A.5 Glossary of Parameters

This is a glossary of all parameters that appear in the objective function and constraints of the detailed model description.

a_k The fraction of pre-2006 transmission line k's capacity available to wind.

BASE_CSP National CSP capacity at the start of the period. (MW)

$BASE\_CSP\_inst_i$ Regional CSP capacity at the start of the period. (MW)

BASETPCA National transmission capacity at the start of the period. (MW)

BASE_WIND National wind capacity at the start of the period. (MW)

$BASE\_WIND\_inst_i$ Regional wind capacity at the start of the period. (MW)

$BioFeedstockLCOF_{bioclass,n}$ Levelized cost of feedstock at each step of the biomass supply curve.

$BioSupply_{bioclass,n}$ Amount of feedstock available at a given step on the biomass supply curve.

CarbTax Amount of carbon tax. (\$/ton CO_2)

CCC_q Overnight capital cost of conventional generating capacity. (\$/MW)

$CCONV_q$ Present value of the revenue required to pay the capital cost of conventional generating capacity (\$/MW) including interest, construction, finance, and taxes.

$CCONVF_q$ Present value of the annual fixed operating costs over the evaluation period for conventional generating capacity. (\$/MW)

$CCONVV_{n,q}$ Present value over the evaluation period of the variable operating and fuel costs for generation from conventional capacity. (\$/MWh)

$CCSP_{cCSP}$ Capital cost of class *cCSP* CSP capacity. (\$/MW)

$CCt_{q,g}$ The present value of the cost of transmitting 1 MWh of power for each of E years between balancing authorities n and p.

$CF_{c,i,m,l}$ Capacity factor by time-slice for new wind of at a class c, location l site in supply region i.

$CF_{cCSP,m}$ Capacity factor by time-slice for new CSP at a class *cCSP* site.

$CFO_{c,i,m,l}$ Average capacity factor of all existing type l, class c wind on pre-2006 lines in region i.

$CFO_{cCSP,m}$ Average capacity factor of all existing class *cCSP* CSP on pre-2006 lines.

$CFTO_{c,i,m,l}$ Average capacity factor of all existing type l, class c wind on new lines in region i.

$CFTO_{cCSP,m}$ Average capacity factor of all existing class *cCSP* CSP on new lines.

CG_g Increase in turbine price due to rapid growth in wind capacity. (\$/MW)

$CGcsp_{gCSP}$ Increase in CSP plant cost due to rapid growth in CSP capacity. (\$/MW)

$CGcspinst_{gCSPinst}$ Increase in CSP installation cost due to rapid growth in CSP capacity. (\$/MW)

$CGinst_{ginst}$ Increase in wind installation cost due to rapid growth in wind capacity. (\$/MW)

$CGStorage_{st,storagebp}$ Increase in storage cost due to rapid growth in storage capacity. (\$/MW)

$CHeatRate_q$ Heat rate (inverse efficiency) of conventional technology. (MMbtu/MWh)

$CHeatrate_{st}$ Heat rate (inverse efficiency) of storage technology. (MMbtu/MWh)

$CONVpol_{q,pol}$ Emissions of pollutant for each MWh of generation by conventional technology q. (ton/MWh)

$CONVold_{n,q}$ Existing conventional generating capacity, prior to the current period. (MW)

$CONVret_{n,q}$ Retirements of aging conventional capacity in a given period.

Cost_Inst_Frac Fraction of wind farm capital cost assigned to installation rather than the turbines themselves.

$cpop_{c,i,l}$ Fractional increase in wind capital cost due to population density.

CQS Cost to modify a combustion turbine to provide a quick-start capability. ($/MW)

CRF Capital recovery factor, i.e. the fraction of the capital cost of an investment that must be returned each year to earn a given rate of return if income taxes and financing are ignored.

$cslope_{c,i,l}$ Fractional increase in wind capital cost per degree of topographical slope.

$CSP2G_{cCSP,i,cspscp}$ New class *cCSP* CSP resource in region *i* available at interconnection cost step *cspscp*.

$CSP2GPTS_{cCSP,i,cspscp}$ Cost to build transmission from a CSP site to the closest available grid transmission capacity.

$CspCVmar_{cCSP,i,rto}$ (CSP Capacity Value - marginal) The effective load-carrying capacity of 1 MW at a new CSP plant at a class *cCSP* site in region *i* delivered to an *rto*.

$CspCVold_{cCSP,i,rto}$ (CSP Capacity Value - old) The effective load-carrying capacity of all the CSP capacity installed in previous periods whose generation is transmitted to an *rto*.

CSPGridConCost Cost to connect a CSP plant to the grid. ($/MW)

$CSP\_inregion\_dis_{cCSP,j,escp}$ Levelized cost—from the *escp* step of the supply curve—for building a transmission line from a CSP site to a load center in the same region.

$CSPO_{cCSP,i,j}$ Existing class *cCSP* CSP capacity on pre-2006 transmission lines from region *i* to region *j*.

$CSPOM_{cCSP}$ Present value of operations and maintenance costs over the evaluation period for CSP capacity ($/MW)

$CSPRuc_{cCSP,i}$ Amount of solar resource available. (MW)

$CSPTO_{cCSP,i,j}$ Existing class *cCSP* CSP capacity on new transmission lines from region *i* to region *j*.

$CSPTturO_{cCSP,i}$ Existing CSP capacity for which new transmission capacity was built. (MW)

$CSPturO_{cCSP,i}$ Existing CSP capacity that utilizes pre-2006 lines. (MW)

$CSRV_{n,q}$ Present value of the variable cost of spinning reserve provided over the evaluation period ($/MWh)

$CSTOR_{st}$ Capital cost of storage capacity. ($/MW)

$Ctranadder_q$ Transmission cost adder by conventional technology. ($/MW)

$CVmar_{c,i,rto}$ (Capacity Value - marginal) The effective load-carrying capacity of 1 MW at a new wind or solar farm at a class *c* site in region *i* delivered to an *rto*.

$CVold_{c,i,rto}$ (Capacity Value - old) The effective load-carrying capacity of all the wind or solar capacity installed in previous periods whose generation is transmitted to an *rto*.

CW_c Present value of the revenue required to pay for the capital cost of class *c* wind capacity—including interest during construction, finance, and taxes. ($/MW)

$CWOM_c$ Present value of operations and maintenance costs over the evaluation period for wind capacity—including property taxes, insurance, and production tax credit. ($/MWh)

$Distance_{i,j}$ Distance between regions. (miles)

$Distance_{n,p}$ Distance between balancing authorities. (miles)

F_q Fraction of capacity that can be available as quickstart.

FO_q Forced outage rate of technology *q*.

$Fprice_{q,n}$ Cost of input fuel for given technology. ($/MWh)

$FSRV_q$ Fraction of capacity available for spinning reserve.

$FSTOR_{st}$ Present value of the annual fixed operating costs over the evaluation period for storage capacity. ($/MW)

$GeoAdder_{geoclass,n}$ Additional capital cost for recoverable geothermal capacity along supply curve. ($/MW)

$GeoEGSadder_{egsclass,n}$ Additional capital cost for recoverable geothermal capacity along supply curve. ($/MW)

$GeoEGSmax_{egsclass,n}$ Amount of recoverable capacity at a given step on the EGS supply curve. (MW)

$GeoEGSOld_{egsclass,n}$ Existing EGS capacity, prior to the current period. (MW)

$GeoMax_{geoclass,n}$ Amount of recoverable capacity at a given step on the geothermal supply curve. (MW)

$GeoOld_{geoclass,n}$ Existing geothermal capacity, prior to the current period. (MW)

GridConCost cost to connect a wind farm or CSP plant to the grid. ($/MW)

Gt_g A fractional multiplier on the national wind capacity that defines the national wind capacity in step g of the wind turbine price multiplier for rapid growth.

$GtCSP_{gCSP}$ A fractional multiplier on the national CSP capacity that defines the national CSP capacity in step *gCSP* of the CSP plant price multiplier for rapid growth.

$GtCSPinst_{gCSPinst}$ A fractional multiplier on the CSP capacity in a region that defines the region's CSP capacity in step *gCSPinst* of the CSP installation price multiplier for rapid growth.

$Gtinst_{ginst}$ A fractional multiplier on the wind capacity in a region that defines the region's wind capacity in step *ginst* of the wind installation price multiplier for rapid growth.

H_m Number of hours per year in time-slice m.

Hen_n Annual hydro energy available in balancing authority n. (MWh)

$L_{j,m}$ Load by region and time-slice. (MW)

$L_{n,m}$ Load by balancing authority and time-slice. (MW)

$L_{rto,m}$ Load by rto and time-slice. (MW)

$lowsuladd\_LCF_n$ Present value of 20-year expected additional levelized cost of fuel for using low sulfur coal.

$minplantload_q$ The minimum level at which a conventional technology can run.

$MW\_inregion\_dis_{c,j,escp}$ Levelized cost—from the *escp* step of the supply curve—for building a transmission line from a wind site to a load center in the same region.

$NERCRm_r$ Reserve margin requirement in the nerc region containing each balancing authority.

$nor2rto_{rto}$ The variance of the usual operating reserve requirement in RTO *rto*.

NRRfrac The fraction of the normal reserve requirement.

$old\_STOR_{n,st}$ Existing grid-based storage at the start of the period. (MW)

$old\_WSTOR_{i,st}$ Existing wind-based storage at the start of the period. (MW)

$old\_WSTORin\_grid_{j,m,st}$ Energy from the grid used to charge existing wind-based storage in region j in time-slice m. (MWh)

$old\_WSTORin\_wind_{c,i,m,st}$ Energy from wind in region i used to charge existing wind-based storage in time-slice m. (MWh)

$old\_WSTOR\_OR_{i,m,st}$ Existing wind-based storage generating capacity in region i held back as operating reserve in time-slice m. (MW)

$old\_WSTORout\_dest_{i,m,p}$ Energy discharged in time-slice m from existing wind-based storage in region i to a destination in balancing area p. The storage technology from which the energy comes is tracked by $old\_WSTORout\_source_{i,m,st}$. (MWh)

old_WSTORout_inregion$_{i,m,st}$ Energy discharged in time-slice *m* from existing wind-based storage in region *i* to a load center in the same region. (MWh)

old_WSTORout_source$_{i,m,st}$ Energy discharged in time-slice *m* from existing wind-based storage of technology *st* in region *i*. The destination of this energy is tracked by *old_WSTORout_dest*$_{i,n,m}$. (MWh)

ORMAR$_{c,i,rto,m}$ The operating reserve requirement induced by the marginal addition of one MW of class *c* wind or solar capacity in region *i* that is consumed in an *rto*.

P_n Peak load in balancing authority *n*. (MW)

P_{rto} Peak load in rto *rto*. (MW)

PcostFrac$_q$ multiplier on the operating costs of conventional generating capacity for use as a peaker.

PO_q planned outage rate

PostStamp$_{i,j}$ the number of balancing authorities that must be crossed to transmit wind between two supply regions.

qsfrac minimum fraction of operating reserve that can be met by quickstart technologies

Resconfint (Reserve Confindence Interval) Operating reserve minimum expressed in terms of the number of standard deviations of operating reserve required.

RPSfraction national renewable portfolio standard level as a fraction of national electric generation.

RPSSCost penalty imposed for not meeting the national RPS requirement. ($/MWh)

St_CSPRPSCost$_{states}$ penalty imposed for not meeting the state RPS requirement for solar. ($/MWh)

st_Invincent$_{states}$ Before-tax value of state-level investment incentive for wind. ($/MW)

STORpol$_{st,pol}$ Emissions of pollutant for each MWh of generation by storage technology *st*. (ton/MWh)

STOR_RTE$_{st}$ round-trip efficiency for storage technologies

st_Prodincent$_{states}$ Before-tax value of state-level production incentive for wind. ($/MW-yr)

St_RPSfraction$_{states}$ state renewable portfolio standard level as a fraction of state electric generation.

St_RPSSCost penalty imposed for not meeting the state RPS requirement. ($/MWh)

SurplusMar$_{c,i,rto,m}$ Fraction of renewable (wind or solar) output (from a new class *c* source in region *i* to rto *rto*) curtailed in time slice *m* because must-run conventionals plus renewable output exceeds load.

SurplusOld$_{rto,m}$ Fraction of renewable (wind or solar) output from all existing sources feeding rto *rto* curtailed in time slice *m* because must-run conventionals plus renewable output exceeds load.

Tk_k Capacity of transmission line k. (MW)

TLOSS Fraction of conventional power lost in each mile of transmission.

TOCOST cost for wind to use pre-2006 transmission lines ($/MWh-mile)

TOR$_{rto,m}$ The operating reserve requirement induced by the load, conventional generation, and existing wind capacity in an *rto*. (MW)

TOWCOST cost of wind transmission on pre-2006 lines ($/MWh-mile)

TNCOST cost of new transmission lines ($/MW-mile)

TNWCOST cost to build a new transmission line. ($/MW-mile)

TPCA_Gt$_{TPCA\_g}$ A fractional multiplier of the national transmission (MW) capacity *BASETPCA* used to establish the size of growth bin *tpca_g*.

TPCAO$_{n,p}$ The transmission capacity between *n* and *p* that existed at the start of the period.

TWLOSSnew The fraction of wind power lost in each mile of transmission, for new wind.

TWLOSSold The fraction of wind power lost in each mile of transmission, for existing wind.

$VSTOR_{st}$ present value over the evaluation period of the variable operating and fuel costs for generation from storage capacity ($/MWh)

$WO_{c,i,j,l}$ Existing class c wind of type l on pre-2006 transmission lines from region i to region j.

$WR2G_{c,i,l,wscp}$ New class c wind resource of type l in region i available at step $wscp$ on the supply curve. (MW)

$WR2GPTS_{c,i,l,wscp}$ Cost associated with step $wscp$ on the supply curve to build transmission from a wind site in region i to the closest available grid transmission capacity. ($/MW)

$WRuc_{c,i,l}$ amount of wind resource available. (MW)

$WTO_{c,i,j}$ Existing class c wind on new transmission lines from region i to region j.

$WturO_{c,i,l}$ Existing wind capacity that utilizes pre-2006 lines. (MW)

$WTturO_{c,i,l}$ Existing wind capacity for which new transmission capacity was built. (MW)