Work Plan for Capacity Expansion Model

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1 Introduction

In December 2017, Michael Craig handled the remaining implementation of the RIPS Capacity Expansion (CE) model to me. This document summarizes the work plan for the next steps still needed to be implemented in the code of the model. This list is mostly based on the word document `RIPSGuide_Craig_7Dec17.docx` available in the git repository.

2 Summary of "to do' list

- Change the source of solar data from NREL Solar Integration Dataset to NSRDB data
- Update python code to use Aviva's regressions that link capacity deratings (NOT related to regulatory limits) to ambient conditions.
- If we use Aviva's data, we need to use cell-specific meteorological data from UW.
- Update demand forecast to include whole SERC (instead of only TVA, which is the current case)
- Change 'specialh' set of hours to include other events (currently it only includes peak demand events)
- Implement plotting script to draw maps of SERC that shows the output of the model (for example where the plants are being built)
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3 Details of to do list

According to Michael, "[T]he Python code for processing inputs to and outputs from the CE model is largely complete, although some debugging may be necessary." He goes on to list some modifications to the model that are pending:

3.1 Update Solar data source

Solar data currently comes from the NREL Solar Integration Dataset. However, Bri recommends we instead use NSRDB data, which provides solar irradiance, then use that data to estimate PV generation. I have downloaded NSRDB data at points in a grid over the entire region (Databases/NSRDBRIPS). In the SolarMOEPaper folder, there are Python scripts for inputting NSRDB data to PVLib to get estimated hourly generation. (`GetRenewableCFs` script)

3.2 Update use of Aviva's regressions

Right now, the Python code has placeholder code to insert Aviva's regressions that link capacity deratings (NOT related to regulatory limits) to ambient conditions. You will need to update the form and coefficients in these regressions and the mapping of plants to regressions. (`CurtailmentRegressions` script)

3.3 Read UW meteo data by cell

The code loads meteorological data at the regional rather than cell-specific data. If you do use regressions from Aviva, you will need to use cell-specific meteorological data from UW. (`ModifyGeneratorCapacity` script and `loadMetData` function)

3.4 Update demand forecast to whole SERC

The CE model currently uses Francisco's demand forecast for TVA. That code should be updated for the Southeast when regressions are available.
`ForecastDemandWithRegression`

3.5 Update 'speciah' set of hours

The CE model has a "specialh' set of hours, which is currently used to include hours from the day with peak demand. However, you may also want to include days with peak curtailment of generators. If so, then you will need to add a set of hours for these peak curtailment hours. I did not because the day with peak demand may very well overlap with the day with peak curtailment. (`DemandFuncsCE` script, `selectWeeksForExpansion` function (also will require modifications to GAMS code))

3.6 Update curtailment 1

Need to finicsh implementing the curtailment equations, which use simple mixing formula, from the CurtailmentEquations.doc document. The environmental regulation equation currently includes water flow (availability), but the availability data is not being loaded in the RIPSMasterScript yet

- For loading water availability data: `ModifyGeneratorCapacityWithWaterTData` script and `loadWaterAndMetData` function

- For including availability in curtailments: `CurtailmentFromEnviroRegs` script and `CurtailmentFromEnviroRegs` function

3.7 Map output

The result of this model will be the decisions of building different classes of power plants in different regions of the southeast according to demand forecast and climate related constraints. It would be interesting to implement a tool/function in order to be able to visualize these results on a plot. I have not decided what this tool would look like. But one possibility is to have a gridded map (or several gridded maps) where we could observe where the power plants are being installed. I know how to do it in R, but I need to look at how to do it in Python.

3.8 Update curtailment 2

Paulina mentioned that the curtailment procedure should be also a function of cooling technologies. Michael's current function does not account for this.

3.9 Low priority: Wind data

Wind generation data right now comes from the WIND dataset. I chose 2009 generation data because it has a moderate average CF, but you may want to select a different year. If there?s a TMY in the WIND data, that would be the best route (you can ask Bri this).

3.10 "Tweaks" and Checks once the model is running

- How quickly the CE model runs will partly determine how many days you can include in it. If you include many, then how I currently handle max generation in each set of days by each hydro plant is OK

- You should revisit special days that are included in the CE model, and think of other possible interesting days to examine. For these days, you?ll have to figure out how you want to set maximum hydropower generation on those days.

- I did not observe charging by the pumped hydro units in the CE model. I?m not sure if this is a bug or if there was never a reason for them to, so I would check that later after adding the features above. Like I said, pumped hydro will add significant computational burden, so you may end up eliminating it.

4 Capacity Expansion model

This section 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).

4.1 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
$P^{MAX}_{c,j,t}$	Maximum electricity generation capacity, accounting for deratings, of plant type $j \in \mathcal{J}^{(c)}$ at cell grid c at time t (MWh)
P^{NP}_{j}	Nameplate electricity generation capacity of plant type $j \in \mathcal{J}$ (MWh)
$P^{MAX}_{i,t}$	Maximum electricity generation capacity, accounting for deratings, of existing generator i (non solar and non wind) at time t (MWh)
$P^{MAX}_{solar,t}$	Maximum electricity generation by all existing solar generators at time t (MWh)
$P^{MAX}_{wind,t}$	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. $z \in \mathcal{Z}$

4.2 Objective Function

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

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

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

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.

4.3 Supply vs Demand constraint

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

4.4 Reserve margin constraint

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

4.5 Maximum generation constraints

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

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

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

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

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

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

4.6 Transmission Constraint

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