Driving Smart Growth: Electric Vehicle Adoption and Off-Peak Electricity Rates

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Executive Summary

Reducing our dependence on fossil fuel is both a major national objective and essential to the long-term health of the national economy. Because transportation accounts for a large share of the demand for fossil-based fuels, shifting to electric vehicles (EVs)[1] is core to reducing reliance on fossil fuels and driving smart growth. This study examines the potential benefits that would emerge specifically in Connecticut from this shift with either flat or variable electricity rates.

Michigan's Detroit Edison Energy (DTE) early experience suggests that identifying neighborhoods with concentrations of hybrids registered provides an early indication of the locale of likely adoption of electric vehicles (EVs). Operating at the five digit zip code level, this paper analyzes their likely adoption rates and market penetration. Market penetration differs with average gross income, affordability criteria household formations and distance over which residents commute to work.

Alternative public policies contribute the relative competitiveness of utilizing an EV compared to other automobiles. Such policies include subsides on EVs and/or home-base recharging units, free parking commensurate with lower emissions, and off-peak or flat electricity rates. While all these are explored this paper focuses on off-peak and on-peak electricity rates. Off-peak pricing combined with smart meters allows utilities to spread their generating load more evenly and to better manage their costs with lowest cost generators being brought on line first.

Rate structures and other economic data hold the keys to identifying when utilities will need to upgrade transformer systems by zip codes. The paper shows that:

- Off-peak electricity rates are integral to managing the dynamics associated with increased electricty demand derived from the adooption of EVs.
- If demands for EVs progress at the same pace as the adoption of hybrids 2005-2009 but capped at penetration of 90% in the light vehicle market, in 2022, Connecticut EV registrations will grow to 222,000 reaching 1,198,000 by 2027.
- Initial requirements to upgrade transformers will take about 10 years to materialize under flat electricity rates and 13 years under peak/off-peak rates.
- By 2022 under flat rates, transformer capacity constraints would need to be redressed in 263 zip codes of the 341 residential ones tested but only 50 zip codes if off-peak rates were adopted and EVs fueled during off-peak periods.
- Concentrations of zip codes needing transformer upgrades indicate urban surburbs that may require transmission attention under off-peak rates by 2022 include:
    a. Hebron
    b. Marlborough
- By 2027, the spread between the two rate systems is closer with transformers in 317 zip codes requiring upgrading under flat rates and 254 under EV recharging at off-peak rates.

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[1] Interview, Anna Medina, EV Project Manager, DTE, June 2011.

- Additional urban centers and their surburbs that may require attention under off-peak rates by 2027 include:
    a. Greater Hartford
    b. Essex-Westbrook-OldSaybrook
    c. Stamford-Greenwich-Norwalk-Darien
    d. Waterbury-Prospect
- Plume analysis aside, zip codes likely to receive the largest benefit from emission reductions by 2022, include:
    a. 06106 (Hartford)
    b. 06897 (Wilton)
    c. 06902 (Stamford)
    d. 06820 (Darien)
    e. 06880 (Westport)
    f. 06437 (Guilford)
- Similarly, by 2027, the largest benefit from GHG emission reductions include:
    a. 06010 (Bristol)
    b. 06902 (Stamford)
    c. 06457 (Middletown)
    d. 06492 (Wallingford)
    e. 06033 (Glastonbury)
    f. 06708 (Waterbury)
- Gross emissions savings in Connecticut from converting from ICEs to EVs are projected to reach 1.4 million tonnes of CO_{2eq} in 2022, 3.03% of total state emissions in 2006,[2] and 7.3 million tonnes in 2027, 15.84% of total state emissions in 2006[3]. The net impact of GHGs will depend on the cleanliness, or lack thereof deployed, to produce the additional electricity required by the EVs. Initial off-peak loads based on nuclear and power from Bay James are relatively benign.
- Since October 2010, the market for credits has been depressed at $0.05/tonne so that credits based on the 2027 savings would currently be worth a paulty $365,000. The previous peak price was at $7.34/tonne on May 27, 2008 which would have resulted in an evaluation of $53.6 million[4]. Alternatively, the United States governemnt has set social benefits at $38.98/tonne[5].
- Better health realized through less mortality, hospital cost savings, less medical leave from work and reduced illness will approach benefits targeted under the Clean Air Act of 1997 in that GHG savings are expected to be 50% greater than under the Clean Air Act, but particulate matter reductions are apt to be less because diesel used infrequently in light rather than heavy vehicles.

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[2] http://www.ct.gov/dep/lib/dep/air/climatechange/inventory/2009_ghg_update_final_-_070110_edit.pdf
[3] http://www.ct.gov/dep/lib/dep/air/climatechange/inventory/2009_ghg_update_final_-_070110_edit.pdf
[4] Chicago Exchange (CEX) August 2011.
[5] Technical Support Document:- Social Costs of Carbon for Regulatory Impact Analysis - Under Executive Order 12866 Interagency Working Group on Social Cost of Carbon, United States Government p. 3. "A domestic social cost of carbon (SCC) value of $33/ton in 2007 is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions." Adjusting for inflation to 2010 and converting from tons to tonnes (metric tons) obtains $38.98/tonne.

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Introduction

Reducing our dependence on fossil fuel is both a major national objective and essential to the long-term health of the national economy. Because transportation accounts for a large share of the demand for fossil-based fuels, shifting to electric vehicles (EVs)[6] is core to reducing reliance on fossil fuels and driving smart growth. This study examines the potential benefits that would emerge specifically in Connecticut from this shift with either flat or variable electricity rates adjustable with on-peak/off-peak electricity loads.

To develop this analysis, the Connecticut Center for Economic Analysis (CCEA) first evaluated the historical demand for hybrids among state residents to project future rates of adoption for innovative vehicles inclusive of EVs and then looked at the linked issue of the requirements for electricity infrastructure to permit efficient recharging. Combining these elements with an analysis of the incentive of offering off-peak pricing of electricity, CCEA projects the total economic benefit that the state would capture from this scenario. These gross benefits include:

- Reductions in greenhouse gases (GHGs) by 1.4 million tonnes of carbon dioxide equivalents CO_{2eq} in 2022, 3.03% of total state emissions in 2006,[7] and 7.3 million tonnes in 2027, 15.84% of total state emissions in 2006;
- $365,000 in CO_{2eq} credits in 2027 assessed at current market rates;[8]
- Because of the airbone nature of GHGs and their reductions being tied to impacts on the ozone layer, thence to human health, it is only possible to comment on health impacts if similar reductions of GHGs were achieved globally. By 2027, the EVs impact would be about 1.5 times that of the Clean Air Act (1997)[9] on the ozone layer but felt less strongly in Connecticut than among the high-density population of New York where estiamtes of the impact of the Clean Air act indicate annual avoidance of 75 deaths, 265 athsamatic hospital adminsions, 255 other hospital admisiond for other respiratory diseases, 3,500 emergency doctor visits, and 180,000 athsmatic atacks requiring additional medication.[10] These data are only indicative of the results of the global adption of EVs at rates indicated for Connecticut in this study.

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[6] Interview, Anna Medina, EV Project Manager, DTE, July 2011.

[7] http://www.ct.gov/dep/lib/dep/air/climatechange/inventory/2009_ghg_update_final_-_070110_edit.pdf

[8] CEX since October 2010 CO_{2eq} credits have traded at $0.05/tonne off their peak of $7.34, May 27, 2008.

[9] George D Thurston, *Scientific Research for Ozone and Fine Particulate Standards*, **Pace Environmental Law Review** Vol. 16, Article 3, 1998 pp 2-3 indicates that EPAs regulations under the Clean Air would result in about a 10% reduction in GHGs and PMs.

[10] Ozone and Particulate Matter Standards: Hearings on the Clean Air Act Before the Subcommittee on Clean Air, Wetlands, Private Property and Nuclear Safety and the Comm. on Env't and Public Works, 105th Congress (1997).

- Where EVs replace EVs diesel vehicles there will be additional savings in particulate matter (PM) that is closely associated with asthma and other respiratory diseases.

In addition to the environmental and health benefits, the analysis reveals that relative to flat rates for electricity there are very substantial benefits to off-peak pricing, delaying and saving large capital costs for system upgrades by smoothing daily demand for electricity. For all 341 residential zip codes studied 263 would require upgraded transformers under flat residential rates by 2022, but only 50 with off-peak rates and fuelling of EVs. By 2027, the spread is closer with transformers in 317 zip codes requiring upgrading under flat rates and 254 under EV recharging at off-peak rates.

The study draws on data of hybrid vehicles registered by Connecticut residents to examine the rate of adoption of innovative vehicles within the state. Michigan's Detroit Edison Energy (DTE) early experience suggests that such an approach provides a good indication of the likely adoption of EVs.

Annual cross-sectional data organized by Connecticut zip codes provides the basis for estimating resident adoption of hybrids in each year 2005 to 2009. CCEA drew on 2007 Internal Revenue Service (IRS) data by zip code to estimate average aggregate household income and the share of income tax filings in each zip code involving two people, from which CCEA then projected the ability of households to buy new vehicles,. IRS data covered 275 of 281 Connecticut zip codes for which CCEA has data on resident owners of hybrids. The U.S Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) provided additional data on residents' commuting distances to work from each of 229 zip codes included above. The LEHD also provides data on an additional 89 zip codes where the vehicle data base shows no purchases of hybrids. Thus CCEA derived EV demand from the overlapping databases to estimate both registrations of hybrids and light vehicles for these 89 additional zip codes to develop potential total Connecticut EV adoption rates and electricity infrastructure requirements.

These data facilitate estimating commuter cost differentials by type of vehicle under various conditions such as gasoline prices, electricity rates, paid and unpaid parking during the day, subsidies on vehicles, expected battery longevity,[11] and end-of-life vehicle values. The share of long-distance commuters in each zip code also impacts rates of hybrid adoption. As a bonus, CCEA has tested demonstration effects where neighbors within zip codes tend to mimic each other in vehicle purchases.

This approach allowed CCEA to estimate penetration effects relative to registered light vehicles by zip code under alternative electricity pricing schemes. DTE had found that if its electricity rates remained flat, it would generally need to upgrade transformers after EV market penetrations reached 5%. But if EV owners recharge their batteries during DTE's off-peak hours of 11:00 pm to 9:00 am, transmission systems would only need to be upgraded as EV market penetration approached 25%. To encourage off-peak recharging, on March 1, 2011 DTE offered to assist the first 2,500 EV owners who signed up for DTE's recommended installation of residential 240-volt EV charging stations with a subsidy of $2,500.

[11] Battery life expectancy for use in EVs is reached at 80% of original capacity. Given the eight remaining years to generate alternative use and or supplement the slightly diminished battery output, end-of-life values for batteries are not well known.

Because the GM Volt takes 3.5 hours to recharge completely on 240 volt feeds rather than 7 hours on 110 volt, smart meters, installed as part of the charging systems, facilitate off-peak load flattening.[12]

This study also analyses commuting patterns from Census data and then estimates concentrations of potential demand, including affordability based on income benchmarks developed from the IRS zip code data. These findings reveal how the rate of growth of hybrid adoptions has varied significantly among Connecticut zip codes, which, with other Census and IRS indicators, facilitate long-term planning for gradual transmission capacity up-grades.

Hybrid Registrations as Proxies for EV Adoption Rates in Connecticut

CCEA studied data on the hybrid vehicles registered as of July 1st annually from 2005 to 2009 by zip code. From the vehicle model additions and absences by zip code that are available from the 2005 basis, CCEA calculated changes for each EV model and year, for 2006 up to 2009, to develop a vehicle matrix. Year-to-year changes may result from new purchases, sales of used vehicles among owners with different zip codes, and migration of owners. DTE experience indicated that earlier purchasers of EVs tend to be concentrated in the same geographic clusters as were hybrids. For that reason, CCEA relied on DTE experience to estimate the number of hybrids annually and changes in hybrid stocks.

Data for each zip code generally represents ownership or leases by residents except for zip codes 06096 and 06106, where there appear to be spikes resulting from registered commercial fleets attached to home offices rather than personal residences in 2008 and 2009. Zip code 06106 data, in Hartford, with a 140 addition in 2008 followed by a 121 decrease in the stock of vehicles in 2009 almost certainly stems from a commercial fleet change, including possible supplies of rental vehicles. Because the intent is to examine personal choices in hybrid purchases, 2008 and 2009 change data for zip code 06106 have been neutralized. Apparent commercial activity in 06096, Windsor Locks, was less significant and ignored.

In the following tables, hybrid data are suffixed with the last two digits of the year and the stock changes are also prefixed by the letter "C". CCEA initially included 281 five-digit Connecticut zip codes in the study because it had data on hybrids registered in each of these zip codes for at least one year from 2005 to 2009. Of these 281 areas, CCEA has IRS tax filler data on all but six zip codes. Each of the omitted areas had only one or two vehicles registered in any given year, so the omission is minor.

In addition, annual data from the Census on the numbers of commuters and their travelling distances were available for 229 of these zip codes for the five years of CCEA's study. Limiting the estimating base to these areas further excluded information on the ownership of a total of 99 hybrids or an average of 2.2 vehicles per zip code out of 15,127 hybrid vehicles in 2009, leaving all the areas where purchases were concentrated within the study. For these 229 zip codes, annual Census data reports commuting distances for all workers: less than 10 miles, 10 to 24.99 miles, 25 to 49.99 miles or more than 50 miles. CCEA has approximated the miles travelled in each direction as an average number, as 7, 17.5, and 35 and 75 respectively. CCEA then derived for each zip code the number of miles covered by commuters to their work location and the related annual costs.

[12] http://dteenergy.mediaroom.com/index.php?s=43&item=593

Combined with benchmark cost data from a variety of sources for different classes of vehicles, CCEA estimated the commuting cost for each distance cohort within each zip code. Alternative vehicles included:

- Full-sized powered by internal combustion engines (ICEs);
- Medium-sized ICEs;
- Hybrids;
- EVs powered by:
    - Gasoline only;
    - Electricity estimated
        - Under flat-rate pricing, and
        - Under proposed off-peak charging systems.

In particular, CCEA breaks out these costs for those travelling less than 25 miles one way, within the Volt's return trip range, and for others beyond that range. These data also contribute to estimates of potential cost savings for hybrid and EV owners relative to other vehicles, i.e. factors influencing the competitiveness of EVs.

These data are also constructive in establishing the need to either recharge Volts at their destinations or to resort to burning gasoline to power the remaining distances after battery reserves hit minimum charge. Where daily commuting distances exceed battery capacity, Volt owners have the option of using gasoline to generate additional electricity or to utilize on-peak electricity at their destinations. That feature ties current and future maximum peak prices that Volt owners would be willing to pay for recharging to the retail price of gasoline as well as future efficiency enhancements to on-board generators.[13] Another alternative is to purchase the more expensive Tesla Roadster, which has considerable greater battery capacity and therefore allows owners to avoid gasoline purchases or on-peak charging.

Costs per Mile by Type of Vehicle

Table 1 provides the key assumptions in estimating potential cost savings per mile. Costs per mile include both fixed and variable costs of driving full-sized vehicles, mid-sized vehicles, hybrids and EVs, where the EV costs consist of three alternatives; (1) gasoline only or solely on electricity valued at (2) flat rates or (3) off-peak power rates. Year-to-year cost details were based on individual price indexes from the U.S. Bureau of Labor Statistics (BLS) for either the North-East or the United State when the former were not available. A 1986-based index was developed consistent with BLS's approach based on BLS's 2010 index. The one exception to these adjustments was for the price of electricity where the Federal

[13] These data then give the CCEA future options for examining purchases by model including each model's contribution to greenhouse gases (GHG) reductions over time as long as it can tie models traveling distances to GHGs. Later it is shown that the average on-peak price of electricity would be less than the current on-board costs of generation but that estimate excludes both higher costs associated with a commercial charging station and a possible two tiered rate structure to reduce peak demand.

Energy Regulatory Commission (FERC) published Connecticut annual residential sales in dollars, volumes, and average rates; CCEA used average residential rates.

Table 1: Key Assumptions and Sources

Variable					
Purchase Price	F $45,000	M $30,000	H $32,000	V $46,000	"F"= Full-sized, M= Medium-sized, H= Hybrid & V= Volt or EV
Annual Insurance (2011)	F $1,800	M $1,500	H $1,200	EV $1,300	
Annual State License (2011)	F $42	M $40	H $ 38	EV $38	http://www.ct.gov/dmv/cwp/view.asp?a=802&q=244546&dmvPNavCtr=|#52409
Subsidies			H 7.5%	EV 17.4%	Volt based on $8000 subsidy
Maintenance ($/Per mile)	F 0.62	M 0.51	H 0.21	V 0.21	CAA adjusted for exchange & metrics
Battery Replacement (Per Mile)			H .50	V .67	Based on travelling 15,000 miles annually and 8 year battery life with no after-use value
Gasoline per mile by type of vehicle	F 18.1 to 25.8	M 20.1 to 28.7	H 44.5 to 48.2	V Gas only 35 to 40	http://www.fueleconomy.gov/feg/findacar.htm for each of full-sized, medium sized and hybrids weighted by number of vehicles in the 2009 the CT stock for urban (55%) and highway (45%)
Gasoline (2011 per gal.)	4.37	3.78	4.02	4.02	Current prices (July 2011)
Amortized Ten years	25% of residual				Average annually over 10 years
Financing	Months: 48	Interest 5%	Buy-Back 35% of purchase price		Standard with minor concessionary finance to come in less than 100 basis points under current initial negotiations.
Average Distance (Miles/Year)	15,000				Consistent with EPA studies and close to American national average
Percentage Highway driving:					
-10 miles or less	40				EPA uses 55% urban in its estimates by model.
- 10 to 24.99 mi.	55				
-Longer than 25	70				
CT Flat Electricity Rates (Cents/KWh)	2011 18.03	2010 19.14			http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html and FERC
Peak Electricity (2011 Cents/KWh)	34.05				Capped at cost of a Volt using gas instead of electricity in 2011
Off Peak Rates (2011 Cents/KWh)	11.0				Initial approximation
Daily Parking (2004)	$5.85				http://www.cityofnewhaven.com/EconomicDevelopment/pdfs/NewHaven_Parking_StrategicPlan.pdf
Working days/yr	220				Standard

In addition the U.S. Census Bureau LEHD program provides a searchable interface to retrieve total number of workers and their commuting distances by zip code annually for 2005-2009 as well as the distribution of the population. CCEA estimated the number of commuters and the proportion of them travelling in excess of 25 miles by postal code in each year the study covers. Combined with the costing data, CCEA projected potential savings from adopting Hybrids and/or EVs compared to utilizing other vehicles.

CCEA used the foregoing data points and assumptions to estimate the average annual cost of commuting in various vehicles from 2005 to 2011, adjusted by price indexes and data from the BLS and FERC. No changes were made for the average distance driven annually. Because some commuters do not pay for parking at their destinations, due to perquisites or because municipalities, e.g. New Haven, grant free parking to drivers of hybrids or EVs, these estimates have been made exclusive and inclusive of parking fees at the destination points.

In order to truncate the description, Tables 2 and 3 present vehicle commuting costs for only 2005 and 2011. Within these tables, costs are based on annual average distance of 15,000 miles. The maximum electricity rates for EVs with on-peak electricity uses on-peak equivalents for gasoline to recharge on-board. Should on-peak electricity be available at lower rates, these operating costs could be lower. The other alternative that would also lower operating costs would be ownership of a Tesla Roadster, but its purchase price is higher with correspondingly augmented fixed costs. Parallel estimates for all the intervening years are presented later in this report.

Table 2: Annual Commuting Costs by Type of Vehicle 2005

Vehicle\Distance: Origin to Workplace	Less than 10 Miles	10 to 24.99 Miles	25 to 49.99 Miles	More than 50 Miles
Free Parking				
Full Sized Vehicle	8,944	9,772	11,089	22,243
Medium Sized	6,194	6,848	8,075	15,816
Hybrid	5,912	6,508	7,493	15,185
EV Operating Entirely on Gasoline	7,452	8,209	9,471	19,512
EV Operating Entirely on Flat Rate Electricity	7,356	7,968	8,988	18,477
EV Operating on Maximum Off-peak Electricity	7,304	7,838	8,728	17,919
Paid Parking				
Full Sized Vehicle	10,301	11,128	12,446	23,599
Medium Sized	7,551	8,204	9,431	17,172
Hybrid	7,269	7,864	8,850	16,541
EV Operating Entirely on Gasoline	8,809	9,566	10,828	20,869
EV Operating Entirely on Flat Rate Electricity	8,712	9,325	10,345	19,834
EV Operating on Maximum Off-peak Electricity	8,660	9,194	10,084	19,276

The insertion of the Volt into the 2005 economy is clearly hypothetical because the vehicle was not introduced until December 2010. Even with current rates of subsidy, it is nevertheless interesting because it would have been cheaper to commute in a Volt than a full sized-vehicle over all commuting distances. Yet, even at off-peak pricing of electricity, in 2005 the Volt would not have been competitive with mid-sized vehicles or hybrids, but it would have been more competitive as commuting distances increase and with the possibility of re-charging at off-peak rates.

Table 2 also indicates an increasing spread between commuting costs in hybrids against costs in ICEs as distances increase. The enhanced savings for longer distance hybrid commuters suggest that consumer interest in hybrids may be higher for long-distance commuters than those commuting shorter distances.

Further, comparing the two blocks of numbers, subsidized parking was worth about $1,356.50 each year, and was clearly a boon to hybrid owners. New Haven's policy to allow free parking for hybrids and EVs could have been sufficient to tilt competition in favor of EV's over medium sized vehicles. In all instances, commuters could save costs by driving hybrids rather than full and medium sized ICEs for any of the distances shown above. Further hybrid savings increase with the distance of the commute.

By 2011, the Volt's competitive landscape changed, as illustrated in Table 3. The increasing price of gasoline has noticeably improved the Volt's competitiveness.

Table 3: Commuting Costs by Type of Vehicle 2011

Vehicle\Distance: Origin to Workplace	**Less than 10 Miles**	**10 to 24.99 Miles**	**25 to 49.99 Miles**	**More than 50 Miles**
Free Parking				
Full Sized Vehicle	9,444	10,624	12,496	25,162
Medium Sized	6,587	7,517	9,258	18,106
Hybrid	6,184	6,937	8,182	16,598
EV Operating Entirely on Gasoline	7,775	8,733	10,330	21,287
EV Operating Entirely on Flat Rate Electricity	7,610	8,322	9,508	19,526
EV Operating on Maximum Off-peak Electricity	7,538	8,142	9,148	18,754
Paid Parking				
Full Sized Vehicle	11,117	12,297	14,169	26,835
Medium Sized	8,260	9,190	10,931	19,779
Hybrid	7,857	8,611	9,856	18,271
EV Operating Entirely on Gasoline	9,448	10,406	12,003	22,960
EV Operating Entirely on Flat Rate Electricity	9,283	9,995	11,182	21,199
EV Operating on Maximum Off-peak Electricity	9,211	9,815	10,821	20,427

From the above vehicular commuting options:

1. Costs rose from 2005 to 2011;
2. Hybrids are the lowest cost of the options tested;
3. EV's, no matter the fuel, have become more cost competitive;
4. Even EV's fueled by gasoline are cheaper than full-sized ICEs;
5. For distances in excess of 25 miles, EVs charged off-peak are lower cost than medium-sized ICEs;
6. For distances in excess of 50 miles, EVs charged on prevailing flat rated electricity approach the costs of medium-sized vehicles, albeit the costs are close enough to make Volts competitive with the least efficient of the medium-sized ICEs;

7. Full parking subsidies for the Volt make electricity powered Volts competitive with medium-sized ICEs with paid parking;
8. Given completely subsidized parking, as in New Haven for hybrids and EVs, either type of vehicle provides lower cost transportation for commuting than do both medium and full-sized vehicles with ICEs over some commuting distances;
9. Significantly, commuters save costs by fuelling their EVs off-peak rather than at extant flat rates, with savings increasing with the length of the commute:
   a. Potential savings from $72 for commuters travelling less than 10 miles, and
   b. Up to $773 dollars in savings for those travelling more than 50 miles one way.

As noted earlier this is a proxy for savings on about 33,000 miles commuted a year compared to the national standard of 15,000 miles. The average driver, travelling 15,000 miles annually, would save $371 by fuelling at off-peak versus flat rates.

Flat, On-Peak, and Off-Peak Electricity Rates and Residential Charging Stations

Possible cost savings in moving from electricity priced at off-peak rather than at flat rates need to be put in the context of family budgets. In 2009, Connecticut residential consumption of electricity totaled 12,578,225 megawatt hours (MWh) sold for $2,557,331,000.[14] Per household[15] in Connecticut, these sales averaged 8.7 MWh at average annual costs of $1,769 per household. The addition of a Volt travelling average distances of 15,000 miles a year would add to the family electricity bill but could be differentiated between flat and off-peak pricing of electricity. The expected costs of electricity for the Volt are based on national consumption data published by GM adjusted for above average Connecticut electricity rates from FERC in 2009. The resulting anticipated total annual electricity bill for a household owning a Volt is then $2,699 with all purchases of electricity at flat rates and $2,318 with the Volt alone utilizing off-peak rates of 11 cents/kWh.

Currently, Northeast Utilities charges peak rates from noon to 8:00 pm on workdays, leaving considerable time for off-peak electricity consumption, including family-focused mass communications and appliance use. Adopting off-peak for re-charging vehicles can then be allow for other activities' savings during off-peak hours. Peak and off-peak pricing encourages such shifts because supplying other household activities becomes more expensive when undertaken during peak rated periods.

Residential Charging Stations and Transmission Systems

DTE has learned that under flat rate cost structures, it would need to make adjustments to its transformers after just a 5% adoption of EVs, but that installing 240 volt time-of-day charging stations, inclusive of smart meters in EV owners' residences and by setting off-peak rates from 11:00 pm to 9:00

[14] FERC, Electricity Sales January 1990-February 2011 by state and market.
[15] http://quickfacts.census.gov/qfd/states/09000.html. This average is higher than that shown on Connecticut Light and Power's web page at $123.74 per month for a typical consumer. http://www.cl-p.com/rates/generationrates/averagebill.aspx

am[16], it can likely delay the transformer and other transmission investments until there is a 25% adoption rate of EVs in any area[17]. To that end it is offering its first 2,500 customers a subsidy of $2,500 for the installation of residential charging stations inclusive of smart thermostats, timers designed to deliver at off-peak hours and the necessary equipment to connect, up to the end of December 2012 with current off-peak rates of $0.07695/kWh and on-peak rates of $0.18195/kWh.[18]

The Brattle Group reviewed the CL&P implementation program in their *Impact of CL&P's Plan-It Wise Energy Program* in 2009. This review reported on the impact of several alternative policies for reducing peak electrical usage by residential, commercial, and industrial clients, in a trial from June 1 to August 31, 2009. Of relevance to the CCEA study was the use of peak time pricing (PTP) assisted by the use of programmable thermostats covering a sample of 169 residential clients who volunteered to participate in the study.[19] While the total Brattle Group sample was considerably larger, this is the number of residences that fell under the PTP. Because the Brattle Group study's primary target was to find ways and means of demand peak reduction, peak pricing was used in contrast to DTE's shorter off-peak and longer on-peak envisaged herein for Connecticut EV users.

The Brattle Group's main finding of interest was in relation to the residential price elasticities with respect to the percentage change in consumption generated for every one percent increase in the spread between on-peak and off-peak rates. Residential elasticity for June and July was -0.117 and for August -0.128.[20] Using the June to July results moving from flat rates, where the ratio of peak to off-peak rates is unity, to a program where the off-peak price is $0.11, CL&P achieves revenue neutrality when on-peak rates are 2.09262 times those of off-peak ones. Under these conditions, peak electricity demand by EV owners would fall by 12.78%. Correspondingly, their off-peak consumption would rise by 2.84%, prior to refueling their EVs. The decline of 12.78% in their peak consumption creates a marginal amount of room for either reduced use of interruptible power contracts and/or minor recharging of EV's during on-peak hours.

The above estimates may be optimistic. The Brattle Groups' elasticities are based on deployment of on-peak pricing for a four hour time period but the EV application is for a 14 hour period that extends the shift from on-peak to off-peak environments, suggesting that there is less consumer flexibility for load shifting in the EV case than in the Brattle case. In addition, the Brattle Group's sample was taken entirely during the summer months when consumers have the option to save peak electricity by eating cold dinners or enjoying barbeques. Such options are less appealing in winter months. Both these factors would lead to lower elasticities than the Brattle Group estimated, even taken over a relatively cool June and July in 2009. At least partially offsetting the above points, air conditioning demands for electricity decline or dissipate during the other seasons.

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[16] DTE timing is consistent with the August 18, 2009 load profile of CL&P reported by the Brattle Group in *Impact of CL7p's Plan It-Wise Energy Program* 2009 Appendix A p.18.
[17] Interview Ana Medina, Detroit Edison July 7, 2011.
[18] http://www.dteenergy.com/residentialCustomers/billingPayment/electricRate/pevRate.html.
[19] Brattle Group in *Impact of CL&P's Plan It Wise Energy Program* 2009 Appendix A p.32.
[20] Ibid p. 46.

At 2.36%, the DTE ratio of on-peak to off-peak rates is larger than the one derived from Brattle-based elasticities. If season-long elasticities for the longer on-peak daily period for CL&P were at about 80% of those in the Brattle study and the ratio of on-peak to off-peak rates were the same as for DTE, then revenue neutral CL&P residential on-peak and off-peak rates could be $0.26198 and $0.11080 respectively.

Note that the $0.262 on-peak rate is lower than the $0.34 rate for Volts to produce electricity from gasoline at current gasoline prices. This electricity charge is however net of any charging-station infrastructure and services costs, as well as any other rates that could be introduced to curtail peak electricity consumption such as contractual brown-outs. Any solar that can contribute to fueling stations below the $0.34 rate would be of interest, subject to changes in the price of gasoline over time.

Cost Sensitivities

Summarized in Table 4, CCEA ran sensitivities with respect to commuting costs including:

- A 1% reduction in off-peak power rates;
- A 25% increase in battery life;
- A $4,000 reduction in the price of EVs to the consumer consistent with either a subsidy or declining prices;
- A 5% increase in the resale value of an EV as could occur with the extended battery life.

Table 4: Possible Annual Savings Related to Commuting Cost in EV Charged Off-Peak: Sensitivities from 2011 above with Free Parking 2111 ($)

Cost Variable	**Less than 10 Miles**	**10 to 24.99 Miles**	**25 to 49.999 Miles**	**More than 50 Miles[1]**
One cent Reduced Rate for Off-Peak Power (11 to 10 cents)	10	26	51	110
25% increase in battery life (8 to 10 years)	41	103	205	440
$4,000 Reduction in the Price of EVs ($46,000 to $42,000 with same % subsidy)	666	666	666	1,332
An increase in the resale value of an EV by 5% or $2,300 e.g. increased battery uses.	314	314	314	NA

Note: 1. Data based on the fixed and variable costs of operating a Volt. Tesla Roadsters for longer distances could be more competitive.

Because the first two of these shocks vary with distances travelled, they affect variable costs. Peak electricity rates would have to fall by four cents/KWh to have similar impacts on cost reductions as a 25% increase in the expected longevity of the battery. Clearly reduced capital costs and/or increases in the buyback values after 4 years could also impact commuting costs. Extending the analysis for eight years, the last of the sensitivities could occur from finding alternative uses for batteries after their expected use in EVs. The same owners who use EVs less for commuting and more for other purposes gain savings more closely akin to those realized by the more distant commuters, except for those commuting beyond 25 miles one-way where additional amortization lowers buy-back values.

Demand for Hybrids 2005-2009

Given the above competitiveness of hybrids, CCEA initially estimated hybrid demand by zip code using 2007 IRS tax data as demand determinants for hybrids, in particular:

1. Tax filers (TAXF75) - with adjusted Gross Incomes (AGI) of $75,000, used to identify financially qualified buyers of new EVs;
2. Average adjusted gross income (AAGI) filed by zip code - used to identify zip codes with above average incomes to support vehicle usage; and
3. Percentage share of multiple income families (SHMULTI). by zip code - % of families with multiple filers in each zip code.

CCEA's initial presumption was that households with multiple incomes would be more inclined to have multiple vehicles and therefore more likely to buy a hybrid. The empirical evidence suggests that this may only be true once hybrids become more established. Although IRS data are limited in that they do not include distance and cost data, they have the virtue of excluding only six of the "Hybrid" zip codes due to the lack of data and/or the need for confidentiality.

Estimators for annual vehicle registration from IRS data appear in Table 5. The first number in each cell is the parameter. The second, bracketed number is the "t-statistic" where parameters with t-statistics equaling or exceeding 2 are significantly different from zero at the 95% level of confidence when the sign (+ or -) is not known and above 1.67 when it is known. Because the signs on parameters for TAX75 and AAGI are expected to be positive, they are statistically significantly greater than zero and affect demand positively in all years. The negative sign and quite small parameter for SHMULTI data is not significantly different from zero, except for $Cstock_{2009}$, well into the adoption process.

Table 5: Determinants of Hybrids Stocks and Changes in Stocks by Connecticut Zip Code (n=275)

Dependent	Constant	TAXF75	AAGI	SHMULTI	Adjusted R^2
Stock					
Stock05	1.043 (0.69)	0.00686 (27.46)	0.02039 (4.52)	-0.0379 (0.96)	0.777
Stock06	4.222 (1.56)	0.01083 (24.08)	0.03491 (4.32)	-0.1295 (1.82)	0.727
Stock07	5.099 (1.32)	0.01906 (26.57)	0.05544 (4.79)	-0.1798 (1.76)	0.799
Stock08	7.305 (1.23)	0.02794 (28.50)	0.08053 (4.57)	-0.2568 (1.67)	0.787
Stock09	0.322 (0.57)	0.03505 (37.12)	0.09301 (5.48)	-0.1271 (0.85)	0.863
Change in Stock					
Cstock06	3.179 (1.74)	0.00397 (13.03)	0.01458 (2.66)	-0.0916 (1.90)	0.423
Cstock07	0.877 (0.57)	0.00822 (32.20)	0.02054 (4.57)	-0.0603 (1.24)	0.824
Cstock08	2.205 (0.89)	0.00888 (21.58)	0.02508 (3.37)	-0.0770 (1.18)	0.679
Cstock09	-6.967 (2.99)	0.00711 (18.35)	0.01248 (1.79)	0.1295 (2.11)	0.613

Data are limited in that, due to availability, the tax filer data on which CCEA relied are for 2007 only. Correlations between stock and both TAXF75 and AAGI rise through time as hybrids gain acceptance, though the rate of the annual increase slows, in part due to the recession. That observation also holds true for SHMULTI among the Cstock estimators, suggesting the adjustment factor for households with multiple drivers may have been hesitant at the early stage of adoption, different from our initial assumption. All parameters confirm increased purchases up through 2008 and then ebb in 2009 due to the influence of the recession.

Demonstration Effect

Of importance in determining local electricity loads is the issue of whether or not hybrid vehicle demands are clustered and the dynamics underlying that clustering. Historically there has been an argument that automotive demand is influenced by this "demonstration effect." If so, CCEA would expect previous purchases in each area to influence future demand. That is, annual changes in stocks in each zip code would be linked to the previous year's change in stock in the same area. Those results appear in Table 2 and are clearly superior to those in Table 6, except for 2006. The capital stock "lagged one-year" is always statistically significant, suggesting that after the first quinquennium the demonstration effect is present and that area clustering can be expected in the adoption of innovative vehicles.

That conclusion has special significance for electricity distribution because it means that early sales by zip code constitute early signals of where additional transmission capacity will be required, but, as established later, off-peak pricing of electricity can massively delay the need for such upgrades.

Table 6: Demonstration Effects of Hybrid Stock Changes within Connecticut Zip Codes (n=275)

Dependent	Constant	TAXF75	AAGI	$CSTOCK_{(t-1)}$	Adjusted R^2
Cstock06	-3.179 (1.74)	0.00400 (13.03)	0.01458 (2.66)	-0.9165 (1.90)	0.436
Cstock07	-0.868 (1.77)	0.00628 (24.12)	0.01330 (3.60)	0.4868 (11.82)	0.883
Cstock08	.3289 (0.41)	0.00127 (1.73)	0.00542 (0.88)	0.9221 (11.48)	0.783
Cstock09	-1.521 (2.58)	0.00594 (14.55)	0.00931 (2.08)	0.1382 (3.75)	0.786

CCEA has supplemented these initial estimates in two important ways: (1) establishing the relative costs of commuting in various sizes and types of vehicles and (2) utilizing the Census information within zip codes to establish distances and relative costs to commuters depending on the type of vehicle deployed. These data lead to estimates of the potential savings from adopting electric vehicles under a series of scenarios considering alternative transportation, parking fees, and electricity rates. The following sections continue the data aggregation to estimate potential savings with electric vehicle adoption, comparing commuting distance and vehicle operating costs

Commuting Distance Data

The Census program, Longitudinal Employer-Household Dynamics (LEHD), provides access to annual information on the numbers of commuters travelling from each of our 229 zip codes, delivered in four distance categories. Using mid points of 7, 17.5, 35 and 75 miles for the above cohorts, CCEA estimated the costs of commuting for each mileage cohort as well as the shares of commuting costs paid by each cohort per zip code. In particular, these data allowed CCEA to develop an alternative determinant of demand for both the annual stock of hybrids 2005-2009 and changes in that stock from 2006-2009; the share in each zip code of the costs paid by daily commuters travelling more than 25 miles one way, namely $SHCOST_t$ where the subscript "t" refers to the year covered by each series. These data are based on single year estimates of both workers and distances driven from each home zip code. In keeping with the subset of data covering only 229 of Connecticut's 281 vehicle registration zip codes, rather than the 275 covered in IRS data, the earlier estimates were rerun based on the initially identified relationship for the 229 zip codes as well as deploying the cost-based shares.

Table 7 presents results parallel to those in Table 1. The second estimate in each case utilizes $SHCOST_t$ adjusted by inflation only. Had adjustment been made for both income and worker variation, estimates for the earlier years would have been expected to be better than achieved in this table. In those years where the parameter on SHMULTI was not significantly different from zero, the one on $CSTOCK_t$ was yielding slightly more explanatory power. TAXF75 continues to be the strongest determinant with AAGI also being statistically significant. Given the recession, the parameters on CSTOCK over time do not follow this pattern.

Table 7: Determinants of Hybrids Stocks and Changes in Stocks by Connecticut Zip Code (n=229)

Dependent	**Constant**	**Taxf75**	**AAGI**	**SHMULTI**	**$SHCOST_t$**	**Adjusted R^2**
Stock						
Stock05	2.989 (1.38)	0.00673 (23.04)	0.0225 (4.41)	-0.0811 (1.51)		0.746
	-3.321 (2.11)	0.00700 (22.46)	0.0159 (3.04)		12.5972 (2.33)	0.750
Stock06	9.401 (2.41)	0.01051 (20.08)	0.0401 (4.38)	-0.2453 (2.45)		0.694
	-2.658 (0.86)	0.01076 (18.58)	0.0299 (3.10)		10.1500 (0.99)	0.687
Stock07	12.240 (2.19)	0.01862 (24.81)	0.0363 (4.08)	-0.3404 (2.46)		0.773
	-4.085 (1.14)	0.01886 (24.07)	0.0496 (3.72)		12.9574 (1.13)	0.768
Stock08	17.911 (2.11)	0.02730 (23.90)	0.0916 (4.59)	-0.4961 (2.36)		0.759
	-9.764 (1.40)	0.02801 (24.40)	0.0680 (3.28)		29.7199 (1.39)	0.755
Stock09	7.043 (0.83)	0.03427 (30.02)	0.1056 (5.29)	-0.3054 (1.45)		0.832
	-17.685 (2.63)	0.03768 (28.51)	0.0823 (4.05)		43.0651 (2.17)	0.834
Change in Stock						
Cstock06	6.413 (2.42)	0.00378 (10.64)	0.0175 (2.82)	-0.1642 (2.51)		0.397
	0.770 (0.37)	0.00374 (9.50)	0.0140 (2.13)		-0.2744 (0.31)	0.380
Cstock07	2.839 (1.28)	0.00810 (27.14)	0.0229 (4.39)	-0.0951 (1.73)		0.799
	-1.926 (1.36)	0.00818 (26.41)	0.0189 (3.59)		4.3980 (0.97)	0.797
Cstock08	1.413 (0.56)	0.00883 (25.88)	0.0271 (4.54)	0.0048 (0.08)		0.787
	-5.553 (2.71)	0.00916 (25.01)	0.0221 (3.64)		14.521 (2.32)	0.792
Cstock09	-2.709 (1.01)	0.00680 (18.90)	0.0158 (2.51)	0.0058 (0.09)		0.655
	-4.686 (2.21)	0.00698 (17.81)	0.0134 (2.08)		7.2016 (1.15)	0.657

Of the 1.23 million commuters residing in zip codes where at least one person owned a hybrid between 2005 and 2009, 0.26 million (or approximately 20%) commuted more than 25 miles to work. The advantage of the SHCOST variable being generally positive from the standpoint of electricity transmission is that those travelling the furthest distances tend to reside where there is less population density than those commuting shorter distances. That greater dispersion is likely to spread demand pressures on transformers. Basically, commuters experiencing the highest cost pressures associated with the rising costs of commuting using ICEs are most apt to purchase hybrids and, by the same token EVs. Rising gas prices in particular drive demands for hybrids and EVs.

As with the larger data set, CCEA also tested this subset to see if the purchase of hybrids the previous year influenced changes in the stock of hybrids; that is if the demonstration effect remained in play. Results in Table 8 confirm this point. Inclusion of the lagged change in stock the previous year is everywhere positive and does improve the explanatory power of the estimate.

These three different indicators of change in the capital stock yield a range of partials for the rates of change in capital stock for a given change in TAX75, AAGI, and SHCOST. In all cases the impact of the recession may be distorting the results for 2009 as indicated by the less than stellar performance for that year's estimates.

Table 8: Determinants of Demonstration Effect in Stock Variations by Connecticut Zip Code (n=229)

Dependent	**Constant**	**TAXF75**	**AAGI**	**$CSTOCK_{(t-1)}$**	**$SHCOST_t$**	**Adjusted R^2**
Stock						
Cstock07	-2.099 (1.82)	0.0063 (20.86)	0.0124 (2.86)	0.4862 (10.79)	4.7217 (1.28)	0.866
Cstock08	-3.849 (2.09)	0.0039 (7.61)	0.0133 (2.39)	0.5106 (7.59)	10.116 (1.80)	0.834
Cstock09	-3.187 (1.54)	0.0043 (5.90)	0.0067 (1.05)	0.2924 (4.29)	3.4697 (0.57)	0.682

The above criteria and equations indicate that hybrids are concentrated more heavily in certain zip codes, hardly surprising given different concentrations of people and particularly financially qualified new vehicle buyers among various zip codes. Chart 1 below indicates the concentration of hybrids among zip codes with relatively high concentrations of those with AAGI above $75,000 and concentrations in line with the estimated equations. For example, 3.42% of registered hybrids in 2009 were located in the zip codes containing the top 1% of the shares of the population with AAGI above $75,000 in 2009. Combining the determinants through the above equation, the top one percent of the zip codes accounted for 4.5% of hybrids in 2009. Except for observations in the 8% range, the equation general y identifies equal or greater concentrations than determined by TAXF75, the affordability criterion.

Zip codes included in the top one- to five-percent of determinants of concentrated hybrid adopters are listed in Table 9. Of the 11 included zip codes, five in **bold text** were either different or ordered differently according to each of the criteria, suggesting that both the single criterion and the joint criteria determined by the estimating equations are useful in identifying locales of likely early adopters of innovative vehicles. The top five percent of the zip codes accounted for 16.09% of the stock of hybrids using the single TAXF75 criterion and 16.48% deploying the estimated equation. None of the zip codes dropped from the larger sample met the TAXF75 criterion.

Chart 1: Percentage Concentration of Hybrids in Top Percentage of Zip Codes for TAXG75

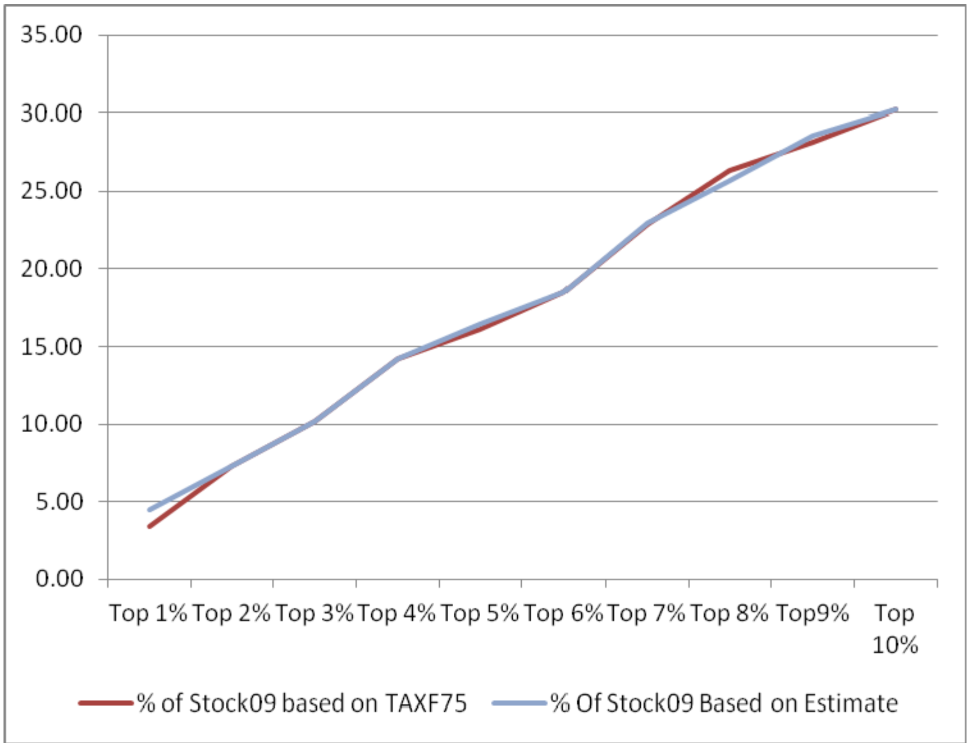


Table 9: Zip Codes of High Concentration 2009 (BOLD zips are in different percentiles)

Top %	Taxf75	Equation
One	**06492 Wallingford** 06902 Stamford	**06880 Westport** 0 6902 Stamford
Two	**06880 Westport** 06010 Bristol	**06492 Wallingford** 06010 Bristol
Three	06033 Glastonbury, 06877 Ridgefield	06033 Glastonbury, 06877 Ridgefield
Four	06410 Cheshire 06457 Middletown **06489 Southington**	06410 Cheshire 06457 Middletown **06820 Darien**
Five	**06082 Enfield** **06820 Darien**	**06840 New Canaan** **06082 Enfield**

It is these zip codes with higher concentrations of hybrid ownership that may need additional transformer capacity as demand grows for EVs. As noted earlier, the timing of the need for additional transformer capacity will depend critically on whether or not EV owners can be persuaded to charge their vehicles in off-peak rather than on-peak hours.

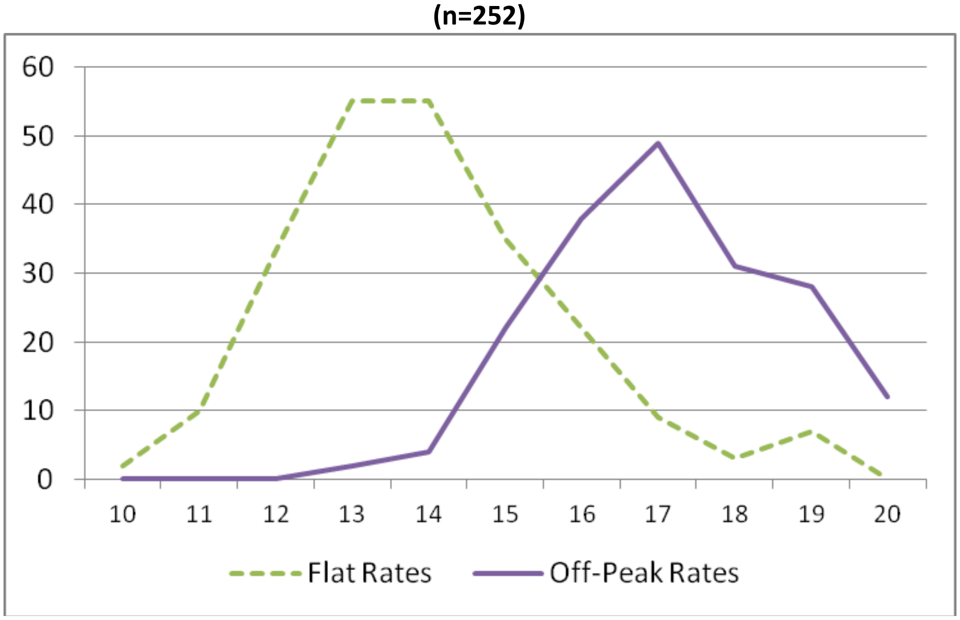
Hybrid Adoption

In order to understand the timing for upgrading transmission systems in Connecticut, CCEA has examined growth rates for hybrids by zip code from 2005 to 2009. Despite the 2009 recession, Connecticut annual growth rate for the adoption of hybrids was 50.1% year-over-year during this five-year period. Rates within zip codes vary considerably. Extrapolating the hybrid adoption rates at the zip code level as well as rates of growth in total vehicle registration permitted CCEA to estimate market penetration rates for EVs over time.

Future EV Market Penetration Rates

Bearing in mind that hybrids have been on the market since 2001, market penetration of EVs would require transmission upgrades from the 11th year based on flat rates for electricity and the 13th year based on off-peak electricity rates. As shown in Chart 2, annual differences in transmission upgrades between the two rate scenarios are significant with many zip codes requiring early upgrades under flat rates relative to off-peak ones. During the first 15 years, this contrast is stark with 190 requiring up-grades under flat rates and 28 under off-peak rates. Even 20 years from the introduction of EVs 231 of the 252 zip codes examined would require upgrades under flat rates compared to 186 under off-peak rates.

Chart 2: Number of Zip Codes Requiring Improved Transmission Annually from Year of Introduction (n=252)



A slowing of the rate of adoption of innovative vehicles could curb these requirements. Should the spread between off-peak and on-peak demands for electricity begin to close, so would the spread in relative rates. A slowing in the rates of adoption of EVs could also arise as the status attached to owning novel vehicles ebbs, somewhat parallel with the slowing rates of adoption of electronic products. As noted in the section on competitiveness, there are a myriad of factors that can impact relative costs of using EVs versus other vehicles.

Future Electrical Transmission Upgrades: Selected Areas

Charts 3a to 3d illustrate concentrations of zip codes requiring transformer and transmission upgrades throughout the state. With the first Connecticut registration of 10 Tesla Roadsters in 2008, CCEA takes that to be the launch year for EV sales in the state.[21] During the 15th year after the launch year, 2022, Chart 3a captures concentrations of zip codes requiring upgrades if electricity rates are kept flat with the darker red colors depicting the highest concentrations of EVs with a 5 mile radius around zip codes needing upgrading and the lighter colors indicating a need for upgrading with low concentration levels among the zip codes. Significantly, data for south central are missing but are estimated in subsequent sections.

Chart 3a: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022
Flat Rates (n=252)

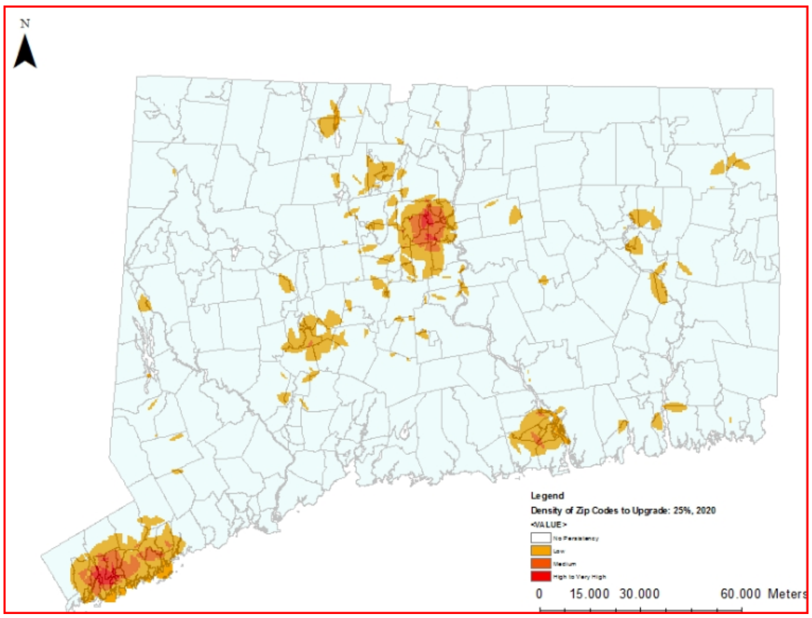
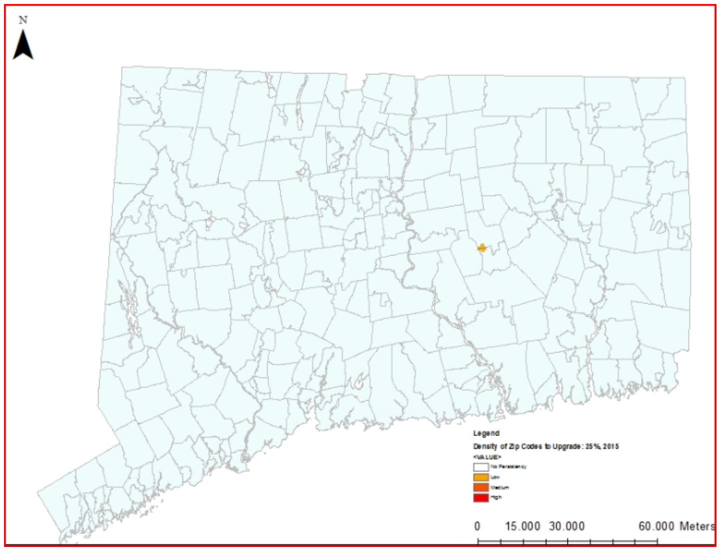


Chart 3b repeats the above procedures but uses off-peak rates for recharging EVs. Because transformer upgrades are not required under those conditions until EV market penetration rates reach 25%, few upgrades are needed and there is practically no concentration of those zip codes. The differences between charts 3a and 3b suggest that there will be little incremental pressure on other transmission facilities with off-peak charging of EVs in contrast with electricity delivered at flat rates.

[21] GM had earlier sales of experimental vehicles but may have recalled some or all of them.

Chart 3b: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022

Off-Peak Rates (n=252)



The next two Charts view the situation five years later in 2027. They illustrate that transformer upgrades will be required by that time and, given the concentrations of zip codes requiring upgrades additional transmission and or capacity in the Greater Hartford and the south-west are likely to be required. The intensity of those needs and their concentrations are much greater under flat rates, Chart 2c, than off-peak ones, chart 3d.

Chart 3c: Concentrations of Zip Codes Requiring Transmission Upgrades in 2027
Flat Rates (n=252)

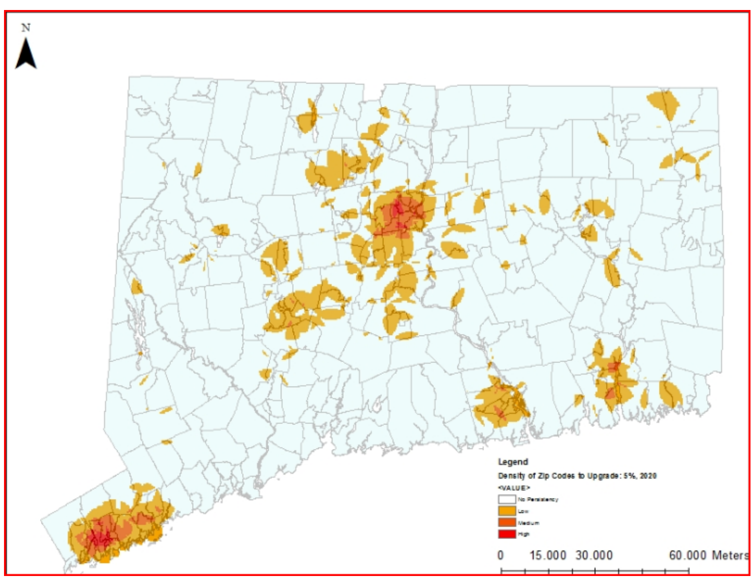
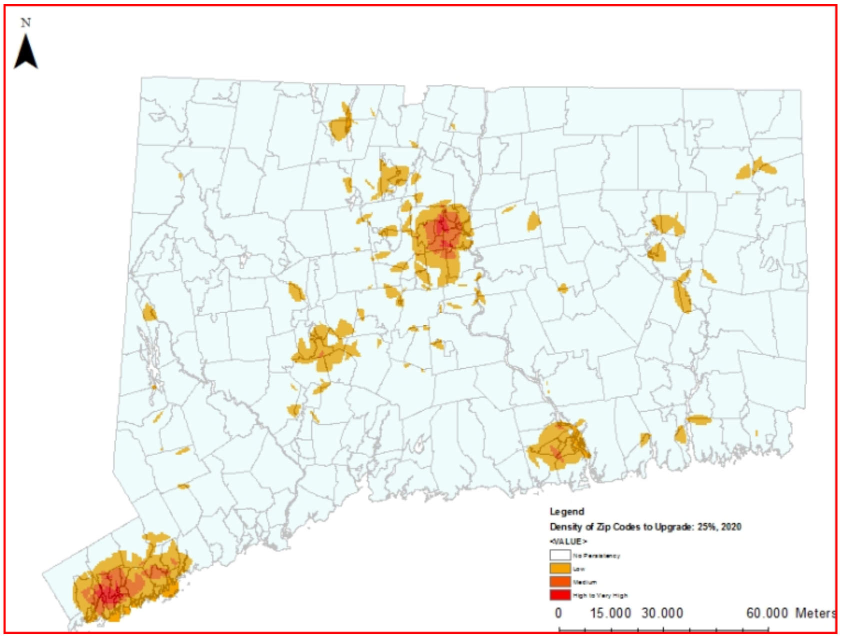


Chart 3d: Concentrations of Zip Codes Requiring Transmission Upgrades in 2027 Off-Peak Rates (n=252)



Greenhouse Gas and Particulate Matter Savings: Selected Areas

Greenhouse gas (GHG) and particulate matter (PM) impacts are assessed from the standpoint of Connecticut residents. For that reason, the paper is silent on the issue of additional GHG releases associated with the production of batteries installed in EVs. Historically, such releases have been about 2-3 tonnes per battery; yet, the environmental assessment of the new battery production plant in far-away Michigan is silent on this issue, suggesting that such releases may be considerably smaller in the new plant. In any event releases from battery manufacturing are expected to have little direct impact on Connecticut.

In its 2005 guidelines on calculating GHGs from a typical passenger vehicle in CO_2 equivalents (CO_{2eq}) annual emissions, DOE concluded that emissions from a typical vehicle should be equated to 5.5 metric tons per year of CO_{2eq}. Two recent standards changes affect GHG estimates: (1) average driving distances increased from 12,000 miles in 2005 to 15,000 miles in 2009 and (2) gasoline efficiency increased so that modern light vehicles, weighted by cars and light trucks, average 26.0 miles per gallon in 2009 rather than 23.3 in 2005. This leads to a revised release of 6.16 tonnes annually per ICE removed from the road. In addition, the adoption of EVs has been capped at 90% of registered light vehicles in each zip code. Data are available on GHG savings for 252 Connecticut zip codes. The resulting gross saving in Connecticut GHGs, prior to electricity generation are 120 thousand tonnes of CO_{2eq} by the 10^{th} year and 5,887 thousand tonnes by the 20^{th} year as illustrated in Chart 4.

Chart 4: Gross Reduced GHGs from Adoption of EVs (1000's tonnes of CO_{2eq}, n=252)

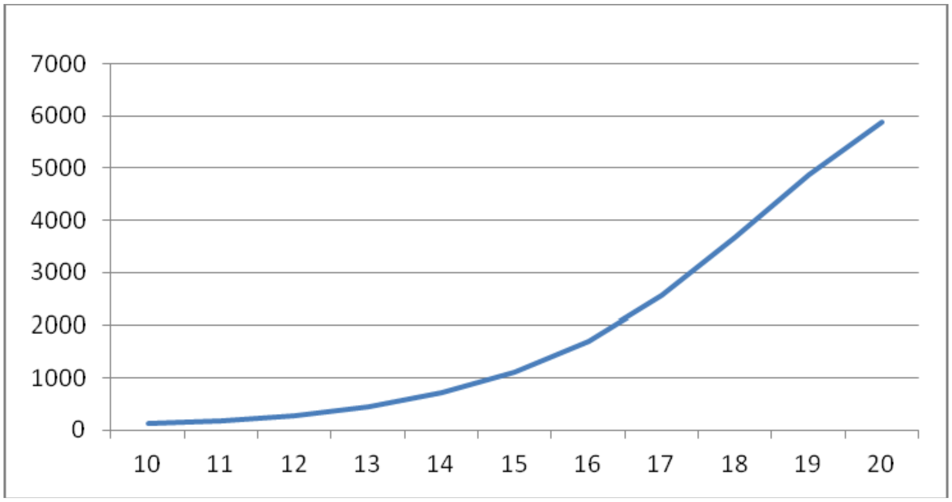
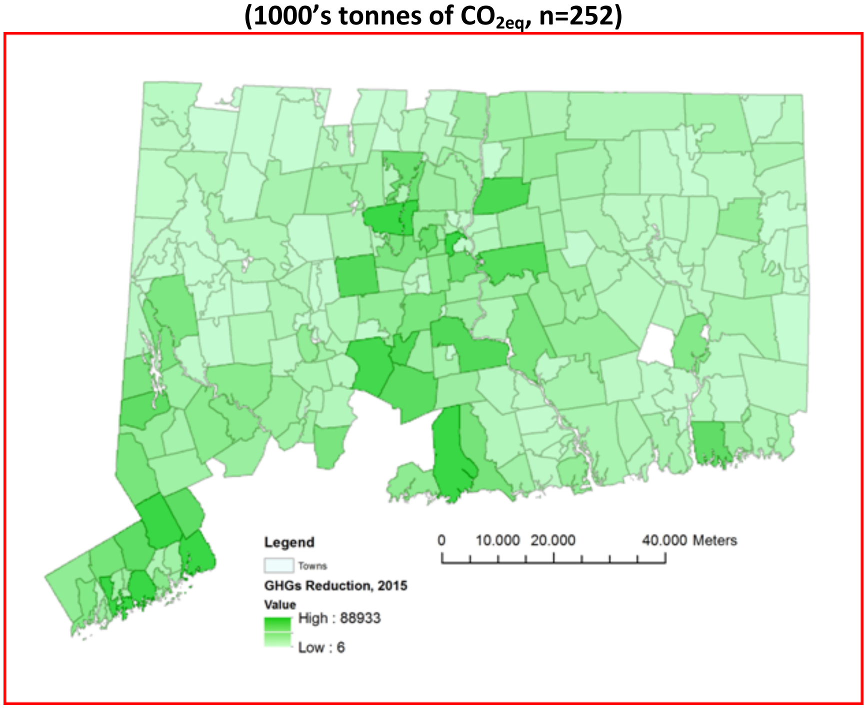


Chart 5a shows the counties lowering their GHGs through EV adoption, 15 years after initial adoption, and Chart 5b, 20 years after initial adoption. Hartford (351,858 t/y) and Fairfield (295,052 t/y) counties will have the highest savings 15 years after initial adoption. New Haven ranks third (154,467 t/y) among the counties for which CCEA has hybrid registration data.

Chart 5a: Counties with Concentrated Reductions in GHGs in 2022

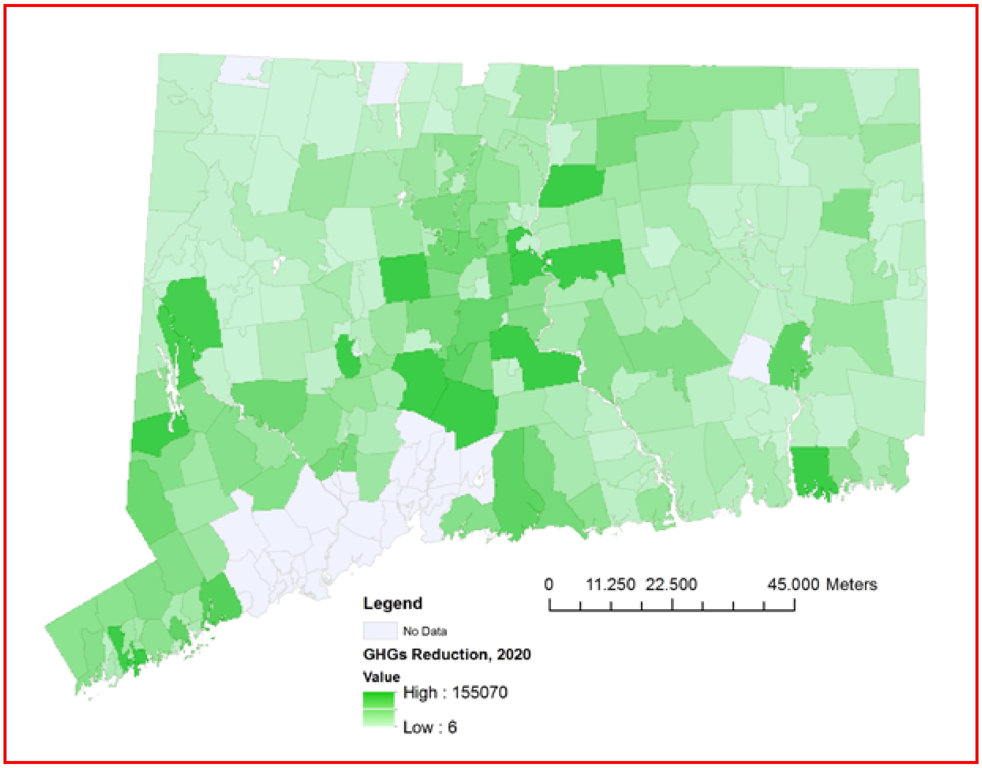
(1000's tonnes of CO_{2eq}, n=252)



Twenty years after the initial adoption, the scene changes, with more weight being placed on the more densely populated zip codes, as illustrated in Chart 5b. Among those benefiting the most from cleaner ambient air are again Hartford (1,659,655 t/y) and Fairfield (1,306,613 t/y), followed by New Haven (1,018,787 t/y). Southern areas around Darien-Stanford (close to the border with New York) and in the Southern-Central area (Wallingford, Cheshire, Guilford) show the highest concentration of savings. This trend changes slightly in 2020, when the Western area of the state (New Milford and other towns close to the western border) enjoys increasing bnefits. Savings appear to be spatially concentrated in the zip codes where upgrades are needed (Stamford area and Hartford area).

Chart 5b: Counties with Concentrated Reductions in GHGs in 2027

(1000's tonnes of CO_{2eq}, n=252)



EV innovations are expected improve to improve their embodied technologies over time due to:

1. More efficient and longer lasting batteries;
2. A greater variety of vehicles with different electricity capacities for extended mileage; and,
3. Squeezing of profits with increased competition.

GHG savings are geographically clustered, as Chart 5a and 5b show for the years 2022 and 2027 respectively. The counties omitted due to lack of data are of potential significance.

Estimates for Remaining Zip Codes

From the above data it is apparent that observations are missing for the entire south central part of the state where much of the population is concentrated. To overcome this problem CCEA utilized the equations in Table 1 to estimate hybrid purchases in each missing zip code. It was also necessary to estimate the stock of registered light vehicles for the same zip codes. To attain these estimates CCEA utilized similar estimating procedures as earlier but, given the lower prices of all new vehicles utilized a lower affordability criterion of filing a tax return rather than the $75,000 used for estimating demand for hybrids. This broader affordability criterion dominates estimates for the registered stock of light vehicles as shown in Table 10.

Table 10: Determinants of Registered Stocks by Connecticut Zip Code (n=275)

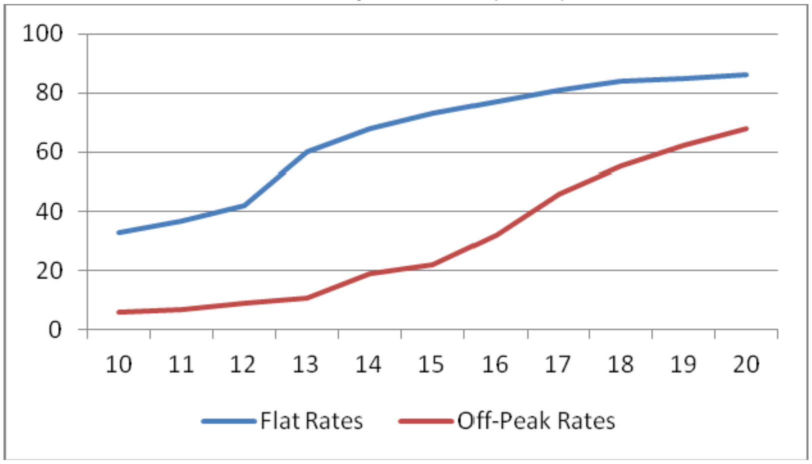
Dependent	TAXF	SHMULTI	Adjusted R^2
Registered			
Registered05	1.11694 (110.27)	-1.9299 (0.95)	0.976
Registered06	1.10184 (146.07)	-0.8676 (0.58)	0.986
Registered07	1.10968 (162.51)	-0.3424 (0.26)	0.989
Registered08	1.08565 (180.83)	0.7867 (0.66)	0.991
Registered09	1.08285 (206.03)	0.5238 (1.47)	0.993

Within all these 89 additional zip codes estimated registrations amount to 423,005 in 2010, of which 10,733 are anticipated to be hybrids. Such estimates cover a significant share of total Connecticut registrations and hybrids on the road. Over time, increasing shares of these will be hybrids many of which will be used and therefore more readily available to many owners.

CCEA deployed the above to estimate registered vehicles by year in 89 missing zip codes, and repeated the above procedures to determine critical timing for upgrading transformers utilizing flat-rates and off-peak rates for fueling EVs.

By year 10, hybrids constituted more than 5% of registrations of light vehicles in 36 zip codes, but exceeded 25% in 6 zip codes. In all of these cases, the number of registrations in these zip codes was small, with less than 218 vehicles estimated to be registered in 2010 in the largest of the areas. Among the exclusions, 318 were expected to be registered in zip codes where hybrids exceeded 5% of the estimated of registered vehicles. Despite a greater share of zip codes approaching transformer capacities sooner, these estimates result in the same patterns with off-peak rates facilitating delays in up grading transmission capacities, relative to the results with flat rates as indicated in Chart 9, that parallels the earlier Chart 2.

Chart 9: Estimated Cumulated Zip Codes Requiring Improved Transmission from Year of Introduction, Previously Excluded (n=89)



Statewide Impacts

Based on the early growth rates in hybrid adoptions throughout Connecticut by 2022, CCEA projects that 222,000 EVs will then be on the roads, growing to 1,198,000 by 2027. As before, the timing of requirements in transformer upgrades and the concentration of zip codes requiring upgrades will dramatically differ with flat and off-peak rates and over time.

Transformer Upgrades

Completion of residential zip code data also facilitates estimates for the concentration of the future requirements to upgrade transmission in the state by zip code, as the next set of four charts shows. The results are similar to the earlier set of four charts, except that some zip codes omitted earlier indicate greater intensities around Hartford than were captured previously under off-peak rates in 2022. In addition, concentrations in and around New Haven and elsewhere in the central southern part of the state also emerge as needing transmission upgrades. As noted earlier, there are far more zip codes under stress and greater concentrations needing upgrades under flat rates, as chart 10a shows, than in Chart 10b, with off-peak rates and recharging. The color designating high concentrations does not even appear in Chart 10b.

Chart 10a: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022 Flat Rates (n=341)

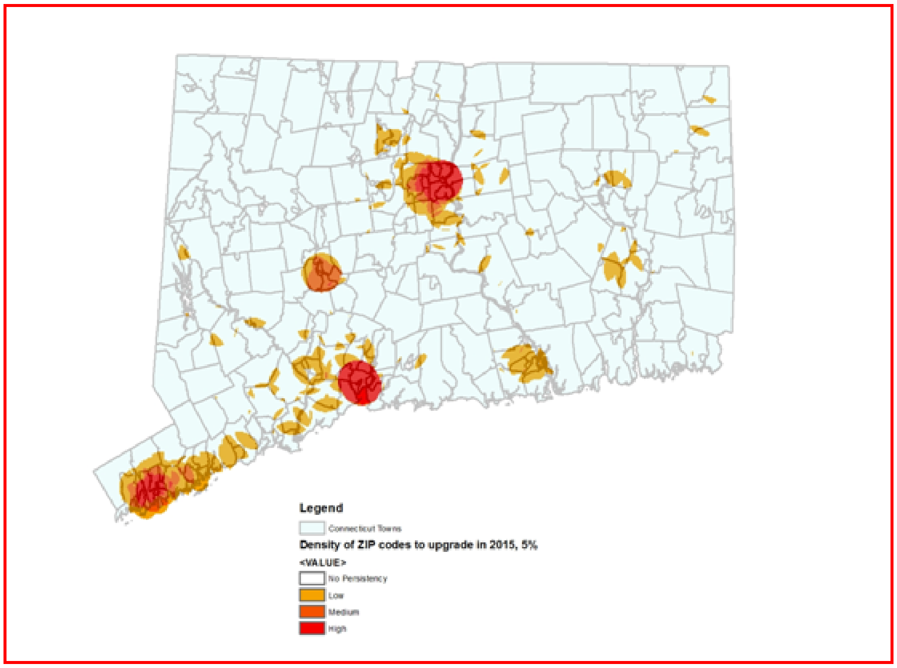
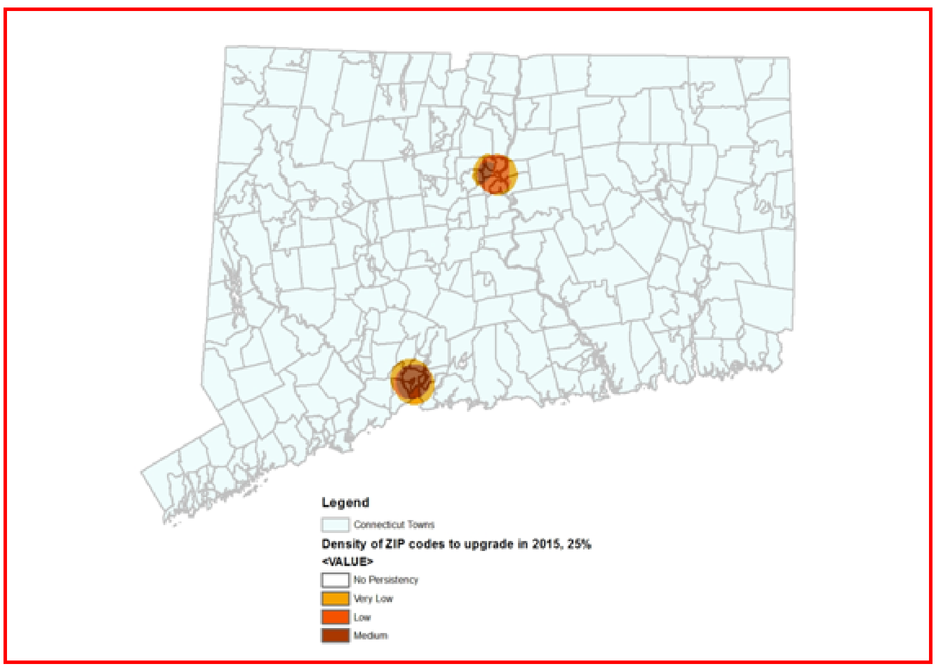


Chart 10b: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022

Off-Peak Rates (n=341)



By 2027, the areas needing upgrades and their concentration will increase considerably with flat rates, Chart 10c, shows, albeit fewer transformers will require upgrading while the transmission system is less stressed using off-peak rates chart 10d.

Chart 10c: Concentrations of Zip Codes Requiring Transmission Upgrades in 2027

Flat Rates (n=341)

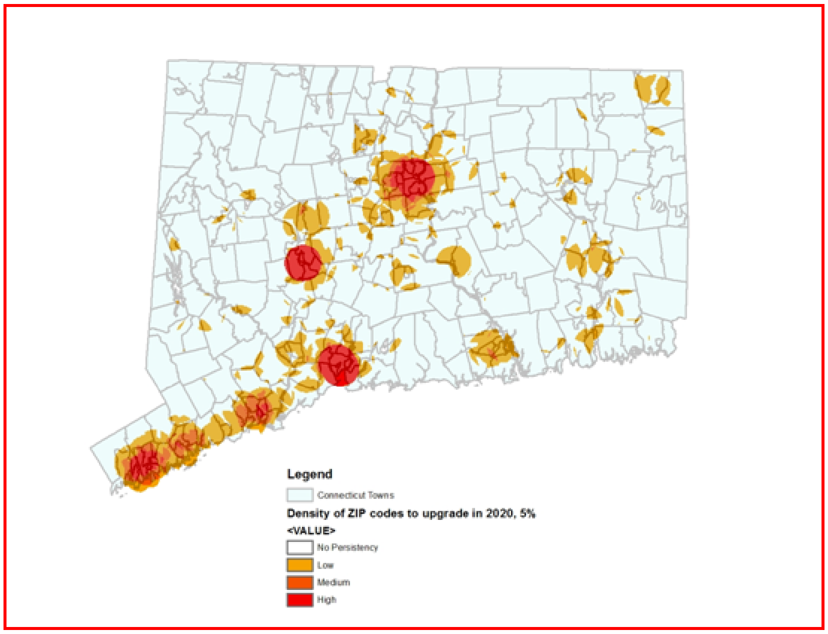
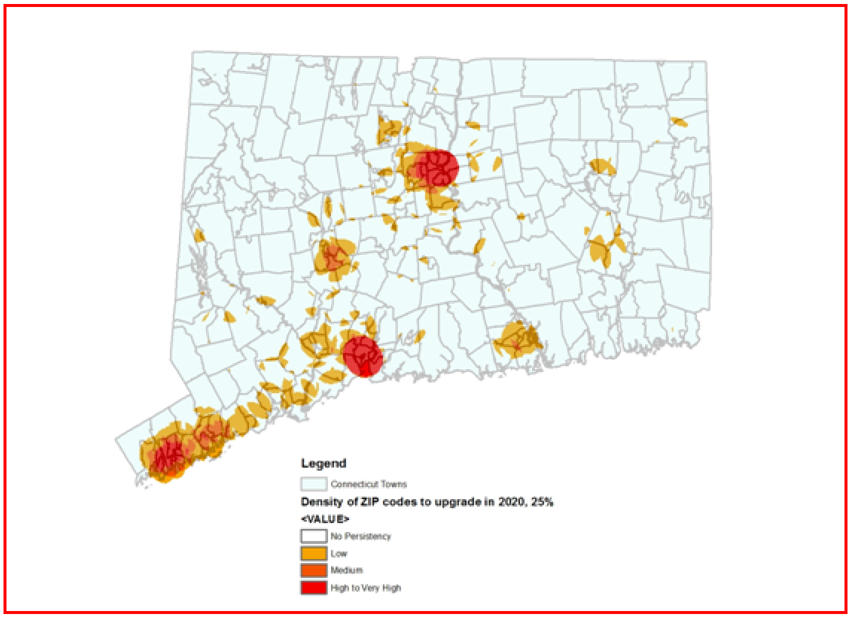


Chart 10d: Concentrations of Zip Codes Requiring Transmission Upgrades in 2027

Off-Peak Rates (n=341)



GHG Savings

These estimates also allow CCEA to complete its previous mapping for most of the state. By 2022, CCEA projects GHG savings in the 89 additional zip codes to reach 240,000 tonnes of CO_{2eq} growing to 1,479,000 tonnes of CO_{2eq} by 2027. (Charts 11a-11b)

Chart 11a: Counties with Concentrated Reductions in GHGs at Off-Peak Rates, 2022 (1000's tonnes of CO_{2eq}, n=341)

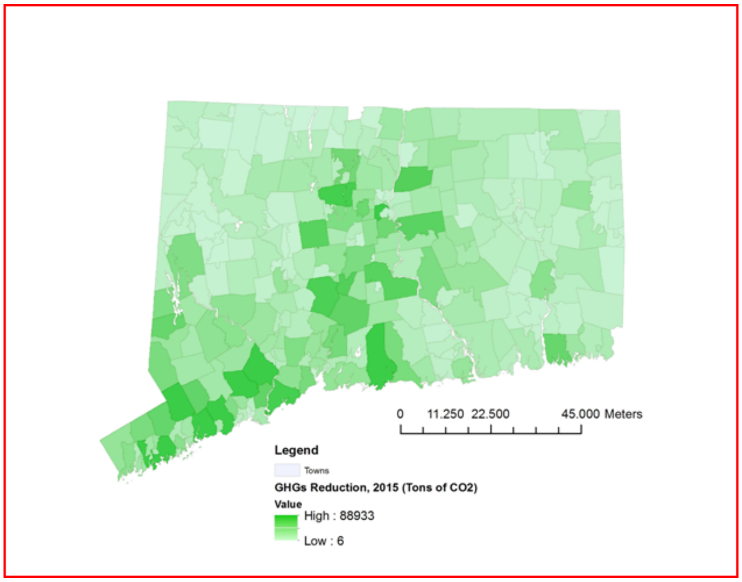
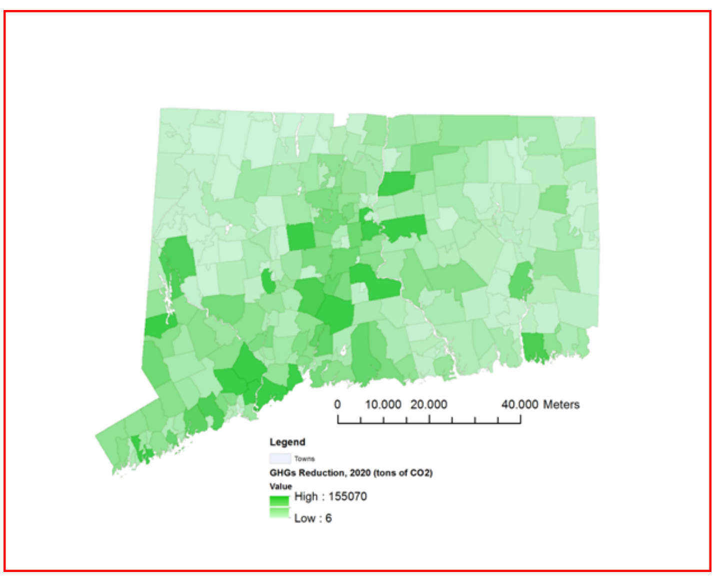


Chart 11b: Counties with Concentrated Reductions in GHGs at Off-Peak Rates, 2027 (1000's tonnes of CO_{2eq}, n=341)



Health Impacts

Even with knowledge of the likely rates of adoption of EVs in Connecticut, health impacts in Connecticut are difficult to determine because most health impacts have been estimated for national programs and because plumes of GHGs and PMs migrate among states. Were rates of adoption of EVs in North America to proceed at the same rate as suggested for Connecticut then CCEA can use the results from the analysis of the health impacts under the Clean Air Act as being indicative with three important caveats. The savings in GHG from the 90% of light vehicles becoming EVs would be about 50% greater than the expected GHG reductions under the Clean Air Act.[22] Due to the small percentage of light vehicles burning diesel reductions of PM may be a smaller percentage than under the Clean Air Act. The estimates for the impact of the Clean Air Act were for New York where population is more concentrated and more vulnerable than in Connecticut. While the greater reductions in GHG could have a greater impact that may not occur with Connecticut's more broadly disbursed population and less concentration of diesel fueled vehicles.

CCEA then takes the previous results as a proxy for the likely health impacts. Namely, avoidance of 75 deaths, 265 athsamatic hospital adminsions, 255 other hospital admissions for other respiratory diseases, 3,500 emergency doctor visits, 180,000 athsmatic atacks requiring additional medication, 930,000 days where patients' activities are restricted due to illness and 2,000,000 days in which patients experieince less serious respiratory illnesses.[23]

Conclusions

This study has found that:

- Off-peak electricity rates are integral to managing the dynamics associated with increased electricty demand derived from the adooption of EVs.
- If demands for EVs progress at the same pace as the adoption of hybrids 2005-2009 but capped at penetration of 90% in the light vehicle market, in 2022, Connecticut EV registrations will grow to 222,000 reaching 1,198,000 by 2027.
- Initial requirements to upgrade transformers will take about 10 years to materialize under flat electricity rates and 13 years under peak/off-peak rates.
- By 2022 under flat rates, transformer capacity constraints would need to be redressed in 263 zip codes of the 341 residential ones tested but only 50 zip codes if off-peak rates were adopted and EVs fueled during off-peak periods.
- Concentrations of zip codes needing transformer upgrades indicate urban surburbs that may require transmission attention under off-peak rates by 2022 include:
    a. Hebron
    b. Marlborough

[22] George D Thurston, *Scientific Research for Ozone and Fine Particulate Standards*, **Pace Environmental Law Review** Vol. 16, Article 3, 1998 pp 2-3 indicates that EPAs regulations under the Clean Air would result in about a 10% reduction in GHGs and PMs. CCEA's estimate for EVs by 2027 is slightly in excess of 15%.

[23] Ozone and Particulate Matter Standards: Hearings on the Clean Air Act Before the Subcommittee on Clean Air, Wetlands, Private Property and Nuclear Safety and the Comm. on Env't and Public Works, 105th Congress (1997).

- Additional urban centers and their surburbs that may require attention under off-peak rates by 2027 include:
    a. Greater Hartford
    b. Essex-Westbrook-OldSaybrook
    c. Stamford-Greenwich-Norwalk-Darien
    d. Waterbury-Prospect
- Plume analysis aside, zip codes likely to receive the largest benefit from emission reductions by 2022, include:
    a. 06106 (Hartford)
    b. 06897 (Wilton)
    c. 06902 (Stamford)
    d. 06820 (Darien)
    e. 06880 (Westport)
    f. 06437 (Guilford)
- Similarly, by 2027, the largest benefit from GHG emission reductions include:
    a. 06010 (Bristol)
    b. 06902 (Stamford)
    c. 06457 (Middletown)
    d. 06492 (Wallingford)
    e. 06033 (Glastonbury)
    f. 06708 (Waterbury)
- Gross emissions savings in Connecticut from converting from ICEs to EVs are projected to reach 1.4 million tonnes of CO_{2eq} in 2022, 3.03% of total state emissions in 2006,[24] and 7.3 million tonnes in 2027, 15.84% of total state emissions in 2006[25]. The net impact of GHGs will depend on the cleanliness, or lack thereof deployed to produce the additional electricity required by EVs. Initial off-peak loads based on nuclear and power from Bay James are relatively benign.
- Since October 2010, the market for credits has been depressed at $0.05/tonne[26] so that credits based on the 2027 savings would currently be worth a paulty $365,000. The previous peak price was at $7.34/tonne on May 27, 2008 which would have resulted in an evaluation of $53.6 million.
- Better health realized through less mortality, hospital cost savings, less medical leave from work and reduced illness will approach benefits targeted under the Clean Air Act of 1997 in that GHG savings are expected to be 50% greater than under the Clean Air Act, but particulate matter reductions are apt to be less because diesel is less frequently used in light rather than heavey vehicles.

[24] http://www.ct.gov/dep/lib/dep/air/climatechange/inventory/2009_ghg_update_final_-_070110_edit.pdf
[25] http://www.ct.gov/dep/lib/dep/air/climatechange/inventory/2009_ghg_update_final_-_070110_edit.pdf
[26] CCX.

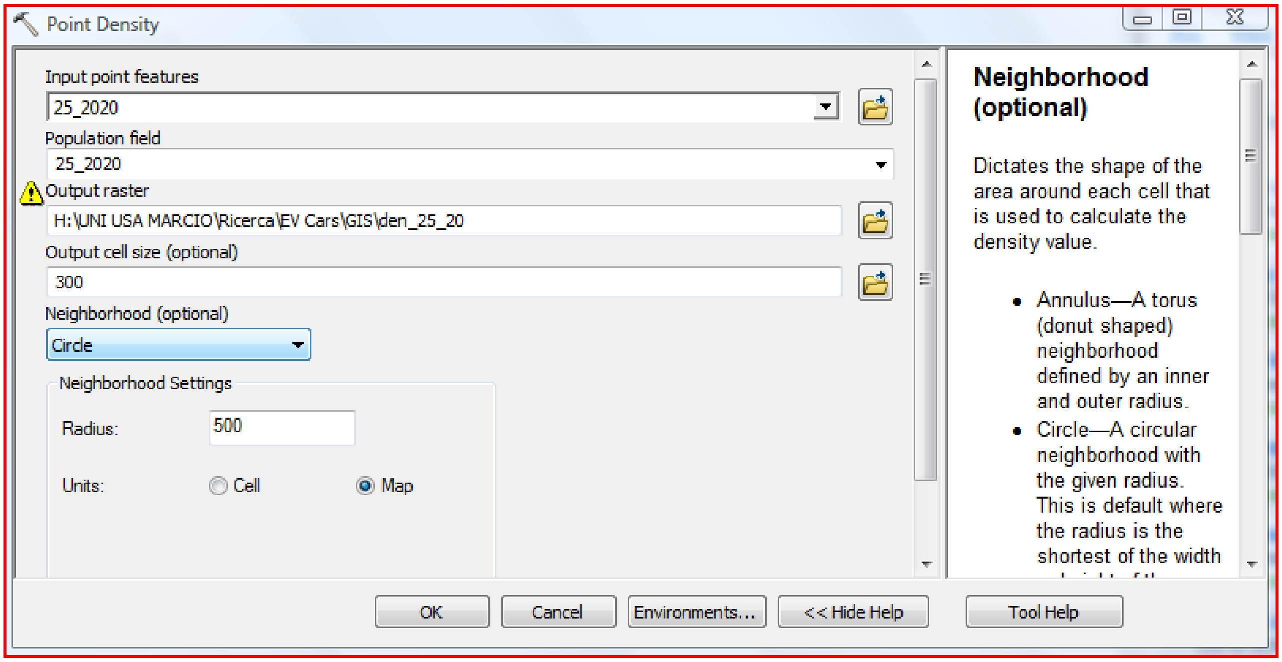
Appendix A: GIS Methodology

Geographic Information System (GIS) has been used to generate a density analysis of the zip codes where transformer and other power lines upgrades should take place in order to satisfy the new demand derived from adopting EVs. CCEA used ArcGIS 10 and its tools, importing the data from an Excel (.xls) format. CCEA used a binary description for each scenario (based on market penetration under flat and off-peak rates for electricity) and two years (2015 and 2020):

- 1 indicates the need of upgrade for a zip code in a given year.
- Conversely, 0 means no upgrade needed.

First, CCEA extracted those zip codes in need of upgrade in each scenario by year to create four new .shp files (one per scenario for each of 15 and 20 years after initial market entry). Then, we geocoded each zip code and attribute, using the "Geocode" function in ArcGIS 10. Thus, we obtained the centroid of each zip code in need of an upgrade. Using the "Point Density" tool we calculated the density (per sq.km), thus identifying the areas where upgrades are likely to be most needed. We used a proximity value of 5,000 meters, circle-shape.

Each file is a 300 by 300 meter resolution in CT State Plane (NAD 83, meters) coordinates system. Finally, each projection (except for the 25%, year 2015 scenario), has been divided into four classes of density, allowing ArcGIS to automatically break down the values, with the exception of the 25% scenario .shp file. The classes have been renamed No Persistency (to show no agglomeration), Low, Medium and High. The first of two manually-renamed layers, 25% year 2015, has been divided into four classes with the same breakdown vales as in the other two cases, such that densities can be compared. For the year 2020, 25% market penetration scenario, we renamed differently the High class. Breaking values (or group differentiators) are the same as the other maps, although the "High" Class has been renamed with "High to Very High", to express the overall higher density compared to the other layers.



GHGs emissions savings per zip code have been first joined with the state zip code map (TIGER File), using the ZIP field as the joining field, and discarding those zip codes where data were not available. Then, we converted to raster this new .shp file using the "covert to Raster" tool, imposing the Emissions, 2015 field as the value field. We used a 300 by300 meters resolution, with CT state plain (meters, NAD83) coordinate system. The result has been displayed using a stretched color scale.