Capacity Expansion Model

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Contents

1 Overview

This document presents the formulation of the Capacity Expansion (CE) optimization model. I tried the definitions of variables and equations as close as possible to the way they are defined in the `.gams` file. This way it should be easier to debug the optimization problem. For example, instead of defining a single variable $n_{(\cdot)}$ for the number of new generators in each pair (location, type), I used the same definitions as the `.gams` file and created three variables: $n^{(c)}_{c,j}$, $n^{(\bar{c})}_{z,j}$ and $n^{(r)}_{z,j}$ (which refer, respectively, to thermal generators that can be curtailed, thermal generators that cannot be curtailed and renewable generators).

2 Definitions

Table 1: Decision Variables

Set	**Definition**
$n^{(c)}_{c,j}$	number of new thermal generators of type j in the class that CAN be curtailed (the (c) superscript) built in CELL c
$n^{(\bar{c})}_{z,j}$	number of new thermal generators of type j in the class that CANNOT be curtailed (the $(\bar{c})$ superscript) built in ZONE z
$n^{(r)}_{z,j}$	number of new generators of type j in the class RENEWABLE (the (r) superscript) built in ZONE z
$p^{(c)}_{c,j,t}$	electricity generation (GWh) at time t of new generators of type j in the class that CAN be curtailed (the (c) superscript) built in CELL c
$p^{(\bar{c})}_{z,j,t}$	electricity generation (GWh) at time t of new generators of type j in the class that CANNOT be curtailed (the $(\bar{c})$ superscript) built in ZONE z
$p^{(r)}_{z,j,t}$	electricity generation (GWh) at time t of new generators of type j in the class RENEWABLE (the (r) superscript) built in ZONE z
$p^{(e)}_{i,t}$	electricity generation (GWh) at time t of existing (the (e) superscript) generator of index i
$\text{flow}_{\ell,t}$	flow on line ℓ (GW) in hour t

Table 2: Sets

Set	Definition
$\mathcal{B}$	set of user-defined time blocks. These are needed for computational purposes. $\mathcal{B}$ = {peak-hours, winter, summer, spring, fall, special periods}
$\mathcal{I}$	set of existing generators in the fleet.
$\mathcal{I}(z)$	subset of existing generators that are located in zone z. $\mathcal{I}(z) \subseteq \mathcal{I}$
$\mathcal{C}$	set of grid cells that new techs can be placed in.
$\mathcal{C}(z)$	subset of grid cells that new techs can be placed in that are located in zone z. $\mathcal{C}(z) \subseteq \mathcal{C}$
$\mathcal{J}$	set of candidate plant types for new construction
$\mathcal{J}^{(c)}$	subset of plant types for new construction that can be curtailed. $\mathcal{J}^{(c)} \subseteq \mathcal{J}$
$\mathcal{J}^{(\bar{c})}$	subset of plant types for new construction that CANNOT be curtailed. $\mathcal{J}^{(\bar{c})} \subseteq \mathcal{J}$
$\mathcal{J}^{(r)}$	subset of plant types for new construction that are renewable. $\mathcal{J}^{(r)} \subseteq \mathcal{J}$
$\mathcal{L}$	set with transmission lines between load zones
$\mathcal{Z}$	set with user defined load zones

Table 3: Parameters

Parameter	Definition
$P_{c,j,t}^{MAX}$	Maximum electricity generation capacity, accounting for deratings, of plant type $j \in \mathcal{J}^{(c)}$ at cell grid c at time t (MWh)
P_j^{NP}	Nameplate electricity generation capacity of plant type $j \in \mathcal{J}$ (MWh)
$P_{i,t}^{MAX}$	Maximum electricity generation capacity, accounting for deratings, of existing generator i (non solar and non wind) at time t (MWh)
$P_{solar,t}^{MAX}$	Maximum electricity generation by all existing solar generators at time t (MWh)
$P_{wind,t}^{MAX}$	Maximum electricity generation by all existing wind generators at time t (MWh)
$\overline{\text{flow}}_\ell$	Upper bound of transmission line ℓ (GW)
FOM_j	Annual fixed operation and maintenance costs of plant type j (\$/MW)
OCC_j	Overnight capital cost of plant type j (\$/MW)
OC_j	Operating cost of plant type j (\$/MWh)
OC_i	Operating cost of existing plant i (\$/MWh)
M	Planning reserve margin as fraction (%) of demand
Q	Discount rate
D_j	lifetime (years) of candidate plant of type j

Table 4: Indices

Indices	Definition
b	Time blocks representing peak-hours, winter, summer, spring, fall, special periods. $b \in \mathcal{B}$
c	grid cells that new techs can be placed in. $c \in \mathcal{C}$
ℓ	Transmission Lines. $\ell \in \mathcal{L}$
i	existing generators in fleet. $i \in \mathcal{I}$
z	sub regions of SERC. $z \in \mathcal{Z}$

3 Objective Function

$$
\begin{aligned}
TC = & \sum_{c\in\mathcal{C}} \sum_{j\in\mathcal{J}^{(c)}} n^{(c)}_{c,j} \times P^{NP}_j \times (FOM_j + OCC_j \times CRF_j) \\
& + \sum_{z\in\mathcal{Z}} \sum_{j\in\mathcal{J}^{(\bar{c})}} n^{(\bar{c})}_{z,j} \times P^{NP}_j \times (FOM_j + OCC_j \times CRF_j) \\
& + \sum_{z\in\mathcal{Z}} \sum_{j\in\mathcal{J}^{(r)}} n^{(r)}_{z,j} \times P^{NP}_j \times (FOM_j + OCC_j \times CRF_j) \\
& + \sum_{b} \Bigg(W_b \sum_{t_b\in T_b} \Bigg(\sum_{c\in\mathcal{C}} \sum_{j\in\mathcal{J}^{(c)}} p^{(c)}_{c,j,t_b} \times OC_{j,t_b} + \sum_{z\in\mathcal{Z}} \sum_{j\in\mathcal{J}^{(\bar{c})}} p^{(\bar{c})}_{z,j,t} \times OC_{j,t_b} \\
& \qquad + \sum_{z\in\mathcal{Z}} \sum_{j\in\mathcal{J}^{(r)}} p^{(r)}_{z,j,t_b} \times OC_{j,t_b} + \sum_{i} p_{i,t_b} \times OC_{i,t_b} \Bigg) \Bigg)
\end{aligned} \tag{1}
$$

CRF_j is the capital recovery ratio of each technology j and is defined as:

$$
CRF_j = \frac{Q}{1 - \big(1/(1+Q)^{D_j}\big)} \tag{2}
$$

The variable operating cost OC (in \$/MWh) for new and existing generators is equal:

$$
OC_j = VOM_j + HR_j \times FC_j \qquad \forall\, j \in \mathcal{J} \qquad \text{(new generators)} \tag{3}
$$

$$
OC_i = VOM_i + HR_i \times FC_i \qquad \forall\, i \in \mathcal{I} \qquad \text{(existing generators)} \tag{4}
$$

NOTE: I followed the same convention as the GAMS code, where the operating cost OC does not change by time t or location c.

4 Supply vs Demand constraint

$$
\begin{aligned}
P^D_{t,z} = & \sum_{i\in\mathcal{I}(z)} p_{i,t} + \sum_{c\in\mathcal{C}(z)} \sum_{j\in\mathcal{J}^{(c)}} p^{(c)}_{c,j,t_b} + \sum_{j\in\mathcal{J}^{(\bar{c})}} p^{(\bar{c})}_{z,j,t_b} + \sum_{j\in\mathcal{J}^{(r)}} p^{(r)}_{z,j,t_b} \\
& + \sum_{\ell:\text{end}(\ell)=z} \text{flow}_{\ell,t} - \sum_{\ell:\text{begin}(\ell)=z} \text{flow}_{\ell,t}
\end{aligned} \tag{5}
$$

5 Reserve margin constraint

$$
\begin{aligned}
(1+M) \times P^D_{t,z} \le & \sum_{c\in\mathcal{C}} \sum_{j\in\mathcal{J}^{(c)}} P^{MAX}_{c,j,t} \times n^{(c)}_{c,j} + \sum_{j\in\mathcal{J}^{(r)}} P^{MAX}_{z,j,t} \times n^{(r)}_{z,j} \times CF_{j,t} \\
& + \sum_{i\in\mathcal{I}\setminus\{\mathcal{I}_w\cup\mathcal{I}_s\}} P^{MAX}_{i,t} + P^{MAX}_{\text{solar},t} + P^{MAX}_{\text{wind},t}
\end{aligned} \tag{6}
$$

6 Maximum generation constraints

$$\sum_{i \in \mathcal{I}_s} p_{i,t} \leq P^{MAX}_{\text{solar},t} \quad \forall\ t \tag{7}$$

$$\sum_{i \in \mathcal{I}_w} p_{i,t} \leq P^{MAX}_{\text{wind},t} \quad \forall\ t \tag{8}$$

$$p_{i,t} \leq P^{MAX}_{i,t} \quad \forall\ t, \forall\ i \in \mathcal{I} \setminus \{\mathcal{I}_w \cup \mathcal{I}_s\} \tag{9}$$

$$p^{(c)}_{c,j,t} \leq P^{MAX}_{c,j,t} \times n^{(c)}_{c,j} \quad \forall\ c, t \text{ and } \forall\ j \in \mathcal{J}^{(c)} \tag{10}$$

$$p^{(\bar{c})}_{z,j,t} \leq P^{MAX}_{z,j,t} \times n^{(\bar{c})}_{z,j} \quad \forall\ z, t \text{ and } \forall\ j \in \mathcal{J}^{(\bar{c})} \tag{11}$$

$$p^{(r)}_{z,j,t} \leq n^{(r)}_{z,j} \times P^{NP}_{j} \times CF_{j,t} \quad \forall\ z, t \text{ and } \forall\ j \in \mathcal{J}^{(r)} \tag{12}$$

7 Transmission Constraint

$$0 \leq \text{flow}_{\ell,t} \leq \overline{\text{flow}}_{\ell} \quad \forall\ \ell, t \tag{13}$$