Appendix

Additional Data

Table A.1: Total variable costs for high and low sulfur oil and diesel, based on the GPA fuel cost forecast and heatrates and variable O&M costs from Shaalan.

	Total Variable Costs [$/MWh]		
Year	HSFO	LSFO	Diesel
2015	$ 130.00	$ 151.00	$ 344.75
2016	$ 136.30	$ 159.41	$ 360.93
2017	$ 142.21	$ 166.30	$ 376.09
2018	$ 148.11	$ 173.19	$ 391.25
2019	$ 154.02	$ 180.08	$ 406.41
2020	$ 159.92	$ 186.97	$ 421.57
2021	$ 165.83	$ 193.86	$ 436.73
2022	$ 171.74	$ 200.76	$ 451.89
2023	$ 177.64	$ 207.65	$ 467.05
2024	$ 183.55	$ 214.54	$ 482.21
2025	$ 189.46	$ 221.43	$ 497.37
2026	$ 195.36	$ 228.32	$ 512.53
2027	$ 201.27	$ 235.21	$ 527.69
2028	$ 207.17	$ 242.10	$ 542.85
2029	$ 213.08	$ 248.99	$ 558.01
2030	$ 218.99	$ 255.88	$ 573.17
2031	$ 224.50	$ 261.25	$ 587.30
2032	$ 230.80	$ 269.67	$ 603.49
2033	$ 236.71	$ 276.56	$ 618.65
2034	$ 242.61	$ 283.45	$ 633.81
2035	$ 248.52	$ 290.34	$ 648.97

Table A.2: Load scaling factors used in model, as taken from and extrapolated from the GPA 2013 IRP

	Sales Forecast [MWh]		Peak Demand Forecast [MW]	
Year	Baseline	EPA Delay	Baseline	EPA Delay
2012	1.550	1.590	264.0	280.0
2013	1.575	1.720	263.5	300.0
2014	1.580	1.740	266.0	320.0
2015	1.590	1.780	270.0	310.0
2016	1.600	1.950	272.0	322.5
2017	1.610	2.200	272.0	329.0
2018	1.610	2.200	271.0	320.0
2019	1.610	1.995	270.0	305.0
2020	1.620	1.970	271.0	300.0
2021	1.630	1.970	272.0	300.0
2022	1.640	1.950	272.5	299.0
2023	1.650	1.950	273.0	301.5
2024	1.660	1.970	273.5	303.0
2025	1.670	1.990	274.0	304.5
2026	1.680	2.027	274.5	306.0
2027	1.690	2.064	275.0	307.5
2028	1.700	2.101	275.5	309.0
2029	1.710	2.138	276.0	310.5
2030	1.720	2.175	276.5	312.0
2031	1.730	2.212	277.0	313.5
2032	1.740	2.249	277.5	315.0
2033	1.750	2.286	278.0	316.5
2034	1.760	2.323	278.5	318.0
2035	1.770	2.360	279.0	319.5

Table A.3: Declining costs of PV as taken from the NW Power and Conservation Council, and converted to 2015 dollars

Year	Cost [2012$/MW]	Cost [2015$/MW]
2012	$ 4,270,000.00	$ 5,230,933.61
2013	$ 3,943,000.00	$ 4,830,344.55
2014	$ 3,718,000.00	$ 4,554,709.87
2015	$ 3,546,000.00	$ 4,344,002.48
2016	$ 3,391,000.00	$ 4,154,120.81
2017	$ 3,249,000.00	$ 3,980,164.71
2018	$ 3,119,000.00	$ 3,820,909.12
2019	$ 2,999,000.00	$ 3,673,903.96
2020	$ 2,888,000.00	$ 3,537,924.18
2021	$ 2,786,000.00	$ 3,412,969.80
2022	$ 2,693,000.00	$ 3,299,040.80
2023	$ 2,607,000.00	$ 3,193,687.10
2024	$ 2,550,000.00	$ 3,123,859.65
2025	$ 2,535,000.00	$ 3,105,484.01
2026	$ 2,520,000.00	$ 3,087,108.36
2027	$ 2,505,000.00	$ 3,068,732.72
2028	$ 2,490,000.00	$ 3,050,357.07
2029	$ 2,475,000.00	$ 3,031,981.43
2030	$ 2,460,000.00	$ 3,013,605.78
2031	$ 2,445,000.00	$ 2,995,230.14
2032	$ 2,431,000.00	$ 2,978,079.53
2033	$ 2,416,000.00	$ 2,959,703.89
2034	$ 2,401,000.00	$ 2,941,328.24
2035	$ 2,387,000.00	$ 2,924,177.64

Model Code

Model file: Project1.mod

```
# Guam Renewable Integration
# Martin Chang and Ryan Satterlee
# ENERGY 291 Final Project

# Parameters to set up sets
param time_o >= 0, default 1; # Time step 1 of study period, currently using weeks as
timestep
param year_o >= 0, default 2015; # Starting year of study period
param year_f >= 0, default 2035; # Ending year of study period

# ------------------------------------SETS-------------------------------------
set TIME;
```

```
set YEARS = year_o .. year_f;
set SITES;
set RENEWABLES within SITES;

#---------------------------------PARAMETERS-----------------------------------
# Transmission costs [$]
param TransCost {s in SITES};

# Capital costs [$/MW]
param CapitalCost {s in SITES, y in YEARS};

# Fixed O&M [$/MW-yr]
param FixedOMCost {s in SITES};

# Variable O&M cost [$/MWh]
param VarOMCost {s in SITES};

# RPS goal as a % of annual sales
param RPS_Goal {y in YEARS};

# Hourly Load [MWh]
param Load {t in TIME};

# Avaiability of resource [MW/km^2]
param ResourceAvailability {s in SITES, t in TIME};

# Amount of resource developed prior to study [MW]
param InitialDevelopedResource {s in SITES};

# Max Capacity of each renewable site [MW]
param MaxCapacity {r in RENEWABLES};

# Slope of increasing variable costs due to forecasted fuel cost increases
param m {s in SITES};

# Intercept of increasing variable costs due to forecasted fuel cost increases
param b {s in SITES};

# Spending limit for capital investment in a given year Y
param AnnualBudget;

# Annual Discount Rate
param DiscountRate;

# ----------------------------DECISION VARIABLES-------------------------------

# Amount of resource installed in the given time period [MW]
var Installed {s in SITES, t in TIME} >= 0;

# Amount of each resource that is actually dispatched [MWh]
var Dispatch {s in SITES, t in TIME} >= 0;


# ----------------------------DEFINED VARIABLES--------------------------------
# Cumulative installed capacity up until the given timestep [MW]
```

```
var CumulativeInstalled {s in SITES, t in TIME} =
        sum{u in time_o .. t} Installed[s,u]
        + InitialDevelopedResource[s];

# Checking the capacity factor of resources, not vital to code function, for
troubleshooting
var CapacityFactor {s in SITES, t in TIME} =
        if CumulativeInstalled[s,t] = 0
        then 0
        else Dispatch[s,t] / (CumulativeInstalled[s,t] * 168); # 168 is for hr/week

# Determines whether a transmission line installation cost needs to included for the
given site s
# Only activates if generation has been constructed, implemented to bypass a binary
build variable which was inhibiting code functionality
var TransInstallCost {s in SITES, t in TIME} =
            if t = time_o or sum{u in time_o .. t-1} # If at first time step OR from
the beginning of study period until now-1 timestep
                    Installed[s,u] <= 0.01 # Check for installations, 0.01 error
factor to ignore small variations of capacity at small orders of magnitude
            then if Installed[s,t] > 0.01 # Error factor for marginally positive
amounts
                        then TransCost[s]
                        else 0 # If nothing was installed in this time step, and
nothing was built before, no need for transmission yet
            else 0; # If something has already been built, then transmission should
already exist

# ----------------------------OBJECTIVE FUNCTION-------------------------------
# Minimize total costs, including capital and operating costs [$]
minimize TotalCosts:
        sum{s in SITES, t in TIME}
        (TransInstallCost[s,t]
        + CapitalCost[s,(2015+floor((t-1)/52))] * Installed[s,t] # Calculate the
applicable year for capital costs to take affect based on time t, needed for PV
        + FixedOMCost[s] * CumulativeInstalled[s,t]
        + (m[s]*(2015+t/52) + b[s]) * Dispatch[s,t]) # Calculate applicable variable
costs due to fuel escalation for time t
        / (1 + DiscountRate / 52)^t; # Discount the cost for that year back into
2015$

# --------------------------------CONSTRAINTS---------------------------------
# Must have developed enough renewbles in each year to meet the RPS target for that
year
subject to Meeting_RPS_Goal {y in YEARS}:
        sum{r in RENEWABLES, t in ((y-2015)*52+1)..((y-2014)*52)} Dispatch[r,t] #
Must only look at applicable values of t for given year y
        >= RPS_Goal[y] / 100 *  sum{s in SITES, t in ((y-2015)*52+1)..((y-2014)*52)}
Dispatch[s,t];

# Cannot dispatch more than has been developed
subject to DispatchLimit {s in SITES, t in TIME}:
        Dispatch[s,t] <= CumulativeInstalled[s,t]*168; # 168 hr/week
```

```
# Cannot dispatch what is not available
subject to AvailabilityLimit {r in RENEWABLES, t in TIME}:
        Dispatch[r,t] <= ResourceAvailability[r,t] * CumulativeInstalled[r,t]; # If
forced dispatch required, set constraint to = rather than <=

# Must meet load at each time step t
subject to Meeting_Load {t in TIME}:
             sum{s in SITES}Dispatch[s,t] = Load[t];

# Cannot install more than there is physical room for
subject to CapacityConstraint {r in RENEWABLES, t in TIME}: CumulativeInstalled[r,t]
<= MaxCapacity[r];

# Cannot exceed an annual budget for capital investments + transmission (costs beyond
typical operation/maintenenace)
subject to BudgetLimit {y in YEARS}:
             sum{s in SITES, t in ((y-2015)*52+1)..((y-2014)*52)} # Only look at
applicable t values for year y
             (TransInstallCost[s,t] + CapitalCost[s,y] * Installed[s,t]) <=
AnnualBudget;
```

Data file: Project1.dat

```
# ------------------------------------SETS--------------------------------------
set SITES := Diesel_1 Oil_1 L450-R3 L177-4-R2 L7163 W3-Cotal W3-Pulantat W2-Navy;
set RENEWABLES := L450-R3 L177-4-R2 L7163 W3-Cotal W3-Pulantat W2-Navy;

# ---------------------------------PARAMETERS-----------------------------------
param:       TransCost    FixedOMCost  InitialDevelopedResource :=
L450-R3      0            31771        0.109
L177-4-R2    224198.62    31771        0
L7163        727130.67    31771        0
W3-Cotal     122504       57245        0
W3-Pulantat  122504       57245        0
W2-Navy      122504       57245        0
Oil_1        0            15175        446
Diesel_1     0            9657         287.2
;

# Capital costs for each year, allows for declining prices of solar PV to be captured
param CapitalCost (tr):
       Diesel_1Oil_1   L450-R3 L177-4-R2       L7163   W3-CotalW3-Pulantat     W2-Navy :=
2015    469035  1655419 4344002.478     4344002.478     4344002.478     5696450 5696450 5696450
2016    469035  1655419 4154120.813     4154120.813     4154120.813     5696450 5696450 5696450
2017    469035  1655419 3980164.707     3980164.707     3980164.707     5696450 5696450 5696450
2018    469035  1655419 3820909.117     3820909.117     3820909.117     5696450 5696450 5696450
2019    469035  1655419 3673903.957     3673903.957     3673903.957     5696450 5696450 5696450
2020    469035  1655419 3537924.184     3537924.184     3537924.184     5696450 5696450 5696450
2021    469035  1655419 3412969.798     3412969.798     3412969.798     5696450 5696450 5696450
2022    469035  1655419 3299040.799     3299040.799     3299040.799     5696450 5696450 5696450
2023    469035  1655419 3193687.101     3193687.101     3193687.101     5696450 5696450 5696450
2024    469035  1655419 3123859.65      3123859.65      3123859.65      5696450 5696450 5696450
2025    469035  1655419 3105484.005     3105484.005     3105484.005     5696450 5696450 5696450
2026    469035  1655419 3087108.36      3087108.36      3087108.36      5696450 5696450 5696450
2027    469035  1655419 3068732.715     3068732.715     3068732.715     5696450 5696450 5696450
2028    469035  1655419 3050357.07      3050357.07      3050357.07      5696450 5696450 5696450
2029    469035  1655419 3031981.425     3031981.425     3031981.425     5696450 5696450 5696450
2030    469035  1655419 3013605.78      3013605.78      3013605.78      5696450 5696450 5696450
```

```
2031    469035  1655419 2995230.135     2995230.135     2995230.135     5696450 5696450 5696450
2032    469035  1655419 2978079.533     2978079.533     2978079.533     5696450 5696450 5696450
2033    469035  1655419 2959703.888     2959703.888     2959703.888     5696450 5696450 5696450
2034    469035  1655419 2941328.243     2941328.243     2941328.243     5696450 5696450 5696450
2035    469035  1655419 2924177.641     2924177.641     2924177.641     5696450 5696450 5696450
;

# RPS goal as a % of annual sales
param RPS_Goal :=
2015 5
2016 5
2017 5
2018 5
2019 5
2020 8
2021 8
2022 8
2023 8
2024 8
2025 10
2026 10
2027 10
2028 10
2029 10
2030 15
2031 15
2032 15
2033 15
2034 15
2035 25
;

# Max Capacity of each renewable site [MW]
param MaxCapacity :=
L450-R3             168.75
L177-4-R2    160.8
L7163        62.4
W3-Cotal     20
W3-Pulantat 10
W2-Navy             20
;

# Slope and intercept of linear trendline for extrapolating variable costs for each
site,
# as a function of the year. Allows for fuel escalation to be captured.
param: m b :=
L450-R3             0 0
L177-4-R2    0 0
L7163        0 0
W3-Cotal     0 0
W3-Pulantat 0 0
W2-Navy             0 0
Oil_1   5.9083 -11775
Diesel_1 15.165 -30213
;
```

```
# Annual budget allowed for capital projects, currently ~1/2 of GPA fiscal budget in
2012
param AnnualBudget := 200000000;

# Discount rate for bringing costs back to 2015$ values
param DiscountRate := 0.07;

# Hourly Load [MWh]
# Coming from excel file read in run script

# Avaiability of resource [MW/km^2]
# Coming from excel file read in run script

# ----------------------------DECISION VARIABLES-------------------------------
# No data required

# ----------------------------DEFINED VARIABLES--------------------------------
# No data required

# ----------------------------OBJECTIVE FUNCTION-------------------------------
# No data required

# ---------------------------------CONSTRAINTS-----------------------------------
# No data required
```

Run Script: Project1.run

```
# Reset AMPL
reset;
reset;
reset;

# Load model and data files
model Project1.mod
data Project1.dat

# Read in excel data for load and resource avaiability for each renewable site
# Excel is after preprocessing by Python code, aggregating time steps from hourly to
weekly
table Energy IN "ODBC" "ENERGY_168hr_21yr_6sites_loadgrowth_rand.xlsx":
        TIME <- [t ~ TIME],
             Load,
             ResourceAvailability["L450-R3",t] ~ L450_R3,
             ResourceAvailability["L177-4-R2",t] ~ L177_4_R2,
             ResourceAvailability["L7163",t] ~ L7163,
             ResourceAvailability["W3-Cotal",t] ~ W3_Cotal,
             ResourceAvailability["W3-Pulantat",t] ~ W3_Pulantat,
             ResourceAvailability["W2-Navy",t] ~ W2_Navy;
read table Energy;

# Set solver options
option solver SNOPT;
```

```
# Solve model
solve;

# Display results, write to file
#display Installed;
display Installed > results.txt;
#display Dispatch;
display Dispatch > results.txt;
display TotalCosts;
display TotalCosts > results.txt;
```