Assessing the Economics of Electrification: Principles and Case Studies

INTRODUCING THE TOTAL VALUE TEST (TVT)

PRESENTED BY
John Higham

WRITTEN BY
Ahmad Faruqui
Ryan Hledik
John Higham

June 27, 2019

THE Brattle GROUP

EPRI’s Efficient Electrification Definition

“The application of electric-powered technology as a substitute for fossil-fueled or non-energized processes at the customer premises (residential, commercial, agricultural, industrial, and government/institutional) that results in net economic benefit to the customer and net environmental benefits to society.”

Evaluating the Economics of Efficient Electrification

Analyzing the cost effectiveness of electrification-focused utility investments requires a different framework from the standard analyses which focus on traditional energy efficiency programs because electrification…

1. Increases electricity consumption
2. Increases need for electricity infrastructure
3. Involves substituting electricity for natural gas, propane, gasoline and diesel
4. Can provide environmental benefits
5. Can improve quality of life and business productivity
6. Can improve system load flexibility

How the EPRI project was done – I

A series of expert interviews with organizations active in the energy efficiency space

- We talked to a dozen experts about the economics of efficient electrification
- The experts provided us a snap shot of how energy efficiency organizations, state commissions, utility trade associations, and national laboratories think about efficient electrification
- The interviews were carried out by phone and email and helped us gain unique insights on the economics of efficient electrification

How the EPRI project was done – II

We also did a careful review of the academic and trade literature on cost-effectiveness

- The literature is surprisingly voluminous
- Our summary of the literature led to some brainstorming sessions within the EPRI-Brattle team
- Through this process, we identified a set of key factors for assessing the cost effectiveness of efficient electrification investments

Key factors in considering cost-effectiveness

1. The Standard Practice Manual (SPM) provides a great starting point for considering cost-effectiveness of electrification investments but some modifications are required
2. Non-energy benefits and costs should be better researched and quantified
3. Multiple test perspectives may be needed to reach a final answer
4. Uncertainty analysis should be included in the evaluation
5. The tests need to consider the flexibility value of electrification
6. Power simulation modeling will be important for valuing electrification investments
7. Electrification pilots may provide insights into feasibility and cost-effectiveness of electrification investments
8. A “free pass” should not be given to investments simply for satisfying certain policy objectives

Comparing traditional energy efficiency investments and efficient electrification

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 rate 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 when power supply mix is dirty	Provides environmental benefit when power supply mix is clean	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

Proposed Framework for Analyzing the Economics of Efficient Electrification

TRC vs. Societal Tests:

- The *total resource cost* test does not easily allow for fuel switching (the three-pronged variant is too restrictive) or consideration of non-energy impacts
- The *societal cost test* allows for such considerations but is a bit too open-ended for regulatory filings and it also leaves the door open to using a much lower "societal" discount rate which means it can pass nearly anything.

Thus, we recommend using a test that uses the same discount rate as the total resource cost test but also includes other fuels and non-energy benefits

It is a cross between the TRC and Societal tests

We are going to call it The Total Value Test (TVT)

Case Studies

- Battery Electric City Buses
- Indoor Agriculture
- Electric Water Heating (Grid-integrated resistance heating and electric heat pump)

Battery Electric City Buses

Battery Electric Bus Case Study Design

Using our proposed framework, we will analyze the costs and benefits of purchasing battery electric buses instead of diesel buses in a medium sized city

- The bus fleet for medium sized cities is around **180 buses**
- Bus lifetime is about 12 years so agency would purchase **15 buses each year**
- Average bus has to drive about **135 miles per day (50,000 miles/year)**
- Newest electric buses with 400-450 kWh battery packs can cover about **90% of existing bus routes**; so assume **1-for-1 replacement of diesel buses**
- We assume the buses will **charge at the bus depot** using DC fast chargers (~120 kW/charger) and require spare chargers (assume 2 spares / 15 buses) due to reliability concerns

Due to several significant uncertainties and regional differences, our final report will include calculations for a range of costs and benefits to demonstrate the framework

Categories of Cost/Benefit Considered

Following the proposed framework, analyzing the cost effectiveness of city buses requires considering the following types of costs and benefits

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 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 • Impact on electricity rates (savings to ratepayers)
Additional Considerations	• Driver health/wellbeing • Customer benefits • Disaster relief • Energy security from reduced imports

Note: **Bold** items were quantified in the case study.

Electric Bus Cost Effectiveness Results

Electric buses cost slightly more than diesel buses from the perspective of the transit agency, but they are cost effective when viewed from the perspective of the Total Value Test (TVT). Below are the costs and benefits for the 12 year lifespan of 15 buses in a medium sized city.

NPV of Costs and Benefits (2018 $)	Participant Test (Transit Agency)	Total Value Test (TVT)
Costs		
Capital Costs	+ $5.4 million	+ $5.4 million
System Upgrade Costs	---	+ $0.4 million
Benefits		
Fuel Cost Savings	- $3.8 million	- $3.4 million
Maintenance Cost Savings	- $0.9 million	- $0.9 million
Avoided GHG Emissions Impacts	---	- $0.2 million
Avoided Air Pollutant Impacts	---	- $6.9 million
Total Quantified	**+ $0.7 million**	**- $5.7 million**
Non-Quantified	Potential flexibility value and revenues, improved customer experience, reduced noise pollution, mobile emergency electricity supply services	

Additional Non-Quantified Benefits

- Electricity prices tend to be less volatile than diesel prices, so will decrease the **fuel cost volatility** for transit agencies
- Electric buses may provide some additional **flexibility value** to the system during the overnight hours (0-4 hours) in which it is not charging; but likely small due to limited need during low load hours
- Flexibility benefits of electrifying bus fleets is likely much higher for school buses that run in the morning and afternoon, but are available mid-day and evening hours
- Electric buses are much **quieter** and **cleaner** than diesel buses and have **smoother acceleration**, which will decrease urban noise pollution and improve the customer experience
- Electric buses can provide cities mobile **emergency electricity supply** during disaster events that can alleviate the impact on high-value demand, such as hospitals and nursing homes

Indoor Agriculture Case Study

Indoor Agriculture Case Study Design

Using our proposed framework, we analyzed the costs and benefits of growing organic spinach in an indoor farm under LED lights rather than on a traditional outdoor farm.

- We estimate the total farm-to-store cost of **5,000 pounds of spinach per week** for consumers in Denver, CO.
- Outdoor scenario – a **13 acre farm in California**
- Indoor scenario – a **10,000 sq. ft. warehouse in Denver**
- Indoor farming **requires far more electricity** to grow crops in a climate controlled, artificially lit environment
- The financial and environmental costs of this electricity are offset by **reduced land use**, **reduced water consumption**, and **shorter transport distances**

Categories of Cost/Benefit Considered

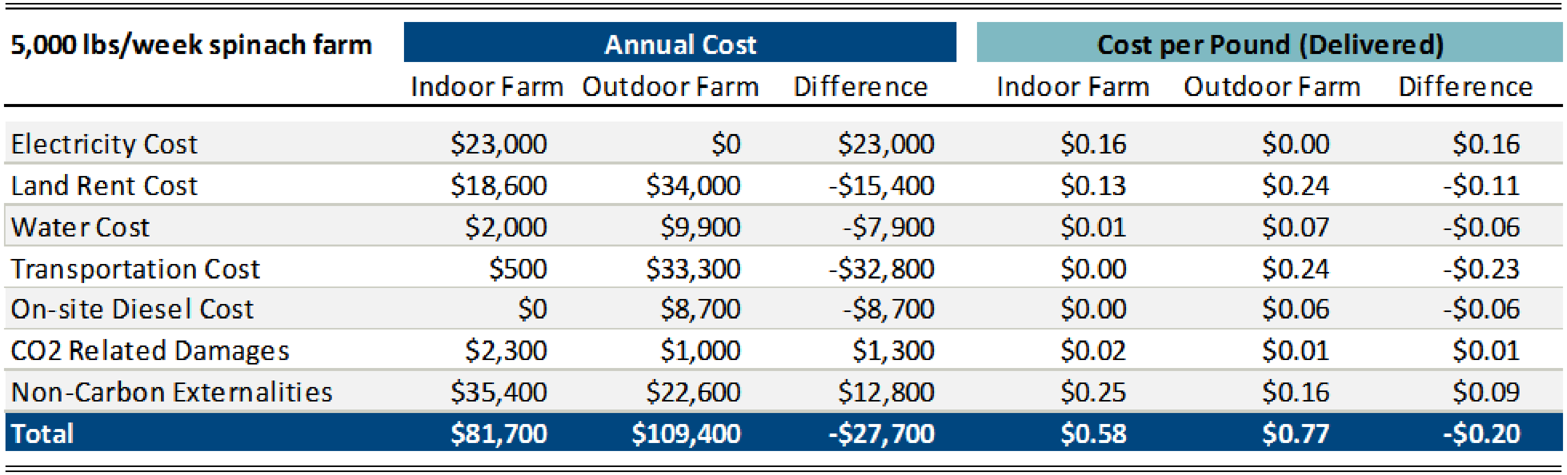
Following the proposed framework, analyzing the cost effectiveness of indoor agriculture requires considering the following types of costs and benefits:

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 were quantified in the case study.

Indoor Agriculture Cost Effectiveness Results

In this case, under the assumption of a highly efficient indoor farm and relatively coal-intensive electricity generation, the indoor farm has higher external costs than the outdoor farm, but a lower Total Value Test Cost due to savings in land rent, water cost, and transportation costs.



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
CO2 Related Damages	$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. Electricity rates reflect the average of 2018 commercial and industrial rates for the Mountain and Pacific regions, based on EIA projections. Diesel costs are reflective of the on-farm delivery of red dye (off-road) diesel in the central coast region. We assume the current generation mix for PG&E and Xcel Energy Colorado.

Additional Non-Quantified Benefits

- **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.
- **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.
- **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.
- **Food Security:** Indoor farming could also increase food security by reducing the potential for disease outbreak through the food supply and reducing food imports.

Electric Water Heating Case Study

Electric Water Heating Case Study Design

Three types of residential water heaters considered:

- Natural Gas Water Heater
- Heat Pump Water Heater
- Grid Interactive Electric Resistance Water Heater

Three main costs considered:

- Cost of electricity relative to natural gas
- Value of load flexibility (frequency regulation)
- CO_2 emissions

Electric Water Heating Cost Effectiveness Results

Based on regional and case-specific differences in fuel costs, CO_2 content of marginal electricity generation, and flexibility value, there is no clear winner across all scenarios.

		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 ($/kWh)	**Flexibility Value** ($/kW-yr)												
High Cost Peak = $0.07 Off-Peak = $0.05	20	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	40	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	60	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	80	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	100	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Moderate Cost Peak = $0.05 Off-Peak = $0.03	20	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	40	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	60	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	80	NG	NG	NG	NG	NG	NG	GI	GI	GI	GI	GI	GI
	100	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
Low Cost Peak = $0.03 Off-Peak = $0.01	20	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
	40	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
	60	HP	HP	HP	HP	HP	HP	GI	HP	GI	GI	GI	GI
	80	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
	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

WRITTEN BY

Ahmad Faruqui, Ph. D.

Principal, San Francisco, CA
+1.415.217.1026
+1.925.408.0149 (cell)
Ahmad.Faruqui@brattle.com

Ahmad's consulting practice is focused on the efficient use of energy. His areas of expertise include electrification, rate design, demand response, energy efficiency, distributed energy resources, advanced metering infrastructure, energy storage, inter-fuel substitution, combined heat and power, microgrids, and demand forecasting.

He has worked for nearly 150 clients on 5 continents, including electric and gas utilities, state and federal commissions, independent system operators, government agencies, trade associations, research institutes, and manufacturing companies. Ahmad has testified or appeared before commissions in Alberta (Canada), Arizona, Arkansas, California, Colorado, Connecticut, Delaware, the District of Columbia, FERC, Illinois, Indiana, Kansas, Maryland, Minnesota, Nevada, Ohio, Oklahoma, Ontario (Canada), Pennsylvania, ECRA (Saudi Arabia), and Texas. He has presented to governments in Australia, Egypt, Ireland, the Philippines, Thailand and the United Kingdom and given seminars on all 6 continents.

His research has been cited in Business Week, The Economist, Forbes, National Geographic, The New York Times, San Francisco Chronicle, San Jose Mercury News, Wall Street Journal and USA Today. Ahmad has appeared on Fox Business News, National Public Radio and Voice of America. He is the author, co-author, or editor of 4 books and more than 150 articles, papers, and reports on energy matters. He has published in peer-reviewed journals such as Energy Economics, Energy Journal, Energy Efficiency, Energy Policy, Journal of Regulatory Economics and Utilities Policy and trade journals such as The Electricity Journal and the Public Utilities Fortnightly. He is on the editorial board of The Electricity Journal.

He holds B.A. and M.A. degrees from the University of Karachi, an M.A. in agricultural economics and Ph.D. in economics from the University of California at Davis.

WRITTEN BY

Ryan Hledik

Principal, San Francisco, CA
+1.415.217.1029
Ryan.Hledik@brattle.com

Ryan Hledik specializes in regulatory and planning matters related to the emergence of distributed energy technologies.

Mr. Hledik has consulted for more than 50 clients across 30 states and eight countries. He has supported his clients in matters related to energy storage, load flexibility, distributed generation, electrification, retail tariff design, energy efficiency, and grid modernization.

Mr. Hledik’s work has been cited in regulatory decisions establishing procurement targets for energy storage and demand response, authorizing billions of dollars in smart metering investments, and approving the introduction of innovative rate designs. He is a recognized voice in debates on how to price electricity for customers with distributed generation. He co-authored Saudi Arabia’s first Demand Side Management (DSM) plan, and the Federal Energy Regulatory Commission’s landmark study, A National Assessment of Demand Response Potential.

Mr. Hledik has published more than 25 articles on retail electricity issues and has presented at industry events throughout the United States as well as in Brazil, Belgium, Canada, Germany, Poland, South Korea, Saudi Arabia, the United Kingdom, and Vietnam. His research on the “grid edge” has been cited in *The New York Times* and *The Washington Post*, and in trade press such as *GreenTech Media*, *Utility Dive*, and *Vox*. He was named to *Public Utilities Fortnightly’s* Under Forty 2019 list, recognizing rising stars in the industry.

Mr. Hledik received his M.S. in Management Science and Engineering from Stanford University, where he concentrated in Energy Economics and Policy. He received his B.S. in Applied Science from the University of Pennsylvania, with minors in Economics and Mathematics. Prior to joining Brattle, Mr. Hledik was a research assistant with Stanford’s Energy Modeling Forum and a research analyst in Charles River Associates’ Energy Practice.

PRESENTED BY

John Higham

Research Analyst, San Francisco, CA
+1.415.217.1000
John.Higham@brattle.com

John Higham is a Research Analyst in The Brattle Group's San Francisco Office, where he supports utility and energy clients around the world.

His areas of expertise include innovative retail rate design, wholesale market design, decarbonization modeling, and electrification forecasting.

Mr. Higham holds a Bachelor's Degree in Mathematical Economics from Colorado College.

About Brattle

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governments around the world. We aim for the highest level of client service and quality in our industry.

OUR SERVICES

Research and Consulting

Litigation Support

Expert Testimony

OUR PEOPLE

Renowned Experts

Global Teams

Intellectual Rigor

OUR INSIGHTS

Thoughtful Analysis

Exceptional Quality

Clear Communication

Our Practices and Industries

ENERGY & UTILITIES

Competition & Market Manipulation

Distributed Energy Resources

Electric Transmission

Electricity Market Modeling & Resource Planning

Electrification & Growth Opportunities

Energy Litigation

Energy Storage

Environmental Policy, Planning and Compliance

Finance and Ratemaking

Gas/Electric Coordination

Market Design

Natural Gas & Petroleum

Nuclear

Renewable & Alternative Energy

LITIGATION

Accounting

Analysis of Market Manipulation

Antitrust/Competition

Bankruptcy & Restructuring

Big Data & Document Analytics

Commercial Damages

Environmental Litigation & Regulation

Intellectual Property

International Arbitration

International Trade

Labor & Employment

Mergers & Acquisitions Litigation

Product Liability

Securities & Finance

Tax Controversy & Transfer Pricing

Valuation

White Collar Investigations & Litigation

INDUSTRIES

Electric Power

Financial Institutions

Infrastructure

Natural Gas & Petroleum

Pharmaceuticals & Medical Devices

Telecommunications, Internet, and Media

Transportation

Water

Our Offices

BOSTON

NEW YORK

SAN FRANCISCO

WASHINGTON

TORONTO

LONDON

MADRID

ROME

SYDNEY

THE POWER OF **ECONOMICS**

brattle.com

THE Brattle GROUP