a surprising finding to some readers. Historically, use of the SPM has been dominated by its application to energy efficiency programs, which have accounted for the vast majority of utility "demand-side" spending and have thus been the focal point of cost-effectiveness analysis. Energy efficiency programs at the state level have traditionally been focused on energy (kWh) reduction as the primary performance metric. As a result, in many people's minds the SPM has implicitly become narrowly associated only with its application in an energy efficiency context.

Being constrained to an "energy efficiency mindset" can result in missing important costs and benefits when applying the SPM to efficient electrification. For instance, energy efficiency programs commonly involve improving the efficiency of a single end-use appliance, without any need to consider the implications of fuel switching. It is necessary to unlearn some of the habits to appropriately apply the SPM to all forms of energy efficiency inclusive of efficient electrification.

Table 4 summarizes important differences between energy efficiency and efficient electrification programs, and the implications of these differences for cost-effectiveness assessment. Awareness of these implications is an important first step in applying the SPM to electrification programs.

Table 4. Comparison of Energy Efficiency and Efficient Electrification

Electric Energy Efficiency Program Features	Efficient Electrification Program Features	Implications for Cost-Effectiveness Assessment of Efficient Electrification
Reduces electricity consumption	Increases electricity consumption	Electrification programs do not present the same risks of cost under-recovery due to a reduced electricity sales base that is observed in energy efficiency programs. Alternatively, in the case of fuel switching, electrification increases risk of rate increase for alternative fuels. Consideration of non-electric bill impacts is important in this regard.
Impacts only one fuel type	Often involves fuel switching	Cost-effectiveness analysis cannot be limited to cost implications for a single utility or fuel type; must analyze costs and benefits across industries
Provides static (i.e., non-dispatchable) energy savings	Adds potentially flexible load	The value of load flexibility must be accounted for in an assessment of the potential benefits of electrification
Provides environmental benefit regardless of carbon-intensity of generation	Provides particular environmental benefit where generation is less carbon-intensive	Must account for future decarbonization of the power supply mix when evaluating environmental benefits; static assumptions are not sufficient
Reduces future need for electricity infrastructure	Increases need for electricity infrastructure; may reduce future need for alternative fuel infrastructure	Analysis must account for net change in infrastructure costs across industries, including stranded assets in non-electricity industries

Recommended Perspective: The Total Value Test

Overview

Among the various cost-effectiveness test perspectives defined in the SPM, the SCT is the most aligned with our recommended framework for evaluating efficient electrification programs. The SCT is the only cost-effectiveness test that explicitly and comprehensively accounts for the unique features of electrification programs. Such features include potentially significant non-energy benefits and changes in environmental externalities, in addition to core customer benefits.

At the same time, the SCT has developed a reputation for being too "open ended" and allowing for a subjective interpretation of which benefits and costs to quantify and include in the assessment. The SCT also uses a low "societal discount rate" which, by putting significant weight on longer-term benefits, tends to be very generous to new demand-side programs.

To mitigate these concerns about the SCT, we propose a revised test known as the **Total Value Test (TVT)**. The TVT uses the higher discount rate of the TRC test, based on the utility's weighted average cost of capital, but also includes the non-energy benefits and costs that are included in the SCT.

The TVT takes the broadest possible perspective on the costs and benefits of efficient electrification programs. While environmental impacts and non-energy benefits are important considerations, the TVT weighs them against similarly important changes in energy resource costs and other benefits that may accrue directly to participants and/or non-participants. An advantage of the TVT is that it comprehensively accounts for all possible sources of value, rather than taking a narrow perspective that may exclude important considerations.

Guidelines for Applying the TVT to Efficient Electrification Programs

The TVT is challenging to implement accurately and comprehensively. Implementation requires quantifying difficult-to-estimate benefits that extend beyond the realm of avoided utility resource costs. The implementation challenges are amplified when applying the test to nascent electrification programs with uncertain impacts that extend across multiple segments of the economy. In this light, the following are practical guidelines in five critical areas of implementation.

1. Identifying costs and benefits

Assessing the cost-effectiveness of efficient electrification programs begins with establishing a comprehensive list of cost and benefits. Table 5 is a list of possible costs and benefits included in the TVT. The applicability of each element should be viewed within the specific context of the program that is being evaluated.

An example is provided for each element. Throughout the table, we present examples for a range of fuels to illustrate that the impacts of efficient electrification programs typically extend significantly beyond the electricity sector.

Table 5 also provides the authors' perspective on the certainty with which each category of benefit and cost can be quantified. Some costs and benefits can be included in cost-effectiveness analysis with more confidence than others, depending on the data and resources available to conduct the analysis as well as the extent to which there is an established methodology for quantifying the impact.

The benefit and cost categories in Table 5 are primarily derived from two excellent resources. The first is a primer on energy efficiency cost-effectiveness assessment by Jim Lazar and Ken Colburn of the Regulatory Assistance Project (RAP), titled "Recognizing the Full Value of Energy Efficiency."[24] The second is the National Efficiency Screening Project's "National Standard Practice Manual," which provides guidelines for cost-effectiveness analyses that are tailored to the objectives of individual states.[25]

There is a nuanced difference between Table 5 as it appears here, and similar tables that have been developed previously in the context of energy efficiency analysis. Energy efficiency analysis focuses heavily on comparing program costs to the benefits of avoided production costs in the electricity system. Changes in the costs of non-electricity energy sources are typically given secondary consideration. However, in evaluating efficient electrification, any given category of system impacts should be quantified as a net change in costs across the multiple fuel systems that are being affected by the program. The change could be either a net cost or a net benefit. Thus, the examples in the table illustrate how the categories present the possibility of either a net societal cost or benefit.

[24] Jim Lazar and Ken Colburn, "Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits)," Regulatory Assistance Project, September 2013.
[25] Tim Woolf et al., "National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources, Edition 1," National Efficiency Screening Project, May 18, 2017.

Table 5. Costs and Benefits of Efficient Electrification in the Total Value Test

Category	Example	Quantifiability
Program costs		
Administration costs	Marketing, measurement & verification	●
Incentive payments	Rebates for equipment purchases	●
Participant contribution to costs	Cost to consumer of equipment, net or rebate	●
Third-party contribution to costs	Trade ally contribution to marketing costs	●
System impacts		
Production capacity costs	New electricity generation peaking capacity	●
Production energy costs	Reduced need for gasoline to power vehicles	●
Cost of environmental regulations	Reduced gas utility compliance fees due to lower demand	●
Fuel transmission capacity costs	Reduced need for natural gas pipeline expansion	●
Fuel distribution capacity costs	Increased need for electric distribution capacity	●
Line losses	Higher electricity line losses due to higher volume of sales	●
Ancillary services	Provision of frequency regulation from new sources of flexible load	●
Risk to the utility	Increased risk of stranded natural gas assets	◑
Renewable resource obligation	Higher RPS requirement due to higher electricity sales	●
Energy market price effect	Increased wholesale electricity price due to peak demand growth	◑
Participant impacts		
Other resource costs	Increased water demand for hydroelectric power	◑
O&M costs	Elimination of need for regular oil changes for a gasoline vehicle	◑
Health impacts	Reduced medical costs	○
Productivity	Reduced product spoilage/defects	◑
Asset value	Improved property values	○
Economic well-being	Reduced foreclosures	○
Comfort	Vehicle noise reduction	○
Societal impacts		
Air quality	Reduced tailpipe emissions from gasoline vehicles	◑
Employment	Vendor/contractor staffing changes	◑
Economic development	Changes in gross domestic product	◑
Energy security	Reduced dependence on fuels from unstable regions	○
Public health	Reduced health insurance costs due to cleaner air	○

Key

Well established methodology, easily obtainable data

Less established methodology or difficult/costly to obtain data

Speculative, subject to high degree of uncertainty

"Quantifiability" represents the extent to which there is a well-established methodology for quantifying the impact, data is readily obtainable at a low cost, and there is limited uncertainty in the results

2. Non-energy costs and benefits

Non-energy costs and benefits – broadly defined as any societal- or participant-level benefit beyond energy savings – are an important consideration for efficient electrification. However, these impacts are also notoriously difficult to quantify.

There is a substantial literature on the measurement of non-energy benefits (NEBs) done in the context of energy efficiency and related programs. A recent review of studies available online identified nearly 300 papers concerning NEBs that have been authored since the early 1990s.[26] In this domain, categories of benefits include operations and maintenance ("O&M") cost savings, environmental impacts and associated public health benefits, participant health impacts, gains in employee productivity, changes in property values, benefits for low-income customers, economic development and improved comfort levels.[27] Of course, not all of these benefits are applicable to electrification programs, and others may exist. A recent LBNL study on the electrification of buildings and industry included balance of trade for fuels, energy security, potential reduction of fuel price risk, and process improvements in industry as additional potential benefits.[28]

The approaches used to quantify NEBs in energy efficiency and related programs vary according to the type of NEBs being quantified. However, three key categories or types of analyses can be identified:[29]

- *Engineering or model-based estimates:* For example, concentration-response models are used to convert avoided emissions into reductions in healthcare costs.[30] Similarly, economic development models such as IMPLAN can be used to quantify local economic impacts such as job creation.[31] In addition, the EPA's Regulatory Impact Assessments provide guidance on cost-benefit calculations to quantify health benefits.[32]
- *Incremental Incidence estimates*: These consist of applying factors from secondary sources to monetize benefits. For example, in the current context, avoided time spent getting oil changes might be valued at the marginal wage rate in a locality.
- *Survey-based analysis*: Survey methods, including contingent valuation, is used in the EE context to measure results related to comfort, for example. In the current context, one could envision the use of these methods to quantify benefits from vehicle noise reduction, for example.

The rigor of studies of NEBs associated with EE and related programs is highly variable. Common critiques include reliance on dated assumptions and inputs[33] and wide uncertainty in NEB estimates.[34]

However, several best practices have emerged. When properly applied, quantification of NEBs can be rigorous and reliable. Primary considerations include:[35]

- While the term NEB (or the closely-related Net Energy Impacts) is commonly used, rigorous studies seek to identify net NEBs, acknowledging that some of the non-energy impacts may be negative on balance.
- It is also crucial that any quantification of NEBs avoid double-

[26] See: Michael Freed and Frank A. Felder, "Non-energy Benefits: Workhorse or Unicorn of Energy Efficiency Programs?" *The Electricity Journal* 30 No. 1 (2017): 43-46, doi:10.1016/j.tej.2016.12.004. See also: Lisa A. Skumatz, "Non-Energy Benefits / Non-Energy Impacts (NEBs/NEIs) and their Role & Values in Cost-Effectiveness Tests: State of Maryland Final Report," Prepared for The Natural Resources Defense Council, Inc. (NRDC), March 2014, which provides an overview of the history and current status of NEB measurement.

[27] See, for example, Jim Lazar and Ken Colburn, "Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits)," Regulatory Assistance Project, September 2013, 47-49. See also: Tim Woolf et al., "National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources, Edition 1," National Efficiency Screening Project, May 18, 2017, 54-58.

[28] Jeff Deason et al., "Electrification of Buildings and Industry in the United States: Drivers, Barriers, Prospects, and Policy Approaches," Lawrence Berkeley National Laboratory, Prepared for the Office of Energy Policy and Systems Analysis, U.S. Department of Energy March 2018, 4-6.

[29] Lisa A. Skumatz, "Non-Energy Benefits / Non-Energy Impacts (NEBs/NEIs) and their Role & Values in Cost-Effectiveness Tests: State of Maryland Final Report," Prepared for The Natural Resources Defense Council, Inc. (NRDC), March 2014, 20.

[30] Michael Freed and Frank A. Felder, "Non-energy Benefits: Workhorse or Unicorn of Energy Efficiency Programs?" *The Electricity Journal* 30 No. 1 (2017): 44, doi:10.1016/j.tej.2016.12.004.

[31] IMPLAN is one of several models that are widely utilized in the analysis of economic impacts. These models begin with a direct effect (such as an expenditure or new jobs) and, using input-output tables, estimate an ultimate economic impact that also includes indirect and induced effects.

[32] https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/regulatory-impact-analyses-air-pollution.

[33] Freed and Felder note that some recent program evaluations cite quantifications of benefits from the early 1990s.

[34] (Freed and Felder 2017, 45); (Skumatz 2014, 31-32).

[35] This discussion of best practices relies in part on (Skumatz 2014, 62-65) and on Bruce Tonn, et al., "Health and Household-Related Benefits Attributable to the Weatherization Assistance Program," Oak Ridge National Laboratory (2014). The latter is a recent example of a well-structured and rigorous analysis of NEBs. It relies in large part on literature reviews and extensive household surveys to estimate health and other household benefits.

counting.[36] For example, each unit of avoided consumption of carbon-based fuels could result in less mining and extraction (potentially generating environmental benefits), or it could result in increased exports of those fuels. However, it would be incorrect to count both.

- Begin with a well-defined scope and framework. Too frequently, quantification of NEBs appears to be an afterthought addressed only after energy-related benefits are satisfactorily quantified.
- Use existing literature to cross-validate results, particularly with respect to survey data. While surveys can be an effective way to collect data on multiple types of NEBs that can either only or most readily derived from user perceptions, it is important to compare these results with values derived from other studies and/or methodologies in order to have increased confidence in the results.

In the analyses of energy efficiency programs, non-energy benefits can be substantial, ranging from 50-400% of the energy benefits from those programs. The relative importance of NEBs in the calculation of cost effectiveness of electrification programs will depend in large part on the specifics of the program being evaluated. It is crucial that the quantification of any such benefits be done in a rigorous and reliable manner.

Non-Energy Benefits Evaluation in Practice

Washington, DC like several states, accounts for NEBs in cost-effectiveness screening for energy efficiency programs through the inclusion of an "adder." The DC Sustainable Energy Utility, which oversees energy efficiency programs throughout the District, uses a 10% adder for NEBs whenever the calculation would otherwise require significant original research. Screening also incorporates an environmental externalities adder (for example, this was $0.0713 per kWh in 2015).[37]

In **Massachusetts**, the Energy Efficiency Advisory Council recently commissioned a study that assessed and monetized eight health- and household-related NEBs experienced by recipients of energy efficiency services residing in income eligible households in MA. This study built upon and adapted the results of a national study of the Department of Energy's Weatherization Assistance Program, modifying and updating the inputs to better fit the Massachusetts context. The ultimate goal was to develop recommendations for integrating the results into the NEB estimates currently used by the Massachusetts program.[38]

The **Vermont** Public Service Board, relying on third-party research supporting the value of NEBs, ordered a 15% NEB adder, plus an additional 15% low-income adder when applicable, both of which are incorporated into cost-effectiveness screening of EE investments in Vermont.[39]

Ameren Missouri recently filed a proposal for a new beneficial electrification ("BE") program with the Missouri Public Service Commission. One aspect of the BE program includes incentives and support to encourage adoption of qualifying electric technologies, such as forklifts and airport ground support equipment. Expert testimony filed in support of this program did not seek to quantify, but explicitly cited non-energy benefits including (i) improvements in workplace safety, cleanliness, and noise levels; (ii) improved productivity; (iii) reduced maintenance costs; (iv) reduced exposure to fossil fuel price volatility; and (v) broader environmental benefits through reduced emissions of CO_2, NO_x, and particulate matter.[40]

[36] Tim Woolf et al., "National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources, Edition 1," National Efficiency Screening Project, May 18, 2017, 57.

[37] Ingrid Malmgren and Lisa A. Skumatz. "Lessons from the Field: Practical Applications for Incorporating Non-Energy Benefits into Cost-Effectiveness Screening." *ACEEE Summer Study on Energy Efficiency in Buildings* Volume 8 (2014): 186-200. Also, Richard Hasselman et al., "Evaluation of the District of Columbia Sustainable Energy Utility: FY2016 Annual Evaluation Report for the Performance Benchmarks (Final Draft)," Prepared for the District of Columbia Department of Energy and Environment, June 2017.

[38] Beth A. Hawkins et al., "Massachusetts Special and Cross-Cutting Research Area: Low-Income Single-Family Health- and Safety-Related Non-Energy Impacts (NEIs) Study," Prepared for Massachusetts Program Administrators, August 2016. Also, Bruce Tonn, et al., "Health and Household-Related Benefits Attributable to the Weatherization Assistance Program," Oak Ridge National Laboratory (2014).

[39] "Order Re: EEU Avoided Costs for 2016-2017 Time Period," State of Vermont Public Service Board, December 22, 2015. http://puc.vermont.gov/sites/psbnew/files/doc_library/order-re-eeu-avoided-cost-2016-2017.pdf.

[40] See: Direct Testimony of David K. Pickles, on behalf of Union Electric Company, Missouri Public Service Commission, File No. ET-2018-0132, February 22, 2018.

3. Accounting for policy goals

Policy goals have direct implications for cost-effectiveness analysis. Cost-effectiveness analysis that is conducted without consideration for policy goals will not produce conclusions that are useful for decision-making.

For instance, certain policies establish an economy-wide carbon reduction requirement. There will be a cost associated with meeting this requirement. From a cost-effectiveness standpoint, the relevant question is whether the proposed efficient electrification program will increase or decrease the all-in cost of satisfying the requirement.

Therefore, the impacts of established policies should be accounted for in the baseline scenarios against which the electrification program is being compared. In other words, the baseline scenario should reflect the costs and market dynamics associated with the achievement of policy goals. The proposed electrification program can then be evaluated on the basis for which it increases or decreases costs under these conditions.

To illustrate this concept, consider a utility proposal to provide rebates on the purchase of home EV chargers to spur adoption of EVs, which, in turn, will reduce carbon emissions. If this program is proposed in a state with a carbon emissions reduction goal, the costs and benefits of the proposed EV charging program need to be evaluated relative to the costs and benefits of alternative approaches that would need to be implemented to achieve the carbon reductions, rather than making the comparison to a world in which the carbon reductions are not achieved.

4. Defining the TVT "boundary"

A defining feature of the TVT is its treatment of subsidies. A literal interpretation of the Societal Cost Test, for instance, would not allow available subsidies to count as a net reduction in costs associated with the electrification program. The reason for this is, from a net societal perspective, subsidies to program participants are a cost to non-participants (e.g., through tax payments). The two cancel each other out in the TVT.

Other tests, such as the TRC test, would allow federal subsidies to reduce the costs that are considered in the cost-effectiveness evaluation. For instance, there is currently a federal tax credit of $2,500 to $7,500 available for the purchase of a new EV.[41] In a program designed to promote EV adoption, the TRC test would allow this credit to reduce the total quantified cost of the vehicle.

[41] The credit varies depending on the size and battery capacity of the vehicle.

Utilities and state regulators may wish to define the boundaries of the TVT at the state level. As a practical consideration, doing so would allow federal subsidies to be included as a benefit (i.e., cost reduction) in the program. This approach has been taken by some utilities in electrification program applications.[42]

5. Near-term versus long-term costs and benefits

It is important to evaluate the cost-effectiveness of efficient electrification programs over a long-term study horizon. There are several reasons for this.

The benefits of electrification programs may extend well beyond the life of the equipment directly associated with the program. Consider, for instance, a utility proposal to develop a network of high-speed charging stations along rural interstates. In the near term, the cost of the program may exceed the benefits, when EV adoption is low and the charging stations are underutilized. But if the program allows customers to overcome concerns about range anxiety, then in the medium-term the program could promote growth of the EV market to a point where benefits of EV adoption exceed the costs of the charging station network. In the long-term, those charging stations will need to be replaced as they reach the end of their useful life. Yet, a portion of the ongoing benefits of the maturing EV market would be attributable to the contribution of the original charging program to overcome pre-existing barriers.

Electrification programs may also drive down technology costs over time. Consider the aforementioned high-speed charging infrastructure example. Utility development of the initial charging station network could cause EV adoption – and demand for charging stations – to cross a threshold point at which it makes economic sense for competitive providers of charging infrastructure to compete in the market. Economies of scale and the benefits of competition could drive cost reductions and technological improvements that extend well beyond the immediate impact of the utility program.

On the cost side of the analysis, there is also the possibility of stranded costs associated with the fuel that was replaced by electricity. For instance, a large-scale shift to high speed "fueling" of EVs

[42] See, for instance, "Transportation Electrification Plan," Portland General Electric, December 2016, Submitted to Public Utility Commission of Oregon, December 27, 2016.

at public charging stations would result in less utilized gas stations, the costs of which would still be borne at the societal level. Stranded costs in non-electric energy sectors would have a negative near-term impact on the overall cost-effectiveness of electrification programs. However, the longer-term avoided need to maintain and replace these assets should be accounted for in the assessment. For example, in the case of under-utilized gas stations, the land could be sold or repurposed for higher-value uses.

A distinction should be made between stranded costs for regulated gas utilities versus stranded costs for non-regulated fuel providers of petroleum, propane, etc. The stranded costs of a regulated utility – which has an obligation to serve – are generally recoverable through the regulatory process. However, stranded costs on non-regulated fuel providers are non-recoverable – at least not in full – since companies in these competitive industries assume inherent risks in their business model.

Ultimately, the impact of these long-term considerations on the cost-effectiveness assessment is determined in part by the discount rate that is used. In the context of the TVT, a utility's weighted-average cost of capital (WACC) is recommended, since it is referenceable, non-arbitrary, and can be uniformly applied to all costs and benefits. We recognize that in practice, this places less emphasis on the longer-term impacts of electrification programs than does the SCT, which uses a lower societal discount rate. However, this low societal discount rate is often cited as a drawback to the practical application of the SCT. The use of the utility WACC as the discount rate, while accounting for the full spectrum of benefits and cost attributable to efficient electrification (or indeed any form of energy efficiency), is seen as a reasonable compromise that is practical to implement.

Do the "Other" Tests Matter?

While the TVT closely resembles the SCT and is the preferred cost-effectiveness perspective for efficient electrification programs, additional test perspectives are secondarily relevant. This section discusses the applicability of the other established tests.

Ratepayer Impact Measure (RIM) Test

The RIM test summarizes impacts from the short-term perspective of billpayers. In the context of electrification, it considers the net impact on the average customer's energy bills. In other words, if a program increases the average customer's electricity bill but decreases the natural gas bill, the RIM test considers the aggregate change across the two bills. Note that the RIM test applies to the average customer and is not just limited to bill impacts for participants in the program.

From a policy standpoint, it is important to consider the distributional impacts of efficient electrification programs. Some industry stakeholders have expressed concerns about the implications of efficient electrification programs for low-income customers. For instance, customers who cannot afford to pay the premium for an EV would effectively be ineligible for many EV-related programs. Policymakers may wish to look specifically at the implications of an electrification program for the energy bills of low-income consumers and other relevant customer segments.

In this regard, it would be appropriate to modify the RIM test to analyze impacts on specific relevant sub-segments of customers. A more detailed view of the distribution of bill impacts – both in the near term and in the longer term – would add value to the test as it is currently defined in the SPM.

Total Resource Cost (TRC) Test

The TRC test limits the "boundaries" of the test to customers within the utility system. As such, the TRC excludes impacts on customers in other service territories and non-utility customers, as well as externalities such as environmental impacts. This is generally an insufficient approach for comprehensively assessing the costs and benefits of efficient electrification.

Practitioners may wish to start with the TRC test, as it focuses primarily on those costs and benefits that are easier to quantify. But at the minimum, an awareness of the societal impacts not captured by the TRC test is necessary before making decisions based solely on this test.

It is worth noting that a focus on utility resource costs is entirely sufficient in other contexts, such as ratemaking, where rates are designed to reflect and collect only those cost incurred by the utility.

Program Administrator Cost (PAC) Test

The PAC test is largely irrelevant in the context of efficient electrification, as it does not account for costs and benefits that extend beyond the scope of the organization implementing the program. This deficiency is recognized in the California SPM, which acknowledges that the test "cannot be used to evaluate load building programs."[43]

[43] "California Standard Practice Manual," California Public Utilities Commission, October 2001, 24.

Participant Test

As with its use in other DSM initiatives, the Participant Test is primarily useful for determining program design, and for assessing the likely participation rate for customers in the program. Including the Participant Test perspective in a cost-benefit analysis also provides an indication of the extent to which net benefits to society of an efficient electrification program are accruing to those participants in the program who are enabling the benefits.

Resource Value Test

The Resource Value Test is not included in the California SPM. It was developed subsequently by the National Efficiency Screening Project and has received industry support as an overall framework for establishing a cost-effectiveness test that is consistent with local policy objectives.

The Resource Value Test is a set of guidelines for conducting a cost-effectiveness assessment. Unlike the California SPM it does not define a specific framework. By contrast, the objective of our study is to recommend a specific framework for evaluating the cost-effectiveness of efficient electrification. This requires making a specific declaration of what is "in" and what is "out" with respect to costs and benefits. As discussed above, the TVT is the most comprehensive perspective in this regard. However, we recommend reviewing the National SPM particularly for implementation guidance, as it addresses in useful detail several issues that were beyond the scope of our study.

Revisiting the "Three-Prong Test"

Several states have policies which implicitly or explicitly prohibit utilities from offering incentive-based fuel switching or fuel substitution programs. Perhaps the most notable of these policies has been California's three-prong fuel substitution test (aka the "Three-Prong Test"), which requires that any fuel switching program satisfy the following criteria: (1) it is cost-effective according to the TRC and PAC tests, (2) it does not adversely impact the environment, and (3) it does not increase source-BTU fuel consumption.[44, 45]

It is important to recognize that the Three-Prong Test is not one of the SPM tests. Rather, it is a tool designed to promote specific policy objectives within the state. It exists entirely outside of the California SPM framework.

The first two conditions of the Three-Prong Test — cost-effectiveness and environmental benefit — are certainly valid policy considerations. However, the third criterion on total source energy use is ambiguous, since source energy reduction in isolation lacks context, is neither a cost nor a benefit, and does not account for the diversity of electricity generation sources. In practice, this third prong artificially prohibits the introduction of fuel substitution programs such as efficient electrification that have the potential to both reduce energy bills and improve the environment.[46]

The Three-Prong Test is not the only example of policies that effectively prohibit fuel switching. For instance, in Minnesota, utilities are not allowed to promote incentive-based fuel substitution programs.

Policies that prohibit fuel switching or substitution should be reconsidered in light of the cost-effectiveness framework established in this report. Rather than evaluating cost-effectiveness and environmental benefits as two separate criteria, the costs or benefits of changes in environmental conditions should be weighed against the costs and benefits of other relevant impacts in order to determine if the program is beneficial in the aggregate.

In August 2019, the California Public Utilities Commission (CPUC) issued a ruling to update the Three-Prong Test, designating the baseline for energy and emissions savings comparisons, and specifying carbon emissions as the primary measure of environmental impact.[47] This ruling is expected to spur utility investment in efficient electrification programs from ratepayer-funded energy efficiency budgets. The Total Value Test can be applied as a screening mechanism for regulators to determine which programs warrant ratepayer funding, and those screened programs can be further prioritized based on factors such as customer benefit.[48]

[44] "Energy Efficiency Policy Manual, Version 5," California Public Utilities Commission, July 2013.

[45] "Source BTUs" or "source energy" refers to the energy content of the fuel required to perform a given task. In the case of electricity, the source BTU calculation is based on assumptions about the fuel composition of the generators that supply electricity to the region.

[46] Seel, Alison. "Three Prongs Don't Make a Right." Sierra Club. April 27, 2018.

[47] "California Opens $1B in Efficiency Funding to Electrification." Utility Dive. August 2, 2019.

[48] "Order Instituting Rulemaking Concerning Energy Efficiency Rolling Portfolios, Policies, Programs, Evaluation, and Related Issues." California Public Utilities Commission. Rulemaking 13-11-005. April 26, 2018.

Case Studies

Introduction

To demonstrate the framework of the proposed Total Value Test (TVT), we conducted three case studies of potential electrification applications. The first case study explores electrification of city buses in a medium sized city. In the second case, we analyze the emerging sector of electrified indoor agriculture. The third case considers the relative benefits of a range of electric and gas water heating technologies. These case studies are designed primarily to illustrate the application of the proposed TVT framework to real-world electrification examples and could be expanded through future research to include additional costs and benefits, as well as other new technologies.

City Bus Electrification Case Study

Transportation electrification is an area of increasing focus as the costs of batteries decline, the availability of electrified models increases, and GHG emission reduction mandates become more stringent. Through this case study, we analyze the costs and benefits of a transit agency purchasing battery electric buses (BEB) as a replacement for diesel buses.

Electrifying city buses has several potential advantages over electrifying personal vehicles: buses maintain a high utilization rate by operating throughout the day, their daily and weekly duty cycles are consistent, and they have a central location for refueling or recharging. In addition, cities with long-term sustainability goals are likely to consider the broader environmental benefits that electric buses can provide, namely reductions in local air pollution and GHG emissions.

To make the case study broadly applicable, we analyze the costs and benefits of a transit agency in a medium sized U.S. city of roughly 1 million residents. The city is considering whether to continue purchasing diesel buses (i.e., the baseline scenario) or to instead purchase new BEBs (i.e., the electrification scenario). We assume that the transition of the fleet would occur according to a normal 12-year replacement schedule.[49] Existing diesel buses are assumed to continue to operate for the remainder of their life, after which they are replaced with electric buses. We assume that this city's transit agency operates a fleet of 180 buses, meaning the agency replaces 15 buses each year. We also assume that the transit agency will purchase BEBs with batteries large enough to allow replacement of diesel buses at a 1:1 ratio.[50] Finally, we assume the electric buses will be charged overnight by 120 kW DC fast chargers. See the Cost Benefit Analysis section of this section for further discussion of these and all other model assumptions.

Findings

As discussed earlier in this report, evaluation of efficient electrification should consider a wider range of costs and benefits than the tests currently applied to electric sector programs (e.g. energy efficiency initiatives). The costs and benefits that are most relevant to bus electrification are listed in Table 6.

Costs and benefits listed in Table 6 were quantified to demonstrate important considerations when applying the TVT, and to illustrate how the TVT differs from the Participant Test. Table 7 below shows the present values of costs and benefits under each test in the Western United States. Under the Participant Test, there is a **net cost of $0.7 million** when purchasing BEBs instead of diesel buses. Alternatively, the TVT indicates a **net savings of $5.7 million** for the same scenario. The discrepancy between these two values is a result of the TVT's different treatment of fuel costs and its inclusion of emissions-based externalities and electrical system upgrade costs. These costs are discussed in detail in the Cost Benefit Analysis section of this section.

In addition to the benefits and costs quantified above, a detailed evaluation of bus electrification would include consideration of various non-energy benefits. These factors are discussed qualitatively below. *A Framework for Evaluating Electrification Cost-Effectiveness* provides discussion of techniques for incorporating these difficult-to-quantify benefits.

- *Load growth and flexibility value:* Electrifying city buses provides the electrical system with consistent and predictable nightly load that may also generate additional flexibility benefits depending on charging needs and infrastructure capabilities.[51] Added flexibility can contribute to system reliability, facilitate greater integration of variable generation and generate revenue for transit agencies through participation in ancillary services markets.

[49] Transit agencies tend to retire buses after roughly 12 years in order to take advantage of federal subsidies for purchasing new vehicles.

[50] The battery size is assumed to be 440 kWh per bus.

[51] If buses are parked at the depot for longer than it takes to recharge them, they have some capability to provide ancillary services to the grid during their down-time.

Table 6. Costs and Benefits Categories of Electrifying City Buses

Cost/Benefit Type	Subcategories
Total Cost of Ownership	• **Vehicle and battery costs, replacement ratios, and lifespan** • **Fuel costs** and cost volatility • **Maintenance costs** • **Charging infrastructure costs** • Revenue generated by grid (V2G) services
Environmental Externalities	• **Greenhouse gas (GHG) emissions** • **Other air pollutant emissions** • Other public health impacts • Noise pollution
System Impacts of Increased Load	• **Local distribution upgrades** • **Impacts on system peak load** • Added grid flexibility[1] • Impact on electricity rates (savings to billpayers)
Additional Considerations	• Driver health/wellbeing • Customer benefits • Disaster relief • Energy security from reduced imports

Note: Bold items are quantified. Other items are discussed qualitatively.
[1] The daily duty cycle of city buses does not generally lend itself to serving grid flexibility needs, which are most acute during the morning through evening periods when the buses are assumed to be on the road. Grid flexibility needs are reduced at night, the time when the buses are plugged in for charging.

Table 7. City Bus Electrification Case Study Results for Illustrative City in Western U.S.

NPV of Costs and Benefits (2018 $)	Participant Test (Transit Agency's Perspective)	Total Value Test
Costs		
Capital Costs	$5.4 million	$5.4 million
Electricity Costs	$1.8 million	-
Generation Costs	-	$0.9 million
Local Distribution Upgrade Costs	-	$0.4 million
Benefits		
Diesel Cost Savings	-$5.6 million	-$4.3 million
Maintenance Cost Savings	-$0.9 million	-$0.9 million
Avoided GHG Emissions Impacts	-	-$0.2 million
Avoided Air Pollutant Impacts	-	-$6.9 million
Net Change in Costs	**$0.7 million**	**-$5.7 million**
Non-Quantified Impacts	Potential flexibility value and revenues, improved customer experience, reduced noise pollution, mobile emergency electricity supply services	

Note: Electricity rates, diesel costs, and electricity fuel mix are reflective of the Pacific coast states, including California, Washington, and Oregon. All values represent differences in costs and benefits associated with replacing 15 diesel buses with 15 electric buses. NPV figures include all costs and benefits incurred over the 12-year lifetime of the buses (2018-2029), calculated using an 8% discount rate.

- *Noise pollution*: Electric buses produce less noise pollution than equivalent diesel buses. Reduced noise results in a better experience for passengers and drivers as well as those who live or work near bus routes.
- *Customer benefits*: The drive train of an electric bus allows for smoother acceleration while the regenerative braking system yields more even deceleration. These attributes provide a more comfortable ride for passengers and drivers while potentially minimizing wear and tear on roads and bridges.
- *Disaster relief*: In addition to the added flexibility that buses can add to the electrical grid during charging hours, the energy stored in bus batteries could potentially serve as backup power for hospitals or other critical infrastructure during a natural disaster or major grid outage.
- *Energy security*: Electrifying transit reduces U.S. dependence on foreign oil while supporting domestically produced electricity.

Assumptions

Capital Costs: Analysis of fleet size and operations data from the Federal Transit Administration indicates that a transit agency serving a city of 1 million people likely owns around 180 city buses driving a total of 24,300 vehicle revenue miles (VRM) each day (average of 135 VRM per bus per day).[52] In the electrification scenario, we assume that the transit agency will purchase electric buses with batteries large enough to achieve a 1-to-1 diesel bus replacement ratio while still serving an entire day's route on a single charge (i.e. no opportunity charging).[53] Based on industry research and interviews with electric bus manufacturers, we analyzed a standard 40-foot electric bus with a 440 kWh lithium ion battery pack. Operating at an expected efficiency of 0.5 miles per kWh, this bus is capable of driving up to 220 miles per day, ample range to complete most if not all of a city's daily bus routes. This strategy avoids any major operational changes as well as the considerably higher costs of high-power opportunity charging infrastructure. A typical bus of this size and capacity costs roughly $750,000, of which $200,000 is the battery pack costs.[54] For reference, a typical 40-foot diesel bus costs roughly $450,000.

We assume the buses will be recharged overnight by 120 kW DC fast chargers, which each cost roughly $50,000 and can provided a full recharge in 3 to 4 hours. Due to the potential for charger-related outages, we assume the transit agency purchases 2 spare chargers for every 15 buses for a total of 17 chargers each year. Depending on the bus operating schedule, it is possible that smaller 60 kW chargers would suffice. However, the larger 120 kW chargers offer a greater assurance that the buses will be fully charged in time for the morning routes. A variety of future charging infrastructure ownership models is possible. In this model, we assume that the transit agency will purchase and operate the chargers. However, several recent regulatory filings (See the *Current Utility Practices* section of A *Review of Current Practices*) suggest that, in some jurisdictions, utilities will seek to invest in charging infrastructure. If the utility company purchases charging infrastructure instead of the transit agency, the capital costs within the Participant Test would decline significantly, but electricity rates would be expected to increase. The TVT would be unaffected by this change.

Fuel Costs: In contrast to their significantly higher capital costs, BEBs provide considerable savings in fuel costs and maintenance costs. We quantify expected fuel expenditures by predicting annual fuel consumption using expected miles driven and bus fuel efficiency and subsequently multiplying fuel consumption by forecasted fuel prices.

Using the assumed VRM of 135 miles per day per bus and a typical fuel efficiency of 4 miles per gallon for diesel and 0.5 miles per kWh for electric, we calculate annual fuel consumption of roughly 185,000 gallons for 15 diesel buses and 1.5 GWh for 15 electric buses.[55] The fuel cost savings vary by year and region, but on average the fuel expenditures in the electrification scenario were roughly one-third of the diesel scenario fuel costs ($0.29 per mile for electric, $0.87 per mile for diesel).

[52] Federal Transit Administration, 2002-2018, "June 2018 Adjusted Database," United States Department of Transportation, accessed August 29, 2018.

[53] Opportunity charging refers to rapid charging at bus stops or terminals during idle periods throughout the operating schedule.

[54] While the expected lifespan of an electric bus battery is likely less than the 12-year lifespan of the bus, electric bus manufacturers are starting to offer purchase alternatives (i.e. battery leasing, extended warranties) that eliminate the uncertainty of battery lifespan. The $200,000 figure quoted above represents a battery with a 12-year unlimited mile warranty.

[55] Hanjiro Ambrose, Alissa Kendall, and Nicholas Pappas, "Exploring the costs of Electrification for California's Transit Agencies," 45, Accessed August 29, 2018. Bloomberg New Energy Finance, "Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2," 32-34, Accessed August 29, 2018.

For the Participant Test, the cost of diesel is the price paid at the pump, whereas the cost of electricity is the applicable retail rate paid to the local utility. The TVT counts fuel costs differently. In the case of electricity, we assume that 50% of the average retail electricity rate is composed of generation costs, and 25% is composed of demand-driven investments in grid infrastructure necessary to meet the incremental load of the electric buses. The remaining 25% is assumed to contribute to the cost recovery for maintaining the existing transmission and distribution systems and reduces the cost burden on other billpayers. The costs of generation and system upgrades are included in the TVT, but the remaining 25% is not. The TVT excludes this portion of electricity costs because while it is a cost to the transit agency, it offsets costs that would otherwise be incurred by other billpayers.

Similarly, in the case of diesel fuel, some portion (between 37 and 99 cents per gallon[56]) of total fuel costs is federal and state diesel fuel taxes which are primarily spent maintaining roads and infrastructure. Therefore, the fuel tax portion of the diesel cost constitutes a transfer payment and is excluded from the TVT. In this case study, we deduct the federal tax and the regional population-weighted average state tax from diesel costs for each region. This holistic treatment of diesel and electricity costs yields lower fuel costs under the TVT than the Participant Test for both scenarios.

Maintenance Costs: Diesel bus maintenance costs are generally well understood and predictable. However, maintenance costs for electric buses are more uncertain due to the nascent state of the industry. There is consensus across the industry that maintenance costs of BEBs are lower than those of diesel buses due to the simpler drive train and regenerative braking systems. However, the extent of those savings remains largely unknown. Some BEB manufacturers claim as high as 40% savings, but early analyses of pilot programs suggest more conservative savings. Our model assumes BEB maintenance costs are 20% lower than those of equivalent diesel buses.[57] Maintenance costs are treated identically by the Participant Test and the TVT.

[56] Energy Information Administration, 2018, "Federal and State Motor Fuels Taxes[1]," United States Department of Energy, August 2018, Accessed August 29, 2018.

[57] California Air Resources Board, *Advanced Clean Transit Program Literature Review on Transit Bus Maintenance Cost (Discussion Draft)*, (Sacramento, CA, 2016), accessed August 29, 2018.

Emissions Costs: The electrification and baseline scenarios of this analysis have vastly different costs of environmental externalities. And while the Participant Test does not explicitly internalize any of these externalities, projected damages caused by emissions are considered costs in the TVT.[58]

In this case study, we estimate emissions damages in two categories: climate-based damages from CO_2 emissions and public health damages from emissions of criteria air pollutants (CAPs). We value CO_2 damages according to the U.S. Government Interagency Working Group's estimates at a 5% discount rate of $11 to $18 per metric ton of CO_2 escalating between the years 2015 and 2035.[59] We estimate the cost of CAP emissions based on values sourced from existing literature.[60] Those values are $4.72 per gallon of diesel fuel, $0.19 per kWh from coal-fired generation, and $0.057 per kWh from natural gas-fired generation.

We use these estimated costs to calculate climate and public health damages from consumption of diesel fuel and electricity generation. This methodology is roughly consistent with the approach to valuing emissions damages in the Societal Cost Test. The fundamental distinction is that the future emissions damages in the TVT are discounted using a discount rate consistent with the cost of capital (8-10%) used to discount all other costs and benefits, rather than using a lower societal discount rate.

[58] If emissions are priced through a Pigovian tax or an emissions trading scheme, the associated externalities are internalized to whatever extent the tax passes through to the end user (presumably through fuel prices). So if emissions are priced, the Participant Test does capture emissions damages but only to the extent that the transit agency is forced to pay for them. Since these costs generate revenue for the government (or profit for a separate, rent-seeking party), they constitute a transfer payment and a net-zero cost under the TVT. However, due to the relative rarity of substantial emissions taxes, these costs are not quantified in this model.

[59] For the social cost of carbon, we chose the value based on a 5% discount rate because it is closest to the discount rate of 8% assumed in our analysis. Interagency Working Group on Social Cost of Greenhouse Gases, "Technical Support Document – Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866," United States Government, August 2016.

[60] Drew T. Shindell, "The Social Cost of Atmospheric Release," Climatic Change 130 no. 2 (February 25, 2015): 313-26, Accessed August 22, 2018, doi:10.1007/s10584-015-1343-0.

Indoor Agriculture Case Study

Indoor agriculture includes several types of enclosed environments for growing various types of produce, including warehouse farms, container farms, and enhanced greenhouses (which supplement natural sunlight). These environments rely on artificial light, climate control, and water delivery systems to grow produce on land and during seasons that are otherwise unsuitable for doing so.[61] In the U.S., there were over 40,000 indoor farms, mostly enhanced greenhouses, as of May 2017.[62] Indoor farms primarily target low-growing, short shelf-life, and high-value produce, such as berries, leafy greens, and herbs. Developers of indoor farms note that these facilities are not necessarily intended to be a perfect substitute for conventional farming, but can provide produce that is more nutritious, fresher, and locally grown compared to alternatives. In addition, indoor agriculture is a pathway to accommodate a growing population with constrained land resources.

In this case study, we analyze the costs and benefits of an indoor warehouse farm located in the Denver metro area. The farm is assumed to produce 5,000 pounds per week of leafy greens (e.g., spinach), which is the typical output of a 10,000 square foot indoor vertical farm. For comparison purposes, we analyze differences in the variable operating costs of producing warehouse-grown spinach versus organic spinach delivered from California.[63] Using the TVT as an evaluation framework, this case study demonstrates the issues a policymaker, regulator, utility, or other stakeholders would want to consider when developing policies that would facilitate growth in the nascent indoor agriculture industry.

As mentioned above, it is difficult to establish definitive tradeoffs between two types of agriculture, as it is unclear whether the indoor farm will displace local or imported produce and there is wide variation in potential unit-level energy consumption. As we explain below, we focus on a side-by-side comparison of the variable operating costs that are reasonably quantifiable, while acknowledging that consideration of other costs and benefits would be warranted when making policy decisions in this context.

Findings

Relevant benefits and costs of indoor agriculture are summarized in Table 8. With indoor agriculture, non-energy benefits are more prominent than energy benefits due to the complexity of the food production and delivery systems. This case study is useful for highlighting the extent to which the benefits and costs of electrification programs can extend well beyond the energy sector.

Annual variable costs of indoor and outdoor farms are compared using the TVT. Table 9 below shows the total annual costs and costs per pound of spinach for the components we quantified in the TVT. For the indoor farm, the TVT indicates a net annual cost decrease of $27,700, or $0.20 per pound of spinach sold, resulting in a benefit/cost ratio of 1.34.

[61] For an overview of the indoor agriculture industry, see: EPRI, "Indoor Agriculture: A Utility, Water, Sustainability, Technology and Market Overview," June 2018.

[62] Allison Kopf, "Let's Talk about Market Size," *Medium*, May 19, 2017, Accessed November 12, 2018.

[63] Roughly 70% of all spinach consumed in the US is grown in California. Brian Palmer, "What Would We Eat If It Weren't for California?" Slate Magazine, July 10, 2013, Accessed November 16, 2018.

Table 8. Cost and Benefit Categories of Indoor Agriculture

Cost/Benefit Type	Subcategories
Costs of Production	• **Electricity costs** • **Water costs** • **Land costs** • **Transportation costs (fuel, wages, maintenance)** • **Other fuel costs (farm equipment)** • Labor costs • Other capital costs (equipment and warehouse) • Fertilizer use and application • Land maintenance costs (weeding, tilling, crop cycling)
Environmental and Human Health Externalities	• **Greenhouse gas (GHG) emissions** • **Other air pollutant emissions** • **Public health impacts** • Environmental/agricultural damages • Groundwater depletion and salt Intrusion • Fertilizer runoff effects • **On-road accidents (shipping)** • Noise pollution (shipping)
System Impacts of Increased Load	• **Local distribution upgrades** • **Impacts on system peak load**
Additional Considerations	• Reduced food waste/loss along supply chain • Fresher and more nutritious produce • Year-round availability of seasonal crops • Reduced susceptibility to disease and inclement weather

Note: Bold items are quantified. Other items are discussed qualitatively.

Table 9. Indoor Agriculture Case Study Results

5,000 lbs/week spinach farm	Annual Cost			Cost per Pound (Delivered)		
	Indoor Farm	**Outdoor Farm**	**Difference**	**Indoor Farm**	**Outdoor Farm**	**Difference**
Electricity Cost	$23,000	$0	$23,000	$0.16	$0.00	$0.16
Land Rent Cost	$18,600	$34,000	-$15,400	$0.13	$0.24	-$0.11
Water Cost	$2,000	$9,900	-$7,900	$0.01	$0.07	-$0.06
Transportation Cost	$500	$33,300	-$32,800	$0.00	$0.24	-$0.23
On-Site Diesel Cost	$0	$8,700	-$8,700	$0.00	$0.06	-$0.06
GHG Emissions Impacts	$2,300	$1,000	$1,300	$0.02	$0.01	$0.01
Non-Carbon Externalities	$35,400	$22,600	$12,800	$0.25	$0.16	$0.09
Total	**$81,700**	**$109,400**	**-$27,700**	**$0.58**	**$0.77**	**-$0.20**

Note: Per-pound values are per pound of spinach that reaches the consumer, assuming 46% of harvested spinach is lost or wasted along the supply chain.[62] Electricity rates reflect the average of 2018 commercial and industrial rates for the Mountain and Pacific regions, based on EIA projections.[63] Diesel costs are reflective of the on-farm delivery of red dye (off-road) diesel in the central coast region.[64] We assume the current generation mix for PG&E and Xcel Energy Colorado.[65]

The electricity cost for the indoor farm is offset by lower land, water, and transportation costs.[68] Due to the heavily fossil-based generation mix in Denver, which consists of 44% coal and 28% natural gas, the indoor farm has higher emissions-related costs. As we explain further below, the costs of the indoor farm are very sensitive to the assumed efficiency of the indoor facility; the costs shown here are based on a highly efficient indoor farm that consumes about 7 MWh per week to produce 5,000 lbs. of spinach.

[64] USDA Economic Research Service, 1970-2017, "Loss-Adjusted Food Availability, Vegetables," United States Department of Agriculture, Accessed November 2, 2018.

[65] Energy Information Administration, 2018-2050, "Annual Energy Outlook 2018: Energy Prices by Sector and Source" ("EIA, 2018"), United States Department of Energy, accessed November 7, 2018.

[66] Laura Tourte, et al., "Sample Costs to Produce and Harvest Organic Spinach, Central Coast Region," Department of Agriculture and Resource Economics, University of California Cooperative Extension, 2015, Accessed November 2, 2018. ("Tourte et al., 2015").

[67] Xcel Energy, *Colorado Energy Plan Fall 2018 Update - Information Sheet,* 2018, accessed November 2, 2018. Pacific Gas & Electric, *Exploring Clean Energy Solutions*, 2018, accessed November 02, 2018.

[68] The costs for operating electric water pumps for the outdoor farm are included in the water costs.

In addition to the benefits and costs quantified above, a detailed evaluation of indoor agriculture could include consideration of the capital costs of building the indoor farm and various additional components. These factors are often difficult to quantify due to lack of accurate information on the potential scale and value of the impacts.

- *Nutritional Value:* More locally grown produce will increase the nutritional value of leafy greens like spinach because nutritional value tends to decrease with increased time between harvesting and consumption.[69]
- *Additional Benefits of Reduced Water Demand:* The reduction in water demand could have greater benefits in regions that are experiencing extreme drought conditions. The reduced water demand will also limit salt intrusion of existing water supplies.[70]

[69] Luke F. Laborde and Srilatha Pandrangi, "Retention of Folate, Carotenoids, and Other Quality Characteristics in Commercially Packaged Fresh Spinach," *Journal of Food Science* 69(9) (December 1, 2004): 702-707.

[70] Julie Nico Martin, "Central Coast Groundwater: Seawater Intrusion and Other Issues," CA Water Plan Update 2013 (4) (August 4, 2014): 1-27.

- *Reduced Fertilizer Run-off:* The environmental impact of fertilizer run-off are well documented but are very specific to the conditions of the local terrain and waterways.[71]
- *Food Security:* Indoor farming could also increase food security by reducing the potential for disease outbreak through the food supply and reducing food imports.[72]

Assumptions

Energy Costs: Due to the electricity demands of growing crops with artificial lighting, electricity use is a significant operating cost for indoor agriculture. Due to differences in efficiency, crop arrangement, and climate, electricity use varies widely across indoor farms. A typical warehouse farm of this size is expected to consume between 7-70 MWh of electricity per week (1.4-14.0 kWh per pound grown) for lighting and HVAC systems.[73] As noted above, we assume a highly efficient indoor farm that consumes 7 MWh per week (365 MWh per year or 1.4 kWh per pound grown). We estimate the electricity costs based on the projected industrial electricity rate of 8.4 cents per kWh, which totals $31,000 per year.[74] As in the electric bus case study, we assume that approximately 50% of the retail electricity rate covers the cost of incremental generation and that 25% of the rate serves as a proxy for the costs of local distribution system upgrades to serve the incremental load. The remaining 25% of the retail rates covers cost of recovery for existing infrastructure that would otherwise be paid by other billpayers.

The outdoor farm electricity use is primarily for water pumps. We estimate that the outdoor farm consumes 8 MWh per year for pumping groundwater, assuming 8.8 acre-inches of water per acre per harvest (10 million gallons per year), water table depth of 120 feet, and pump efficiency of 48%.[75]

The outdoor farm consumes diesel for operating its equipment and shipping its products to market. We estimate that the outdoor farm uses about 3,000 gallons per year of diesel, assuming on average 76 gallons of diesel fuel per acre per harvest.[76] At an assumed price of $2.86 per gallon, this fuel costs roughly $9,000 per year.[77] In both scenarios, we assume that the spinach is shipped in 12-meter refrigerated trucks with fuel efficiency of 6.5 miles per gallon.[78] For the indoor farm located approximately 20 miles from the point of consumption, shipping requires just 50 gallons of diesel per year, whereas the outdoor farm located 1,300 miles from the point of consumption requires 3,000 gallons of diesel per year. The costs of transportation diesel are included in the shipping costs, but the externalities associated with the diesel consumption are separately included in the TVT and discussed further below.

Water Costs: Indoor farms use water much more efficiently than outdoor farm by capturing and recycling runoff. Like electricity use, estimates of the water consumption of indoor farms vary widely, ranging from an 80 to 99% reduction compared to outdoor farms.[79] For this case, we assume the indoor farm achieves a 95% reduction in water consumption. We estimate that the outdoor farm uses 350 acre-inches (10 million gallons) of water per year, or 37 gallons per pound of spinach grown. The price of pumped groundwater in the Santa Cruz region has fluctuated between $18 and $36 per acre-inch in recent years.[80] Assuming $27 per acre-inch, water for the outdoor farm costs $10,000 per year.[81] On the other hand, the indoor farm consumes 18 acre-inches (480,000 gallons) of water per year or 1.8 gallons per pound grown. Based on municipal water prices in Denver of $111 per acre-inch, the indoor farm spends $2,000 per year ($.007 per pound grown) on water. Even with the significantly more expensive municipal water, the indoor farm pays far less for water.

Land Costs: The indoor farm's efficient use of land reduces land costs, even with the higher cost of land closer to urban centers. For the indoor farm, we assume a floor area ratio (FAR) of 0.4, meaning the 10,000 square foot indoor farm requires a 25,000 square foot (0.57 acre) lot to produce 260,000 pounds of spinach per year. We estimate that renting an industrial lot of this size in the Denver metro area would cost roughly $19,000 per year.[82] The outdoor

[71] Daniel J. Sobota, Jana E. Compton, Michelle L. McCrackin, and Shweta Singh, "Cost of Reactive Nitrogen Release from Human Activities to the Environment in the United States," *Environmental Research Letters* 10(2) (February 17, 2015): 1-13.

[72] Purdy, Chase. "A Startup Is about to Build 300 Vertical Farms in China, Thanks in Part to Jeff Bezos." Quartz. January 26, 2018. Accessed November 15, 2018.

[73] Frank Sharp, Senior Technical Leader at the Electric Power Research Institute, Telephone interview by author, October 23, 2018, ("Sharp, 2018").

[74] EIA, 2018.

[75] Tourte et al., 2015.

[76] Tourte et al., 2015.

[77] Tourte et al., 2015.

[78] Brandon Schoettle, et al., "A Survey of Fuel Economy and Fuel Usage by Heavy-Duty Truck Fleets," American Transportation Research Institute, October 2016, Accessed November 2, 2018.

[79] Sharp, 2018.

[80] Tourte et al., 2015.

[81] Note: the 25% of the underlying electricity costs (8 MWh per year at $100 per MWh) that is a transfer payment is subtracted from the price paid for water.

[82] Kimmons (2018) estimates an average floor area ratio of 0.29-0.4 for commercial buildings. Albouy et al. (2018) estimate the average price of land in Denver to

farm requires roughly 13 acres to produce an equivalent quantity of spinach. The estimated cost of leasing agricultural land in the central coast is $2,400 per acre per year, resulting in land costs of $34,000 per year.[83]

Transportation Costs: By growing the spinach near the point of consumption, the indoor farm avoids significant shipping costs and the associated externalities. Assuming a shipping density of raw spinach of 279 lbs. per cubic meter[84] and a volume of 60.6 cubic meters for a 12-meter refrigerated truck,[85] we estimate that 5,000 lbs. of spinach each week will fill about a third of a delivery truck.[86] For the outdoor farm scenario, shipping 260,000 lbs. of spinach 1,300 miles from California to Denver requires a total of 20,000 truck-miles. For the indoor farm scenario, shipping the same weight of spinach a distance of 20 miles requires a total of 300 truck miles. At a marginal cost of $1.59 per truck-mile, the transportation cost for the outdoor farm is $33,000 per year.[87] The corresponding figure for the indoor farm is $500 per year. These figures only represent the variable costs of on-road transportation and do not include the fixed costs associated with loading, unloading, and planning the shipment. However, assuming both scenarios require the same number of shipments, those fixed costs are likely similar in both scenarios.

Public Health Costs: We use the same figures used in the city bus case study to estimate the damages from electricity generation and on-farm diesel consumption.[88] Based on the 3,000 gallons of diesel consumed on-site by the outdoor farm, the estimated damages of criteria air pollutants are $14,000 per year. The air pollution costs from electricity use vary significantly depending on how the electricity in a region is generated. Using the 2018 power mix for Santa Cruz County (20% natural gas, 80% clean) and Denver (44% coal, 28% natural gas, 28% clean), the air-pollution damages from electricity consumption are 0.7 cents per kWh in California and 10 cents per kWh in Denver. Based on these figures and the electricity consumed, the annual air pollution damages from electricity are $50 per year for the outdoor farm and $50,000 per year for the indoor farm.[89]

Based on existing literature, the costs of air pollution from delivery trucks has been estimated to be 1.9 cents per ton-mile, which corresponds to a 16 cents per truck-mile for a truck carrying a 17,000 pound load.[90] The costs of on-road injuries are estimated to be 25 cents per mile due to additional trucks on the road.[91] Combined, we estimate damages of $.41 per truck-mile, or $8,000 per year for the outdoor farm and $130 for the indoor farm.

Climate Costs: As in the city bus electrification case study, we estimate the social cost of carbon according to the U.S. Government Interagency Working Group's 5% discount rate values, which escalates from $11 to $18 per metric ton of carbon dioxide between the years 2015 and 2035. Based on the carbon intensity of diesel fuel, and electricity generated from coal and natural gas, we calculate the following annual carbon emissions: The indoor farm emits 229 tons per year from electricity use and 0.5 tons per year from diesel consumption, while the outdoor farm emits 0.7 tons/year from electricity use and 70 tons/year from diesel consumption. The resulting climate-related damages are $1,000 per year for the outdoor farm and $3,000 per year for the indoor farm.

be $539,000 per acre. Schnitkey (2016) calculates common land rental price to land price ratios. Applying a conservative ratio of 0.05, we calculate an annual land rent cost of $27,000 per acre. James Kimmons, "Learn How to Calculate the Land to Building Ratio," The Balance Small Business, September 9, 2018, Accessed November 21, 2018. David Albouy, Gabriel Ehrlich, and Minchul Shin, "Metropolitan Land Values," *Review of Economics and Statistics* 100(3) (July 2018): 454-466. Gary Schnitkey, "Cash Rent as a Percent of Farmland Price," farmdoc daily (6):211 (November 8, 2016).

[83] Tourte et al., 2015.

[84] AVCalc LLC, "Density: Spinach, Raw, and Links to Volume/weight Conversions," 2018, Accessed November 02, 2018.

[85] Milind Ladaniya, "13 - Transportation," In *Citrus Fruit: Biology, Technology and Evaluation*, 375-389, London: Academic, 2008, Accessed November 2, 2018.

[86] Assuming that transportation costs are shared in proportion to volume, the costs of shipping the spinach are the same whether it is shipped in whole or partial loads.

[87] Dan Murray and Alan Hooper, "An Analysis of the Operational Costs of Trucking: 2017 Update," American Transportation Research Institute, October 2017, Accessed November 2, 2018. N.B. This figure is a comprehensive estimate which includes fuel costs.

[88] Drew T Shindell, "The Social Cost of Atmospheric Release," Climatic Change 130, no. 2 (February 2015): 313-26, Accessed August 22, 2018, doi:10.1007/s10584-015-1343-0.

[89] To illustrate how these damages are impacted by an increasingly clean generation mix, we performed the same calculation using the proposed 2026 generation mix in Denver (24% coal and 23% natural gas). In this future generation mix scenario, the air pollution damages from the indoor farm's electricity drop to $29,000 per year.

[90] Mark Delucchi and Don McCubbin, "External Costs of Transport in the United States," A Handbook of Transport Economics (2010), Accessed November 2, 2018, doi:10.4337/9780857930873.00023, ("Delucchi and McCubbin, 2010")

[91] Delucchi and McCubbin, 2010.

Water Heating Case Study

Water heating has unique characteristics that make it a potentially attractive candidate for electrification. First, water heating accounts for a significant portion of household energy consumption (20 percent of the typical U.S. household).[92] Currently, roughly 48 percent of U.S. households have natural gas water heating, 46 percent have some form of electric water heating, and 6 percent use other fuels like fuel oil or propane. Conversion of gas or oil water heating to electric heating would have environmental benefits in a decarbonized power system, particularly when taking advantage of the high efficiency of heat pump technology.[93]

Second, electrification of water heating has the potential to introduce increased flexibility to the power system. Conventional electric resistance water heaters have participated in utility load control programs for decades. More recently, technological advancements have enabled "grid interactive water heating." Grid-interactive water heating allows the heating element of an electric resistance water heater to ramp up or down in response to real-time signals from the grid operator, providing valuable ancillary services or other load shifting benefits.[94]

At the same time, currently there are many conditions under which natural gas water heaters can more efficiently meet household water heating needs. Whether or not water heating electrification makes sense from an economic and environmental standpoint will depend on the market conditions in which the opportunity is being evaluated.

In this case study, we evaluate the costs and benefits of water heating technologies for a new single family home. We consider three water heating technologies: a natural gas water heater, a heat pump water heater, and a grid interactive electric resistance water heater.[95] For each technology, we estimate the net cost of meeting household water heating needs using the TVT. We evaluate the net costs under a range of market conditions to illustrate the relative advantages of each technology.

Market conditions vary across the scenarios according to the following factors: (1) the cost of electricity relative to natural gas, (2) the value of load flexibility, and (3) the marginal CO_2 emissions rate of electricity generation.

- *Electricity cost*: Marginal electricity costs have an average peak-to-off-peak price differential of $20/MWh and range from $30/MWh (peak) and $10/MWh (off-peak) at the lower end to $70/MWh (peak) and $50/MWh (off-peak) at the upper end.[96] In all cases, the natural gas price is held constant at $0.40 per therm.[97]
- *Value of load flexibility*: The value of load flexibility ranges from $20/kW-yr to $100/kW-yr consistent with observed frequency regulation prices.[98] The capacity of load flexibility for each water heater technology reflects the ability of the grid interactive water heater to provide real-time increases or decreases in load.
- *CO_2 emissions rate*: The CO_2 emissions rate of generation ranges from zero (e.g. wind or solar) to 1.2 tons/MWh (a typical coal plant). The range varies by peak and off-peak period across scenarios. As in the previous two case studies, we estimate the social cost of carbon according to the U.S. Government Interagency Working Group's 5% discount rate values, which escalates from $11 to $18 per metric ton of carbon dioxide between the years 2015 and 2035. The CO_2 emissions rate of the natural gas water heater is based on a constant assumption of the carbon content of natural gas of 0.0053 tons/therm.[99]

[92] Energy Information Administration, "Today in Energy: Space heating and water heating account for nearly two thirds of U.S. home energy use," November 7, 2018, Accessed February 19, 2019.

[93] David Farnsworth, Jim Lazar, and Jessica Shipley, "Beneficial Electrification of Water Heating," Regulatory Assistance Project, January 2019.

[94] A large smart water heating pilot was recently conducted by Bonneville Power Administration. See BPA, "CTA-2045 Water Heater Demonstration Report," BPA Technology Innovation Project 336, November 9, 2018. Also, see Ryan Hledik, Judy Chang, and Roger Lueken, "The Hidden Battery: Opportunities in Electric Water Heating," prepared for NRECA, NRDC, and PLMA, January 2016.

[95] Heat pump water heating load could potentially be controlled to reduce system costs. However, given the lower overall load and operational constraints of the technology, the incremental benefits of managing heat pump water heater load currently are low relative to the cost of the control technology and are not modeled in this case study.

[96] The 2018 average real-time peak and off-peak prices at the Duquesne transmission zone in PJM were $44.74/MWh and $30.40/MWh respectively, representing an average price differential of $14.35/MWh. See LCG Consulting, "PJM (PJM Interconnection) Real-time Price," 2018, Accessed February 19, 2019.

[97] Energy Information Administration, 1922-2017, "Natural Gas Prices," United States Department of Energy, January 31, 2019, Accessed February 15, 2019.

[98] Prior Brattle analysis found that a grid interactive water heater participating in the PJM RegD market in 2014 could have earned $180 in frequency regulation revenues in that year, or $80/kW-yr. See Ryan Hledik, Judy Chang, and Roger Lueken, "The Hidden Battery: Opportunities in Electric Water Heating," prepared for NRECA, NRDC, and PLMA, January 2016.

[99] Environmental Protection Agency, "Greenhouse Gases Equivalencies Calculator – Calculations and References," December 18, 2018, Accessed February 19, 2019. Consistent with the other case studies in this section, we have valued CO2 emissions at a rate of $15/ton.

The TVT is used to assess the net costs of each water heating technology, consistent with a system-level view rather than the cost to an individual consumer (which alternatively could be captured by the Participant Test). Costs include the upfront cost of the water heater, the cost of fuel (natural gas or electricity) used to heat water, the cost of supporting natural gas or electricity delivery infrastructure, and the cost of carbon emissions. Costs account for the time-specific profile of the water heating technology and assume that the grid interactive water heater is operated to minimize system costs (e.g., avoiding heating the water during peak hours). The flexibility value is treated as an offset to costs, and so subtracted from the total cost estimate.

Findings

When electricity costs are the highest – \$50/MWh (off-peak) to \$70/MWh (peak) – natural gas water heating is the most economic option. Figure 1 below shows that the flexibility value of grid interactive water heaters or the carbon emissions profile of the power supply mix are unable to offset the operating cost of the water heaters at higher electricity costs.

At low electricity costs of \$10/MWh (off-peak) to \$30/MWh (peak), electric water heating is the dominant option. Heat pump water heaters are most cost-effective when the value of load flexibility is low, and the grid-interactive water heaters become the most cost-effective option when the value of load flexibility rises to at least \$80/kW-yr. The two electric water heating technologies are similarly competitive when load flexibility value is in the middle of this range, with the higher efficiency heat pumps preferable for systems with higher emissions rates.

At moderate electricity costs of \$30/MWh (off-peak) to \$50/MWh (peak), the cost-effective technology is more sensitive to the flexibility value and emissions rates. Heat pump water heaters are more cost-effective than natural gas water heaters when the flexibility value is lower (\$60/kW-year or less) and electricity generation CO_2 emissions are low (0.4 tons/MWh or less). This is equivalent to the emissions rate of an efficient natural gas combined cycle unit, or a blend of a less efficient gas-fired unit and renewables. Grid interactive water heaters become the most economic option when CO_2 emissions rates are relatively low and the value of load flexibility is high (\$80/kW-yr to \$100/kW-yr).

Figure 1 summarizes the most cost-effective water heating technology under this range of market conditions, according to the TVT.

Natural gas water heaters have the most value in markets with a more carbon-intensive power supply mix, high electricity costs (relative to natural gas costs), and low flexibility value. Electric water heating will be the most competitive option in jurisdictions with a decarbonized power supply mix, but only if electricity costs do not rise significantly. If decarbonization is largely achieved through development of renewable generation, the increased flexibility needs of this system could place an emphasis on the value of grid interactive water heaters. Ultimately, additional considerations that are not captured in this case study, such as technical feasibility (e.g., physical space available for installation of the water heater), climate, and consumer preferences will likely lead to a mix of technologies in any given market.

Assumptions

Water heater installed costs: We have assumed an installed water heater cost (capital and installation) of \$1,300 for natural gas, \$1,800 for heat pump, and \$1,900 for grid interactive. Natural gas and heat pump cost assumptions are derived from a recent report by the Regulatory Assistance Project.[100] Grid interactive water heater costs are based on prior Brattle research and include the cost of communications and control technology as well as the incremental cost of a larger (i.e., 80-gallon) tank to accommodate greater thermal storage ability.[101]

Operating costs: Consistent with the TVT framework, electricity costs in this analysis are the wholesale cost of energy (i.e., fuel and O&M). The assumed electricity costs capture a wide range of possible average annual peak and off-peak prices, as described earlier in this section of the report. As a reference point, the median peak and off-peak prices at the MISO Indiana Hub were \$42/MWh and \$22/MWh, respectively, in 2018. We define the peak period as the period of daytime hours when water heating load could be avoided by a grid interactive water heater without sacrificing service to the

[100] David Farnsworth, Jim Lazar, and Jessica Shipley, "Beneficial Electrification of Water Heating," Regulatory Assistance Project, January 2019.

[101] Ryan Hledik, Judy Chang, and Roger Lueken, "The Hidden Battery: Opportunities in Electric Water Heating," prepared for NRECA, NRDC, and PLMA, January 2016.

				CO2 content of marginal electricity generation (tons/MWh)											
			Off-Peak	1.0	1.0	0.8	0.8	0.6	0.6	0.4	0.4	0.2	0.2	0.0	0.0
			Peak	1.2	1.0	1.2	0.8	1.0	0.6	0.8	0.4	0.6	0.2	0.4	0.0
Electricity Cost ($/kWh) Peak	Off-Peak	**Electricity Cost** ($/kWh)	**Flexibility Value** ($/kW-yr)												
0.07	0.05		20	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
0.07	0.05	**High Cost**	40	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
0.07	0.05	Peak = $0.07	60	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
0.07	0.05	Off-Peak = $0.05	80	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
0.07	0.05		100	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
0.05	0.03		20	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
0.05	0.03	**Moderate Cost**	40	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
0.05	0.03	Peak = $0.05	60	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
0.05	0.03	Off-Peak = $0.03	80	NG	NG	NG	NG	NG	NG	GI	GI	GI	GI	GI	GI
0.05	0.03		100	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
0.03	0.01		20	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
0.03	0.01	**Low Cost**	40	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
0.03	0.01	Peak = $0.03	60	HP	HP	HP	HP	HP	HP	GI	HP	GI	GI	GI	GI
0.03	0.01	Off-Peak = $0.01	80	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
0.03	0.01		100	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI

NG	= Natural Gas Water Heater
HP	= Heat Pump Water Heater
GI	= Grid Interactive Electric Resistance Water Heater

Figure 1. Most Cost-effective Water Heating Technology According to the Total Value Test (at Various Combinations of Electricity Costs, Flexibility Value, and Generation Emissions Rates)

customer, corresponding roughly to a period from 10 am through 10 pm. Natural gas prices are $0.25/therm and held constant across scenarios.[102]

We also account for non-fuel costs in the analysis, which largely consist of the cost of the infrastructure necessary to produce and deliver the fuel (natural gas or electricity). For natural gas water heating, non-fuel costs are $0.60/therm, based on the non-fuel portion of a typical residential natural gas electricity rate. For electric water heating, non-fuel costs are $0.07/kWh. We reduced these non-fuel costs for grid interactive water heaters to account for their ability to avoid capacity-related costs by shifting electricity consumption to off-peak hours when there is excess capacity. We assume that the net benefit of the modified load pattern accounts for avoided generation capacity cost of $60/kW-yr and marginal (i.e. avoidable) transmission and distribution capacity cost of $30/kW-yr.

Operating characteristics: We assume that a typical natural gas water heater uses 250 therms per year, based on a standard efficiency water heater. The grid interactive water heater uses 4,000 kWh per year, with all electricity consumption occurring during off-peak hours. While the range of electricity consumed by a heat pump water heater can vary significantly depending on the efficiency of the unit and the climate in which it is located, we assume that it would consume half the electricity of a grid interactive electric resistance water heater. We assume that the load profile of the heat pump water heater is split equally between peak and off-peak hours (i.e., 1,000 kWh of consumption annually in each period).

[102] Energy Information Administration, 1922-2017, "Natural Gas Prices," United States Department of Energy, January 31, 2019, Accessed February 15, 2019.

The maximum load of the grid interactive water heater's heating element is 4.5 kW and we assume its load flexibility capability is roughly half of its load (2.25 kW). During off-peak hours, the heating element could heat the water at an average level of 2.25 kW. When a load increase is needed to balance the system, the heating element could ramp up to 4.5 kWh. When a load decrease is needed, it could drop to zero. As long as the water heater is managed to heat the water at an average of 2.25 kW, it would meet the customer's hot water needs for the day.

Commentary on Case Studies

The purpose of these case studies is to illustrate the application of the TVT under a hypothetical set of conditions and associated assumptions. The three examples developed for this report were selected because they compare economically competitive electric and non-electric technology options under a reasonable set of conditions and constraints. They were selected independent of how other energy efficiency cost-effectiveness tests, each with its own unique stakeholder perspective, may evaluate them.

There are compelling examples of other efficient electrification technologies that have already been demonstrated to provide clear economic benefits to customers. For example, electric forklifts have been demonstrated in the field to provide a lower cost of ownership for customers compared to conventional forklifts with internal combustion engines, with an average payback of less than two years depending on local energy prices and usage levels. Electric forklifts feature fewer moving parts, so they are less costly to maintain. EPRI research indicates that an electric forklift is a more economical option for customers when usage exceeds 1,000 hours per year.[103]

In addition, electric lift trucks for materials handling have been shown to be economically favorable for customers compared to the traditional propane-powered alternatives. EPRI analysis indicates that electric lift trucks provide customers with a 37% cost savings compared to propane-powered lift trucks over a three year period, inclusive of capital and maintenance costs.[104]

Conclusion

This study undertook the assignment of identifying the most appropriate cost-effectiveness methodology and metric for all forms of energy efficiency, inclusive of efficient electrification. Based on a detailed review of the history and literature of energy efficiency cost-effectiveness analysis, coupled with insights from interviewed industry experts, the study examined how best to leverage the foundational elements of energy efficiency cost-effectiveness analysis in the California Standard Practice Manual (SPM) into a broader context.

The resultant test, which we have named the Total Value Test (TVT) has it roots firmly in the established cost-effectiveness tests of the SPM, with an emphasis on capturing the more comprehensive sets of benefits and costs associated with efficient electrification, while also being applicable to more traditional energy efficiency pursuits. The TVT strives to couple the Societal Cost Test's emphasis on valuing environmental externalities with the Total Resource Cost's approach to discounting future cost and benefit streams, while explicitly accounting for impacts on participating customers and society at-large.

The examples in *Case Studies* illustrate the application of the TVT in evaluating the cost-effectiveness of different types of efficient electrification activities. As evidenced by the water heating example, under different circumstances the TVT may find either the electric or non-electric technology the most favorable. The test is objective and not predisposed to favor any particular type of technology based on how it is powered or fueled.

While no cost-effectiveness metric is perfect, and there is room for constructive debate on the usefulness and challenges of the TVT, it does represent an effort to advance the discourse on cost-effectiveness in the context of new forms of energy efficiency such as efficient electrification.

This study is intended to inform all stakeholders involved in the design, approval, implementation, and evaluation of efficient electrification programs – and indeed any type of energy efficiency program – including utilities, regulators, third party program administrators, policy makers, and non-government agencies that influence public policy in the energy and environmental spheres.

EPRI intends to continue this area of study to further elucidate and illustrate the TVT with more case studies, and to engage stakeholders in outreach and dialogue towards advancing a new generation of energy efficiency and efficient electrification programs.

[103] "Electric Forklifts." Electric Power Research Institute. Palo Alto, CA. 3002014688. October 2018.

[104] "Rolling Along with Electric Lift Trucks." Electric Power Research Institute. Palo Alto, CA. 3002014681. November 2018.

Appendix: Assessing the Grid Flexibility Value of Electrification

This section elaborates on the grid flexibility impacts of electrification, including considerations for quantifying and monetizing this value.

Background

Multiple supply-, demand-, transmission- and distribution- side technologies and resources work in real-time coordination to meet energy demands and maintain the reliability of the electric system. Instantaneously balancing generation to meet electricity demand is a precise balancing act between both the supply-side and demand-side (and transmission-side when delivery constraints exist) to ensure that deviation is minimized.

The more the supply-side or demand-side varies across time, the more flexibility is required from the overall set of resources and technologies to maintain this delicate balance. Flexibility can be generally offered in the form of larger power output adjustable ranges, faster response rates, quicker start-up or shut-down times, longer sustainment times, and fewer constraints that limit the way a resource or technology can operate to meet the changing needs. More specifically, a large suite of reliability services across different time frames with different attributes are required to maintain system reliability, as shown in the figure below. The ability to provide these services and adjust how energy is provided fall under the category of power system flexibility.

Additional flexibility, just like additional energy supply, has associated costs, which vary among different flexibility resources and technologies. In restructured markets, such as those operated by Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs), there are also different levels of monetary rewards for providing flexibility to the system, and corresponding incentives for incurring those costs of flexibility provision.

There are generally two metrics for quantifying the monetary value of a resource or technology providing flexibility.

1. The overall cost reduction that occurs when a resource provides flexibility at a lower cost than the existing resources. This is important to the system operator and the utility.
2. The revenue that a flexibility resource earns from providing flexibility in a market region. This is important for the owner, operator, or aggregator of the flexibility resource.

Both metrics can be used by organizations that conduct studies to evaluate the value of flexibility from a new resource, technology, market or set of resources, paradigm, or operating structure.

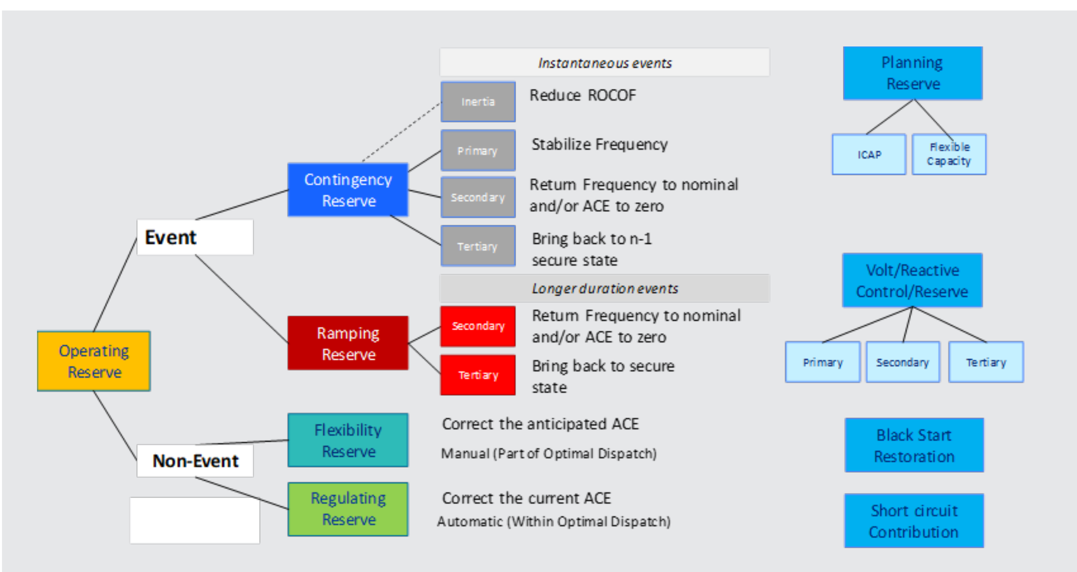

Figure 2. Grid Reliability Services

Methods for Monetizing Value of Grid Flexibility

Approaches for determining the monetary value of a new technology or paradigm, such as efficient electrification, can vary depending on the time horizon considered. There is no single, uniform value of flexibility to the system, i.e., flexibility is not worth a specific $/kW value at all times nor for all regions. The value depends on the region, the time of day, day of week, season, future time horizon, and the specific flexibility attribute or reliability service. The transmission network, technologies already on the system, policies and reliability standards, electricity market design and structure, and fuel costs can all have impacts on the value as it changes temporally and spatially. To add to this complexity, the variation of values from different regions and time frames is not small – the value of a flexibility attribute may be null, and then hundreds of dollars per kW just hours or even minutes later. This makes the quantification difficult; however, there are useful approximation means that are meaningful enough to support policy decisions.

In the context of efficient electrification, it is useful to frame three cases of grid flexibility:

1. Incremental electrification, near term

2. Larger scale electrification, near term

3. Electrification, long term

Incremental Electrification, Near Term

To quantify the grid flexibility value of adding incremental amounts of electrification to the existing system, existing data can be used without much need for advanced simulation. All organized power markets in the U.S. post and store electric energy prices for all historic time periods as well as the reliability services that have organized markets. These prices can be evaluated to better understand the value of different electrification categories and technologies. Quantifying flexibility value for technologies that shift energy across time periods (e.g. reduce demand during high energy cost periods and increase demand during low energy cost periods) can be assessed through multiplying the energy reduction by the peak prices, offset by incremental energy consumption during the low-priced periods. In this case, only market energy prices are needed with simple calculations. For electrification technologies that can provide ramping capability, the prices during the highest ramp periods may be reduced, and those values can be used to quantify the value of flexibility. For those technologies that provide reliability services, like regulation or operating reserve, the prices of those services can be used to calculate value based on the time periods that the electrification technology is able to provide service.

Larger Scale Electrification, Near Term

The previous method works well for incremental electrification, because it can be assumed that it will not impact the price. When studying the value of large amounts of flexibility on the system, using the existing prices that an ISO posts may be less accurate, because larger scale electrification could potentially alter prices. In this case, it may be more accurate to gather data from the existing system and run production cost modeling simulations with the electrification resource added. The simulation will produce new prices for all services, which can then be used to better assess the value of added electrification in a similar manner to the previous incremental case. A simulation tool allows one to quantify the flexibility value of the reduced costs in addition to the flexibility value of revenue earned from flexibility provision.

Electrification, Long Term

Quantifying the grid flexibility value of electrification on a future system using existing system prices is typically not a feasible option. The ways in which prices of energy and ancillary services are set depend on many factors, such that simple scaling or trending assumptions for future prices from today's prices are not useful. Again, a power system simulation is generally required with the additional electrification technology added as part of the simulation. However, many other variables may need adjustment in the simulation to reflect the potential scenarios of the future system, such as future fuel prices, future resource mix, or other changes to factors that influence value. In this case, it is often useful to run multiple simulations to include different potential future scenarios. The resulting range of flexibility values can then be applied.

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