# 2021 Electric Integrated Resource Plan

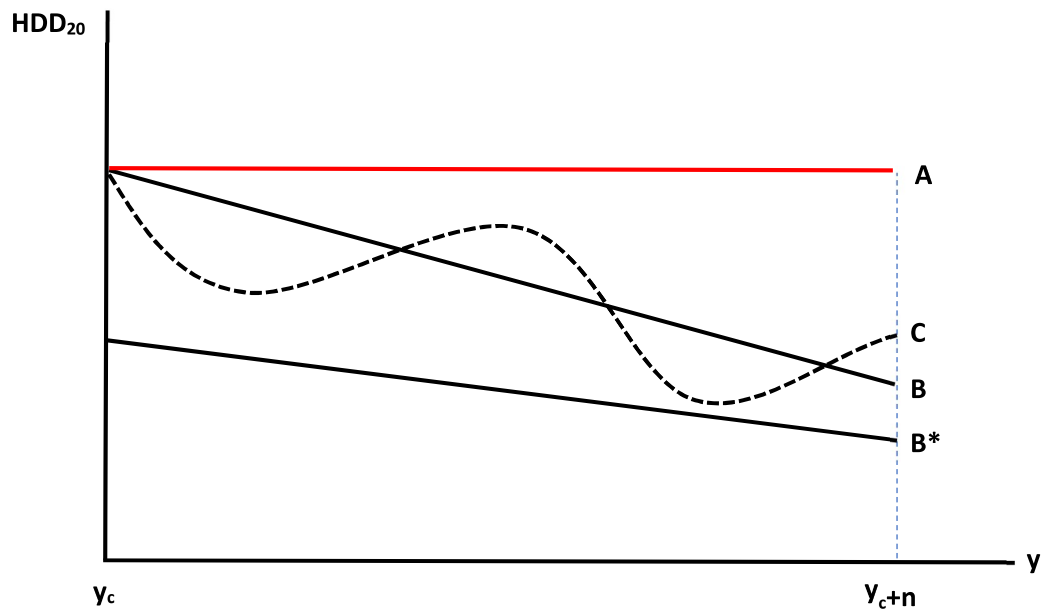
# Appendix K – Load Forecast Supplement

# Appendix K

## Climate Change

The process of integrating climate change into the load forecast starts with estimating the long-run trend in the 20-year average of annual heating degree days (HDD) and cooling degree days (CDD). Ideally, trending the 20-year moving average introduces climate change while still maintain a smoothed measure of normal (average) weather. Figure K.1 demonstrates the issues that need to be considered when choosing a method to introduce climate change using HDD.

**Figure K.1: Issues Related to Forecasted HDD and CDD**




Line A reflects the most recent 20-year moving average ($HDD_{20}$) ending with the current calendar year ($y_c$). In the current IRP, this is the 2000-2019 period. Without a climate change adjustment, Line A is the assumed normal weather over $Y_{c+n}$. Line A will only shift up or down as the 20-year average is updated with a new year of HDD data. If climate change is occurring, then line A will gradually shift down over time along the vertical axis.

A forward-looking climate change adjustment to line A requires introducing a trended moving going forward in time—this is shown by line B or C. However, a method that produces line C is problematic because, compared to line B, it introduces a significant amount of year-to-year variation over the forecast period. In turn, this produces significant amount of volatility in forecasted load, revenues, and earnings that may not be acceptable to the planning process. However, even if a method produces a smooth trend over the forecast horizon, another problem can arise. Specifically, if the method that produces line B generates large shifts in the slope and intercept between forecast runs (i.e., the forecast completed in year y versus the forecast completed in year y+1), this method will also produce a level of volatility that may not be acceptable. This is shown by line B* compared to line B. This analysis shows that the method chosen should be stable over and between forecast runs, yet still capture the current best guess path of climate change over the forecast horizon.

The method used by Avista, starts with an analysis of the 20-year moving average of HDD and CDD using a 20-year moving average time-series going back to 1967. In other words, the first observation in the time series is the 20-year moving average for the period 1948-1967, where 1948 is the start of Avista's (AVA) annual billing adjusted HDD data (discussed above). After analyzing the time-series behavior of both series, the following time series regression equations are estimated:

[1A] $\Delta HDD_{20,y}^{AVA} = \delta_{HDD} + \theta_1 \Delta HDD_{20,y-1}^{AVA} + \theta_2 \Delta HDD_{20,y-2}^{AVA} + \theta_3 \Delta HDD_{20,y-3}^{AVA} + \theta_4 \Delta HDD_{20,y-4}^{AVA} + \theta_5 \Delta HDD_{20,y-5}^{AVA} + \epsilon_y$

[2A] $\Delta CDD_{20,y}^{AVA} = \delta_{CDD} + \gamma_1 \Delta CDD_{20,y-1}^{AVA} + \gamma_2 \Delta CDD_{20,y-2}^{AVA} + \gamma_3 \Delta CDD_{20,y-3}^{AVA} + \gamma_4 \Delta CDD_{20,y-4}^{AVA} + \gamma_5 \Delta CDD_{20,y-5}^{AVA} + \epsilon_y$

Here, $\varepsilon_y$ is a white noise, mean zero error term.

Assuming model stationarity, the constant value δ can be used to calculate the long-run expected change in annual HDD and CDD:

[3A] $\mu_{\Delta HDD} = \frac{\hat{\delta}_{HDD}}{1-(\hat{\theta}_1+\hat{\theta}_2+\hat{\theta}_3+\hat{\theta}_4+\hat{\theta}_5)}$

[4A] $\mu_{\Delta CDD} = \frac{\hat{\delta}_{CDD}}{1-(\hat{\gamma}_1+\hat{\gamma}_2+\hat{\gamma}_3+\hat{\gamma}_4+\hat{\gamma}_5)}$

This can then be applied to the current 20-year moving average to generate trended values out a total of N years:

[5A] $F(HDD_{20,y_c+n}^{AVA}) = HDD_{20,y_c}^{AVA} + n\mu_{\Delta HDD}\ for\ n = 1, \dots, N$

[6A] $F(CDD_{20,y_c+n}^{AVA}) = CDD_{20,y_c}^{AVA} + n\mu_{\Delta cDD}\ for\ n = 1, \dots, N$

For most IRPs, N = 25. If monthly values are needed over the forecast period, then the annual values can be allocated monthly as follows:

[7A] $F(HDD_{20,t,y_c+n}^{AVA}) = \bar{h}_t F(HDD_{20,y_c+n}^{AVA})\ where\ \bar{h}_t = \frac{\sum_{j=0}^{19} h_{t,y_c-j}}{20}\ for\ t = Jan, \dots, Dec$

[8A] $F(CDD_{20,t,y_c+n}^{AVA}) = \bar{c}_t F(CDD_{20,y_c+n}^{AVA})\ where\ \bar{c}_t = \frac{\sum_{j=0}^{19} c_{t,y_c-j}}{20} for\ t = Jan, \dots, Dec$

Here, $\bar{h}_t$ and $\bar{c}_t$ are the 20-year average share of HDD and CDD, respectively, in month t. These monthly values can be used to convert the annual IRP simulation model forecasts to monthly values or, alternatively, adding climate change to the peak load forecast. It should be noted that an analysis of the share of HDD and CDD by month going back to 1948 do not show any apparent trends. This suggests, even under climate change, the relative allocation of HDD and CDD across the months each year will not change significantly going forward.

Returning to the annual, trended moving average forecasts of HDD and CDD, those can be used to estimate the long-run impact on annual residential UPC ($UPC_{r,y}$) in the face of climate change, which can be applied to the long-run annual residential UPC forecast in the IRP simulation model. This process starts with the following regression model:

[9A] $UPC_{r,y} = \alpha_0 + \alpha_1 HDD_y^{AVA} + \alpha_2 CDD_y^{AVA} + \alpha_3 T^* + \alpha_4 D_{1997-1999=} + \alpha_5 D_{2017-2009=1} + \epsilon_y$

Here $HDD_y^{AVA}$ and $CDD_y^{AVA}$ are the actual Avista adjusted degree days in year y; T* is a linear trend starting with T*= 1 in 1997 (the beginning of the historical series); the structural change dummies control for a change in data reporting after 1999 and the LEAP gas program that ended in 2019;and $\varepsilon_y$ is N(0, σ). None linear trends were also tried, by the linear trend produced the best fit on the annual data. Using the estimated coefficients (a), a forecast for UPC under climate change can be generated as follows:

[10A] $F(UPC_{r,y_c+n}) = a_0 + a_1(HDD_{20,y_c}^{AVA} + n\mu_{\Delta HDD}) + a_2(CDD_{20,y_c}^{AVA} + n\mu_{\Delta HDD}) + a_3(T_{y_c}^* + n)\ for\ n = 0, \ldots, N$

Simplifying terms:

[11A] $F(UPC_{r,y_c+n}) = a_0 + a_1 HDD_{20,y_c}^{AVA} + a_2 CDD_{20,y_c}^{AVA} + a_3(T_{y_c}^* + n) + (a_1\mu_{\Delta HDD} + a_2\mu_{\Delta CDD})n$

[12A] $F(UPC_{r,y_c+n}) = (a_0 + a_1 HDD_{20,y_c}^{AVA} + a_2 CDD_{20,y_c}^{AVA}) + a_3(T_{y_c}^* + n) + bn\ where\ b \equiv (a_1\mu_{\Delta HDD} + a_2\mu_{\Delta CDD})$

Note that $b \equiv (a_1\mu_{\Delta HDD} + a_2\mu_{\Delta CDD})$ is treated as the annual marginal impact of total climate change on UPC. Using the times series questions [3A] and [4A], we have $\mu_{\Delta HDD}$ = -9.6 and $\mu_{\Delta HDD}$ = 3.4. Combining these with the estimated values of $a_1$ = 0.732 and $a_2$ = 1.170 we have:

[13A] $b = a_1\mu_{\Delta HDD} + a_2\mu_{\Delta CDD} = 0.732 \cdot (-9.6) + 1.170 \cdot (3.4) = -3.049$

This means the net impact of falling HDD and rising CDD is to reduce residential UPC approximately 3 kWh a year, or a total cumulative impact b·N. Note that in the case of the NPCC data, [x.x] becomes:

[14A] $b = 0.732 \cdot (-38) + 1.170 \cdot (8) = -18.455$

In the context of the IRP simulation model, it is necessary to convert the annual load and energy forecasts into a monthly number. Without climate change, this is straightforward because it only requires extrapolating out the most recent 5-year forecast using the forecasted long-run annual growth rates from the simulation model. This approach essentially assumes the share of load by month in each year will not change significantly over time, which is equivalent to assuming the most current 20-year moving average of HDD and CDD is constant over the forecast horizon (see again Line A in Figure 1A).

However, with climate change, the share of load occurring each month will change overtime. This means a method for estimating those future monthly load shares is necessary to allocate the annual load values from the IRP simulation model. Since total load can be trended over time, the method chosen here estimates a regression using the first difference of month-to-month changes in total load and HDD and CDD, monthly dummies ($D_{t,y}$), and an ARIMA error correction term to account for short-term autocorrelation:

[15A] $\Delta L_{t,y} = \beta_0 + \beta_1 \Delta HDD_{t,y}^{AVA} + \beta_2 \Delta CDD_{t,y}^{AVA} + \boldsymbol{\beta_{3,SD} D_{t,y}} + ARIMA\epsilon_{t,y}(p,d,q)(p_{12},d_{12},q_{12})_{12}$

Here $\Delta L_{t,y} = L_t - L_{t-1}$; $\Delta HDD_{t,y}^{AVA} = HDD_t^{AVA} - HDD_{t-1}^{AVA}$; $\Delta CDD_{t,y}^{AVA} = CDD_t^{AVA} - CDD_{t-1}^{AVA}$. Note that as will be shown shortly, $\beta_0$ reflects the growth in load that occurs each month over the forecast horizon. If $\beta_0 > 0$, then this reflects positive load growth; $\beta_0 = 0$ means no load growth; and $\beta_0 > 0$.

For the purposes of forecasting future load shares, the ARIMA portion is ignored and the forecasted change in load relies solely on the estimated coefficients (b). This is done because simulations including and excluding error term corrections found little impact after the first year:

[16A] $F(\Delta L_{t,y_c+n}) = b_0 + b_1 F(\Delta HDD_{20,t,y_c+n}^{AVA}) + b_2 F(\Delta CDD_{20,t,y_c+n}^{AVA}) + \boldsymbol{b_{3,SD} D_{t,y+n}} \; for \; n = 1,\ldots,N$

Given [16A] and forecast of HDD and CDD, a monthly load forecast can start with, $L_{12,Yc}$, the last actual value for December of the most recent full calendar year, and the forecast would carry to year N. For simplicity, note that the forecast notation, F(·), has been dropped:

$$L_{1,y_c+1} = L_{12,y_c} + \Delta L_{1,y_c+1}$$

$$L_{2,y_c+1} = L_{1,y_c+1} + \Delta L_{2,y_c+1}$$

$$L_{3,y_c+1} = L_{2,y_c+1} + \Delta L_{3,y_c+1}$$

$$\vdots$$

$$L_{11,y_c+1} = L_{10,y_c+1} + \Delta L_{11,y_c+1}$$

$$L_{12,y_c+1} = L_{11,y_c+1} + \Delta L_{12,y_c+1}$$

$$L_{1,y_c+2} = L_{12,y_c+1} + \Delta L_{1,y_c+2}$$

$$\vdots$$

$$L_{11,y_c+2} = L_{10,y_c+2} + \Delta L_{11,y_c+2}$$

$$L_{12,y_c+2} = L_{11,y_c+2} + \Delta L_{12,y_c+2}$$

$$\vdots$$

$$L_{11,y_c+N} = L_{10,y_c+N} + \Delta L_{11,y_c+N}$$

$$L_{12,y_c+N} = L_{11,y_c+N} + \Delta L_{12,y_c+N}$$

This process generates a series of total load values for each calendar year, n, over the forecast horizon.

[17A] $L_{y_c+n} = \sum_{t=1}^{12} L_{t,y_c+n}$

Therefore, for each year, n, the forecasted load share over that year can be calculated as:

[18A] $\sum_{t=1}^{12} \left( \frac{L_{t,y_c+n}}{L_{y_c+n}} \right) = \sum_{t=1}^{12} \lambda_{t,y_c+1} = 1$

The monthly load shares can be applied to the annual forecast values in the simulation model convert the annual forecasts to monthly values. However, prior to this allocation, it may be required to manually adjust the estimated constant, $b_0$, so that the average annual load growth rate associated with [16A] matches the average annual growth rate from the IRP simulation model. That is, because [16A] is being estimated from historical data, $b_0$ reflects historical non-weather related growth. This can be seen by re-arranging [17A] as follows:

[19A] $L_{y_c+n} = \sum_{t=1}^{12} L_{t,y_c+n} = L_{12,y_c-(n-1)} + \sum_{t=1}^{11} L_{t,y_c+n} + \sum_{t=1}^{12} \Delta L_{t,y_c+n} \ for\ n = 1, \ldots, N$

Substituting in the estimated regression [16A]:

[20A] $L_{y_c+n} = L_{12,y_c-(n-1)} + \sum_{t=1}^{11} L_{t,y_c+n} + \sum_{t=1}^{12} (b_0 + b_1 \Delta HDD_{20,t,y_c+n}^{AVA} + b_2 \Delta CDD_{20,t,y_c+n}^{AVA} + \boldsymbol{b_{3,SD} D_{t,y}})$

[21A] $L_{y_c+n} = 12b_0 + L_{12,y_c-(n-1)} + \sum_{t=1}^{11} L_{t,y_c+n} + \sum_{t=1}^{12} ( b_1 \Delta HDD_{20,t,y_c+n}^{AVA} + b_2 \Delta CDD_{20,t,y_c+n}^{AVA} + \boldsymbol{b_{3,SD} D_{t,y}})$

[21A] shows that for any calendar year, non-weather-related load accumulates by $12b_0$. Accounting for the accumulation over all N periods:

[22A] $L_{12,y_c+N} = L_{12,y_c} + \sum_{t=1}^{12} \Delta L_{t,y_c+1} + \sum_{t=1}^{12} \Delta L_{t,y_c+2} + \sum_{t=1}^{12} \Delta L_{t,y_c+3} \ldots + \sum_{t=1}^{12} \Delta L_{t,y_c+(N-1)} + \sum_{t=1}^{12} \Delta L_{t,y_c+N}$

[23A] $L_{12,y_c+N} = L_{12,y_c} + \sum_{n=1}^{N} (\sum_{t=1}^{12} \Delta L_t)_{y_c+n}$

[24A] $L_{12,y_c+N} = L_{12,y_c} + \sum_{n=1}^{N} \left( \sum_{t=1}^{12} \left( b_0 + b_1 \Delta HDD_{20,t}^{AVA} + b_2 \Delta CDD_{20,t}^{AVA} + \boldsymbol{b_{3,SD} D_{t,y}} \right) \right)_{y_c+n}$

[25A] $L_{12,y_c+N} = L_{12,y_c} + N12b_0 + \sum_{n=1}^{N} \left( \sum_{t=1}^{12} \left( b_1 \Delta HDD_{20,t}^{AV} + b_2 \Delta CDD_{20,t}^{AVA} + \boldsymbol{b_{3,SD} D_{t,y}} \right) \right)_{y_c+n}$

Non-weather related load accumulation over all N periods is $N12b_0$.

To integrate climate change into the peak load model, note that any 20-year moving average can be used to calculate the implied average temperature associated with a given month, t; note that C is the cut-off for CDD and HDD, which Avista sets at 65 degrees, and D is the number of days in month t:

[26A] $CDD_{20,t,y}^{AVA} = \frac{\sum_{j=0}^{20} CDD_{t,y-j}}{20} = \frac{\sum_{j=0}^{19} D\,(\bar{T}_{d,t,y-j} - C)}{20} = \frac{\sum_{j=0}^{19} (D\bar{T}_{d,t,y-j} - D \cdot C)}{20} = \frac{-20 \cdot D \cdot C + N \sum_{y=0}^{19} \bar{T}_{d,t,y}}{20} = -D \cdot C + D \frac{\sum_{j=0}^{19} \bar{T}_{d,t,y-j}}{20} = -D \cdot C + D\bar{T}_{20,t,y} \Rightarrow \bar{T}_{20,t,y} = \frac{D \cdot C + CDD_{20,t,y}^{AVA}}{D}$

[27A] $HDD_{20,t,y}^{AVA} = \frac{\sum_{j=0}^{19} HDD_{t,y-j}}{20} = \frac{\sum_{j=0}^{19} D\,(C - \bar{T}_{d,t,y-j})}{20} = \frac{\sum_{j=0}^{19} (D \cdot C - D\bar{T}_{d,t,y-j})}{20} = \frac{20 \cdot D \cdot C - D \sum_{j=0}^{19} \bar{T}_{d,t,y-j}}{20} = D \cdot C - D \frac{\sum_{j=0}^{19} \bar{T}_{d,t,y-j}}{20} = D \cdot C - D \cdot \bar{T}_{20,t,y} \Rightarrow \bar{T}_{20,t,y} = \frac{D \cdot C - HDD_{20,t,y}^{AVA}}{D}$

Given forecasted values for the 20-year moving average of HDD and CDD (equations [5A] and [6A]), the formulas above are used to calculate the implied 20-year moving average of average temperature forecasted for month t. The average annual change in this temperature can be applied to calculate the expected change in average summer and winter peak temperatures for integrating climate change into the peak load forecast. Note that the growing (summer) or falling (winter) temperatures with act to accelerate growth (in the case of summer) or decelerate growth (in the case of winter), in addition to any impact associated with assumed economic growth. Thus:

[28A] $\Delta\bar{T}_{20,t} = \frac{\bar{T}_{20,t,2045} - \bar{T}_{20,t,y_c}}{(2045- \quad _c)}\ for\ either\ CDD\ or\ HDD\ for\ month\ t$

[29A] $F(A_{t,y_c+n,MAX}) = \frac{\sum_{j=0}^{19} A_{t,y_c-j,MAX}}{20} + n \cdot \Delta\bar{T}_{CDD20,t}\ for\ n = 1, \ldots, N\ years$

[30A] $F(A_{t,y_c+n,MIN}) = \frac{\sum_{j=0}^{19} A_{t,y_c-j,MIN}}{20} + n \cdot \Delta\bar{T}_{HDD20,t}\ for\ n = 1, \ldots, N\ years$

From each series $A_{t,y,}$ MAX is based on maximum daily average temperature and MIN is based on minimum average daily temperatures. The first expression on the right of the equals sign is the current 20-year historic average of MAX and MIN temperatures. The second expression is the trending factor applied to the 20-year average. These trended averages can then be converted back into CDD and HDD to be used in the peak-load forecast model. These provide a trended values of CDD and HDD associated with peak load.