Ground-truth Analysis of Washington State's aECI:

Investigating the effect of the heat rate applied to hydroelectric power

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Introduction

This report is one in a series of short ground-truth efforts that seek to understand historical residential sector energy consumption trends observed in state specific simulations using the proposed Performance based State Efficiency Program (PSEP) metric.[1,2] Initial simulations of the PSEP metric used historical data to estimate the number of years that the state would have made progress with respect to weather adjusted energy consumption intensity (aECI), where progress is defined as a downward slope over the five year period that ends in the evaluation year. Over the period from 1985-2007, Washington would have acheived 13 progress years; the most of any state and three more than the next leading state, California (Figure 1 (L)). Despite Washington’s history of effective energy policies, this unparalleled performance in the historical simulation merits investigation.

A distinguishing feature of Washington State’s total energy use is the high proportion of hydroelectricity in its electricity generation profile. The PSEP metric uses data from the State Energy Data System (SEDS)[3] which, when calculating the primary energy associated with electricity generation, applies an average fossil-fuel heat rate to renewable electricity generation. Use of this high heat rate makes hydroelectric power generation appear to be extremely energy intensive, and makes changes in electricity consumption appear to have an unrealistic effect on the state’s total energy consumption. Additionally, SEDS applies a national average heat rate to all states, regardless of their generation profile. As described in the following analysis, we propose the use of state-specific heat rates for the calculation of primary energy associated with residential electricity consumption and further suggest that no heat rate should be applied to renewable energy sources. After the historical simulation is repeated using revised state-specific heat rates, Washington’s results are much more plausible; Washington would have shown progress in seven years, which is the second-highest number of progress years (Figure 1 (R)).

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[1] **Exploring Strategies for Implementing a Performance Based State Efficiency Program: State Energy Consumption Metrics – Residential Sector Analyses**, Colin Sheppard, Charles Chamberlin and Arne Jacobson, Schatz Energy Research Center, Humboldt State University in collaboration with Yerina Mugica and Rick Duke, Center for Market Innovation, Natural Resources Defense Council. Released: May 15, 2009.
For additional information on the PSEP metric:
SERC webpage: http://www.schatzlab.org/projects/psep/psep.php
NRDC webpage: http://www.nrdc.org/globalWarming/cap2.0/energybargain.asp

[2] Unless otherwise stated, the energy data used in this report are from the Energy Information Agency of the U.S. Department of Energy’s State Energy Data System (SEDS).

[3] The energy data are from the Energy Information Agency of the U.S. Department of Energy’s State Energy Data System (SEDS). A discussion of how this data set calculates primary energy associated with electricity is included in Appendix A.

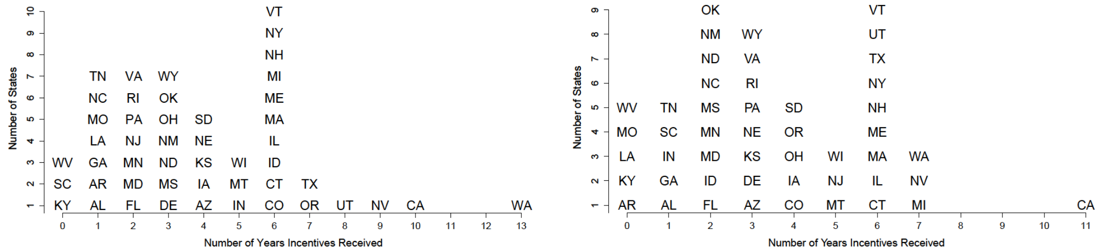

Figure 1. Histograms of States by Number of Progress Years. The left histogram displays the distribution of the states using the original analysis with a high heat rate applied to renewables. The right histogram displays the distribution of the states using state-specific heat rates calculated assuming no additional primary energy is consumed in the production of electricity from renewable sources. Note the change in scale of both the x and y axes.

Analysis

When calculating the primary energy associated with electricity generation, the SEDS database applies an average fossil-fuel heat rate to renewable electricity generation, making hydroelectric power generation appear to be extremely energy intensive. Because of the prevalence of hydroelectric power in Washington, changes in the other forms of electricity generation seem negligible (Figure 2).

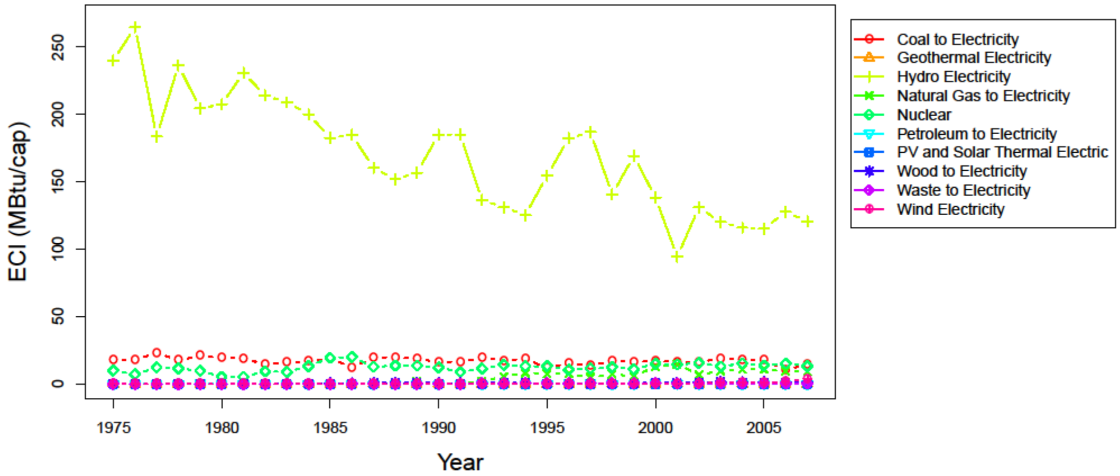

Figure 2. Electricity generation profile per capita for Washington State using SEDS heat rates.

Hydroelectric energy is currently converted from its physical units of kWh to comparative units of Btu by heat rates ranging between 10,760 Btu – 9,884 Btu per kWh from 1960 to 2007. These rates are based on the fossil-fuel steam-electric power plant conversion factor (FFETKUS), which is an average heat rate of all fossil fuel steam-electric power plants in the US. The heat rate can be considered comparable to an efficiency measure of the fossil fuel steam-electric power plants.

For the purposes of the PSEP metric, we suggest that renewable sources of electricity (hydro, wind, wave, solar and geothermal), as well as nuclear energy, should not have heat rates applied in addition to their conversion from kWh to Btu. Instead only the conversion of 1kWh = 3412 Btu should be used to convert units, but not increase the primary energy associated with the electricity generation. Figure 3 shows Washington State's profile of electricity generation if these new heat rates are applied.

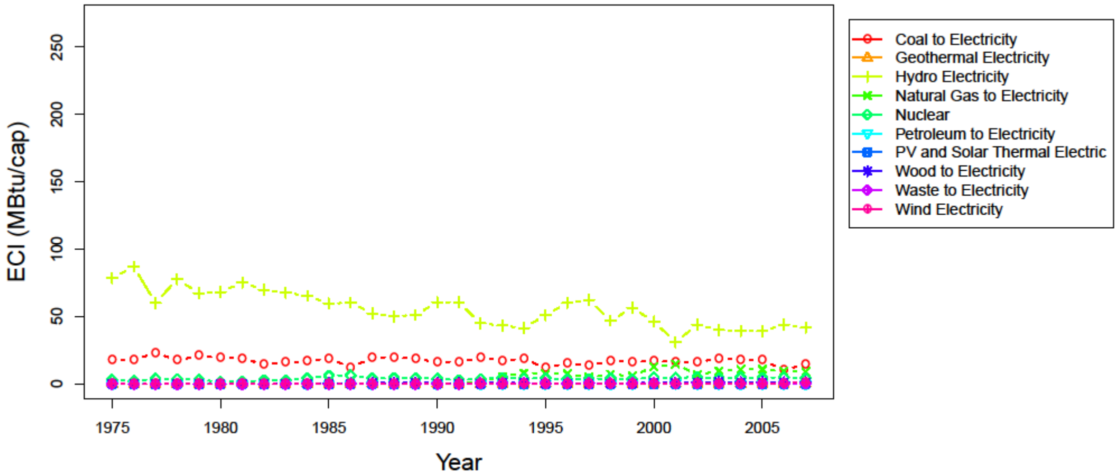

Figure 3. Electricity generation profile for Washington State using revised heat rates. This graph uses a heat rate of 1 kWh=3,412 Btu for hydroelectric, wind and nuclear power. Hydroelectric power appears to use approximately 1/3 the primary energy as suggested by the SEDS database.

The previous graphs represent the total per capita energy used in the generation of electricity, however, our current analysis focuses only on electricity consumption in the residential sector. Because of the prevalence of hydroelectric power in Washington, adjusting the heat rates applied to the electricity generation profile significantly reduces the total primary energy associated with electricity consumption in the residential sector (Figures 4 and 5). Details on the methods of this analysis are found in Appendix H.

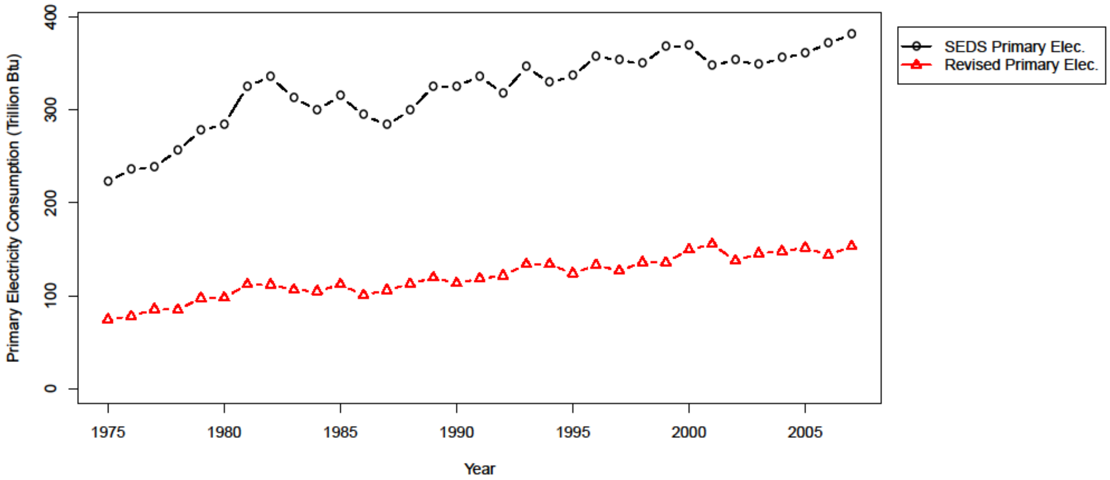

Figure 4. Primary energy associated with residential electricity use in Washington State. The upper line represents total primary energy associated with residential electricity use (including estimated transmission and distribution losses) using the SEDS heat rates. The lower line represents the same quantity using the revised heat rates.

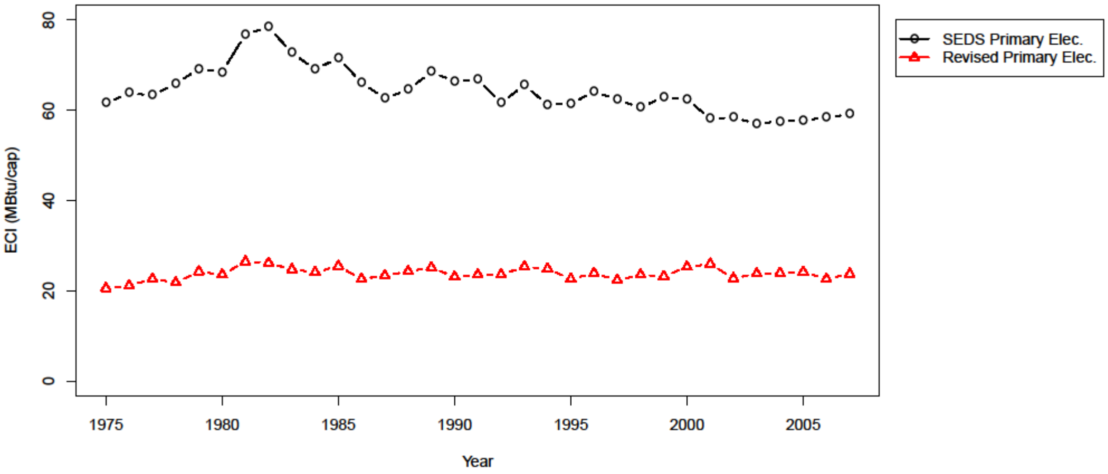

Figure 5. Primary energy associated with residential electricity use per capita in Washington State. The upper line represents total primary energy associated with residential electricity use per capita (including estimated transmission and distribution losses) using the SEDS heat rates. The lower line represents the same quantity using the revised heat rates.

Washington's total energy use is also significantly affected by the revised heat rate. Using the SEDS heat rate, the energy associated with electricity use in the state dominates the state's total energy consumption (Figure 6). When the revised heat rates are used, the energy associated with electricity use is reduced and other energy sources (natural gas in particular) begin to have greater influence on the total energy profile of the state.

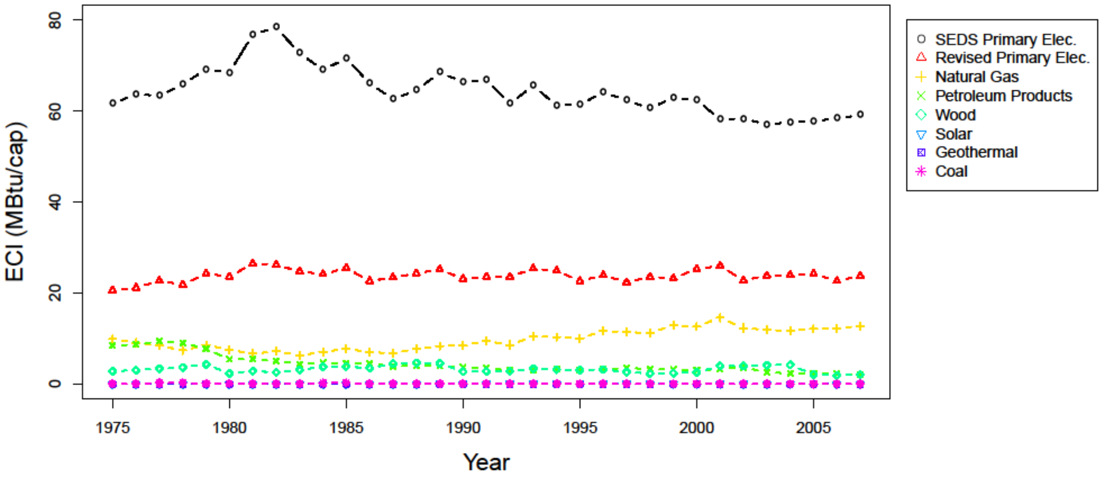

Figure 6. The energy use profile for Washington State. The major types of residential energy use are plotted to compare the energy use profile with primary energy associated with electricity calculated using SEDS heat rates against this same value calculated using the revised heat rates.

If primary energy is calculated using the SEDS heat rates, reductions in residential electricity consumption result in artificially large decreases in total energy use. The revised heat rates attempt to more accurately represent the primary energy associated with electricity, resulting in a more realistic interaction between electricity consumption and total energy use. When the revised values of total energy are plotted as adjusted ECIs, not only does the magnitude of the graph change, but the shape and slope of the graph are affected as well (Figures 7 and 8). These shifts affect the number of years a state would demonstrate progress.

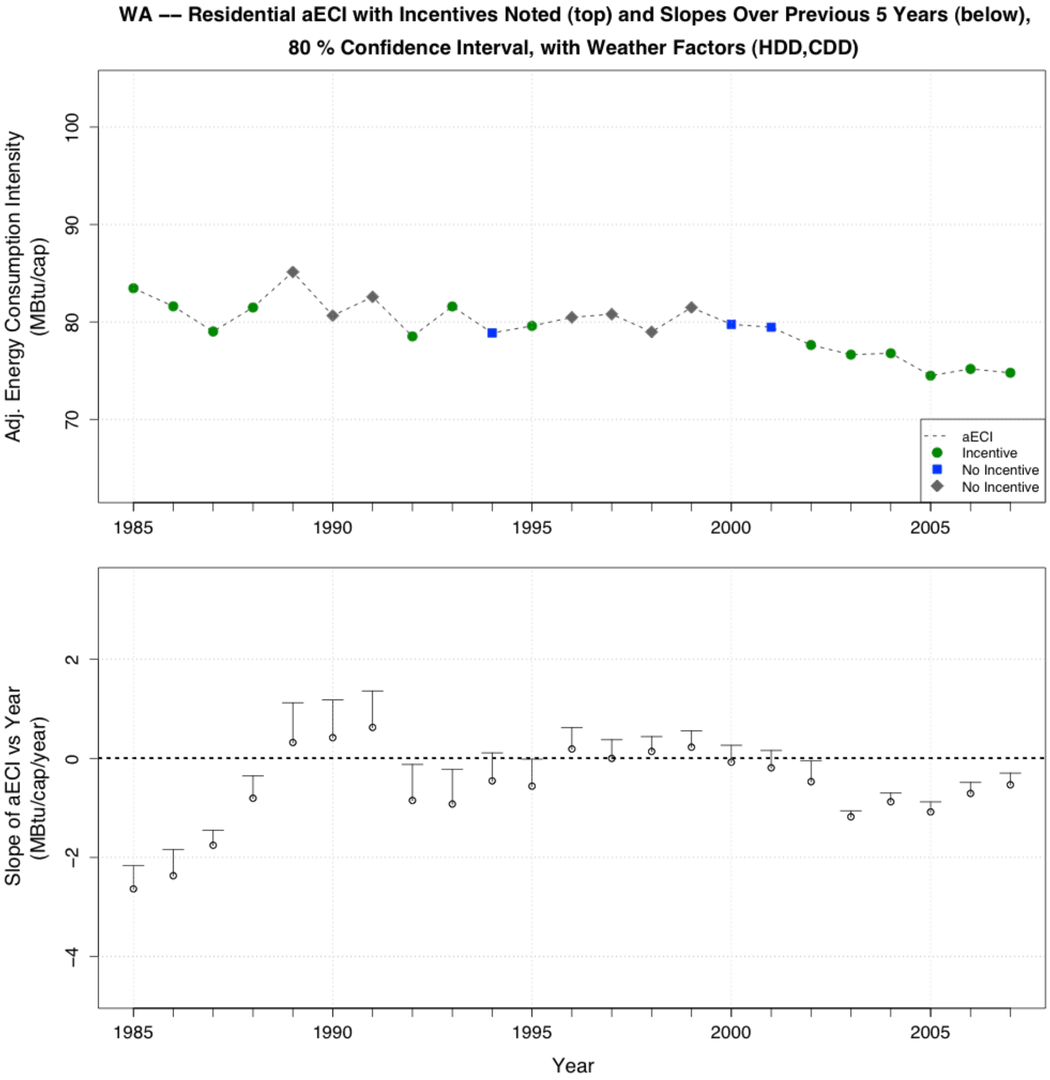

Figure 7. An aECI for WA using the SEDS heat rates. Based on five-year slopes, Washington would be the best performer, showing progress in thirteen years.

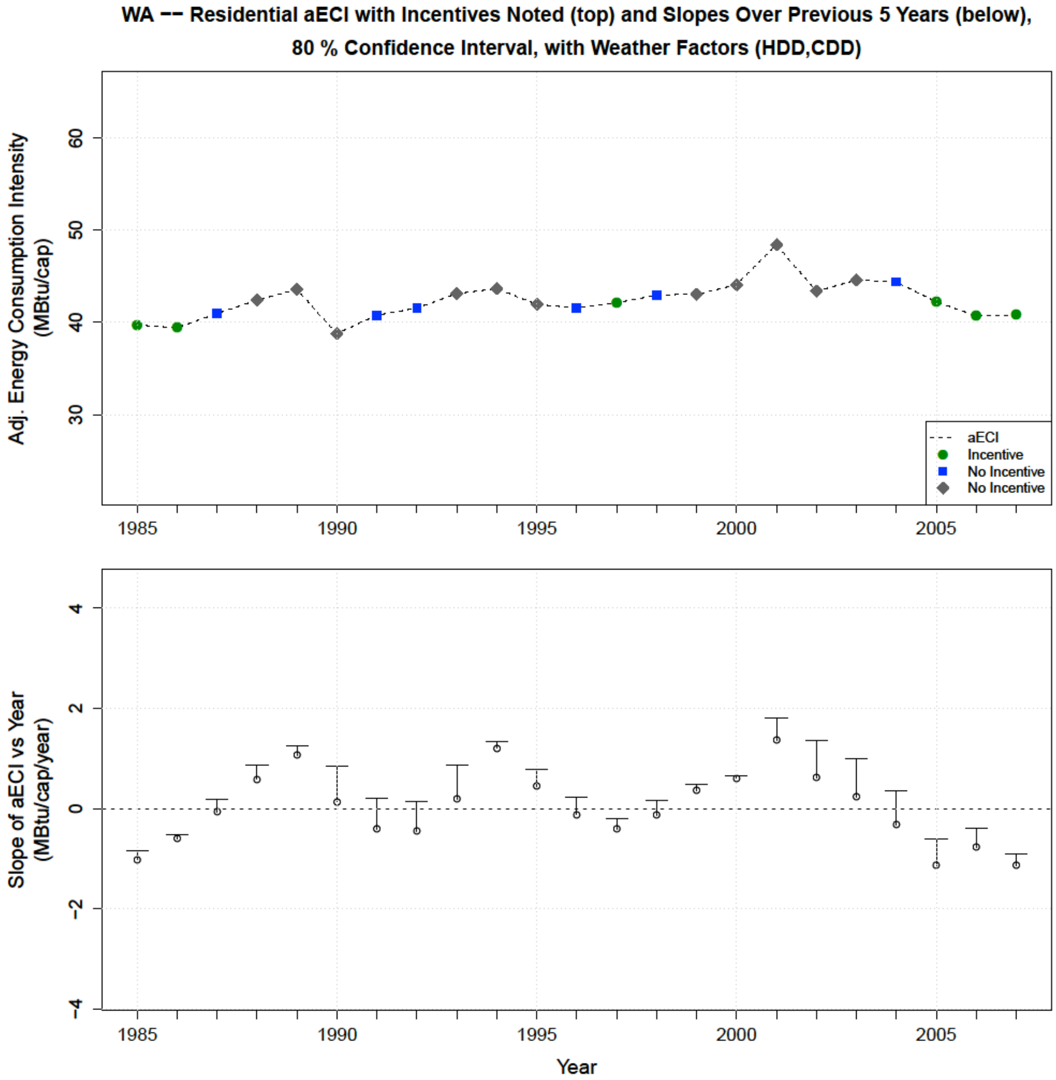

Figure 8. An aECI for WA using the revised heat rates. Based on five-year slopes, Washington would show progress in six rather than thirteen years. Note the change in scale of the y-axis from Figure 7.

To ensure that changes in the electric power sector are not taken into consideration when calculating the slope of the graph of per capita residential energy consumption, the heat rate should be held constant over each 5-year period. This practice could lead to seemingly inconsistent and confusing comparisons between the shape of the graph and the calculated value of the slope. To avoid this discrepancy, one method proposed was to calculate an average heat rate for the entire analysis period (1980-2007) and use this heat rate to graph the aECI for the period (Figures 9 and 10).

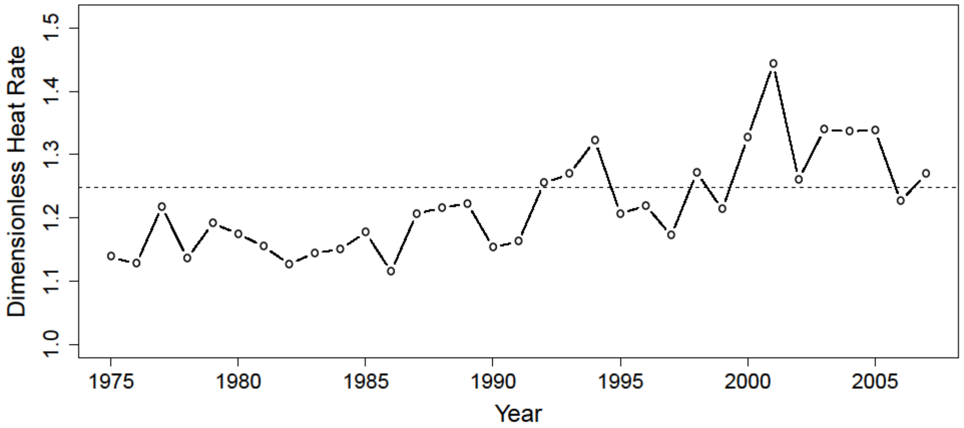

Figure 9. Revised heat rates for Washington State. The dimensionless heat rate calculated for Washington State ranges from 1.11 to 1.43 with a slightly increasing trend over the period between 1980 to 2007. The increase in the heat rate is due to the increasing percentage of natural gas use for electricity generation. The average heat rate is approximately 1.22.

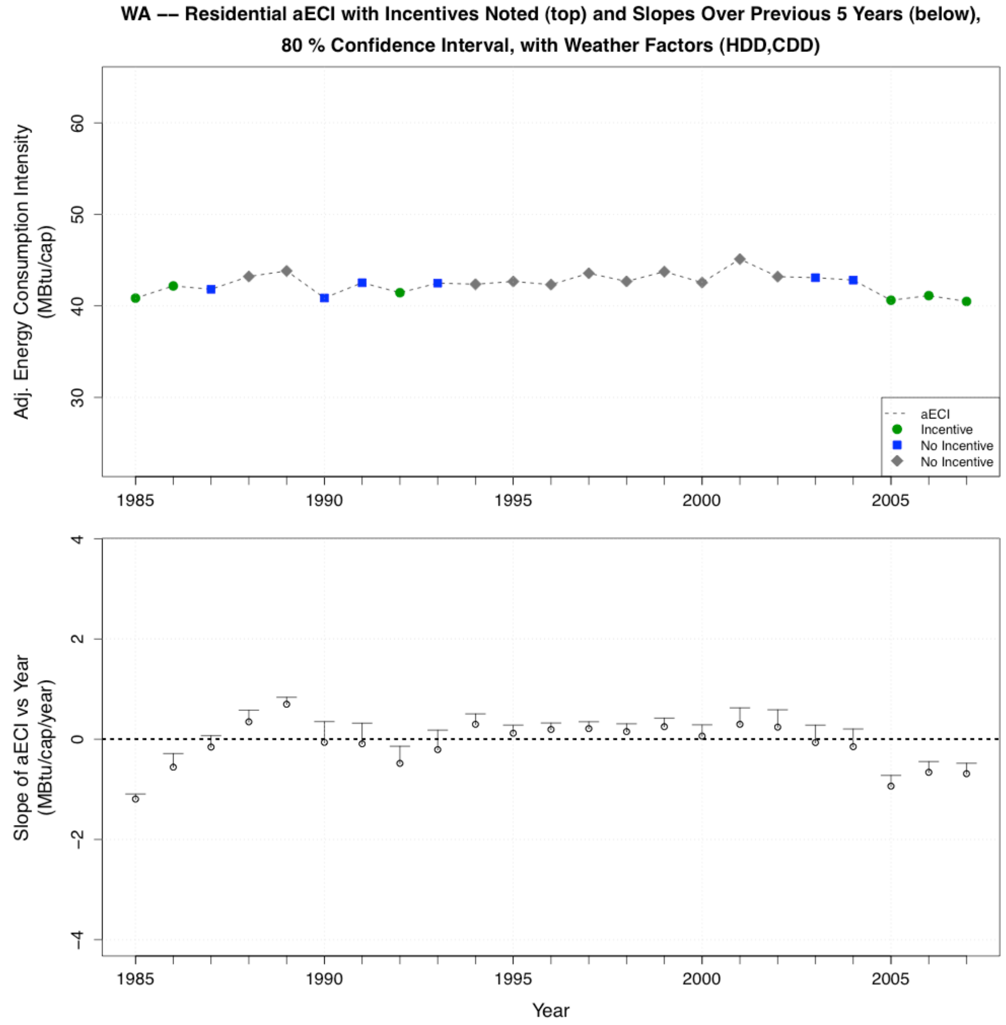

Figure 10. An aECI for WA using a single average revised heat rate of 1.22. This adjustment in the methodology substantially changes the shape of the aECI graph, but does not affect the number of years Washington would show progress.

Though using a single average heat rate over the entire 1985-2007 period did not significantly affect Washington's overall performance, certain states with more highly fluctuating heat rates were impacted. In an effort to more accurately reflect reality, we instead propose to use average heat rates held constant over the 5-year period used to calculate the slope of the aECI in each year. In Figure 11, each colored line represents the five points of the aECI which were calculated using a fixed average heat rate over that 5-year period. The values of the aECI calculated using this 5-year moving average heat rate are then used to determine the slope at the end of each 5-year period.

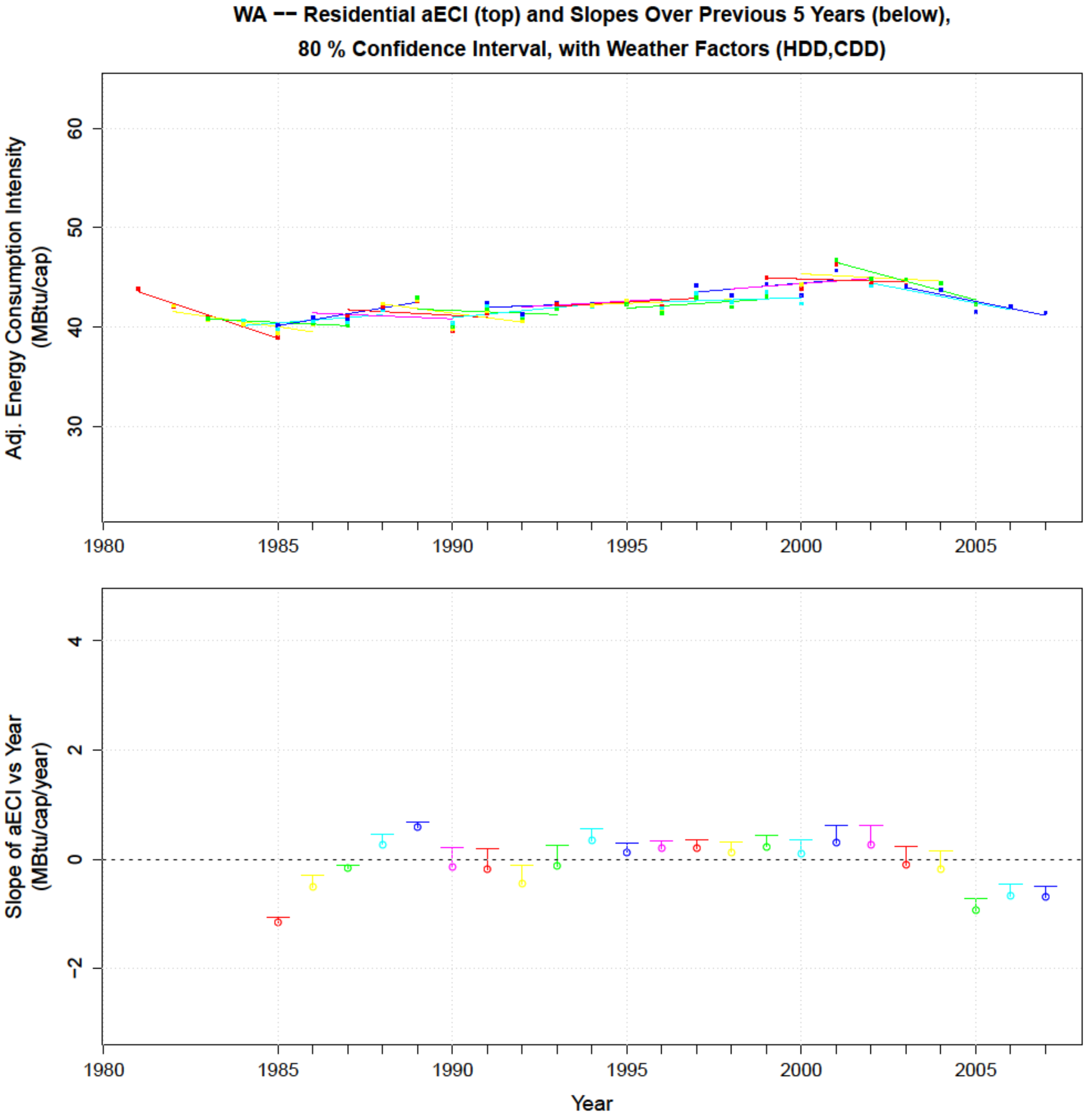

Figure 11. An aECI for WA using 5-year moving average revised heat rates. Each colored line represents the five points of the aECI used to calculate the slope at the end of the 5-year period. Using this scenario, Washington would show progress in seven rather than six years.

This change in the methodology makes the graph of the aECI slightly more difficult to interpret; however, it better reflects the realistic primary energy associated with electricity generation in each state while not incentivizing changes in the electricity generation sector directly. Though the graphical representation of this method may change, state specific heat rates using 5-year moving average analyses seem to most accurately represent the total energy use by the residential sector, and therefore provide the best basis for analysis based on changes in this total energy use.

Conclusions:

In states such as Washington where renewable power sources represent a significant percentage of the electricity generation, using total energy as calculated by the SEDS database artificially inflates the primary energy associated with electricity use in the state. Eliminating the inappropriate heat rates applied to renewables and then recalculating the value of the primary energy associated with electricity use results in a much more accurate representation of a state's total energy use. To best represent the realistic primary energy associated with residential electricity use, without inadvertently incentivizing changes in the electric generation sector, we propose using state specific heat rates which are averaged and held constant over each 5-year analysis period. These 5-year moving average heat rates would not apply an additional heat rate to renewables and would provide the most credible representation of the total residential energy consumption.

Remaining Questions:

Washington State is an extreme case where the high heat rate applied to hydroelectric power generation makes a large difference in the aECI for the state. When running similar analysis for other states, it is clear that many others are significantly impacted by this change as well. A few questions then arise:

A) Should a heat rate be applied to nuclear electricity generation? In SEDS, a national average nuclear steam-electric power plant heat rate (NUETKUS) is applied. In our current analysis, no heat rate is applied.

B) Do heat rates need to be established separately for coal, natural gas and petroleum fuels? Currently all three are using the national average fossil fuel steam-electric power plant heat rate (FFETKUS). After some searching, it is clear that the separate heat rates are not easily obtained, but could be calculated if we determine this is important (but it would take a while). Appendix L documents an email from Howard Stone at the eia who suggests using the raw data from form 923.

C) What values should be used for transmission and distribution losses? There does not seem to be an established number. Appendix K lists a few different sources and methods to estimate transmission and distribution losses. The current analysis uses transmission and distribution losses from the eia form stb0801: Table 8.1 Electricity Overview 1949-2008.

D) What grid mix should be used? This final question is complicated and tied-in to the question of interstate flow of electricity, especially in the case of Washington State. According to Washington's Biennial Energy Report from 1999, Washington's electricity generation mix (which was used in our current analysis) is significantly different from their consumption mix, as their grid is part of the Northwest Power Pool (Figure 12).

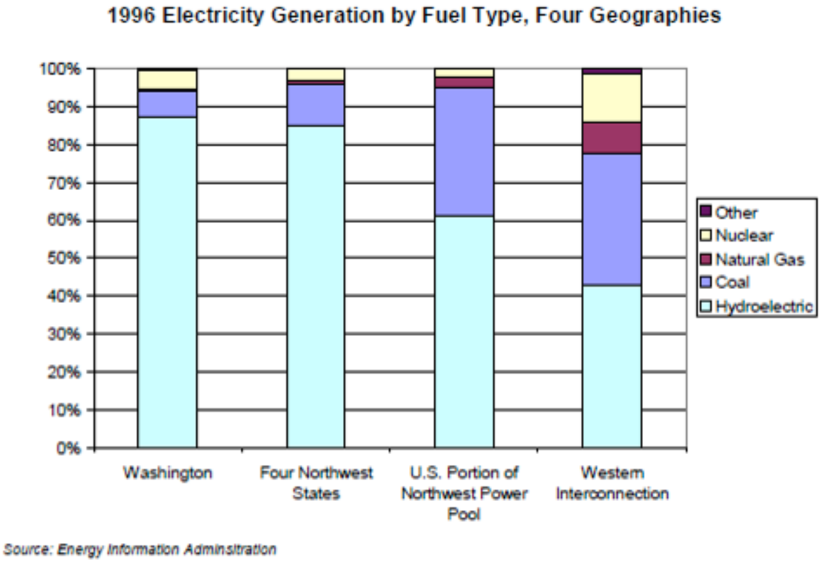

Figure 12. Washington's electricity mixes. The first bar represents the electricity generation mix for the state, while the second represents the generation mix for the four northwest states (Washington, Oregon, Idaho and Montana?) and the third bar represents the Northwest Power Pool which includes coal plants in Oregon, Montana, Wyoming and Utah owned by utilities which serve Washington. The Western Interconnection encompasses seasonal purchases of nuclear, coal and natural gas from the Southwest. (Washington's Biennial Energy Report, Douglas, 1999).

To see how much the grid mix affected the calculation of total energy, the total energy was calculated for Washington in 1996 using both the generation grid mix as determined by the previous methodology and using the NWPP grid mix reported here (Table 1).

Table 1. Comparison of Heat Rates and per Capita Primary Energy in WA (1996)

	Dimensionless Heat Rate	Primary Energy for Residential Electricity per Capita (MBtu/cap/year)
SEDS	3.274	64.21
Revised - generation grid mix	1.208	25.34
Revised - NWPP consumption grid mix	1.741	36.53

As would be expected, the grid mix did make a substantial change in the calculated value of the primary energy associated with residential electricity. It would make the most sense to use the grid mix associated with residential consumption, unfortunately, state-specific values for this do not seem to be easily available. Grid mixes for electric companies and the major grid sectors can be found, yet these grid sectors do not follow state boundaries (Figure 13).

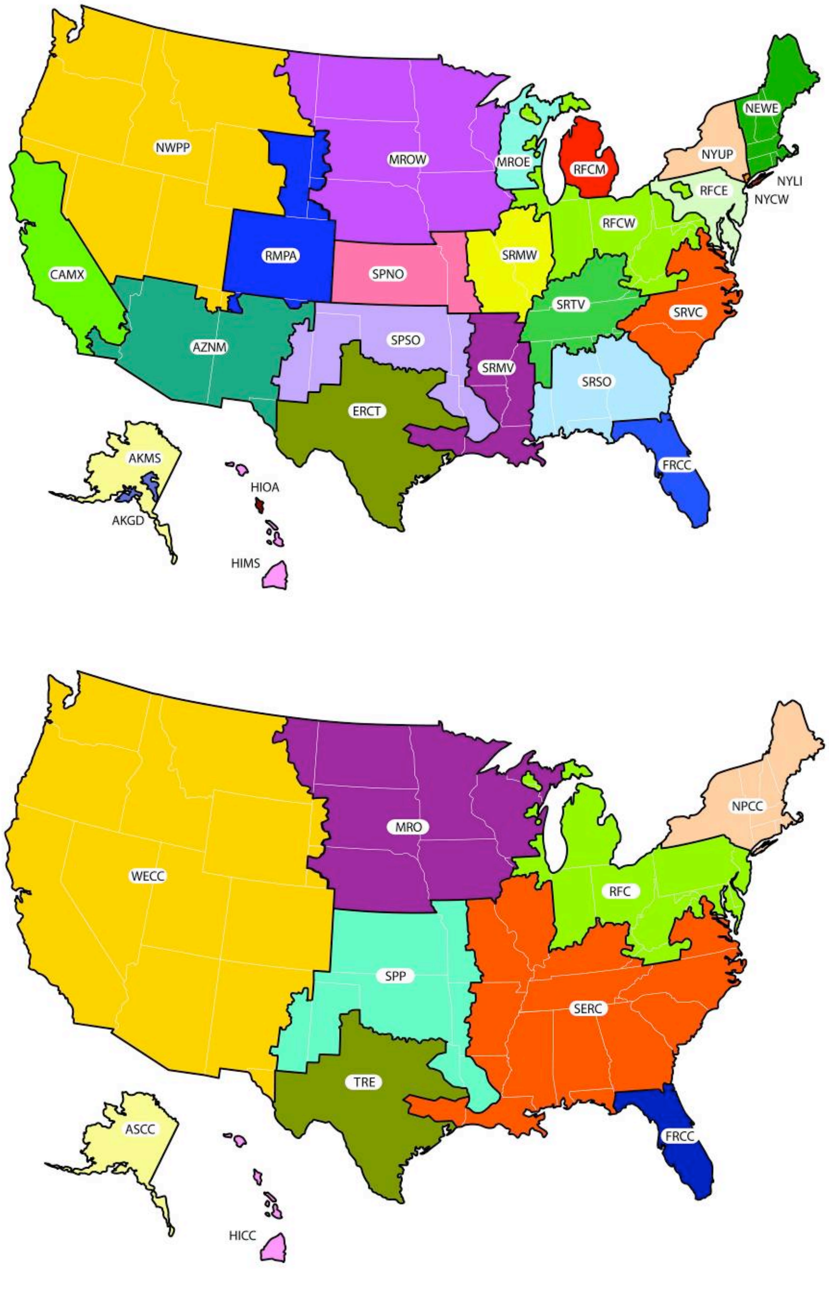

Figure 14. US Maps of the Electricity Grid Subregions (top) and Regions (bottom). Both the electricity grid subregions and regions cross state boundaries, making the determination of certain states' consumption grid mixes difficult. Additionally, grid resource mixes differ between the regions and subregions, leaving a choice to be made as to which grid mix to use. Image source: EPA's eGRID: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html#download

Appendix H - Calculation of Heat Rates in SEDS and by the Revised Method

Current SEDS Heat Rate Methodology

SEDS reports the electricity sales to the residential sector in terms of MkWh and converts these to BBtus using the unit conversion of 3.412 BBtu/MkWh. To account for the primary energy associated with these electricity sales, SEDS calculates a "Losses" term (LORCB). To determine the value of LORCB for each state, SEDS first calculates a total electricity losses term for the US (LOTCBUS) by subtracting the total electricity sales (ESTCBUS) from the total energy consumed by the electric power sector (TEEIBUS):

$$\text{LOTCBUS} = \text{TEEIBUS} - \text{ESTCBUS}$$

The total energy term (TEEIBUS) is calculated after applying a high heat rate to renewables, nuclear and geothermal energy. Electricity generated from renewable sources (hydroelectric, wind and solar) is converted from its physical units of kWh to units of Btu by multiplying by heat rates ranging between 10,760 Btu – 9,884 Btu per kWh. These rates are based on the fossil-fuel steam-electric power plant conversion factor (FFETKUS), which is an average heat rate of all fossil fuel steam-electric power plants in the US. The heat rate can be considered comparable to an efficiency measure of the fossil fuel steam-electric power plants. A similar process is done with nuclear and geothermal generation using the national average nuclear steam-electric power plant heat rate (NUETKUS) and the national average geothermal steam-electric power plant heat rate (GEETKUS).

After determining the total electricity losses (LOTCBUS), the losses for just the lower 48 states (LOTCB48) are calculated by subtracting the losses for Alaska and Hawaii:

$$\text{LOTCB48} = \text{LOTCBUS} - (\text{LOTCBAK} + \text{LOTCBHI})$$

In addition to accounting for the primary energy associated with the electricity sales, the calculation attempts to account for the likelihood of interstate sales of electricity throughout the lower 48 states by calculating a "losses to sales ratio" (ELLSS48) for the lower 48 states:

$$\text{ELLSS48} = \frac{\text{LOTCB48}}{\text{ESTCB48}} = \frac{\text{TEEIB48} - \text{ESTCB48}}{\text{ESTCB48}} = \frac{\text{TEEIB48}}{\text{ESTCB}} - 1$$

The value of ELLSS48 ranges from 2.15 to 2.47 over the period from 1960 to 2007. This national "losses to sales ratio" is then used to calculate the losses associated with electricity in each state for each sector by simply multiplying the ratio by the electricity sales to that sector in that state. For the residential sector, the electricity losses associated with electricity sales to the residential sector (LORCBZZ) are equal to the electricity sales to the residential sector (ESRCBZZ) multiplied by the "losses to sales" ratio (ELLSS48):

$$\text{LORCBZZ} = \text{ESRCBZZ} * \text{ELLSS48}$$

Finally, when calculating the total energy used by the residential sector (TERCB), SEDS adds the energy use in BBtus from all sources of energy, along with energy in the form of electricity sales (ESRCB) and the losses associated with the electricity (LORCB):

$$TERCB = CLRCB + NGRCB + PARCB + WDRCB + GERCB + SORCB + ESRCB + LORCB$$

Total Res. Energy = Coal + Natural Gas + Petroleum Products + Wood + Geothermal + Solar + Electricity Sales + Electricity Loses

In summary, because electricity sales and the losses are accounted for separately, the total energy associated with electricity is essentially calculated by multiplying the electricity sales by a factor between 3.47 and 3.15 (ELLSS48 + 1), depending on the year. This factor is the same for all states, regardless of their production or consumption grid mix, and includes large heat rates applied to renewables, geothermal and nuclear electricity production.

Revised Heat Rate Methodology

We propose that these high heat rates on renewables should not be incorporated into the calculation of primary energy associated with electricity use. Additionally we propose that an overall heat rate should be calculated for each state based on the state's electricity grid mix. To recalculate the total primary energy for the residential sector, using state specific heat rates, we used the following methodology.

The first step in determining a state's revised heat rate is to determine the grid mix of the residential electricity use. Because residential electricity sales are represented by a single term and not divided according to generation source, the grid mix is based on the state's generation grid mix for all sectors rather than the consumption grid mix. Our definition of the grid mix is therefore the percentage of the state's total electricity generation contributed by each generation source.

Quantities of fuel used for total electricity generation are reported in SEDS in physical units (short tons, cubic feet, million kWh. . .). These quantities are then converted to BBtu using the conversion factors listed in SEDS. This number now represents the total primary energy associated with each electricity generation source. The primary energy used for each generation source is then divided by an appropriate heat rate to determine the electricity generated (in GWh) by each generation source. The national average fossil fuel steam-electric power plant heat rate (FFETKUS) is applied to natural gas, coal and petroleum products, while no heat rate (only the 3.412 BBtu/GWh unit conversion) is applied to renewables, geothermal or nuclear generation. In our current analysis, the amount of electricity generated in GWh is again multiplied by 3.412 to determine the equivalent energy in BBtu. Using coal and hydroelectric as examples, where CLEIP is the physical amount of coal used by the electric power industry in short tons, CLEIK is the conversion factor from short tons to BBtu and HYEGP is the electricity generated using hydropower in GWh:

$$\text{BBtu of electricity generated using coal} = ((CLEIP * CLEIK)/FFETKUS)*3.412$$
$$\text{BBtu of electricity generated using hydroelectric power} = ((HYEGP*3.412)/3.412)*3.412$$

The values of BBtu of electricity generated for each generation type are summed to determine the total BBtu of electricity generated by the electric power industry. The value of BBtu of electricity generated by each generation type is then divided by the total electricity generated to determine the grid mix percentages. These percentages are then used to create a weighted average heat rate for the state. Each percentage of a generation source is multiplied by its associated heat rate (again, these are FFETKUS for fossil fuel sources and 3.412 for renewables and nuclear). These terms are then summed to determine the average heat rate for the state:

State-specific heat rate = %Coal*FFETKUS +%Natural Gas*FFETKUS + %Petroleum*FFETKUS + %Hydro*3.412 + %Wind*3.412 + %Solar*3.412 + %Geothermal*3.412 + %Nuclear*3.412

This heat rate is then divided by 3.412 to create a dimensionless heat rate for the state. The dimensionless heat rate determined for Washington ranged from 1.00 – 1.46 over the period from 1960 to 2007. These values can be compared to the dimensionless "heat rate" used by SEDS (ELLSS48+1), which ranged from 3.15 – 3.47 over the same period.

Once a heat rate is established, this heat rate can be multiplied by the electricity sales to the residential sector (ESRCB) to determine the primary energy associated with the electricity consumption in the residential sector. Because this method no longer accounts for transmission and distribution losses, an estimate of these losses is added to the primary energy term.

Primary Energy for Residential Electricity = ESRCB*State-specific heat rate + T&D losses

To then calculate the total energy used by the residential sector, the electricity sales (ESRCB) and electricity losses (LORCB) are subtracted from the total energy term (TERCB) reported in the SEDS database and the new value of primary energy associated with electricity use is added. To determine the per capita energy use, this value is divided by the population reported by the Census in the SEDS database.

Revised Total Energy = TERCB – ESRCB – LORCB + Revised Primary Energy for Residential Electricity

The Revised Total Energy per capita can then be used in the established analysis to create an aECI and determine progress years for the state.

Appendix K. E-mail from the EIA regarding T&D losses, with links to other energy information sites:

EIA does not have a specific estimate for distribution losses.

You can derive approximate total transmission and distribution losses as follows:

Using the data in our State Electricity Profiles at:
http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html

Take for example the USA Profile:
http://www.eia.doe.gov/cneaf/electricity/st_profiles/us.html
Scroll down to find Table 10:
http://www.eia.doe.gov/cneaf/electricity/st_profiles/sept10us.xls
T&D losses, as a percentage = Total Losses / (Total Disposition - Direct Use)

Or, you can use the data in Table 8.1 at:
http://www.eia.doe.gov/emeu/aer/elect.html
Where T&D losses, as a percentage = T&D Losses... / (Total Net Generation + Imports + Exports - Direct Use)

Total "Losses" (which include more than just T&D, but are mostly T&D I'm guessing) by utility, can be accessed in the database files for Form EIA-861 which you get to at:
http://www.eia.doe.gov/cneaf/electricity/page/eia861.html File 1 (for each year) contains losses in column W.

Other potential sources for specific estimates for distribution losses are:
http://www1.eere.energy.gov/buildings/appliance_standards/commercial/distribution_transformers.html
www.oe.doe.gov
www.epri.com
www.eei.org
www.appanet.org
www.nreca.org
www.ieee.org
www.pur.com
www.mcgraw-hill.com
www.pennwell.com
http://tdworld.com/
www.electricenergyonline.com

I hope this information helps. Please contact us again if you need further assistance with energy data and statistics.

Sincerely,
Paul Hesse
National Energy Information Center
Energy Information Administration (EIA)
Web site: www.eia.doe.gov
Phone: 202-586-8800

Appendix L. E-mail from Howard Stone at the EIA regarding heat rates for natural gas:

If you wish to focus on Washington state and get a more accurate assessment of heat rates by prime mover and fuel type, unit level data, including fuel consumption, net generation and heat rates are collected on our form 923. There are excel spread sheets on the electricity web page on EIA's web site. The latest year available is 2007.

http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html

We are looking at a similar issue in the efficiency ratings for non-combustible renewables in the revisions to our forms, which was the subject of a presentation that Jackie attended. The Federal Register Notice and draft forms are in process for publication. I do not know the exact date. In any event, other organizations such as the IEA use 3412 BTU/kWh as the value of energy input to non-combustible renewables.