# Sustainable Engineering Lab Clean Energy Model (SELCEM) formulation

## Nomenclature

| | |
|---|---|
| $A$ | capital annualization rate for annualization period *P* and interest rate $i$ |
| $C_{capacity}$ | total capital cost and fix operations and management cost [$] |
| $C_{generation}$ | total generation cost and variable operations and management cost [$] |
| $C_{cap}$ | capital cost [$/MW] |
| $C_{fom}$ | fixed operations and management cost [$/MW-yr] |
| $C_{fuel}$ | fuel cost based on thermal energy [$/MWh] |
| $C_{vom}$ | variable operations and management cost [$/MWh] |
| $D$ | electricity demand [MWh] |
| $E$ | battery storage state of charge [MWh] |
| $G$ | generation utilized [MWh] |
| $I$ | initial battery storage state of charge ratio |
| $i$ | interest rate |
| $loss$ | transmission losses |
| $P$ | annualization period [years] |
| $W$ | potential generation [MW/MW] |
| $X_{batt}$ | battery storage energy capacity installed [MWh] |
| $X_g$ | generator capacity installed [MW] |
| $X_{trans,rr'}$ | capacity of transmission from region *r* to adjacent region *r'* [MW] |
| $Z_{rr'}$ | energy transmitted from region *r* to adjacent region *r'* [MWh] |
| $\eta_g$ | generation efficiency |
| $\eta_{batt}$ | battery storage efficiency |

| | |
|---|---|
| $\varphi$ | battery storage power-to-energy ratio |
| $\gamma$ | increase in battery storage state of charge [MW] |
| $\delta$ | decrease in battery storage state of charge [MW] |
| $\kappa$ | storage self-discharge |

***Subscripts and Superscripts***

| | |
|---|---|
| *batt* | battery storage |
| *g* | generation technology |
| *r* | region |
| *r'* | region adjacent to *r* |
| *T* | total hours in the simulation |
| *t* | hourly time step |
| *trans* | transmission |

## Formulations

The objective function is minimizing the total cost, shown in equations (1- 4). The capacity cost includes installation cost and fixed operations and management cost of generators, batteries and transmission lines. And the generation cost includes fuel cost and variable operations and management cost of some generators. The annualization rate is calculated as equation (4).

$$obj = minimize(C_{capacity} + C_{generation}) \tag{1}$$

$$C_{capacity} = \sum_{r} \sum_{g} [\,(C_{g,cap} * A_g + C_{g,fom}) * X_{g,r}] + C_{batt,cap} * A_{batt} * X_{batt,r} + \sum_{r'} [\,C_{trans,rr'} * A_{trans} * X_{trans,rr'}] \tag{2}$$

$$C_{generation} = \sum_{r} \sum_{g} \sum_{t \in 1,2,\ldots,T} [(\frac{C_{g,fuel}}{\eta_g} + C_{g,vom}) * G_{g,r}^t]$$

(3)

$$A_{P,i} = \frac{i * (1+i)^P}{(1+i)^P - 1}$$

(4)

The constraints are shown in equations (5 - 14). The decision variables in the model are all equal or greater to 0. The energy balance in each region is set in equation (5).

$$D_r^t = \sum_{g} U_{g,r}^t - \gamma_r^t + \delta_r^t - \sum_{r\prime} [(1 - loss) * Z_{r\prime r}^t - Z_{rr\prime}^t] \qquad \forall r, t$$

(5)

In equation (6), the electricity generated to the grid is limited by the generation potential, $W$. The potential of the generator such as gas turbine, nuclear and hydro is 1, while the potential of variable resources is the uncurtailed capacity factor.

$$G_{g,r}^t \leq X_{g,r} * W_{g,r}^t \qquad \forall g, r, t$$

(6)

The battery constraints are described in equation (7 - 12). The battery is initially charged with the ratio $I$ before the simulation, and the battery is required to achieve this state at the last hour. The battery efficiency is applied to both charge and discharge processes.

$$\frac{\delta_r^t}{\sqrt{\eta_{batt}}} - \sqrt{\eta_{batt}} * \gamma_r^t = (1 - \kappa) * I * X_{batt,r} - E_r^t \qquad \forall r, t = 1$$

(7)

$$\frac{\delta_r^t}{\sqrt{\eta_{batt}}} - \sqrt{\eta_{batt}} * \gamma_r^t = (1 - \kappa) * E_r^{t-1} - E_r^t \qquad \forall r, t \in 2,3,\ldots,T$$

(8)

$$E_r^t \leq X_{batt,r} \qquad \forall r, t$$

(9)

$$\delta_r^t \leq \frac{X_{batt,r}}{\psi} \qquad \forall t$$

(10)

$$\gamma_r^t \le \frac{X_{batt,r}}{\psi} \qquad \forall t \tag{11}$$

$$E_r^{t=T} = I * X_{batt,r} \tag{12}$$

The transmission constraints are described in equation (13 - 14). In this study, we set the round-trip capacities the same, and the installation cost is the both-way cost.

$$Z_{rr\prime}^t \le X_{trans,rr\prime} \qquad \forall r, r', t \tag{13}$$

$$X_{trans,rr\prime} = X_{trans,r\prime r} \tag{14}$$