Electric Vehicle Adoptions among CT Zip Codes at Flat and Off-Peak Electricity: County Impacts

Prepared for

REMI Annual Users' Conference

Lake Tahoe, 12 October 2012

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Introduction

At its most fundamental level, adoption of electric vehicles (EVs) allows consumers to substitute cleaner and lower cost transportation fuel for relative to vehicles powered by internal combustion engines (ICEs). This paper starts by applying savings in gasoline expenditures realized by EV owners in Connecticut counties to re-charging with electric and allocating their net savings to "Consumption reallocation". In this paper, the Connecticut Center for Economic Analysis (CCEA) traces the affect of this vehicle transition among the sectors and industries within Connecticut counties. An earlier paper demonstrated that with the long-term rising gasoline costs that EVs have become more cost-competitive against a growing variety of new medium and full-sized light vehicles powered by internal combustion. Current trends continuing, EVs are likely to become increasingly competitive with design improvements.

Consumer net savings on EV re-charging differ among jurisdictions that maintain flat rates and those where all EVs may be fully fueled at off-peak rates. Savings on fuel expenditures are not only smaller but also consumer reallocations are less concentrated under flat rates than off-peak ones. Correspondingly, dollar savings under off-peak charging rather than flat rates are higher and more heavily concentrated in consumer reallocations. Two initial runs establish these basic differences. Subsequent simulations with REMI then forecast environmental amenity benefits from reduced greenhouse gas emissions measured in tonnes of carbon dioxide equivalents (CO_{2eq}). This is only part of the amenity values anticipated because no account is taken of reductions in either particulate matter or noise. Because vehicle batteries are not produced in Connecticut, there is no need to include any offsetting releases embodied in EVs. For the purposes of this paper any incremental energy is assumed to be generated by green sources.

A problem that arises in all these simulations is that REMI's actual capital stock adjustments lag behind its estimated optimal capital stock. Given the importance of reliable electricity for the economy, subsequent simulations accelerate investments - closing the gap between optimal and actual capital stock in the initial scenarios. These investments are allocated to construction, engines and turbines and upgraded transmission. As noted in an earlier paper the timing and amounts of these investments will depend on the rate structure but also need to precede expanded electricity demands, not follow them. Because charging EVs at night puts less pressure on high-cost generation, transformer and transmission capacity, electricity rate structures are strong determinants of the timing of required incremental capital stock. In addition, the amount and capacity of transmission capacity will be influenced by the rollout of green rather than conventional generation or interstate transfers of electricity supply.

Background

Background information for this paper comes from earlier work on the likely adoption of EVs by zip code in Connecticut. Because adopters of innovative vehicles tend to have similar characteristics, the basic hypothesis of the earlier paper was that EV adopters will follow similar geographic patterns and rates of adoption as their hybrid predecessors. In addition, Detroit Edison, an early researcher on this issue, discovered the need to improve transformer capacities for EVs at 5% of light vehicle market penetration rates under flat rates for electricity and at 25% under off-peak re-charging of EVs.

In this paper, the EV adoption pattern starts in Connecticut eight years after hybrids. The EV initial year of adoption is 2008 when ten new Tesla Roadsters were registered in Connecticut. Based on the number of hybrids registered annually from 2005 to 2009 by Connecticut zip code[1] as well as parallel total light vehicle registrations, CCEA has projected market penetration at constant growth rates within each zip code through the forecast period. By capping EV registrations by zip code at 90% of light vehicle registrations, CCEA has estimated the number of registered EVs out to 2028. In order to obtain a sense of what happens if EV market demand flattens out, the 2028 estimate was flat lined out to 2030.

While EVs are relatively expensive compared to the average retail value of new light vehicles, because early adopters tend to have previously driven full-sized vehicles Volt price differentials may not be significant. In addition, Nissan's Leaf with five seats and 100 miles capacity powered by electricity is retailing at $35,700 prior to subsidies and in the $28,000 range after subsidies[2], thereby reducing the price gap between ICEs and EVs to the point where EVs are competitive with medium-sized vehicles.

For modeling purposes, vehicles are assumed to be driven the American average distance of 15,000 miles annually. Gasoline prices for 2010 have been set at the Connecticut average of $2.92/gallon[3] while the flat rate for electricity is 19.2 cents and the off-peak one at the cost neutral price for households' other uses of $0.11/ kwh.[4]

From the earlier paper CCEA mapped the geographic distributions of zip codes with market penetrations highly likely to warrant upgraded transformers. The need varies with both market penetration rates among zip codes and between electricity selling at flat and off-peak rates, as shown in Charts 1a and 1b for 2022.

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[1] Of the residential zip codes, vehicle registrations were known for 252, with 89 areas estimated from cross-section demographic and Internal Revenue data.

[2] http://www.nissan.ca/vehicles/ms/leaf/en/faq.aspx#/faq

[3] http://www.connecticutgasprices.com/Retail_Price_Chart.aspx

[4] Peter E. Gunther, Carstensen F. V. Graziano, M. and Coghlan, J. et al, Driving Smart Growth: Electric Vehicle Adoption and Off-Peak Rates, CCEA website, http://ccea.uconn.edu/studies/ElectrivVehichels_2011sept.pdf

Chart 1a: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022 Flat Rates (n=341)

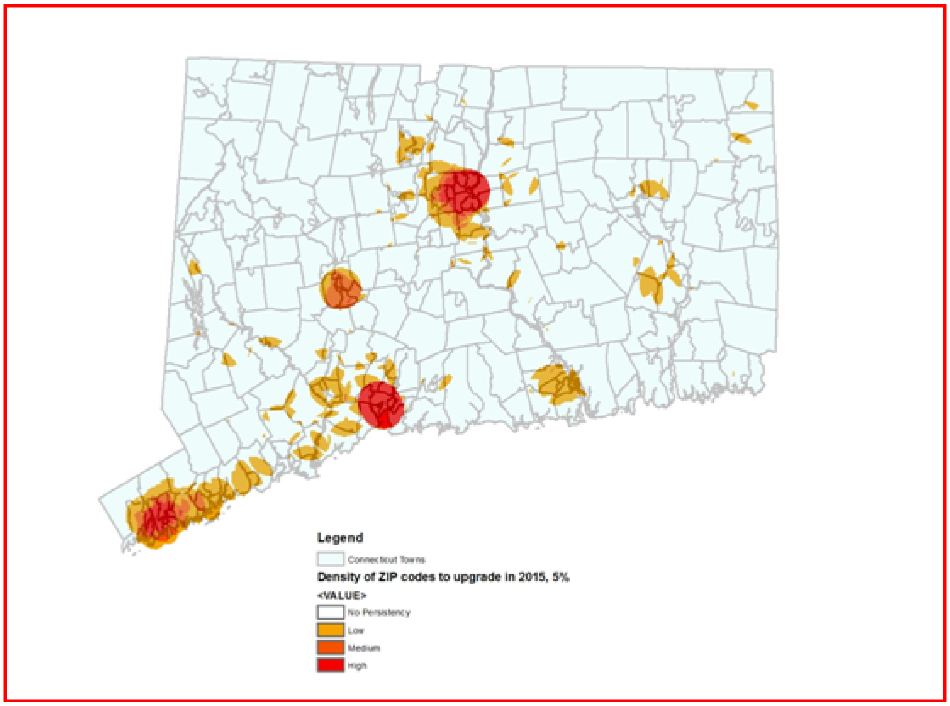
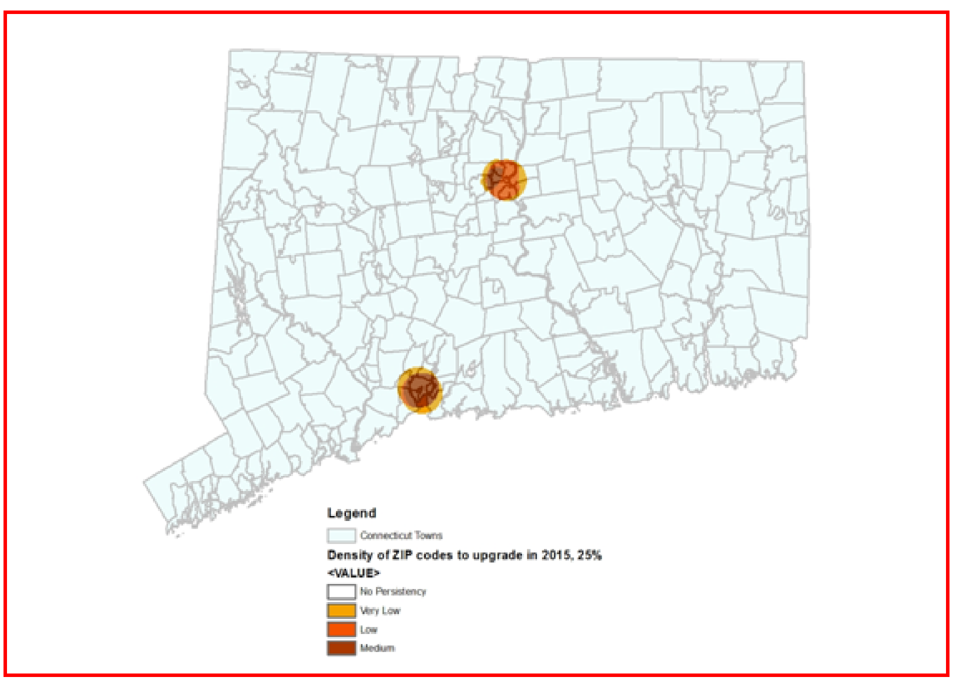


Chart 1b: Concentrations of Zip Codes Requiring Transmission Upgrades in 2022 Off-Peak Rates (n=341)



Expenditure Substitutions

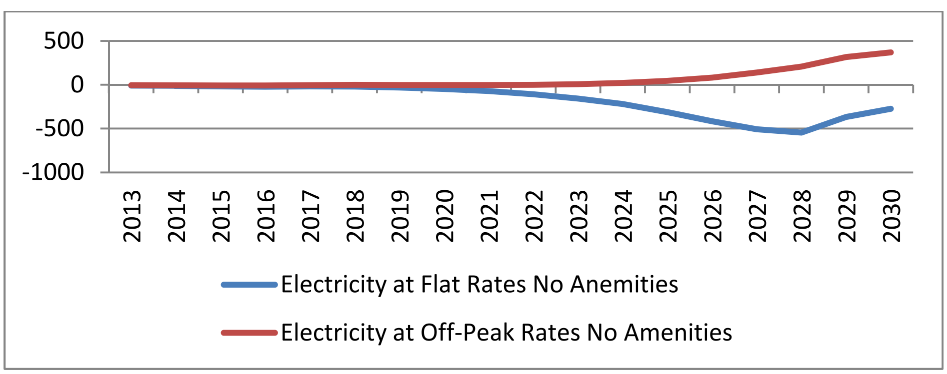
The simplest model in the transition from fossil-fueled light vehicles to EVs is to substitute electricity consumption for consumption of gasoline with residual savings being allocated to consumption reallocation. In this case, the savings in fuel are then reallocated to other expenditures and the economy modeled. Gasoline savings for each EV were estimated in 2010 at 24 miles per gallon with expected decreases for the fleet at 1% annually with the average vehicle being driven 15,000 miles/year. Gasoline savings are modeled as the drop in consumer expenditures on gasoline and oil. Because REMI runs at the county level, CCEA aggregated the zip code registrations of EVs annually into counties.[5] Electricity required per car is based on GM's specifications for Volts being driven the same distance as above. The flat and off-peak rates charged for electricity are those noted above in 2010 dollars.

Job Impacts

Flat and Off-Peak Rates

Statewide employment impacts with electricity at flat and off-peak rates are illustrated in Chart 2. While annual aggregate job impacts are not large prior to the mid 2020s, the transformation can clearly be cushioned by use of off-peak rates. With flat rates there is too little residual consumption after paying for electricity to avoid prolonged negative unemployment impacts in the state without other policies. Negative impacts on employment result from the layoffs associated with reduced demand for gasoline throughout its entire supply chain downstream from the refinery while electricity distribution is relatively capital intensive. Negative impacts are only partially offset when electricity rates are flat because the residual increase in consumption expenditures – consumer savings on gasoline less additional electricity purchases – is too small to stimulate alternative direct indirect and induced employment.

Chart 2: Connecticut Job Impacts from Adopting EVs 2013-2030 Flat and Off-Peak Electricity Rates, No Amenity Considerations (# of Jobs)



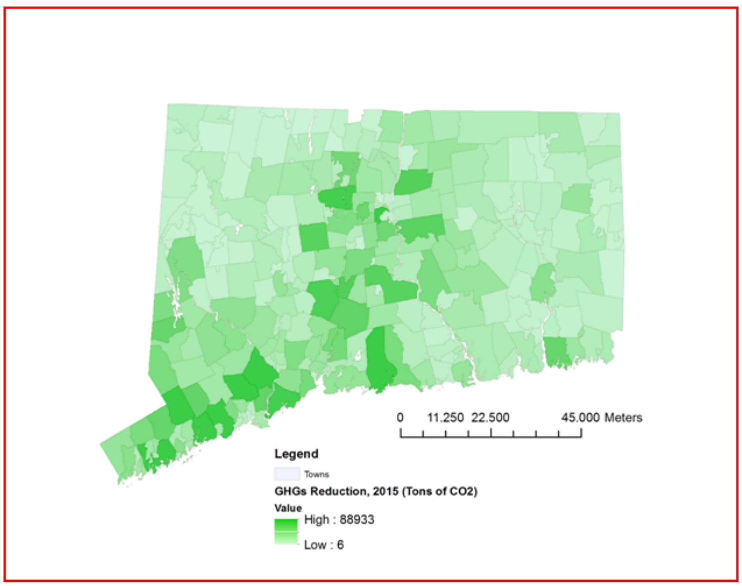
Recharging at off-peak rates results in larger offsets by increased household expenditures that lead to positive job impacts, as noted in the chart.

[5] Where five (5) zip codes straddled county lines half the registrations was allocated to each county.

Amenity Considerations

The above estimates exclude any analysis of amenities. Yet, a key factor favoring EV adoption is reductions in tailpipe GHG emissions. From Connecticut's perspective those reductions are centered on vehicle emissions. Annual emissions from light vehicles amount to 6.16 tonnes of CO_{2eq}.[6] Valued at $38.98/tonne,[7] amenity values from adopting EVs would grow from $961,000 in 2013 to an estimated $287 million by 2028 in 2010 $. These estimates only account for the elimination of GHGs - covering neither particulate matter nor noise. By 2022, CCEA projects GHG savings in the 341 zip codes to reach 240,000 tonnes of CO_{2eq} growing to 1,479,000 tonnes of CO_{2eq} by 2027. (Charts 3a-3b) The beneficial impacts of reduced GHGs are concentrated in the more heavily populated areas where the uptake of EVs is also expected to be the strongest due to shorter commuting distances. Uptake is relatively low in more sparsely populated counties such as Litchfield and Windham Counties – in the extreme northwest and northeast respectively.

Chart 3a: Counties with Concentrated Reductions in GHGs in 2022 (1000's tonnes of CO_{2eq}, n=341)



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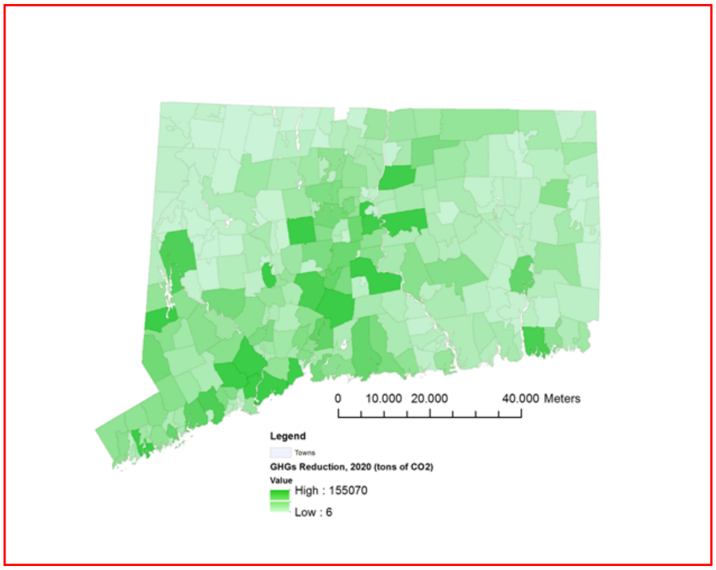
6 http://www.epa.gov/oms/climate/420f05004.htm adjusted to accommodate further distance averages and improve miles per gallon.

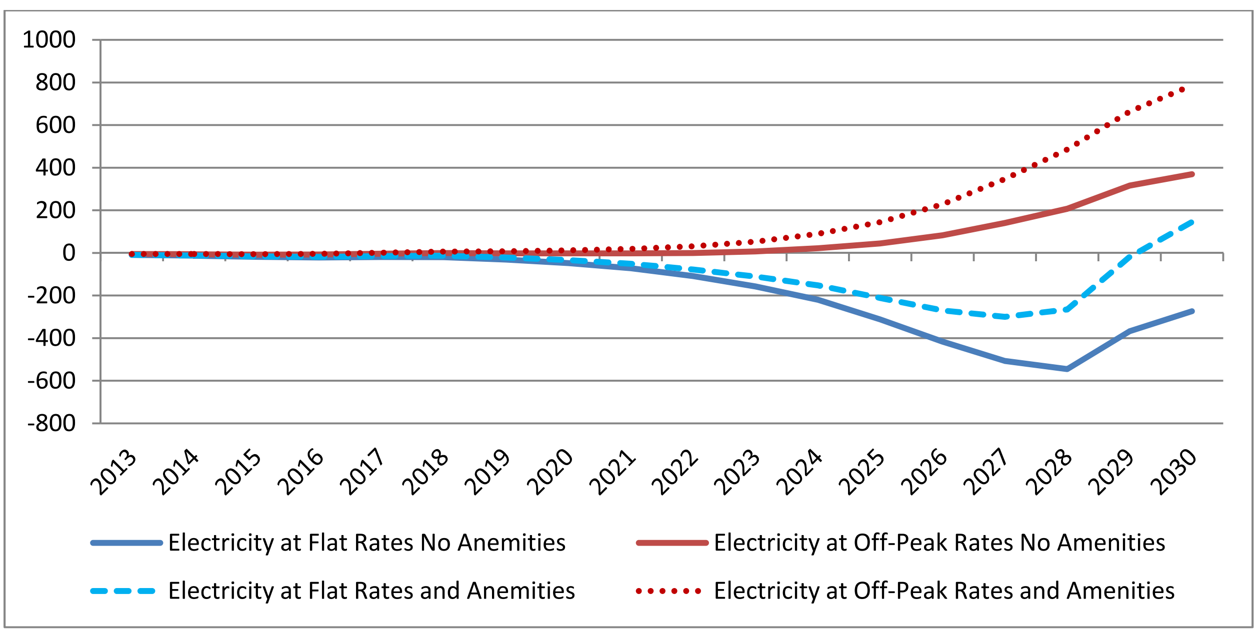
7 Technical Support Document:- Social Costs of Carbon for Regulatory Impact Analysis - Under Executive Order 12866 Interagency Working Group on Social Cost of Carbon, United States Government p. 3. "A domestic social cost of carbon (SCC) value of $33/ton in 2007 is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions." Adjusted $33 in 2007 for inflation to 2010 and converting from tons to tonnes (metric tons) obtains $38.98/tonne.

Chart 3b: Counties with Concentrated Reductions in GHGs in 2027 (1000's tonnes of CO_{2eq}, n=341)



Adding these amenity values to the impacts attracts more people to the area and improves job levels as shown in Chart 4

Chart 4: Connecticut Job Impacts from Adopting EVs 2013-2030 Flat and Off-Peak Electricity Rates with and without Amenity Considerations (Jobs)



Including the influence of both off-peak rates and amenity values significantly improves statewide employment impacts. Throughout, employment impacts are close to neutral or positive when off-peak rates lead to off-peak recharging of EVs but negative for at least a decade with or without inclusion of amenity benefits with flat-rate electricity leading to ongoing recharging of EVs. There are however significant differences in impacts among the industry sectors and counties.

Job Impacts by Sector

The decline in gasoline consumption profoundly affects service stations, a retail segment that is not fully offset by the expansion of other retail stemming from the general increase in consumption. It is after all only a fraction of the decline in gasoline sales. While it is possible to model sector employment differences annually for each of the above scenarios, CCEA chose to show results for 2025 and 2030. The off-peak rate with amenities scenario is characterized as impacting retail employment the least negatively, at a drop of 3,278 in 2030 compared to the most severely impacted scenario at 3,729, about 1.7% of all retail employment with flat rates and no consideration of amenity values. Because the flat rate scenario increases utility revenues the most and requires more capitalization than the off-peak one, utilities, construction and professional services employment outpace employment impacts under off-peak pricing. The opposite is true for sectors that serve consumer demand. Because the shock is to gasoline sales per se, other retailing activities associates with gasoline stations are assumed to continue elsewhere in the economy. There may be some chains that could consolidate those activities to survive much as other convenience store chains do elsewhere in the economy.

Chart 5a: Key Sector Employment Impacts 2025

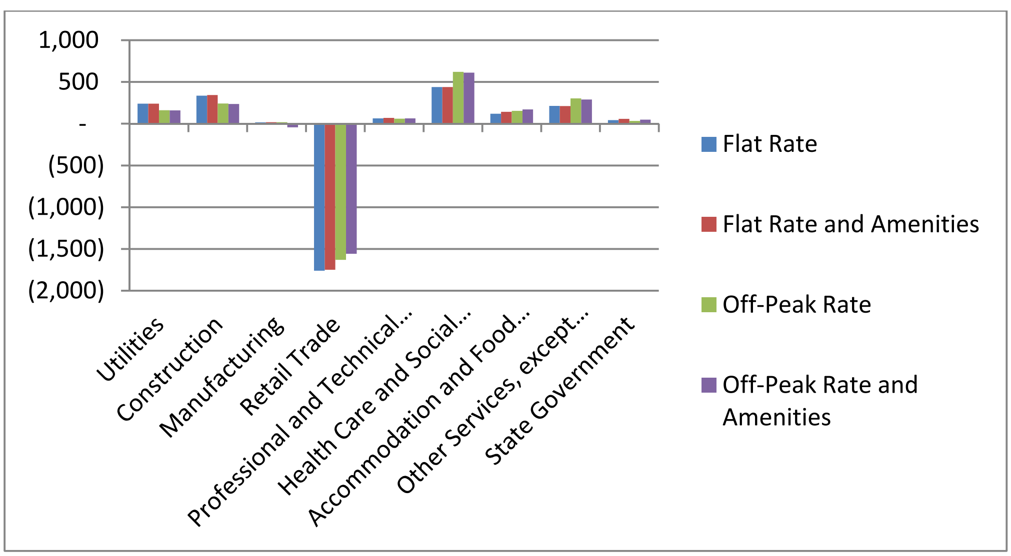
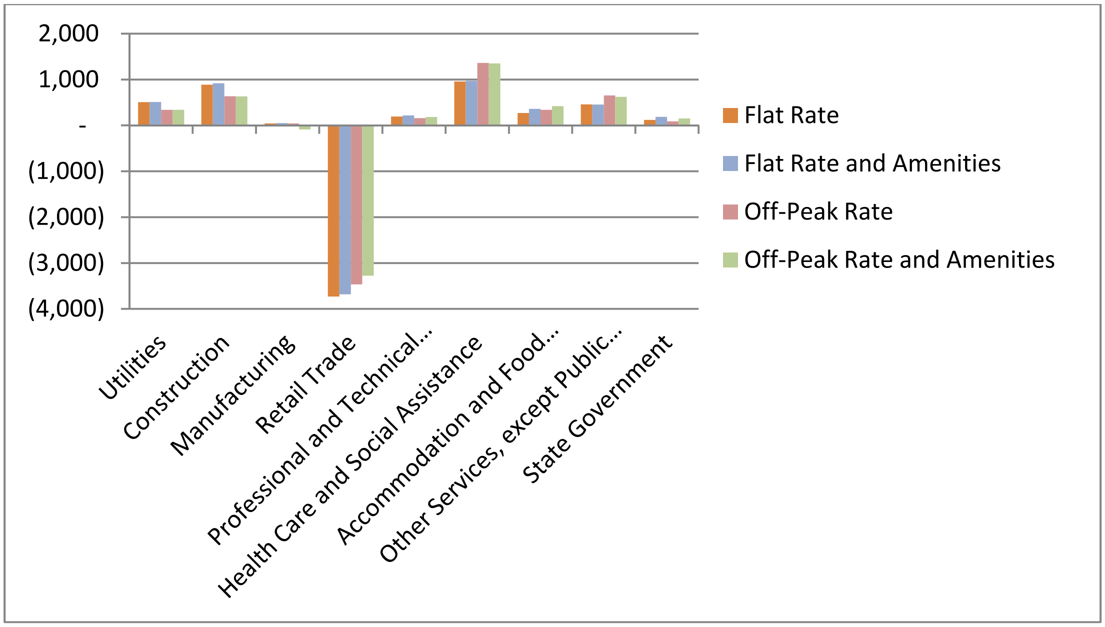


Chart 5b: Key Sector Employment Impacts 2030

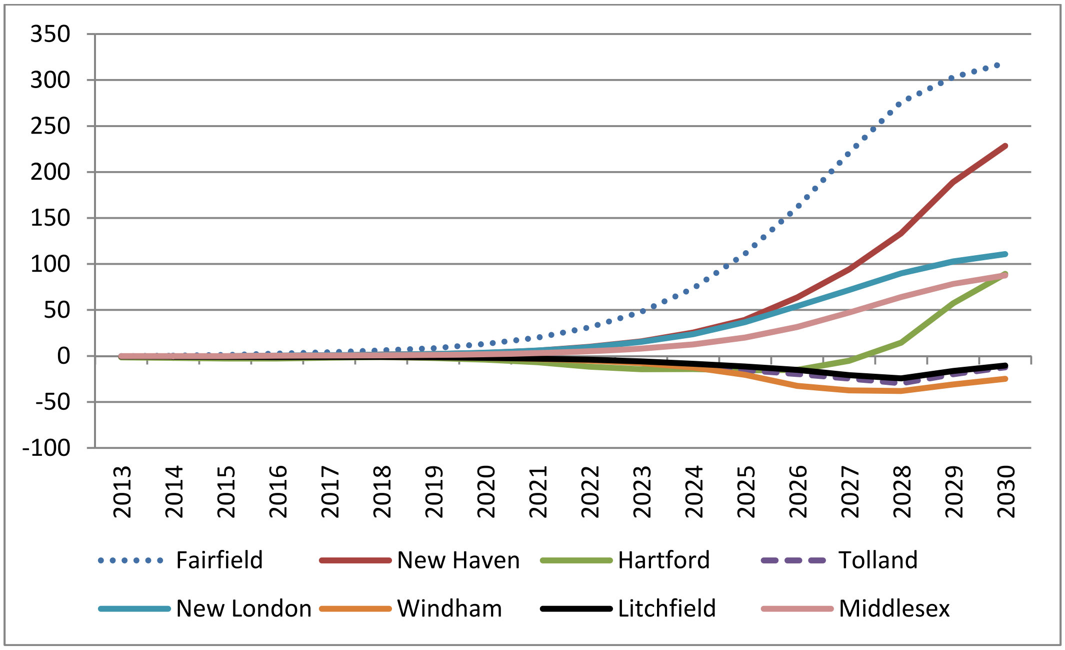


Sector labor market transitions in moving to EVs are challenging with an obvious need for retraining. There has been some consideration for converting gasoline stations to recharging stations but that direction is uncertain.

County Employment Impacts

Early indications from hybrid sales are that counties will not all embrace EVs at the same rate. Generally early adopter zip codes are typified by high average gross incomes, larger shares of income earners with gross incomes in excess of $75,000 annually and neighbors who have purchased innovative vehicles. By 2028, market saturation of EVs reaches 25% or higher in 80-86% of the zip codes in Fairfield and Middlesex in contrast to Windham 54%, Litchfield 61% and Tolland 73%. While slow rates of adoption of EVs explains the negative employment impacts on Windham and Litchfield shown in Chart 6, they do not fully account for Tolland’s relatively poor performance which may be linked to its role in distributing petroleum. Percentage reductions in retail jobs are highest in Tolland and Windham (2.4%) followed by Middlesex (2.3%), severe in New London (2.1%), New Haven (2.0%) and Hartford (1.7%) and less serious in Fairfield (1.3%) and Litchfield (1.2%).

Chart 6: County Employment Impacts Off-Peak Rates and Amenities (Jobs)



Non-Residential Capital Stock

By 2023 and 2028, Table 1 indicates the number of zip codes by county that are likely to require transmission upgrades under the two types of pricing structures.

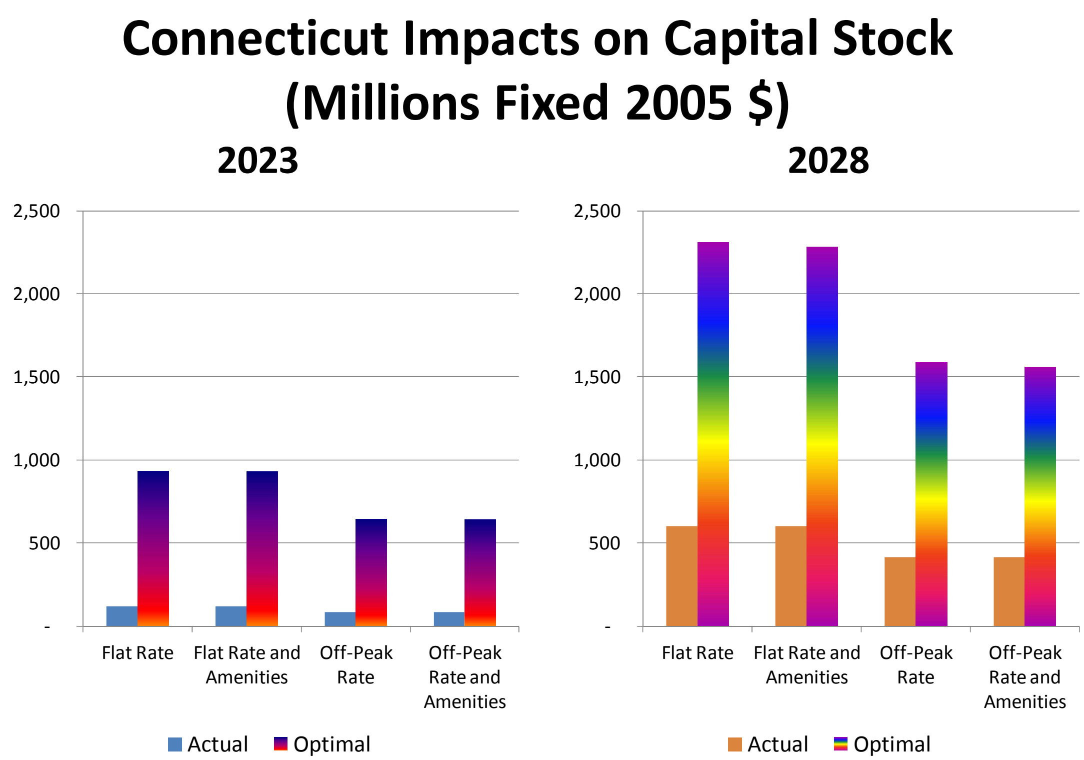
Table 1: Number of Zip Codes Requiring Upgraded Transformers

	2023		2028	
	Flat Rate Electricity	Off-Peak Electricity	Flat Rate Electricity	Off-Peak Electricity
Fairfield	47	11	53	49
New Haven	49	9	59	50
Hartford	57	12	69	54
Tolland	15	3	18	14
New London	29	7	37	28
Windham	20	2	26	18
Litchfield	27	4	34	23
Middlesex	20	3	22	19
Total	263	50	317	254

This table makes it clear that there is a considerable spread in capital requirements between the two cases up to 2023 with the off-peak one playing considerable catch up during 2023-2028.

REMI may not be capturing sufficient investment to accommodate the transition to EVs. Its forecast impacts on capital stock generate a considerable spread between "Actual" and "Optimum" non-residential capital stocks as shown in Chart 7. Because electricity generation and transmission companies target minimum disruptions in order to avoid costly interruptible charges, they target supplies to slightly lead, not follow demand. For this reason, electricity generating and distribution industry spreads between optimum and actual capital stocks are apt to be thinner than derived by these initial REMI results. Nevertheless the results cover all sectors so that declining ones in this scenario may be disinvesting and the problem may not be as large as implied.

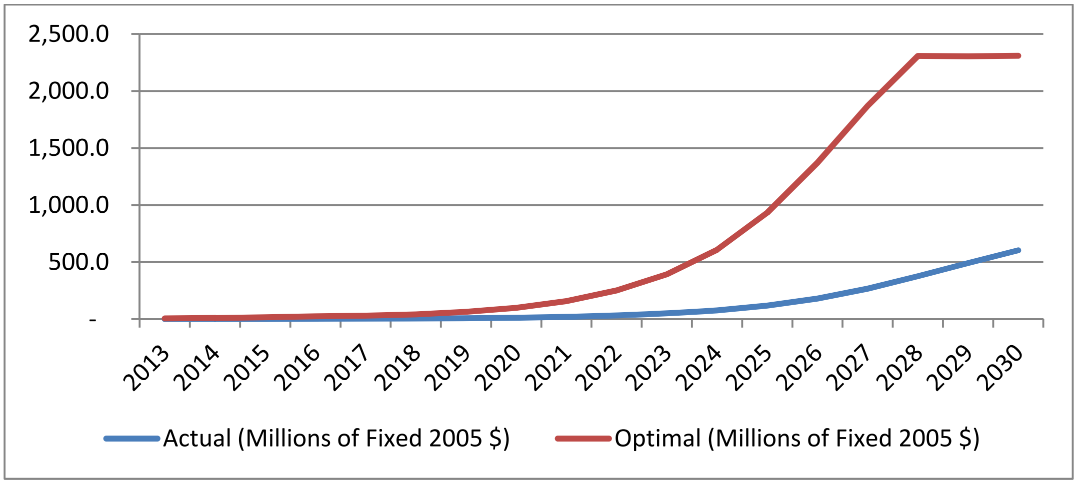
Chart 7:



REMI is clearly capturing the smaller capital requirements with off-peak rates, but it is difficult to accept that with home recharging stations costing at least $2,500 each and nearly 1.2 million EVs operational by 2028, that, even discounting inflation to 2010 levels, that the capital stock series do not react more strongly. They should include additional transmission and generation.

The dynamics of the shortfall between optimum and actual non-resident capital impacts are shown in Chart 8 for the flat rate case. This pattern does not differ significantly between the inclusion or exclusion of amenity benefits, as noted in the previous charts.

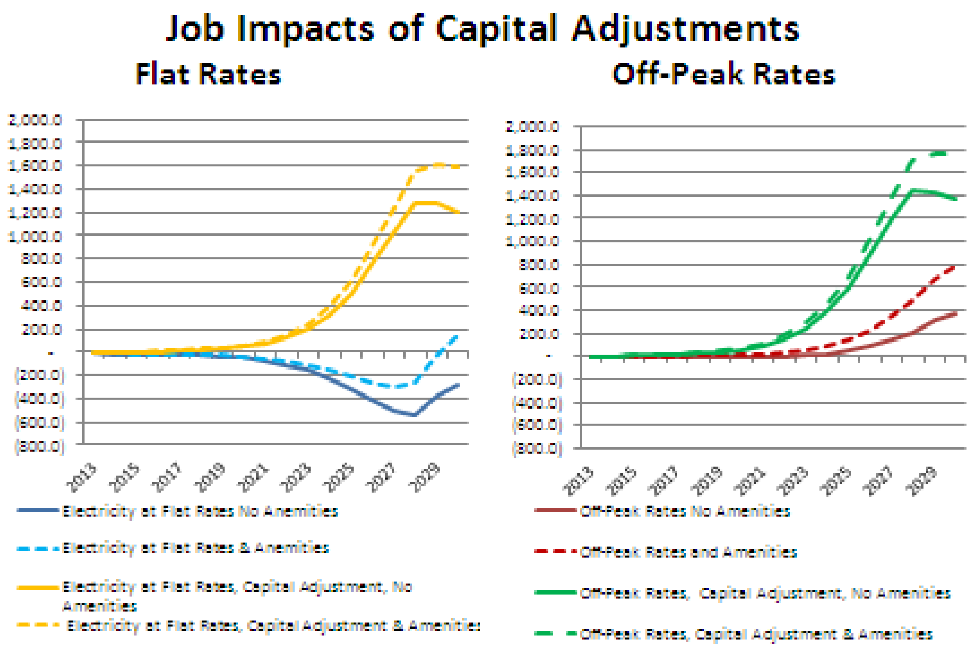
Chart 8: Dynamics of Shortfalls between Optimal and Actual Capital Stocks 2013-2030



Even with greater demands demonstrated earlier for upgrades to transformer technologies, the bulk of the spread between optimum and actual capital stock occurs between 2023 and2028.

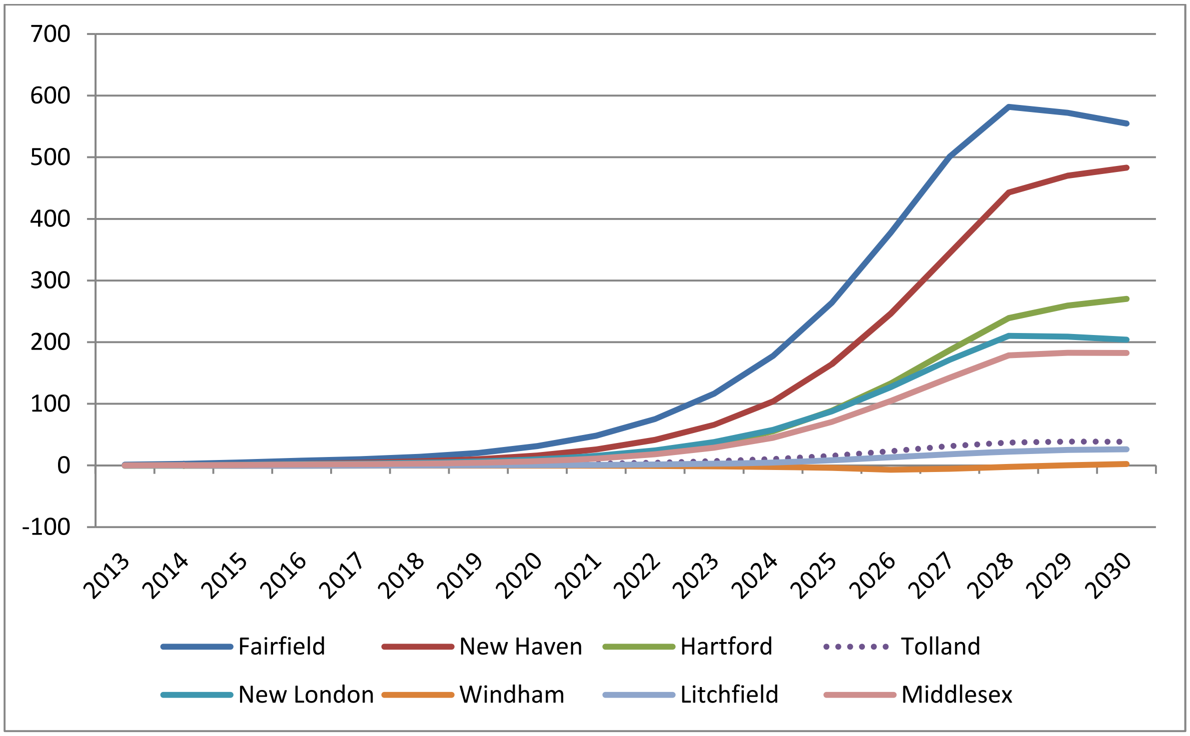
Tailoring future investments to meet these needs through a $1.94 billion (2005) capital adjustment to electricity generation and distribution infrastructure adds to the above impacts in the flat rate scenario and $1.34 billion in the off-peak scenario. In the flat rate scenario, the cumulated investment exceeds the capital stock gap of $1.71 billion (2005) in 2030 due to the depreciation of the earlier investments by that time. Similarly, the cumulated investment in the off-peak case exceeds the capital stock gap of $1.17 billion. Treating the investments as coincident with the initially estimated shortfall in capital stock, backloads the investments and keeps these differences between cumulated investment and the initially estimated shortfall in the capital stock in 2030 to a minimum. For modeling purposes, this investment is approximated as 40% construction and 30% in each of (a) producers' durable equipment investments in electricity distribution infrastructure and '(b) engines and turbines. The capital adjustments clearly add to Connecticut employment impacts under either rate regime, as noted in Chart 9.

Chart 9:



Capital adjustments are sufficient to generate positive employment impacts to all counties by 2030, albeit Windham, primarily due to its slow adoption of EVs, continues to experience a decline prior to that time.

Chart 10: County Employment Impacts Off-Peak Rates, Amenities and Capital Adjustments (Jobs)

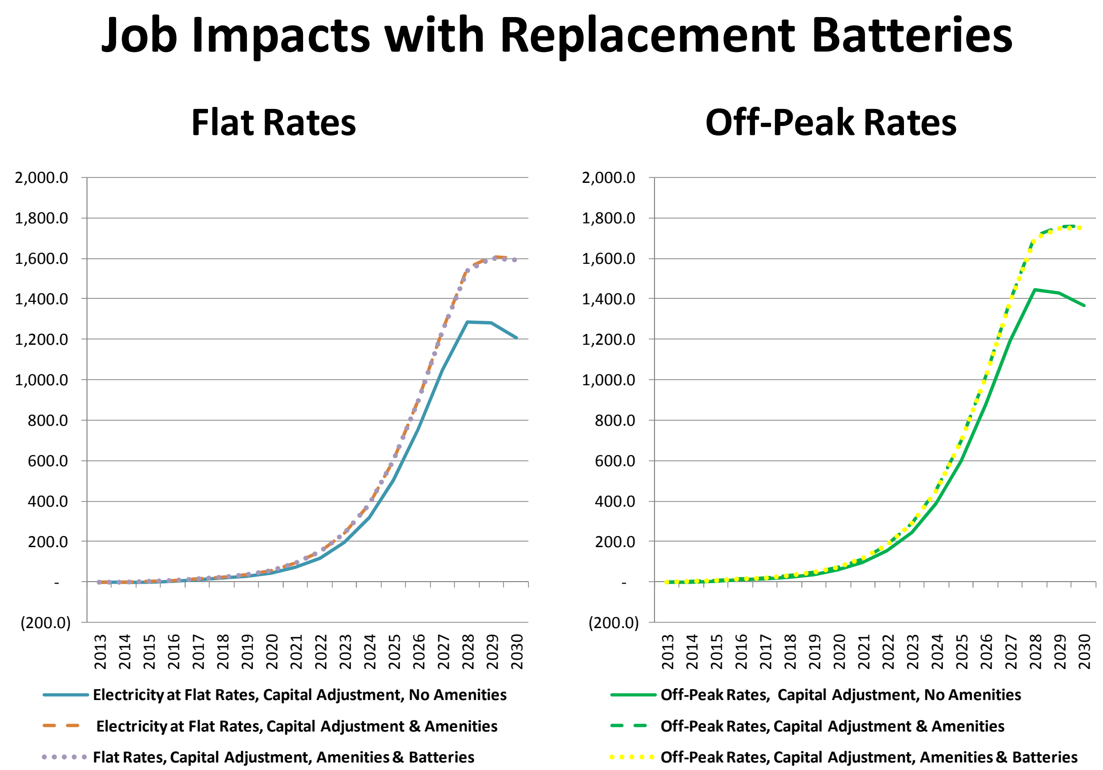


Replacement Batteries

EVs are expected to require battery replacements after they fall to 80% of initial capacity in the eighth year of use. Current estimates that these replacements will cost about $8,000 from which the salvage value of the initial battery needs to be deducted. NREL among others is searching for ways to minimize theses costs and or increase market demands for the retired batteries. In this example, CCEA assumes the net cost of battery replacements will be $6,000. Household expenditures on replacement batteries clearly cut into the amounts allocated to increased general household expenditures, but this substitution of a specific type of expenditure for general consumption has only very minor employment impacts as Chart 11 indicates.

Due to the capital intensive nature of motor vehicle parts and Connecticut's lack of participation in that industry, taking account of battery purchase only curtails employment impacts by 10 or 11 jobs in 2030 with even smaller impacts in the intervening years. Shifting expenditures explicitly to consumptions reduces the negative impact on retail employment by about 100 jobs by 2030.

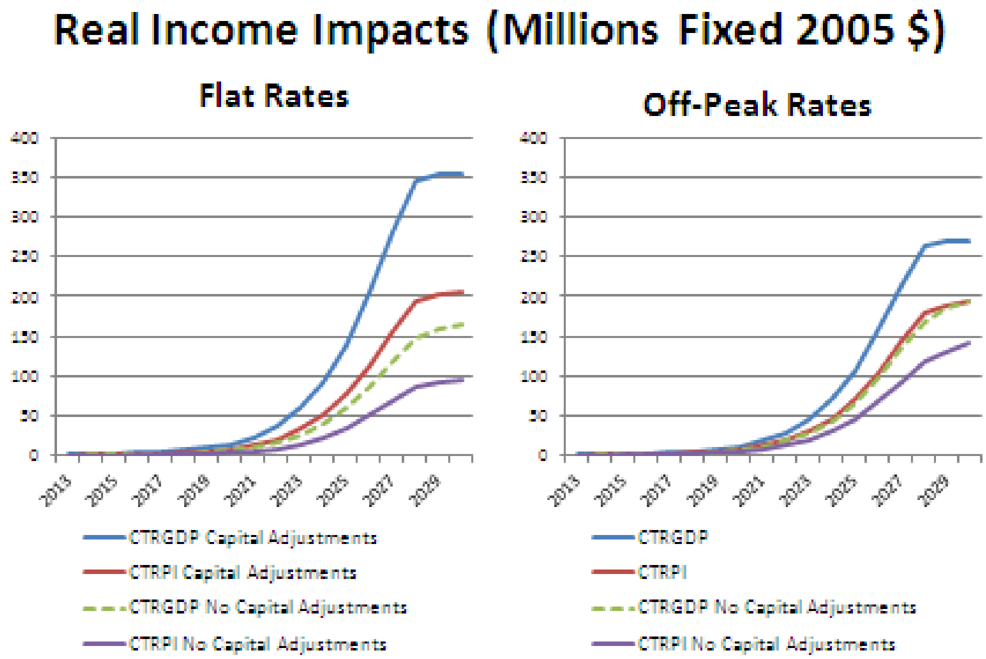
Chart 11:



Impacts on Real Income

Prior to capital adjustments, relative impacts on real income are higher under the off-peak rates than flat-rate ones, due to the greater savings to consumers and the consequentially higher redistribution of consumer expenditures. Due to the considerably larger capital adjustments under the flat rate scenario the opposite holds after capital adjustments. That generalization holds true for both Connecticut real gross domestic product, (CTRGDP) and real personal income, (RPI) as shown in Chart 12. Inclusion of the battery replacements adds about 1% to the CTRGDP impacts 2028-2030.

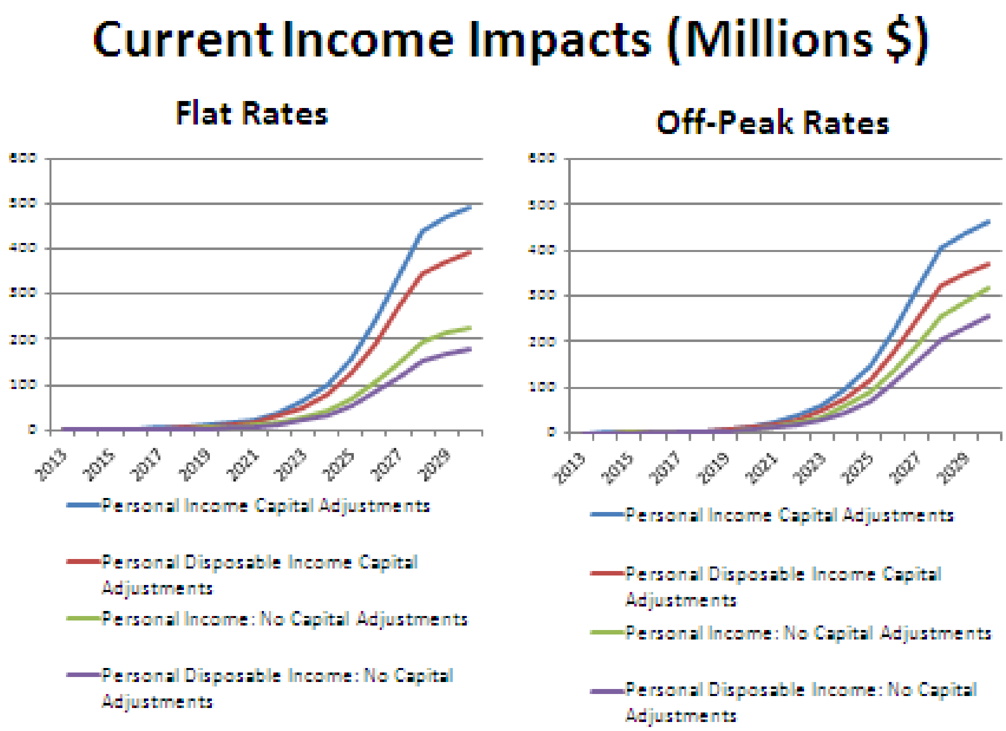
Chart 12:



Impacts on Current Dollar Income

Similar results for personal income in current dollars pertain for both personal income (PI) and personal disposable income (PDI) with the difference between the two being personal income taxes. (Chart 13) Inclusion of the battery replacements adds decreases personal income impacts by 1.7-1.8% in each of the last three years.

Chart 13:

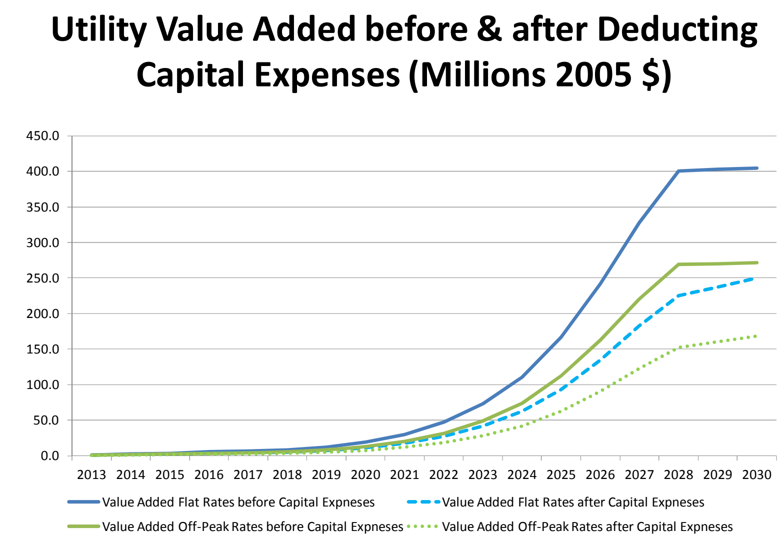


Financing Considerations

Financing of the incremental capacity has not been modeled above. Payments have been estimated as a series of annual mortgages at 3.5%[8] on the annual incremental capital stock plus the investment needed to offset annual depreciation on the previous year's additional capital stock, for 15 years. The impacts on value added before and after these adjustments are shown in Chart 14. Solid lines represent annual value added prior to accounting for capital costs and the perforated ones of a similar color the post capital expense situations with the spreads being the capital expenses under each scenario.

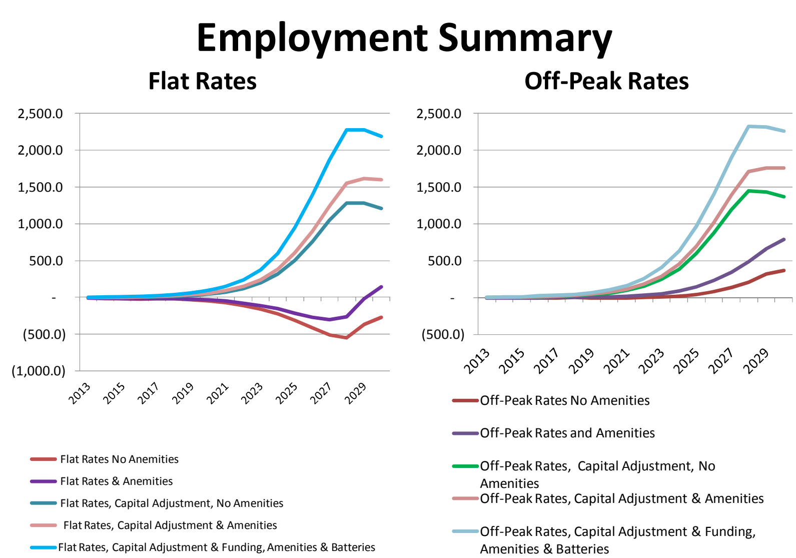
[8] REMI, current industry standards.

Chart 14



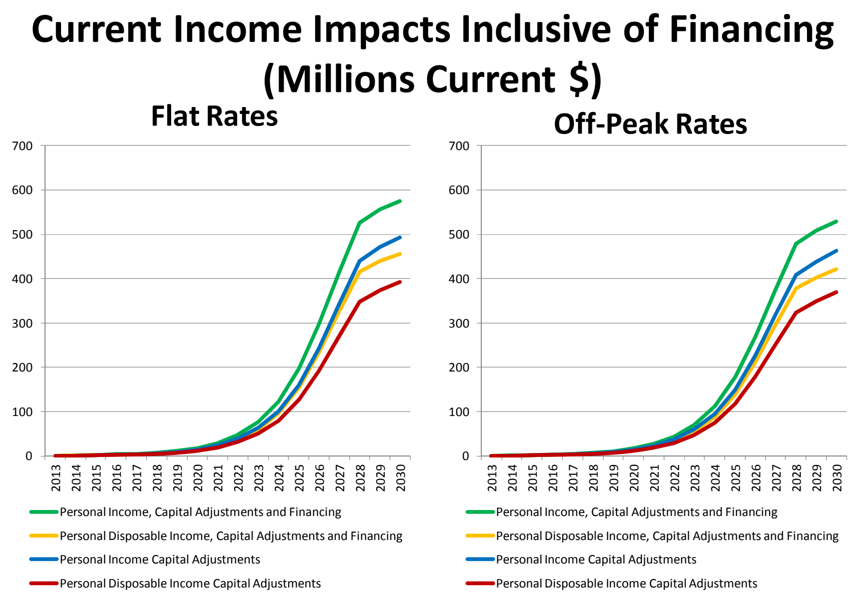
The better alternative approach is to integrate the capital costs within the model. This has been accomplished by reducing utility value added and correspondingly increasing revenues of financial intermediaries initially with no adjustments to electricity rates, subject to later testing. Because financial intermediaries are more labor intensive than utilities, employment impacts rise. See Chart 15

Chart 15



Increased employment impacts incomes. The current dollar ones in Chart 16 indicate that they too are positively impacted in both rate scenarios relative to the previous impacts inclusive of all the drivers prior to financing considerations. The green and the orange lines represent personal income impacts in millions of current dollars to personal income and personal disposable income respectively inclusive of financial charges and the blue and the red lines prior to inclusion of the financing considerations.

Chart 16



Currently, values added is about 70% output for utilities. There is an aggregation problem with this concept since electrical utilities are clearly more capital intensive than other utilities and spend significant proportions of their budgets on fuel so that their value added would be expected to be very much smaller than their output. In comparison with a strictly electricity generating and transmission utility, Ontario One, in 2010 it had revenues of $5,124 million with value added of $1,724 million[9] or value added at about a third of revenues (Output).

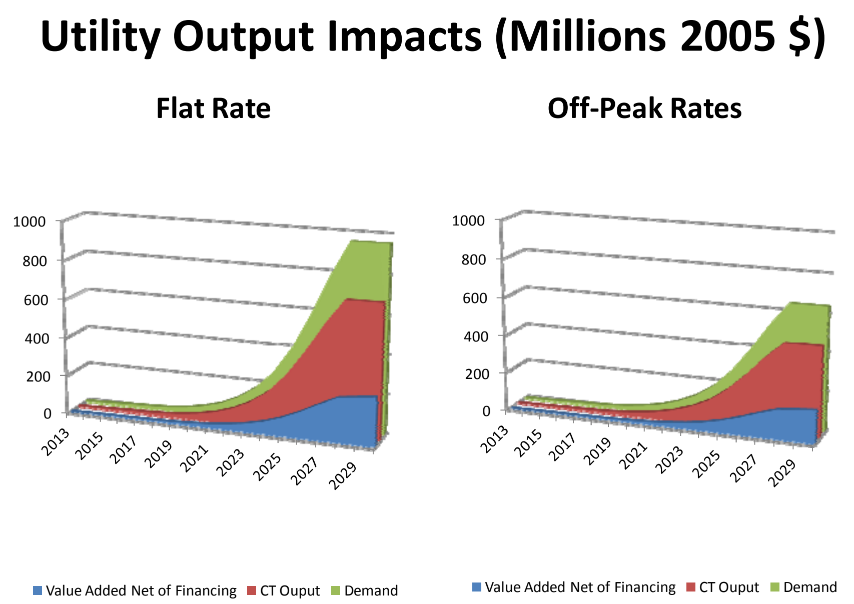
The output results for utilities in each of the scenarios are also influenced by rising relative fuel costs, underlying model assumptions about the ascendancy of non-utility generation and distribution of power and intertie shipments of electricity into Connecticut. The impacts of the various measures of output are shown in Chart 17

For all counties but Tolland, value added remained positive after financing the expanded utility infrastructure. There it was only marginally negative. Since Tolland is part of a broader territory served by the same utility so that is not a serious issue. Generally utility output impacts measured under off-

[9] Ontario One, *Transforming Energy: Annual Report 2010* p. 52.

peak are about two-thirds of those under flat rates, albeit value added is a lower share of the output indicating either imports or production of outside of utilities *per se* inclusive of local generators and distributors or grid connections.

Chart 17



By 2030, utility output in the flat rate scenario exceeds its value added of $249.7 by $449.9 million of which $153.2 million is used to pay off debt. In the off-peak scenario by 2030, the incremental value added at $168.8 million is a smaller share of output of $463.8 million leading to a difference of $295.0 million of which $103.3 million is used to repay interest and principle. In both scenarios interest and principle payments in 2030 are slightly more than a third of the gap between output and value added. As new demand for EVs flattens out and the utilities' mortgages are paid-off, value added will become an increasing share of utility output.

In comparison with Ontario One, these ratios of value added to output are similar. For this reason, no adjustments to electricity rates other than those in those in the initial assumptions are warranted.

Conclusions

Off-peak electricity rates position EV owners to save on operating costs and to allocate more household income to other consumption than occurs with flat rates. Commensurate with the gradual adoption of EVs, key economic impacts are concentrated in the 2020s timeframe. With flat rate electricity, impacts on electricity demand take place sooner and employment benefits can be negative when amenity benefits and capital adjustments are not taken into consideration. That could conclusion could be reversed if parking for a large number of commuters using EV's were free, as they are in New Haven, so that savings for commuting in EVs were be enhanced freeing up additional funds for consumption reallocations as happens with off-peak rates and fueling.

With curtailed demand for gasoline, a share of stations will close causing a drop in retail employment in all scenarios. In all scenarios, counties whose adoption rates for EVs are expected to lag and fare less well than those with relatively higher adoption rates.

Employment performance is best for the scenario with off-peak pricing inclusive of amenities and capital adjustments and funding inclusive of replacement batteries. Employment impacts are generally higher for the off-peak rate cases when compared to similar flat rate cases e.g. excluding both amenities and capital adjustments and including either or both of amenities and capital. But impacts for flat rate cases inclusive of capital are not economically sound since $600 of the investment in the flat rate case emanates from non-optimal rates structure rather than off-peak rates for electricity. The macro-economic impacts of replacement batteries are very small.

Those relative relationships hold for real and nominal income measures prior to the inclusion of capital adjustments but do not hold if the capital adjustments are included, largely due to the application of unnecessary investments in the flat rate cases.

Clearly further work is required to include pollution by county if conventional generating facilities were factored into the amenity benefits. Possible generation with green technologies could be covered by alternative specifications of the additional investments that would require less transmission but would otherwise be specific to each alternative technology. Results could also change for alternative investment profiles for the electrical utilities. Those profiles may or may not require further rate adjustments.