

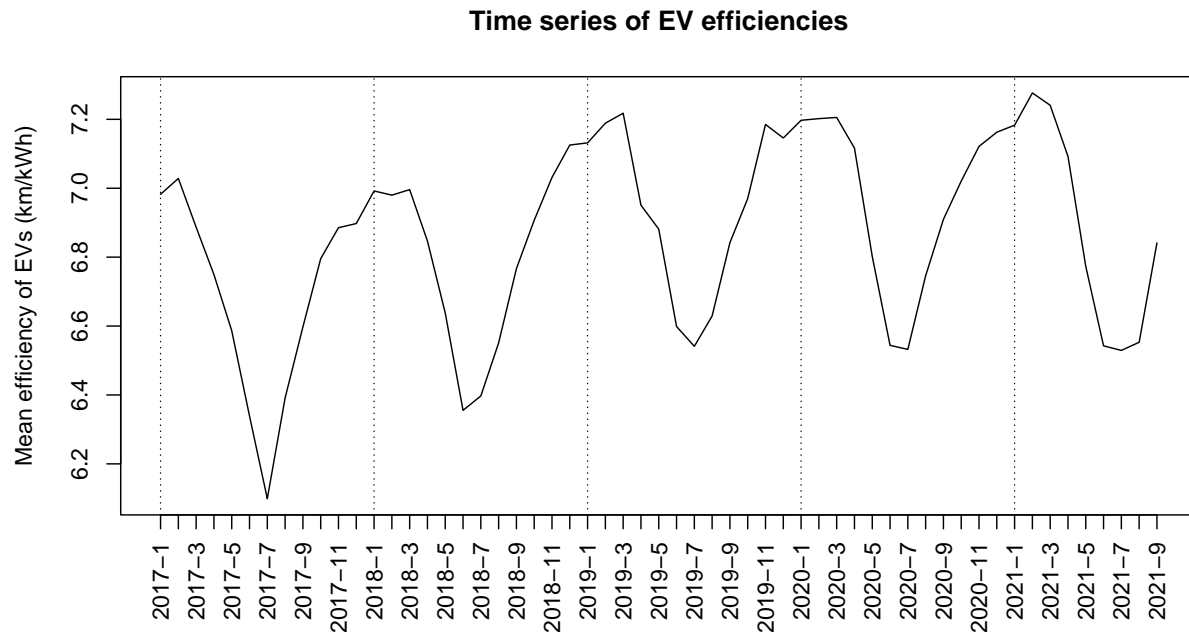
EV data findings

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```
## # A tibble: 25 x 3
## # Groups:   region [25]
##   region      weather_region count
##   <fct>      <fct>      <int>
## 1 Auckland      Auckland      330
## 2 Wellington    Upper Hutt      238
## 3 Christchurch   Christchurch    146
## 4 Coastal Otago   Dunedin        132
## 5 Waikato         Hamilton        65
## 6 Bay of Plenty   Rotorua         53
## 7 North Canterbury Christchurch     34
## 8 Central Otago    Clyde           31
## 9 Mid Canterbury   Christchurch     31
## 10 Nelson          Nelson           31
## # ... with 15 more rows
```

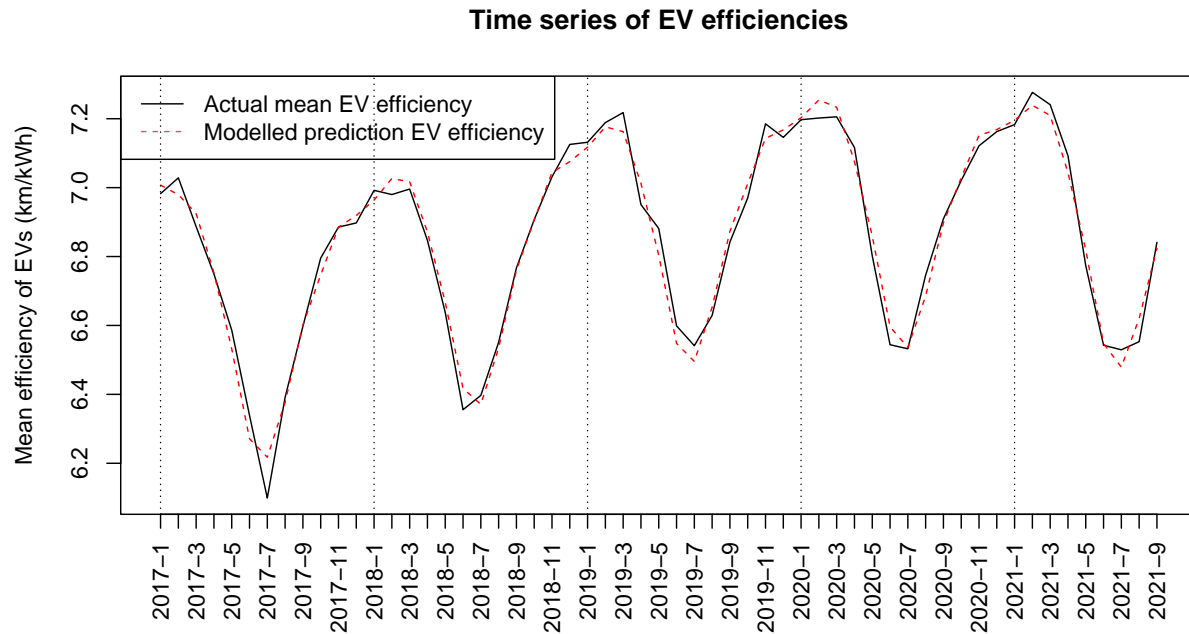
```
## # A tibble: 26 x 2
##   model                                count
##   <fct>                                <int>
## 1 Nissan Leaf (24 kWh) 2013-2016      527
## 2 Nissan Leaf (30 kWh)                275
## 3 Nissan Leaf (24 kWh) 2011-2012      204
## 4 Nissan Leaf (40 kWh)                 68
## 5 Nissan e-NV200 (24 kWh)              62
## 6 Hyundai Ioniq (EV)                   26
## 7 BMW i3                               23
## 8 Hyundai Kona (EV)                    14
## 9 Renault Zoe                          14
## 10 Tesla Model 3                       14
## # ... with 16 more rows
```



simple linear model with $\text{mean_eff} = t + \ln t + t^2 + \text{month}$ (as factor). negative squared term means can not use for long term efficiency trend as it will get negative but allows it to better fit the seasonal trend

```
##
## Call:
## lm(formula = mean_ef ~ m + I(log(m)) + I(m^2) + factor(month),
##     data = monthly_EV_data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.118463 -0.027742 -0.003732  0.037674  0.077820
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   6.971e+00  3.686e-02 189.156 < 2e-16 ***
## m             3.612e-02  4.303e-03   8.394 1.59e-10 ***
## I(log(m))     -1.607e-01  3.253e-02  -4.941 1.29e-05 ***
## I(m^2)        -3.834e-04  4.952e-05  -7.743 1.28e-09 ***
## factor(month)2  4.870e-02  3.037e-02   1.604   0.116
## factor(month)3  2.504e-02  3.066e-02   0.817   0.419
## factor(month)4 -1.343e-01  3.089e-02  -4.346 8.61e-05 ***
## factor(month)5 -3.518e-01  3.108e-02 -11.321 2.43e-14 ***
## factor(month)6 -6.154e-01  3.123e-02 -19.709 < 2e-16 ***
## factor(month)7 -6.753e-01  3.135e-02 -21.539 < 2e-16 ***
## factor(month)8 -5.247e-01  3.147e-02 -16.675 < 2e-16 ***
## factor(month)9 -3.109e-01  3.157e-02  -9.847 1.78e-12 ***
## factor(month)10 -1.776e-01  3.299e-02  -5.384 3.04e-06 ***
## factor(month)11 -5.172e-02  3.299e-02  -1.568   0.124
## factor(month)12 -3.111e-02  3.299e-02  -0.943   0.351
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Residual standard error: 0.04766 on 42 degrees of freedom
## Multiple R-squared:  0.9784, Adjusted R-squared:  0.9712
## F-statistic: 135.6 on 14 and 42 DF,  p-value: < 2.2e-16
```

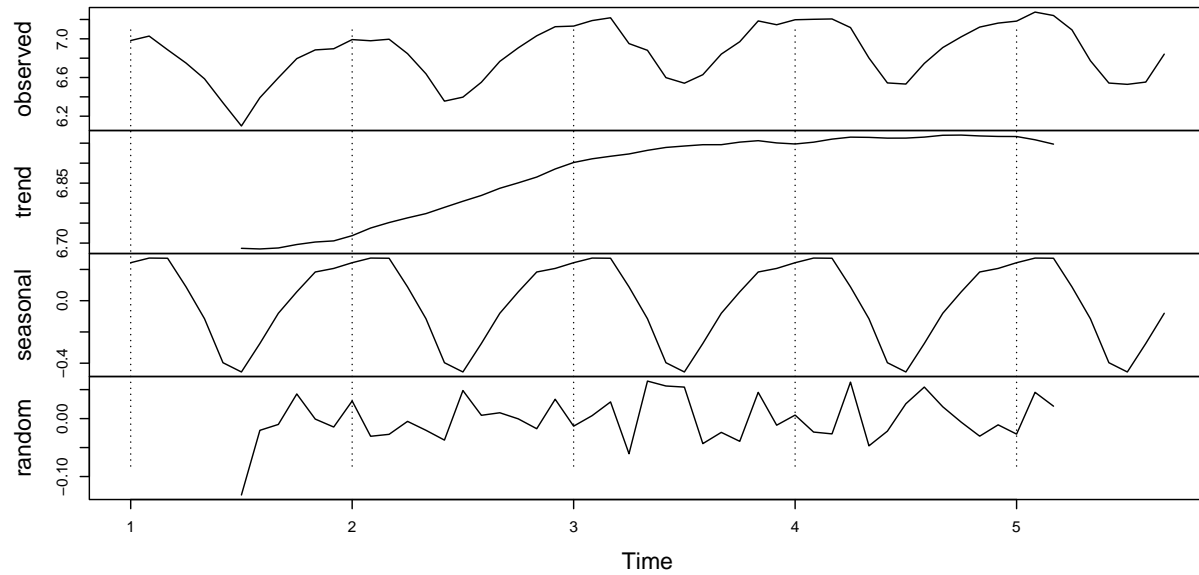


```
## Warning in adf.test(eff_series, alternative = "stationary"): p-value smaller
## than printed p-value
```

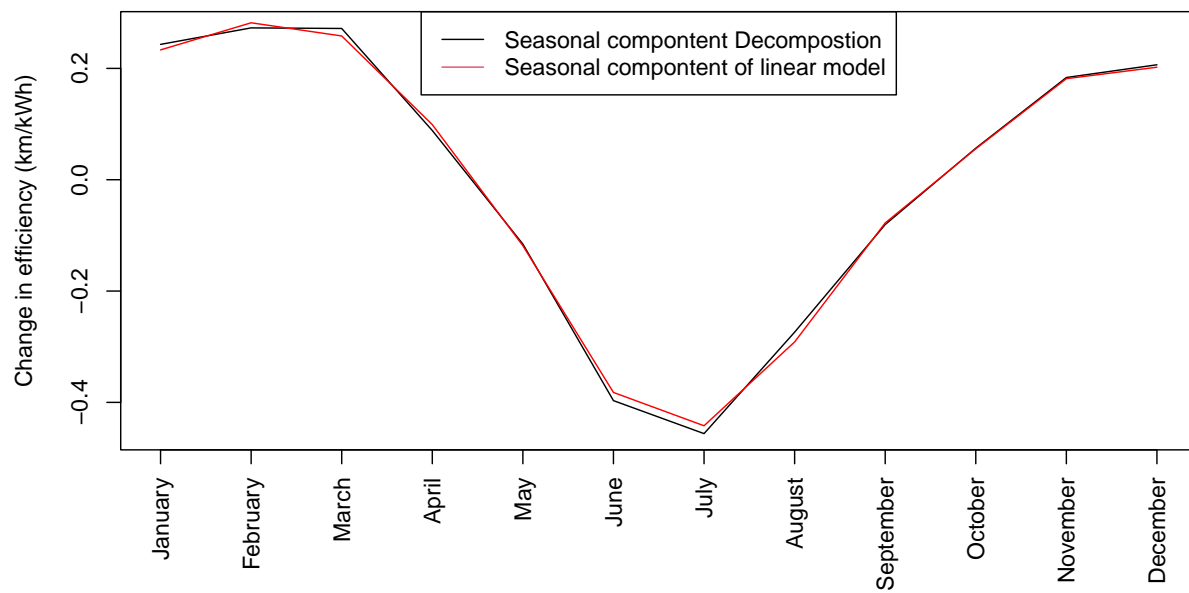
```
##
## Augmented Dickey-Fuller Test
##
## data:  eff_series
## Dickey-Fuller = -4.7294, Lag order = 3, p-value = 0.01
## alternative hypothesis: stationary
```

we can reject null hypothesis that data is not-stationary. this makes sense as average efficiency should not have significantly changed in a couple of years. use multiplicative instead of additive as preferable to know estimated extra power use? or should i know total extra power used in season?

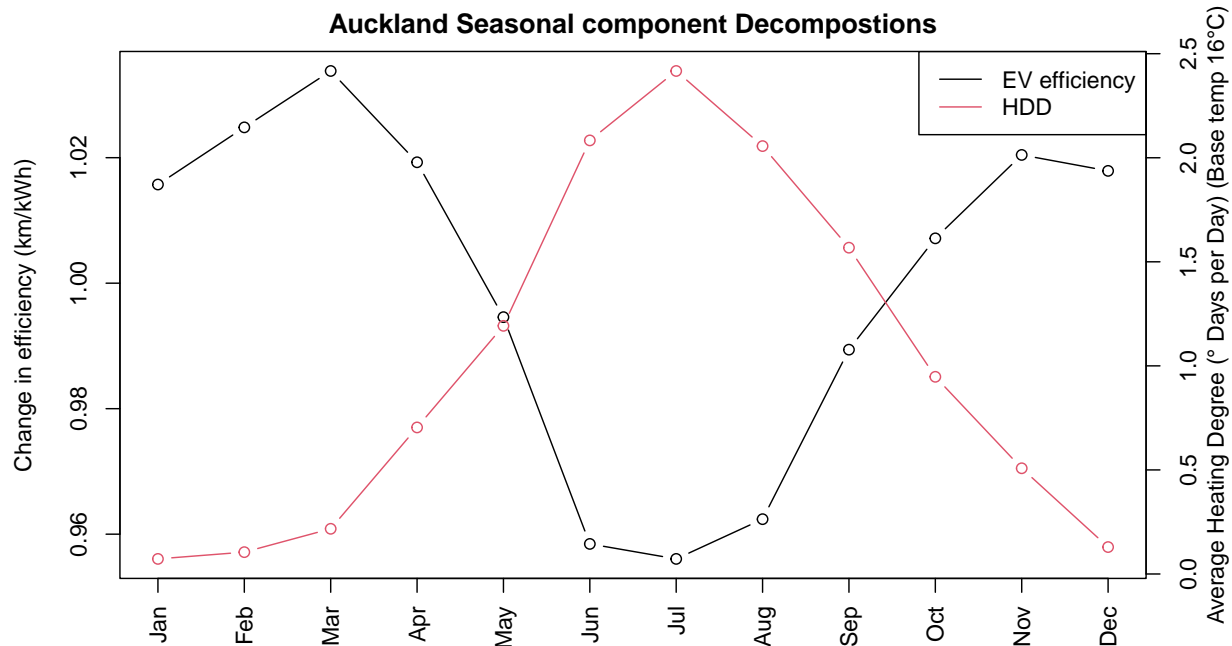
Decomposition of additive time series



Seasonal component of Efficiency of EV



will only do for Auckland as too many lines would get crowded



intercept base line is Nissan Leaf (24 kWh) 2013-2016

```
##
## Call:
## lm(formula = efficiency ~ HDD + model, data = EV_data[year >=
## 2017, ], na.action = na.omit)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -5.5433 -0.4961 -0.0240  0.4956  6.3890
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    7.550e+00  1.058e-02  713.269 < 2e-16 ***
## HDD            -3.615e-03  6.293e-05  -57.443 < 2e-16 ***
## modelNissan Leaf (30 kWh) -1.329e-01  1.302e-02  -10.208 < 2e-16 ***
## modelNissan Leaf (24 kWh) 2011-2012 -6.467e-01  1.551e-02  -41.699 < 2e-16 ***
## modelNissan Leaf (40 kWh) -5.194e-01  2.764e-02  -18.794 < 2e-16 ***
## modelNissan e-NV200 (24 kWh) -1.270e+00  2.456e-02  -51.691 < 2e-16 ***
## modelHyundai Ioniq (EV)    8.904e-01  3.503e-02   25.419 < 2e-16 ***
## modelBMW i3              -1.606e-01  4.106e-02   -3.912 9.19e-05 ***
## modelHyundai Kona (EV)    -4.530e-02  4.892e-02   -0.926 0.354426
## modelRenault Zoe         -4.531e-01  4.555e-02   -9.949 < 2e-16 ***
## modelTesla Model 3       -5.871e-01  5.570e-02  -10.542 < 2e-16 ***
## modelNissan Leaf (62 kWh) -1.031e+00  8.627e-02  -11.950 < 2e-16 ***
## modelKia Niro (EV)       -4.818e-01  6.321e-02   -7.621 2.61e-14 ***
## modelTesla Model S       -2.109e+00  7.921e-02  -26.628 < 2e-16 ***
## modelVolkswagen e-Golf   -6.872e-02  6.943e-02   -0.990 0.322293
## modelConversion to EV    -2.311e+00  9.793e-02  -23.598 < 2e-16 ***
## modelTesla Model-X       -3.063e+00  8.571e-02  -35.740 < 2e-16 ***
## modelKia Soul            -4.245e-01  7.116e-02   -5.965 2.48e-09 ***
## modelMG ZS EV           -7.368e-01  1.985e-01   -3.712 0.000206 ***
```

```
## modelRenault Kangoo (van)          -2.161e+00  9.634e-02 -22.428 < 2e-16 ***
## modelJaguar I-PACE                  -2.517e+00  1.340e-01 -18.793 < 2e-16 ***
## modelAudi A3 e-tron                 -1.388e+00  2.717e-01  -5.110 3.25e-07 ***
## modelMitsubishi iMiev - car         -3.178e+00  5.432e-01  -5.850 4.98e-09 ***
## modelPeugeot e-208                  -3.421e-01  3.437e-01  -0.995 0.319521
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.7682 on 22805 degrees of freedom
## (67 observations deleted due to missingness)
## Multiple R-squared:  0.3353, Adjusted R-squared:  0.3346
## F-statistic: 500.2 on 23 and 22805 DF,  p-value: < 2.2e-16
```

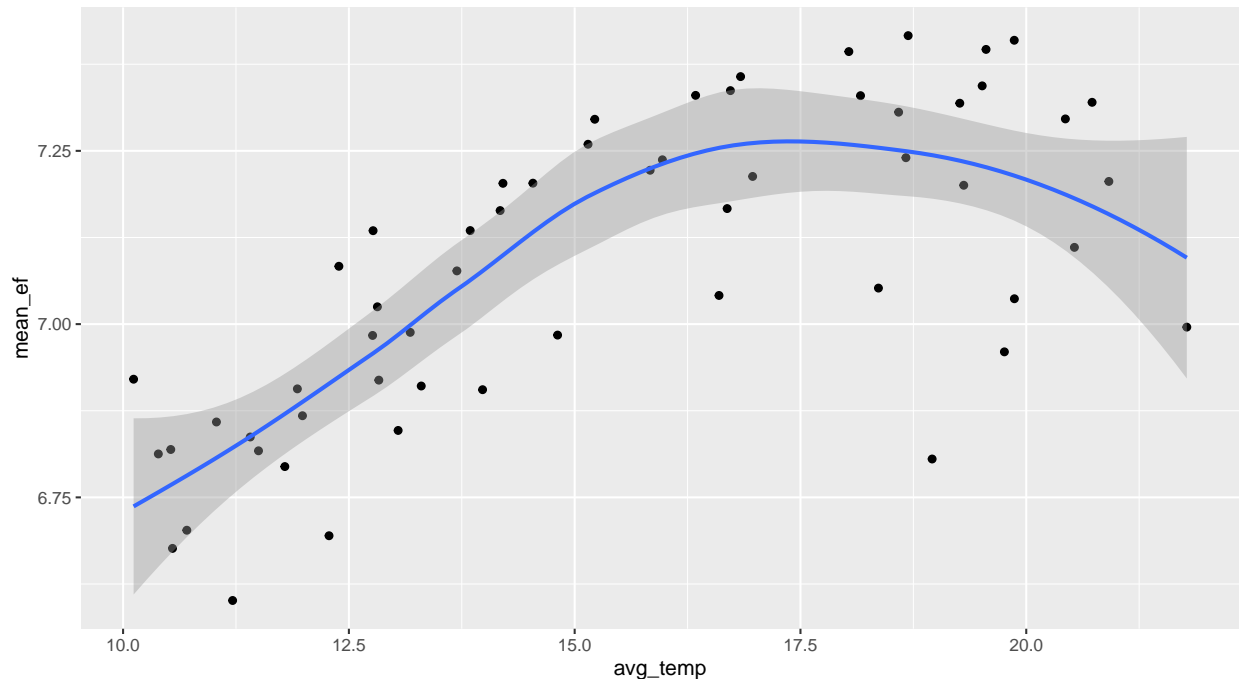
different city weather stations may be measuring colder or warmer regions of the city and therefore may need a slightly different scaling. interesting that Rotorua has lower effect on HDD, could be cause Rotorua is inland Bay of Plenty so its temperature change is more significant that coastal Tauranga which would also be included in bay of plenty.

```
##
## Call:
## lm(formula = efficiency ~ HDD + weather_region + model, data = EV_data[year >=
## 2017, ], na.action = na.omit)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -5.6146 -0.4748 -0.0181  0.4735  6.2852
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      7.621e+00  1.180e-02 646.079 < 2e-16 ***
## HDD              -3.339e-03  6.622e-05 -50.417 < 2e-16 ***
## weather_regionUpper Hutt      -3.601e-02  1.504e-02  -2.394  0.0167 *
## weather_regionChristchurch      9.499e-02  1.534e-02   6.192 6.03e-10 ***
## weather_regionDunedin      -5.146e-01  1.814e-02 -28.361 < 2e-16 ***
## weather_regionHamilton      -3.404e-01  2.662e-02 -12.790 < 2e-16 ***
## weather_regionRotorua      -1.965e-02  2.706e-02  -0.726  0.4677
## weather_regionNelson      -9.176e-03  2.293e-02  -0.400  0.6890
## weather_regionClyde      -1.743e-01  3.794e-02  -4.593 4.40e-06 ***
## weather_regionPalmerston North      -6.844e-01  3.469e-02 -19.729 < 2e-16 ***
## weather_regionStratford      -3.567e-01  4.373e-02  -8.157 3.62e-16 ***
## weather_regionNapier      -3.331e-01  4.184e-02  -7.961 1.79e-15 ***
## weather_regionInvercargill      -6.209e-01  6.898e-02  -9.001 < 2e-16 ***
## modelNissan Leaf (30 kWh)      -1.530e-01  1.268e-02 -12.069 < 2e-16 ***
## modelNissan Leaf (24 kWh) 2011-2012 -6.734e-01  1.504e-02 -44.770 < 2e-16 ***
## modelNissan Leaf (40 kWh)      -5.137e-01  2.672e-02 -19.228 < 2e-16 ***
## modelNissan e-NV200 (24 kWh)      -1.298e+00  2.371e-02 -54.750 < 2e-16 ***
## modelHyundai Ioniq (EV)       9.768e-01  3.457e-02  28.256 < 2e-16 ***
## modelBMW i3              -4.694e-02  4.015e-02  -1.169  0.2424
## modelHyundai Kona (EV)      -9.098e-02  4.722e-02  -1.927  0.0540 .
## modelRenault Zoe          -5.311e-01  4.405e-02 -12.057 < 2e-16 ***
## modelTesla Model 3         -5.751e-01  5.412e-02 -10.626 < 2e-16 ***
## modelNissan Leaf (62 kWh)      -1.132e+00  8.334e-02 -13.584 < 2e-16 ***
## modelKia Niro (EV)          -5.084e-01  6.206e-02  -8.193 2.69e-16 ***
## modelTesla Model S         -2.212e+00  7.657e-02 -28.890 < 2e-16 ***
```

```
## modelVolkswagen e-Golf          -9.458e-02  6.792e-02  -1.393  0.1638
## modelConversion to EV          -1.834e+00  1.075e-01 -17.049 < 2e-16 ***
## modelTesla Model-X            -3.151e+00  8.414e-02 -37.442 < 2e-16 ***
## modelKia Soul                  -4.021e-01  7.009e-02  -5.737  9.76e-09 ***
## modelMG ZS EV                  -7.522e-01  1.914e-01  -3.929  8.55e-05 ***
## modelRenault Kangoo (van)      -2.244e+00  9.615e-02 -23.340 < 2e-16 ***
## modelJaguar I-PACE             -2.627e+00  1.292e-01 -20.328 < 2e-16 ***
## modelAudi A3 e-tron            -1.480e+00  2.619e-01  -5.650  1.62e-08 ***
## modelMitsubishi iMiev - car    -2.589e+00  5.245e-01  -4.936  8.04e-07 ***
## modelPeugeot e-208             -5.681e-01  3.313e-01  -1.715  0.0864 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.7402 on 22794 degrees of freedom
## (67 observations deleted due to missingness)
## Multiple R-squared:  0.3831, Adjusted R-squared:  0.3822
## F-statistic: 416.3 on 34 and 22794 DF, p-value: < 2.2e-16
```

<https://www.geotab.com/blog/ev-range/>

based on this AC should also decrease range. not too obvious in NZ as is kind of cold but in Auckland can see such a trend what if we include cooling degree days in analysis too? unlike this direct average temp vs efficiency plot this would allow for cooling and heating in the same month that could reduce efficiency. could explain the couple month that have very bad efficiency, possibly have a few cold and warm days but average is nothing unusual



```
##
## Call:
## lm(formula = efficiency ~ CDD + HDD + weather_region + model,
##     data = EV_data[year >= 2017, ], na.action = na.omit)
##
## Residuals:
```

```

##      Min      1Q  Median      3Q      Max
## -5.5686 -0.4725 -0.0184  0.4724  6.3033
##
## Coefficients:
##
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      7.651e+00  1.396e-02  548.101 < 2e-16 ***
## CDD              -3.862e-03  9.608e-04   -4.020 5.83e-05 ***
## HDD              -3.540e-03  8.298e-05  -42.657 < 2e-16 ***
## weather_regionUpper Hutt      -3.226e-02  1.506e-02   -2.142 0.032217 *
## weather_regionChristchurch      1.119e-01  1.590e-02    7.037 2.02e-12 ***
## weather_regionDunedin        -5.112e-01  1.816e-02  -28.154 < 2e-16 ***
## weather_regionHamilton        -3.302e-01  2.673e-02  -12.354 < 2e-16 ***
## weather_regionRotorua        -1.165e-02  2.712e-02   -0.430 0.667466
## weather_regionNelson         -5.093e-03  2.294e-02   -0.222 0.824316
## weather_regionClyde          -1.381e-01  3.898e-02   -3.544 0.000395 ***
## weather_regionPalmerston North -6.827e-01  3.468e-02  -19.686 < 2e-16 ***
## weather_regionStratford        -3.567e-01  4.372e-02   -8.159 3.55e-16 ***
## weather_regionNapier          -3.190e-01  4.197e-02   -7.601 3.06e-14 ***
## weather_regionInvercargill     -6.110e-01  6.900e-02   -8.856 < 2e-16 ***
## modelNissan Leaf (30 kWh)       -1.533e-01  1.268e-02  -12.091 < 2e-16 ***
## modelNissan Leaf (24 kWh) 2011-2012 -6.729e-01  1.504e-02  -44.750 < 2e-16 ***
## modelNissan Leaf (40 kWh)       -5.153e-01  2.671e-02  -19.294 < 2e-16 ***
## modelNissan e-NV200 (24 kWh)    -1.297e+00  2.371e-02  -54.733 < 2e-16 ***
## modelHyundai Ioniq (EV)         9.767e-01  3.456e-02   28.264 < 2e-16 ***
## modelBMW i3                   -4.748e-02  4.013e-02   -1.183 0.236777
## modelHyundai Kona (EV)         -9.090e-02  4.720e-02   -1.926 0.054161 .
## modelRenault Zoe              -5.313e-01  4.404e-02  -12.066 < 2e-16 ***
## modelTesla Model 3            -5.767e-01  5.410e-02  -10.658 < 2e-16 ***
## modelNissan Leaf (62 kWh)      -1.134e+00  8.331e-02  -13.607 < 2e-16 ***
## modelKia Niro (EV)            -5.110e-01  6.204e-02   -8.237 < 2e-16 ***
## modelTesla Model S            -2.213e+00  7.654e-02  -28.907 < 2e-16 ***
## modelVolkswagen e-Golf        -9.576e-02  6.790e-02   -1.410 0.158460
## modelConversion to EV         -1.834e+00  1.075e-01  -17.059 < 2e-16 ***
## modelTesla Model-X            -3.149e+00  8.412e-02  -37.441 < 2e-16 ***
## modelKia Soul                 -4.018e-01  7.007e-02   -5.735 9.90e-09 ***
## modelMG ZS EV                 -7.565e-01  1.914e-01   -3.953 7.75e-05 ***
## modelRenault Kangoo (van)     -2.245e+00  9.612e-02  -23.359 < 2e-16 ***
## modelJaguar I-PACE            -2.630e+00  1.292e-01  -20.355 < 2e-16 ***
## modelAudi A3 e-tron           -1.487e+00  2.619e-01   -5.680 1.36e-08 ***
## modelMitsubishi iMiev - car   -2.602e+00  5.244e-01   -4.962 7.01e-07 ***
## modelPeugeot e-208            -5.701e-01  3.312e-01   -1.721 0.085226 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.74 on 22793 degrees of freedom
## (67 observations deleted due to missingness)
## Multiple R-squared:  0.3835, Adjusted R-squared:  0.3826
## F-statistic: 405.1 on 35 and 22793 DF, p-value: < 2.2e-16

```

cooling degree days does explain extra variance but not much. likely as not many cooling days above 20 in nz

```

## Analysis of Variance Table
##

```



```

## Model 1: efficiency ~ HDD + model
## Model 2: efficiency ~ HDD + weather_region + model
## Model 3: efficiency ~ CDD + HDD + weather_region + model
##   Res.Df   RSS Df Sum of Sq      F    Pr(>F)
## 1  22805 13458
## 2  22794 12490 11    967.18 160.565 < 2.2e-16 ***
## 3  22793 12482  1     8.85  16.162 5.835e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```