1 Optimization Model ($\mathcal{R}$)

We define here indices and sets, parameters, and variables, in that order, and then state the objective function and the constraints. We choose as our naming convention calligraphic capital letters to represent sets, lower-case letters to represent parameters, and upper-case letters to represent variables; in the latter case, Z-variables are binary, and represent design and operational decisions, respectively. X-variables represent continuous decisions, e.g., quantities of energy. All subscripts denote indices. Names with the same "stem" are related, and superscripts and "decorations" (e.g., hats, tildes) differentiate the names with respect to, e.g., various indices included in the name or maximum and minimum values for the same parameter.

1.1 Sets and Parameters

Table 1: REopt Lite, sets and parameters.

Sets		**Units**
$\mathcal{S}$	Segments defining the capital cost	
$\mathcal{M}$	Months of the year	
$\mathcal{R}$	Ratchets of rate tariff	
$\mathcal{U}$	Fuel bins	
$\mathcal{E}$	Ratcheted demand bins in utility tariff	
$\mathcal{N}$	Monthly demand bins in utility tariff	
$\mathcal{B}$	Battery systems	
$\mathcal{C}$	Technology classes	
$\mathcal{T}$	Technologies	
$\mathcal{H}$	Time steps	
$\mathcal{D}$	Electrical loads	
$\mathcal{V}$	Net metering regimes	
$\mathcal{M}^{LB}$	Look-back months	
$\mathcal{T}^{td} \subseteq \mathcal{T}$	Subset of technologies that cannot turn down, i.e., PV and wind	
$\mathcal{T}_c \subseteq \mathcal{T}$	Subset of technologies in class c	
$\mathcal{T}_d^{ld} \subseteq \mathcal{T}$	Subset of technologies that can serve load d	
$\mathcal{T}^u \subseteq \mathcal{T}$	Subset of technologies that are utilities	
$\mathcal{D}^s \subseteq \mathcal{D}$	Subset of electrical loads due to charging storage	
$\mathcal{D}^r \subseteq \mathcal{D}$	Subset of loads that include site load	
$\mathcal{D}^w \subseteq \mathcal{D}$	Subset of loads that include wholesale generation	
$\mathcal{D}^\delta \subseteq \mathcal{D}$	Subset of loads that can serve annual load	
$\mathcal{H}_r \subseteq \mathcal{H}$	Subset of time steps within a given rate tariff ratchet r	
$\mathcal{H}_m \subseteq \mathcal{H}$	Subset of time steps within a given month m	
Counting Parameters		
n^{tss}	Time step scaling	[h]
n^{tsc}	Time step count	[count]
Cost Parameters		
c_{ts}^{cA}	Slope of capital cost curve for technology t in segment s	[$/kW]
c_{ts}^{cy}	Y-intercept of capital cost curve for technology t in segment s	[$]
c_{ts}^{cx}	X-value of the inflection point for technology t in segment s	[kW]
c_b^{kW}	Capital cost of inverter for battery system b	[$/kW]
c_b^{kWh}	Capital cost of storage per kWh for battery system b	[$/kWh]
c_{tuh}^{U}	Fuel cost for technology t using fuel bin u in timestep h	[$/MMBTU]
c_{tdu}^{fbrA}	Slope of the fuel rate curve for technology t under load d using fuel bin u	[MMBTU/kWh]
c_{tdu}^{fbrB}	Y-intercept of the fuel curve for technology t under load d using fuel bin u	[MMBTU/h]
c^{fmc}	Utility rate fixed monthly charge	[$]
c_t^{om}	Operation and maintenance cost of technology t per unit of system size	[$/kW]
c_{tdh}^{e}	Export rate of technology t in load d in time step h	[$/kWh]

Demand Parameters

δ	Electrical energy used at location for the year	[kWh]
δ^{r}_{re}	Demand rate for ratchet r in ratcheted demand bin e	[$/kW]
δ^{rm}_{mn}	Monthly demand rate for month m in demand month bin n	[$/kW]
$\bar{\delta}^{t}_{e}$	Maximum demand in tier for demand bin e	[kW]
$\bar{\delta}^{mt}_{n}$	Maximum demand months in tier for demand months bin n	[kW]
$\bar{\delta}^{tu}_{u}$	Maximum energy usage from fuel bin u	[kWh]
δ^{lp}	Look-back proportion	[fraction]

Incentive parameters

i^{N}_{v}	The actual net metering limits and interconnect limits numbers in net metering regime v	[kW]
i^{ttN}_{tv}	Net metering incentive levels for technology t produces electric in bin v	[Unitless]
$\bar{\imath}_{t}$	Upper bound of incentives for technology t	[$]
i^{r}_{td}	Incentive rate for technology t and demand d	[$/kWh]
$\bar{\imath}^{\sigma}_{t}$	Maximum system size to obtain production incentive for technology t	[kW]

Factor Parameters

f^{P}_{tdh}	Production factor of technology t for load d time step h	[Unitless]
f^{d}_{t}	Derate factor for turbine technology t	[Unitless]
$\underline{f}^{td}_{t}$	Minimum turn down for technology t	[kW]
f^{e}	Energy present worth factor	[Unitless]
f^{om}	Operations and maintenance present worth factor	[Unitless]
f^{pi}_{t}	Present worth factor for incentives for technology t	[Unitless]
f^{l}_{t}	Levelization factor of technology t	[fraction]
f^{lp}_{t}	Levelization factor of production incentive for technology t	[fraction]
f^{tow}	Tax rate factor for owner	[fraction]
f^{tot}	Tax rate factor for offtaker	[fraction]

Performance Parameters

$\underline{b}^{\sigma}_{c}$	Minimum system size for technology class c	[kW]
$\bar{b}^{\sigma}_{t}$	Maximum system size for technology t	[kW]
b^{d}_{dh}	Electricity or fuel load profile for demand d in time step h	[kW]
b^{fa}_{tu}	Amount of available fuel for technology t and fuel bin u	[MMBTU]

Storage Parameters

w^{esi}_{t}	Efficiency of charging storage using technology t	[Unitless]
w^{eso}	Efficiency of discharging storage	[Unitless]
$\bar{w}^{b^{kWh}}$	Maximum energy capacity of storage	[kWh]
$\underline{w}^{b^{kWh}}$	Minimum energy capacity of storage	[kWh]
$\bar{w}^{b^{kW}}$	Maximum power output of storage	[kW]
$\underline{w}^{b^{kW}}$	Minimum power output of storage	[kW]
$\underline{w}^{mcp}$	Minimum state of charge of the battery	[fraction]
w^{i}	Initial state of charge of the battery	[fraction]

1.2 Variables

Table 2: REopt Lite, Variables

Continuous Variables

X_{ts}^{ss}	System size of technology t in segment s	[kW]
X_{dheun}^{g}	Power from grid dispatched to meet load d, in time step h, from ratcheted demand bin e, fuel bin u, and demand months bin n	[kW]
X_{tdhsu}^{rp}	Rated production of technology t in load d during time step h in segment s from fuel bin u	[kW]
X_{mu}^{t}	Energy usage in tier during month m using fuel bin u	[kWh]
X_{t}^{pi}	The production incentive of technology t	[$]
X_{re}^{de}	The peak energy demand in ratchet r in ratchet demand bin e	[kW]
X_{mn}^{dn}	The peak energy demand in months m in monthly demand bin n	[kW]
X_{h}^{ts}	Electricity going to the storage system during each time step h	[kW]
X_{h}^{fs}	Electricity coming from the storage system during each time step h	[kW]
X_{h}^{se}	State of charge of the storage system in time step h	[kWh]
X_{b}^{skW}	Maximum amount of energy charging or discharging battery b	[kW]
X_{b}^{skWh}	Physical size of storage system b	[kWh]
X_{tu}^{fc}	Fuel cost of technology t from fuel bin u	[$]
X^{plb}	Peak electric demand look back	[kW]
X^{mc}	Utility minimum charge adder	[$]
X_{t}^{eb}	Power dispatched to charging battery from technology t	[kW]

Binary Variables

Z_{v}^{NMIL}	1 If generation is in net metering interconnect limit regime v; 0 otherwise	[Unitless]
Z_{ts}^{sc}	1 If technology t is in cost segment s is chosen; 0 otherwise	[Unitless]
Z_{t}^{pi}	1 If production incentive is available for technology t; 0 otherwise	[Unitless]
Z_{tc}^{sbt}	1 If technology t is used for technology class c; 0 otherwise	[Unitless]
Z_{h}^{b+}	1 If battery is charging in time step h; 0 otherwise	[Unitless]
Z_{h}^{b-}	1 If battery is discharging in time step h; 0 otherwise	[Unitless]
Z_{th}^{to}	1 If technology t is operating in time step h; 0 otherwise	[Unitless]
Z_{re}^{dt}	1 If ratchet r is in demand bin e; 0 otherwise	[Unitless]
Z_{mn}^{dmt}	1 If month m is in monthly demand bin n; 0 otherwise	[Unitless]
Z_{mu}^{ut}	1 If month m is in fuel bin u; 0 otherwise	[Unitless]
Z_{b}^{bl}	1 If storage system is in battery b; 0 otherwise	[Unitless]

1.3 Objective Function

$$
\begin{aligned}
\text{Minimize} & \underbrace{\sum_{t\in\mathcal{T},s\in\mathcal{S}} \left(c^{cA}_{ts}\cdot X^{ss}_{ts} + c^{cy}_{ts}\cdot Z^{sc}_{ts}\right)}_{\text{Total Techcnology Capital Costs}} + \underbrace{\sum_{b\in\mathcal{B}} \left(c^{kW}_{b}\cdot X^{skW}_{b} + c^{kWh}_{b}\cdot X^{skWh}_{b}\right)}_{\text{Total Storage Capital Costs}} + \\
& (1-f^{tow})\cdot \underbrace{\sum_{t\in\mathcal{T},s\in\mathcal{S}} \left(c^{om}_{t}\cdot f^{om}\cdot X^{ss}_{ts}\right)}_{\text{Total Operation and Maintenance Costs}} + \\
(1-f^{tot})\cdot \Bigg(& \underbrace{\sum_{t\in\mathcal{T}^{ld}_{d},u\in\mathcal{U},h\in\mathcal{H},d\in\mathcal{D}} \left(n^{tss}\cdot c^{U}_{tuh}\cdot f^{e}\cdot (f^{P}_{tdh}\cdot f^{l}_{t}\cdot c^{fbrA}_{tdu}\cdot \sum_{s\in\mathcal{S}} X^{rp}_{tdhsu} + c^{fbrB}_{tdu}\cdot Z^{to}_{th})\right)}_{\text{Total Energy Charges}} + \\
& \underbrace{\sum_{r\in\mathcal{R},e\in\mathcal{E}} f^{e}\cdot \delta^{r}_{re}\cdot X^{de}_{re}}_{\text{Total Demand Charges}} + \underbrace{\sum_{m\in\mathcal{M},n\in\mathcal{N}} f^{e}\cdot \delta^{rm}_{mn}\cdot X^{dn}_{mn}}_{\text{Demand Flat Charges}} - \\
& \underbrace{\sum_{t\in\mathcal{T}^{ld}_{d},d\in\mathcal{D},h\in\mathcal{H},s\in\mathcal{S},u\in\mathcal{U}} n^{tss}\cdot f^{e}\cdot c^{e}_{tdh}\cdot f^{l}_{t}\cdot f^{P}_{tdh}\cdot X^{rp}_{tdhsu}}_{\text{Total Energy Exports}} + \\
& \underbrace{f^{e}\cdot c^{fmc} + X^{mc}}_{\text{Total Fixed Charges}} \Bigg) - (1-f^{tow})\cdot \underbrace{\left(\sum_{t\in\mathcal{T}} X^{pi}_{t}\right)}_{\text{Production Incentives}}
\end{aligned}
$$

The objective function minimizes the sum of capital costs, fixed operations and maintenance costs, total energy costs and subtracts incentive. The capital cost is comprised of equipment costs and storage costs. The total energy costs is a combination of total energy charges, total demand charges, total energy exports, total fixed charges, and the fixed minimum charge.

1.4 Constraints

This section contains both mathematical expressions and text descriptions for all constraints in the model. In general, the text descriptions are written to convey the spirit of the constraint and may not address every index in *for all* or *summation* statements when they are not central to how the constraint operates. For complete sets of indices included in the constraint, please refer to the mathematical notation.

1.4.1 Fuel constraints

$$\sum_{h\in\mathcal{H},d\in\mathcal{D},s\in\mathcal{S}:t\in\mathcal{T}_d^{ld}} n^{tss}\cdot f_t^l\cdot c_{tdu}^{fbrA}\cdot f_{tdh}^P\cdot X_{tdhsu}^{rp}+ \sum_{h\in\mathcal{H},d\in\mathcal{D}} c_{tdu}^{fbrB}\cdot n^{tss}\cdot Z_{th}^{to} \leq b_{tu}^{fa} \quad \forall t\in\mathcal{T}, u\in\mathcal{U} \quad (1)$$

Constraint (1) restricts the fuel consumed by a technology to a prespecified limit for each fuel type. Here, we define the each technology's fuel consumption as a function of (i) its total energy produced, and (ii) its number of operating hours.

1.4.2 Switch Constraints

$$\sum_{d\in\mathcal{D},s\in\mathcal{S},u\in\mathcal{U}:t\in\mathcal{T}_d^{ld}} f_{tdh}^P\cdot X_{tdhsu}^{rp} \leq \bar{b}_t^\sigma\cdot Z_{th}^{to} \quad \forall t\in\mathcal{T}, h\in\mathcal{H} \quad (2a)$$

$$\sum_{s\in\mathcal{S}} \underline{f}_t^{td}\cdot X_{ts}^{ss} - \sum_{d\in\mathcal{D},s\in\mathcal{S},u\in\mathcal{U}:t\in\mathcal{T}_d^{ld}} X_{tdhsu}^{rp} \leq \bar{b}_t^\sigma\cdot(1-Z_{th}^{to}) \quad \forall t\in\mathcal{T}, h\in\mathcal{H} \quad (2b)$$

Constraint set (2) restricts the rate of production to an operating window between a system's minimum turn down and its maximum size. Constraint (2a) defines if a system is on it must be less than the the maximum system size. Constraint (2b) forces a lower bound for the minimum downturn a technology can operate.

1.4.3 Storage System Constraints

Boundary Conditions and Size Limits

$$X_0^{se} = w^i\cdot\sum_{b\in\mathcal{B}} X_b^{skWh} \quad (3a)$$

$$\underline{w}^{b^{kWh}} \leq \sum_{b\in\mathcal{B}} X_b^{skWh} \leq \bar{w}^{b^{kWh}} \quad (3b)$$

$$\underline{w}^{b^{kW}} \leq \sum_{b\in\mathcal{B}} X_b^{skW} \leq \bar{w}^{b^{kW}} \quad (3c)$$

Constraint (3a) sets the initial state of charge across all of the battery systems based on the physical size of the storage system and Constraints (3b) - (3c) restrict the size of the storage system system between the upper lower bounds for capacity and output, respectively.

Battery Operations

$$X_h^{ts} = \sum_{t\in\mathcal{T}_d^{ld},s\in\mathcal{S},u\in\mathcal{U},d\in\mathcal{D}^s} f_{tdh}^P\cdot f_t^l\cdot w_t^{esi}\cdot X_{tdhsu}^{rp} \quad \forall h\in\mathcal{H} \quad (3d)$$

$$X_h^{se} = X_{h-1}^{se} + n^{tss} \cdot (X_h^{ts} - X_h^{fs}/w^{eso}) \quad \forall h \in \mathcal{H} \tag{3e}$$
$$X_h^{fs} \leq w^{eso} \cdot X_{h-1}^{se}/n^{tss} \quad \forall h \in \mathcal{H} \tag{3f}$$
$$X_h^{se} \geq \underline{w}^{mcp} \cdot \sum_{b\in\mathcal{B}} X_b^{skWh} \quad \forall h \in \mathcal{H} \tag{3g}$$

Constraint (3d) defines the amount of energy dispatched to the battery system as the sum of all production dispatched to battery storage for each time step. Constraint (3e) is inventory balance, the stored energy of the previous step added to the difference between electricity to storage and the electricity from storage. Constraint (3f) limits the amount of discharge from the battery system from exceeding the amount of electricity available. Constraint (3g) forces the state of charge to always be greater than the minimum battery system size.

Operational Nuance

$$\sum_{b\in\mathcal{B}} X_b^{skW} \geq X_h^{ts} \quad \forall h \in \mathcal{H} \tag{3h}$$
$$\sum_{b\in\mathcal{B}} X_b^{skW} \geq X_h^{fs} \quad \forall h \in \mathcal{H} \tag{3i}$$
$$\sum_{b\in\mathcal{B}} X_b^{skWh} \geq X_h^{se} \quad \forall h \in \mathcal{H} \tag{3j}$$
$$X_h^{ts} \leq \bar{w}^{b^{kW}} \cdot Z_h^{b+} \quad \forall h \in \mathcal{H} \tag{3k}$$
$$X_h^{fs} \leq \bar{w}^{b^{kW}} \cdot Z_h^{b-} \quad \forall h \in \mathcal{H} \tag{3l}$$
$$Z_h^{b-} + Z_h^{b+} \leq 1 \quad \forall h \in \mathcal{H} \tag{3m}$$
$$X_t^{eb} = \sum_{h\in\mathcal{H}, s\in\mathcal{S}, u\in\mathcal{U}, d\in\mathcal{D}^s} f_{tdh}^P \cdot f_t^l \cdot X_{tdhsu}^{rp} \quad \forall t \in \mathcal{T} \tag{3n}$$

Constraints (3h) and (3i) keep the dispatch to and from storage within the system size. Constraint (3j) defines the mean state of charge of the battery. Constraints (3k) and (3l), force battery system to be turned on in order to charge or discharge. Constraint (3m) force the battery to be either charging or discharging but never both. Constraint (3n) defines the amount of power dispatched to the battery from each technology.

Battery Level

$$X_b^{skWh} \leq \bar{w}^{b^{kWh}} \cdot Z_b^{bl} \quad \forall b \in \mathcal{B} \tag{4a}$$
$$X_b^{skW} \leq \bar{w}^{b^{kW}} \cdot Z_b^{bl} \quad \forall b \in \mathcal{B} \tag{4b}$$
$$\sum_{b\in\mathcal{B}} Z_b^{bl} = 1 \tag{4c}$$

Constraints (4a) limit the battery storage to be less than the maximum battery storage available. Constraints (4b) limit the battery storage to be less than the maximum amount of energy charging or discharging the battery. Constraint (4c) restricts the battery technology selection to a single level.

1.4.4 Capital Cost Constraints

Capital Cost Constraints

$$X^{ss}_{ts} \le c^{cx}_{ts} \cdot Z^{sc}_{ts} \quad \forall t \in \mathcal{T}, s \in \mathcal{S} \tag{5a}$$
$$X^{ss}_{ts} \ge c^{cx}_{t,s-1} \cdot Z^{sc}_{ts} \quad \forall t \in \mathcal{T}, s \in \mathcal{S} : s \ge 2 \tag{5b}$$

Constraints (5a) and (5b) determine in which segment of the piece wise linear cost curve the system is operating.

Technology Selection Constraints

$$\sum_{s \in \mathcal{S}} Z^{sc}_{ts} = 1 \quad \forall t \in \mathcal{T} \tag{6a}$$
$$\sum_{t \in \mathcal{T}} Z^{sbt}_{tc} \le 1 \quad \forall c \in \mathcal{C} \tag{6b}$$

Constraint (6a) limits each technology to fall into one segment of the capital cost curve. Constraint (6b) this ensures that there is only one technology per technology class.

1.4.5 Production Incentive Cap

Production Incentive Cap Module

$$X^{pi}_t \le \bar{\imath}_t \cdot f^{pi}_t \cdot Z^{pi}_t \quad \forall t \in \mathcal{T} \tag{7a}$$
$$X^{pi}_t \le \sum_{d \in \mathcal{D}, h \in \mathcal{H}, s \in \mathcal{S}, u \in \mathcal{U} : t \in \mathcal{T}^{ld}_d} n^{tss} \cdot i^r_{td} \cdot f^{pi}_t \cdot f^P_{tdh} \cdot f^{lp}_t \cdot X^{rp}_{tdhsu} \quad \forall t \in \mathcal{T} \tag{7b}$$
$$\sum_{s \in \mathcal{S}} X^{ss}_{ts} \le \bar{\imath}^{\sigma}_t + \bar{b}^{\sigma}_t \cdot (1 - Z^{pi}_t) \quad \forall t \in \mathcal{T} \tag{7c}$$

Constraint (7a) limits the production incentives available for a given technology. Constraint (7b) calculates the production incentive based on the energy produced. Constraint (7c) sets an upper bound on the size of system that qualifies for production incentives, if production incentives are available.

1.4.6 System size

System size constraints

$$X^{ss}_{ts} \le \bar{b}^{\sigma}_t \quad \forall t \in \mathcal{T}, s \in \mathcal{S} \tag{8a}$$
$$\sum_{t \in \mathcal{T}_c, s \in \mathcal{S}} X^{ss}_{ts} \ge \underline{b}^{\sigma}_c \quad \forall c \in \mathcal{C} \tag{8b}$$
$$\sum_{d \in \mathcal{D}, u \in \mathcal{U} : t \in \mathcal{T}^{ld}_d} X^{rp}_{tdhsu} \le X^{ss}_{ts} \quad \forall t \in \mathcal{T}, s \in \mathcal{S}, h \in \mathcal{H} \tag{8c}$$
$$\sum_{t \in \mathcal{T}^{ld}_d, s \in \mathcal{S}, u \in \mathcal{U}} f^P_{tdh} \cdot f^l_t \cdot X^{rp}_{tdhsu} \le b^d_{dh} \quad \forall d \in \mathcal{D} \setminus \mathcal{D}^{\delta}, h \in \mathcal{H} \tag{8d}$$

$$\sum_{t\in\mathcal{T}_d^{ld},s\in\mathcal{S},u\in\mathcal{U}} \left(f_{tdh}^{P}\cdot f_t^{l}\cdot X_{tdhsu}^{rp}\right) + X_h^{fs} \geq b_{dh}^{d} \quad \forall d\in\mathcal{D}^r, h\in\mathcal{H} \tag{8e}$$

Constraint (8a) limit the system size to the maximum system size for a technology. Constraint (8b) limit the system size to the minimum allowed system size for a technology class. Constraint (8c) limits rated production from all loads to be less than the system size. Constraint (8d) limits rate of production by all technologies to be less than maximum load for each fuel type. Constraint (8e) allows electric load to be met from either generation or storage.

1.4.7 Rate Tariff Constraints

Net Meter Module

$$\sum_{v\in\mathcal{V}} Z_v^{NMIL} = 1 \tag{9a}$$

$$\sum_{t\in\mathcal{T},s\in\mathcal{S}} i_{tv}^{ttN}\cdot f_t^{d}\cdot X_{ts}^{ss} \leq i_v^{N}\cdot Z_v^{NMIL} \quad \forall v\in\mathcal{V} \tag{9b}$$

Constraint (9a) limits the net metering interconnect limit to only be in one regime at a time. Constraint (9b) limits the sum of the electricity output of all technologies to be less than the limit for the net metering interconnect limit regime.

Rate Variable Definitions

$$\sum_{s\in\mathcal{S}} X_{tdhsu}^{rp} = \sum_{e\in\mathcal{E},n\in\mathcal{N}} X_{dheun}^{g} \quad \forall d\in\mathcal{D}, u\in\mathcal{U}, h\in\mathcal{H}, t\in\mathcal{T}^u \tag{10a}$$

$$X_{mu}^{t} = n^{tss}\cdot \sum_{d\in\mathcal{D},h\in\mathcal{H}_m,s\in\mathcal{S}} X_{tdhsu}^{rp} \forall u\in\mathcal{U}, m\in\mathcal{M}, t\in\mathcal{T}^u \tag{10b}$$

Constraint (10a) defines the power dispatched from the grid to be equal to the rate of production supplied from the utility company. Constraint (10b) parses out the power from the grid to be used in calculating tiered pricing of electricity.

Fuel Bins

$$X_{mu}^{t} \leq \bar{\delta}_u^{tu}\cdot Z_{mu}^{ut} \quad \forall m\in\mathcal{M}, u\in\mathcal{U} \tag{11a}$$

$$Z_{mu}^{ut} \leq Z_{m,u-1}^{ut} \quad \forall u\in\mathcal{U}: u\geq 2, m\in\mathcal{M} \tag{11b}$$

$$\bar{\delta}_{u-1}^{tu}\cdot Z_{mu}^{ut} \leq X_{m,u-1}^{t} \quad \forall u\in\mathcal{U}: u\geq 2, m\in\mathcal{M} \tag{11c}$$

Constraint (11a) limits the usage of electricity in a given month from a specified fuel bin to the maximum available electricity from that fuel bin if the fuel bin is available. Constraint (11c) forces fuel bins to be full before moving to the next fuel bin.

Peak Demand Energy Ratchets

$$X_{re}^{de} \leq \bar{\delta}_e^{t}\cdot Z_{re}^{dt} \quad \forall e\in\mathcal{E}, r\in\mathcal{R} \tag{12a}$$

$$Z_{re}^{dt} \leq Z_{r,e-1}^{dt} \quad \forall e\in\mathcal{E}: e\geq 2, r\in\mathcal{R} \tag{12b}$$

$$\bar{\delta}^{t}_{e-1} \cdot Z^{dt}_{re} \leq X^{de}_{r,e-1} \quad \forall e \in \mathcal{E} : e \geq 2, r \in \mathcal{R} \tag{12c}$$

$$X^{de}_{re} \geq \sum_{d \in \mathcal{D}, u \in \mathcal{U}, n \in \mathcal{N}} X^{g}_{dheun} \quad \forall e \in \mathcal{E}, r \in \mathcal{R}, h \in \mathcal{H}_r \tag{12d}$$

$$X^{de}_{re} \geq \delta^{lp} \cdot X^{plb} \quad \forall e \in \mathcal{E}, r \in \mathcal{R} \tag{12e}$$

Constraint (12a) limits the peak energy demand to the maximum energy available. Constraint (12b) forces demand bins to become active in order. Constraint (12c) forces demand to be met before moving to the next demand tier. Constraint (12d) defines the peak demand to be greater than all of the demands across the time horizon. Constraint (12e) defines the look-back value to be used with necessary tariffs.

Peak Demand Energy Months

$$X^{dn}_{mn} \leq \bar{\delta}^{mt}_{n} \cdot Z^{dmt}_{mn} \quad \forall n \in \mathcal{N}, m \in \mathcal{M} \tag{13a}$$

$$X^{dn}_{mn} \leq M \cdot Z^{dmt}_{mn} \quad \forall m \in \mathcal{M}, n \in \mathcal{N} : n = |\mathcal{N}| \tag{13b}$$

$$\bar{\delta}^{mt}_{n-1} \cdot Z^{dmt}_{mn} \leq X^{dn}_{m,n-1} \quad \forall n \in \mathcal{N} : n \geq 2, m \in \mathcal{M} \tag{13c}$$

$$X^{dn}_{mn} \geq \sum_{d \in \mathcal{D}, e \in \mathcal{E}, u \in \mathcal{U}} X^{g}_{dheun} \quad \forall n \in \mathcal{N}, m \in \mathcal{M}, h \in \mathcal{H}_m \tag{13d}$$

$$X^{plb} \geq \sum_{n \in \mathcal{N}} X^{dn}_{mn} \quad \forall m \in \mathcal{M}^{LB} \tag{13e}$$

These are analagous to constraint set (12), except they focus on demand for months rather than ratchets. Specifically, constraint (13a) limits the energy demand to the maximum demand required. Constraint (13b) forces the demand tier to be available if it is to be used. Constraint (13c) forces demand to be met before moving to the next demand tier. Constraint (13d) defines the peak demand to be greater than all of the demands across the time horizon. Constraint (13e) defines the look-back value to be used with necessary tariffs.

Site Load

$$\sum_{t \in \mathcal{T}^{ld}_{d}, d \in \mathcal{D}^{r} \cup \mathcal{D}^{w} \cup \mathcal{D}^{s}, h \in \mathcal{H}, s \in \mathcal{S}, u \in \mathcal{U}} f^{P}_{tdh} \cdot f^{l}_{t} \cdot n^{tss} \cdot X^{rp}_{tdhsu} \leq \delta \tag{14a}$$

$$\sum_{s \in \mathcal{S}} X^{ss}_{ts} \leq M \cdot Z^{sbt}_{tc} \quad \forall t \in \mathcal{T}_c, c \in \mathcal{C} \tag{14b}$$

$$X^{ss}_{ts} = \sum_{u \in \mathcal{U}, d \in \mathcal{D} : t \in \mathcal{T}^{ld}_{d}} X^{rp}_{tdhsu} \quad \forall t \in \mathcal{T}^{td}, h \in \mathcal{H}, s \in \mathcal{S} \tag{14c}$$

Constraint (14a) enforces for demands in the subset that can serve annual loads, the rate of production across all technologies, hours, and capital cost segments, reduced by the appropriate production an levelization factors cannot exceed electricity used. Constraint (14b) refers to the concept of single basic technology being available for any given technology class. Constraint (14c) prevents renewable technologies from turning down. They output at their nameplate capacity.

1.4.8 Minimum Utility Charge

$$X^{mc} \geq \underbrace{\sum_{t \in \mathcal{T}_d^{ld}, u \in \mathcal{U}, h \in \mathcal{H}, d \in \mathcal{D}} \big(n^{tss} \cdot c^{U}_{tuh} \cdot f^e \cdot (f^P_{tdh} \cdot f^l_t \cdot c^{fbrA}_{tdu} \cdot \sum_{s \in \mathcal{S}} X^{rp}_{tdhsu} + c^{fbrB}_{tdu} \cdot Z^{to}_{th})\big)}_{TotalEnergyCharges} + \underbrace{\sum_{r \in \mathcal{R}, e \in \mathcal{E}} f^e \cdot \delta^r_{re} \cdot X^{de}_{re}}_{TotalDemandCharges} + \underbrace{\sum_{m \in \mathcal{M}, n \in \mathcal{N}} f^e \cdot \delta^{rm}_{mn} \cdot X^{dn}_{mn}}_{DemandFlatCharges} - \underbrace{\sum_{t \in \mathcal{T}_d^{ld}, d \in \mathcal{D}, h \in \mathcal{H}, s \in \mathcal{S}, u \in \mathcal{U}} n^{tss} \cdot f^e \cdot c^e_{tdh} \cdot f^l_t \cdot f^P_{tdh} \cdot X^{rp}_{tdhsu}}_{TotalEnergyExports} \tag{15}$$

Constraint (15) enforces a minimum payment to the utility provider, which may be covered by energy and demand charges from the utility, net of any exports produced by the system.

1.4.9 Non-negativity

$$X^{plb}, X^{mc} \geq 0 \tag{16a}$$
$$X^{ss}_{ts} \geq 0 \quad \forall t \in \mathcal{T}, s \in \mathcal{S} \tag{16b}$$
$$X^{g}_{dheun} \geq 0 \quad \forall d \in \mathcal{D}, h \in \mathcal{H}, e \in \mathcal{E}, u \in \mathcal{U}, n \in \mathcal{N} \tag{16c}$$
$$X^{rp}_{tdhsu} \geq 0 \quad \forall t \in \mathcal{T}_d^{tl}, d \in \mathcal{D}, h \in \mathcal{H}, s \in \mathcal{S}, u \in \mathcal{U} \tag{16d}$$
$$X^{t}_{mu} \geq 0 \quad \forall m \in \mathcal{M}, u \in \mathcal{U} \tag{16e}$$
$$X^{pi}_{t} \geq 0 \quad \forall t \in \mathcal{T} \tag{16f}$$
$$X^{de}_{re} \geq 0 \quad \forall r \in \mathcal{R}, e \in \mathcal{E} \tag{16g}$$
$$X^{dn}_{mn} \geq 0 \quad \forall m \in \mathcal{M}, n \in \mathcal{N} \tag{16h}$$
$$X^{ts}_{h}, X^{fs}_{h}, X^{se}_{h} \geq 0 \quad h \in \mathcal{H} \tag{16i}$$
$$X^{skW}_{b}, X^{skWh}_{b} \geq 0 \quad b \in \mathcal{B} \tag{16j}$$
$$X^{fc}_{tu}, X^{fu}_{tu} \geq 0 \quad \forall t \in \mathcal{T}, u \in \mathcal{U} \tag{16k}$$
$$X^{eb}_{t} \geq 0 \quad \forall t \in \mathcal{T} \tag{16l}$$

1.4.10 Integrality

$$Z^{NMIL}_{v} \in \{0,1\} \quad \forall v \in \mathcal{V} \tag{17a}$$
$$Z^{sc}_{ts} \in \{0,1\} \quad \forall t \in \mathcal{T}, s \in \mathcal{S} \tag{17b}$$
$$Z^{pi}_{t} \in \{0,1\} \quad \forall t \in \mathcal{T} \tag{17c}$$

$$Z_{tc}^{sbt} \in \{0,1\} \quad \forall t \in \mathcal{T}, c \in \mathcal{C} \tag{17d}$$

$$Z_{h}^{b+}, Z_{h}^{b-} \in \{0,1\} \quad \forall h \in \mathcal{H} \tag{17e}$$

$$Z_{th}^{to} \in \{0,1\} \quad \forall t \in \mathcal{T}, h \in \mathcal{H} \tag{17f}$$

$$Z_{re}^{dt} \in \{0,1\} \quad \forall r \in \mathcal{R}, e \in \mathcal{E} \tag{17g}$$

$$Z_{mn}^{dmt}, Z_{mu}^{ut} \in \{0,1\} \quad \forall m \in \mathcal{M}, n \in \mathcal{N} \tag{17h}$$

$$Z_{b}^{bl} \in \{0,1\} \quad \forall b \in \mathcal{B} \tag{17i}$$

Finally, constraints (16) ensure all of the variables in our formulation assume non-negative values. In addition to non-negativity restrictions, constraints (17) establish the integrality of the appropriate variables.