Sets

Name	Alias	Description
weather	$wth1, wth1p, wth1e, wth1n$	weather
tech	t, tp, te, tn	technology
sup	$s1, s1p, s1e, s1n$	supply
dem	d, dp, de, dn	demand
stg	$st1, st1p, st1e, st1n$	storage
expp	e, ep, ee, en	export to the rest of the world (ROW)
imp	i, ip, ie, in	import from the rest of the world
trade	$t1, t1p, t1e, t1n$	trade between regions
group	g, gp, ge, gn	group of input or output commodities in technology
comm	c, cp, ce, cn	commodity
region	r, rp, re, rn	region
year	y, yp, ye, yn	year
slice	s, sp, se, sn	time slice

Mapping parameters

Name	Alias	Description
mSameRegion(region, region)	$SameRegion_{r,r}$	The same region (used in GLPK)
mSameSlice(slice, slice)	$SameSlice_{s,s}$	The same slice (used in GLPK)
mMilestoneFirst(year)	$MilestoneFirst_{y}$	First period milestone
mMilestoneLast(year)	$MilestoneLast_{y}$	Last period milestone
mMilestoneNext(year, year)	$MilestoneNext_{y,y}$	Next period milestone
mMilestoneHasNext(year)	$MilestoneHasNext_{y}$	Is there next period milestone
mStartMilestone(year, year)	$StartMilestone_{y,y}$	Start of the period
mEndMilestone(year, year)	$EndMilestone_{y,y}$	End of the period
mMidMilestone(year)	$MidMilestone_{y}$	Milestone year
mCommSlice(comm, slice)	$Slice^{Comm}{}_{c,s}$	Commodity to slice
mCommSliceOrParent(comm, slice, slice)	$SliceOrParent^{Comm}{}_{c,s,s}$	
mTechRetirement(tech)	$Retirement^{Tech}{}_{t}$	Early retirement option
mTechUpgrade(tech, tech)	$Upgrade^{Tech}{}_{t,t}$	Upgrade technology (not implemented yet)
mTechInpComm(tech, comm)	$InpComm^{Tech}{}_{t,c}$	Input commodity

mTechOutComm(tech, comm)	$OutComm^{Tech}{}_{t,c}$	Output commodity
mTechInpGroup(tech, group)	$InpGroup^{Tech}{}_{t,g}$	Group input
mTechOutGroup(tech, group)	$OutGroup^{Tech}{}_{t,g}$	Group output
mTechOneComm(tech, comm)	$OneComm^{Tech}{}_{t,c}$	Commodity without group
mTechGroupComm(tech, group, comm)	$GroupComm^{Tech}{}_{t,g,c}$	Mapping between commodity-groups and commodities
mTechAInp(tech, comm)	$AInp^{Tech}{}_{t,c}$	Auxiliary input
mTechAOut(tech, comm)	$AOut^{Tech}{}_{t,c}$	Auxiliary output
mTechNew(tech, region, year)	$New^{Tech}{}_{t,r,y}$	Technologies available for investment
mTechSpan(tech, region, year)	$Span^{Tech}{}_{t,r,y}$	Availability of each technology by regions and milestone years
mTechSlice(tech, slice)	$Slice^{Tech}{}_{t,s}$	Technology to slice-level
mSupSlice(sup, slice)	$Slice^{Sup}{}_{s1,s}$	Supply to slices-level
mSupComm(sup, comm)	$Comm^{Sup}{}_{s1,c}$	Supplied commodities
mSupSpan(sup, region)	$Span^{Sup}{}_{s1,r}$	Supply in regions
mDemComm(dem, comm)	$Comm^{Dem}{}_{d,c}$	Demand commodities
mUpComm(comm)	$UpComm_c$	Commodity balance type PRODUCTION ¡= CONSUMPTION
mLoComm(comm)	$LoComm_c$	Commodity balance type PRODUCTION ¿= CONSUMPTION
mFxComm(comm)	$FxComm_c$	Commodity balance type PRODUCTION == CONSUMPTION
mStorageFullYear(stg)	$FullYear^{Storage}{}_{st1}$	Mapping of storage with joint slice
mStorageComm(stg, comm)	$Comm^{Storage}{}_{st1,c}$	Mapping of storage technology and respective commodity
mStorageAInp(stg, comm)	$AInp^{Storage}{}_{st1,c}$	Aux-commodity input to storage
mStorageAOut(stg, comm)	$AOut^{Storage}{}_{st1,c}$	Aux-commodity output from storage
mStorageNew(stg, region, year)	$New^{Storage}{}_{st1,r,y}$	Storage available for investment
mStorageSpan(stg, region, year)	$Span^{Storage}{}_{st1,r,y}$	Storage set showing if the storage may exist in the year and region
mStorageOMCost(stg, region, year)	$OMCost^{Storage}{}_{st1,r,y}$	
mStorageEac(stg, region, year)	$Eac^{Storage}{}_{st1,r,y}$	
mSliceNext(slice, slice)	$SliceNext_{s,s}$	Next slice
mSliceFYearNext(slice, slice)	$SliceFYearNext_{s,s}$	Next slice joint
mTradeSlice(trade, slice)	$Slice^{Trade}{}_{t1,s}$	Trade to slice
mTradeComm(trade, comm)	$Comm^{Trade}{}_{t1,c}$	Trade commodities
mTradeRoutes(trade, region, region)	$Routes^{Trade}{}_{t1,r,r}$	
mTradeIrAInp(trade, comm)	$IrAInp^{Trade}{}_{t1,c}$	Auxiliary input commodity in source region
mTradeIrAOut(trade, comm)	$IrAOut^{Trade}{}_{t1,c}$	Auxiliary output commodity in source region
mExpComm(expp, comm)	$ExpComm_{e,c}$	Export commodities

mImpComm(imp, comm)	$ImpComm_{i,c}$	Import commodities
mExpSlice(expp, slice)	$ExpSlice_{e,s}$	Export to slice
mImpSlice(imp, slice)	$ImpSlice_{i,s}$	Import to slice
mDiscountZero(region)	$DiscountZero_{r}$	
mSliceParentChildE(slice, slice)	$SliceParentChildE_{s,s}$	Child slice or the same
mSliceParentChild(slice, slice)	$SliceParentChild_{s,s}$	Child slice not the same
mTradeSpan(trade, year)	$Span^{Trade}{}_{t1,y}$	
mTradeNew(trade, year)	$New^{Trade}{}_{t1,y}$	
mTradeOlifeInf(trade)	$OlifeInf^{Trade}{}_{t1}$	
mTradeEac(trade, region, year)	$Eac^{Trade}{}_{t1,r,y}$	
mTradeCapacityVariable(trade)	$CapacityVariable^{Trade}{}_{t1}$	
mTradeInv(trade, region, year)	$Inv^{Trade}{}_{t1,r,y}$	
mAggregateFactor(comm, comm)	$AggregateFactor_{c,c}$	
mWeatherSlice(weather, slice)	$Slice^{Weather}{}_{wth1,s}$	
mWeatherRegion(weather, region)	$Region^{Weather}{}_{wth1,r}$	
mSupWeatherLo(weather, sup)	$WeatherLo^{Sup}{}_{wth1,s1}$	
mSupWeatherUp(weather, sup)	$WeatherUp^{Sup}{}_{wth1,s1}$	
mTechWeatherAfLo(weather, tech)	$WeatherAfLo^{Tech}{}_{wth1,t}$	
mTechWeatherAfUp(weather, tech)	$WeatherAfUp^{Tech}{}_{wth1,t}$	
mTechWeatherAfsLo(weather, tech)	$WeatherAfsLo^{Tech}{}_{wth1,t}$	
mTechWeatherAfsUp(weather, tech)	$WeatherAfsUp^{Tech}{}_{wth1,t}$	
mTechWeatherAfcLo(weather, tech, comm)	$WeatherAfcLo^{Tech}{}_{wth1,t,c}$	
mTechWeatherAfcUp(weather, tech, comm)	$WeatherAfcUp^{Tech}{}_{wth1,t,c}$	
mStorageWeatherAfLo(weather, stg)	$WeatherAfLo^{Storage}{}_{wth1,st1}$	
mStorageWeatherAfUp(weather, stg)	$WeatherAfUp^{Storage}{}_{wth1,st1}$	
mStorageWeatherCinpUp(weather, stg)	$WeatherCinpUp^{Storage}{}_{wth1,st1}$	
mStorageWeatherCinpLo(weather, stg)	$WeatherCinpLo^{Storage}{}_{wth1,st1}$	
mStorageWeatherCoutUp(weather, stg)	$WeatherCoutUp^{Storage}{}_{wth1,st1}$	
mStorageWeatherCoutLo(weather, stg)	$WeatherCoutLo^{Storage}{}_{wth1,st1}$	
mvSupCost(sup, region, year)	$vSupCost_{s1,r,y}$	
mvTechInp(tech, comm, region, year, slice)	$vTechInp_{t,c,r,y,s}$	
mvSupReserve(sup, comm, region)	$vSupReserve_{s1,c,r}$	
mvTechRetiredNewCap(tech, region, year, year)	$vTechRetiredNewCap_{t,r,y,y}$	

mvTechRetiredStock(tech, region, year)	$vTechRetiredStock_{t,r,y}$	
mvTechAct(tech, region, year, slice)	$vTechAct_{t,r,y,s}$	
mvTechOut(tech, comm, region, year, slice)	$vTechOut_{t,c,r,y,s}$	
mvTechAInp(tech, comm, region, year, slice)	$vTechAInp_{t,c,r,y,s}$	
mvTechAOut(tech, comm, region, year, slice)	$vTechAOut_{t,c,r,y,s}$	
mvDemInp(comm, region, year, slice)	$vDemInp_{c,r,y,s}$	
mvBalance(comm, region, year, slice)	$vBalance_{c,r,y,s}$	
mvInpTot(comm, region, year, slice)	$vInpTot_{c,r,y,s}$	
mvOutTot(comm, region, year, slice)	$vOutTot_{c,r,y,s}$	
mvInp2Lo(comm, region, year, slice, slice)	$vInp2Lo_{c,r,y,s,s}$	
mvOut2Lo(comm, region, year, slice, slice)	$vOut2Lo_{c,r,y,s,s}$	
mInpSub(comm, region, year, slice)	$InpSub_{c,r,y,s}$	For increase speed eqInpTot
mOutSub(comm, region, year, slice)	$OutSub_{c,r,y,s}$	For increase speed eqOutTot
mvStorageAInp(stg, comm, region, year, slice)	$vStorageAInp_{st1,c,r,y,s}$	
mvStorageAOut(stg, comm, region, year, slice)	$vStorageAOut_{st1,c,r,y,s}$	
mvStorageStore(stg, comm, region, year, slice)	$vStorageStore_{st1,c,r,y,s}$	
mStorageStg2AOut(stg, comm, region, year, slice)	$Stg2AOut^{Storage}{}_{st1,c,r,y,s}$	
mStorageCinp2AOut(stg, comm, region, year, slice)	$Cinp2AOut^{Storage}{}_{st1,c,r,y,s}$	
mStorageCout2AOut(stg, comm, region, year, slice)	$Cout2AOut^{Storage}{}_{st1,c,r,y,s}$	
mStorageCap2AOut(stg, comm, region, year, slice)	$Cap2AOut^{Storage}{}_{st1,c,r,y,s}$	
mStorageNCap2AOut(stg, comm, region, year, slice)	$NCap2AOut^{Storage}{}_{st1,c,r,y,s}$	
mStorageStg2AInp(stg, comm, region, year, slice)	$Stg2AInp^{Storage}{}_{st1,c,r,y,s}$	
mStorageCinp2AInp(stg, comm, region, year, slice)	$Cinp2AInp^{Storage}{}_{st1,c,r,y,s}$	
mStorageCout2AInp(stg, comm, region, year, slice)	$Cout2AInp^{Storage}{}_{st1,c,r,y,s}$	
mStorageCap2AInp(stg, comm, region, year, slice)	$Cap2AInp^{Storage}{}_{st1,c,r,y,s}$	
mStorageNCap2AInp(stg, comm, region, year, slice)	$NCap2AInp^{Storage}{}_{st1,c,r,y,s}$	
mvTradeIr(trade, comm, region, region, year, slice)	$vTradeIr_{t1,c,r,r,y,s}$	
mTradeIrCsrc2Ainp(trade, comm, region, region, year, slice)	$IrCsrc2Ainp^{Trade}{}_{t1,c,r,r,y,s}$	
mTradeIrCdst2Ainp(trade, comm, region, region, year, slice)	$IrCdst2Ainp^{Trade}{}_{t1,c,r,r,y,s}$	
mTradeIrCsrc2Aout(trade, comm, region, region, year, slice)	$IrCsrc2Aout^{Trade}{}_{t1,c,r,r,y,s}$	
mTradeIrCdst2Aout(trade, comm, region, region, year, slice)	$IrCdst2Aout^{Trade}{}_{t1,c,r,r,y,s}$	
mvTradeCost(region, year)	$vTradeCost_{r,y}$	
mvTradeRowCost(region, year)	$vTradeRowCost_{r,y}$	
mvTradeIrCost(region, year)	$vTradeIrCost_{r,y}$	

mvTotalCost(region, year)	$vTotalCost_{r,y}$	
mvTotalUserCosts(region, year)	$vTotalUserCosts_{r,y}$	
mTechInv(tech, region, year)	$Inv^{Tech}{}_{t,r,y}$	
mTechInpTot(comm, region, year, slice)	$InpTot^{Tech}{}_{c,r,y,s}$	Total technology input mapp
mTechOutTot(comm, region, year, slice)	$OutTot^{Tech}{}_{c,r,y,s}$	Total technology output mapp
mTechEac(tech, region, year)	$Eac^{Tech}{}_{t,r,y}$	
mTechOMCost(tech, region, year)	$OMCost^{Tech}{}_{t,r,y}$	
mSupOutTot(comm, region, year, slice)	$OutTot^{Sup}{}_{c,r,y,s}$	
mEmsFuelTot(comm, region, year, slice)	$EmsFuelTot_{c,r,y,s}$	
mTechEmsFuel(tech, comm, comm, region, year, slice)	$EmsFuel^{Tech}{}_{t,c,c,r,y,s}$	
mDummyImport(comm, region, year, slice)	$Import^{Dummy}{}_{c,r,y,s}$	
mDummyExport(comm, region, year, slice)	$Export^{Dummy}{}_{c,r,y,s}$	
mDummyCost(comm, region, year)	$Cost^{Dummy}{}_{c,r,y}$	
mTradeIr(trade, region, region, year, slice)	$Ir^{Trade}{}_{t1,r,r,y,s}$	
mvTradeIrAInp(trade, comm, region, year, slice)	$vTradeIrAInp_{t1,c,r,y,s}$	
mvTradeIrAInpTot(comm, region, year, slice)	$vTradeIrAInpTot_{c,r,y,s}$	
mvTradeIrAOut(trade, comm, region, year, slice)	$vTradeIrAOut_{t1,c,r,y,s}$	
mvTradeIrAOutTot(comm, region, year, slice)	$vTradeIrAOutTot_{c,r,y,s}$	
mImportRow(imp, comm, region, year, slice)	$ImportRow_{i,c,r,y,s}$	
mImportRowUp(imp, comm, region, year, slice)	$ImportRowUp_{i,c,r,y,s}$	
mImportRowAccumulatedUp(imp, comm)	$ImportRowAccumulatedUp_{i,c}$	
mExportRow(expp, comm, region, year, slice)	$ExportRow_{e,c,r,y,s}$	
mExportRowUp(expp, comm, region, year, slice)	$ExportRowUp_{e,c,r,y,s}$	
mExportRowAccumulatedUp(expp, comm)	$ExportRowAccumulatedUp_{e,c}$	
mExport(comm, region, year, slice)	$Export_{c,r,y,s}$	
mImport(comm, region, year, slice)	$Import_{c,r,y,s}$	
mStorageInpTot(comm, region, year, slice)	$InpTot^{Storage}{}_{c,r,y,s}$	
mStorageOutTot(comm, region, year, slice)	$OutTot^{Storage}{}_{c,r,y,s}$	
mTaxCost(comm, region, year)	$Cost^{Tax}{}_{c,r,y}$	
mSubCost(comm, region, year)	$SubCost_{c,r,y}$	
mAggOut(comm, region, year, slice)	$AggOut_{c,r,y,s}$	
mTechAfUp(tech, region, year, slice)	$AfUp^{Tech}{}_{t,r,y,s}$	
mTechFullYear(tech)	$FullYear^{Tech}{}_{t}$	
mTechRampUp(tech, region, year, slice)	$RampUp^{Tech}{}_{t,r,y,s}$	

mTechRampDown(tech, region, year, slice)	$RampDown^{Tech}{}_{t,r,y,s}$	
mTechOlifeInf(tech, region)	$OlifeInf^{Tech}{}_{t,r}$	
mStorageOlifeInf(stg, region)	$OlifeInf^{Storage}{}_{st1,r}$	
mTechAfcUp(tech, comm, region, year, slice)	$AfcUp^{Tech}{}_{t,c,r,y,s}$	
mSupAvaUp(sup, comm, region, year, slice)	$AvaUp^{Sup}{}_{s1,c,r,y,s}$	
mSupAva(sup, comm, region, year, slice)	$Ava^{Sup}{}_{s1,c,r,y,s}$	
mSupReserveUp(sup, comm, region)	$ReserveUp^{Sup}{}_{s1,c,r}$	
mOut2Lo(comm, region, year, slice)	$Out2Lo_{c,r,y,s}$	
mInp2Lo(comm, region, year, slice)	$Inp2Lo_{c,r,y,s}$	
meqTechRetiredNewCap(tech, region, year)	$eqTechRetiredNewCap_{t,r,y}$	
meqTechSng2Sng(tech, region, comm, comm, year, slice)	$eqTechSng2Sng_{t,r,c,c,y,s}$	
meqTechGrp2Sng(tech, region, group, comm, year, slice)	$eqTechGrp2Sng_{t,r,g,c,y,s}$	
meqTechSng2Grp(tech, region, comm, group, year, slice)	$eqTechSng2Grp_{t,r,c,g,y,s}$	
meqTechGrp2Grp(tech, region, group, group, year, slice)	$eqTechGrp2Grp_{t,r,g,g,y,s}$	
meqTechShareInpLo(tech, region, group, comm, year, slice)	$eqTechShareInpLo_{t,r,g,c,y,s}$	
meqTechShareInpUp(tech, region, group, comm, year, slice)	$eqTechShareInpUp_{t,r,g,c,y,s}$	
meqTechShareOutLo(tech, region, group, comm, year, slice)	$eqTechShareOutLo_{t,r,g,c,y,s}$	
meqTechShareOutUp(tech, region, group, comm, year, slice)	$eqTechShareOutUp_{t,r,g,c,y,s}$	
meqTechAfLo(tech, region, year, slice)	$eqTechAfLo_{t,r,y,s}$	
meqTechAfUp(tech, region, year, slice)	$eqTechAfUp_{t,r,y,s}$	
meqTechAfsLo(tech, region, year, slice)	$eqTechAfsLo_{t,r,y,s}$	
meqTechAfsUp(tech, region, year, slice)	$eqTechAfsUp_{t,r,y,s}$	
meqTechActSng(tech, comm, region, year, slice)	$eqTechActSng_{t,c,r,y,s}$	
meqTechActGrp(tech, group, region, year, slice)	$eqTechActGrp_{t,g,r,y,s}$	
meqTechAfcOutLo(tech, region, comm, year, slice)	$eqTechAfcOutLo_{t,r,c,y,s}$	
meqTechAfcOutUp(tech, region, comm, year, slice)	$eqTechAfcOutUp_{t,r,c,y,s}$	
meqTechAfcInpLo(tech, region, comm, year, slice)	$eqTechAfcInpLo_{t,r,c,y,s}$	
meqTechAfcInpUp(tech, region, comm, year, slice)	$eqTechAfcInpUp_{t,r,c,y,s}$	
meqSupAvaLo(sup, comm, region, year, slice)	$eqSupAvaLo_{s1,c,r,y,s}$	
meqSupReserveLo(sup, comm, region)	$eqSupReserveLo_{s1,c,r}$	
meqStorageAfLo(stg, comm, region, year, slice)	$eqStorageAfLo_{st1,c,r,y,s}$	
meqStorageAfUp(stg, comm, region, year, slice)	$eqStorageAfUp_{st1,c,r,y,s}$	
meqStorageInpUp(stg, comm, region, year, slice)	$eqStorageInpUp_{st1,c,r,y,s}$	
meqStorageInpLo(stg, comm, region, year, slice)	$eqStorageInpLo_{st1,c,r,y,s}$	

meqStorageOutUp(stg, comm, region, year, slice)	$eqStorageOutUp_{st1,c,r,y,s}$	
meqStorageOutLo(stg, comm, region, year, slice)	$eqStorageOutLo_{st1,c,r,y,s}$	
meqTradeFlowUp(trade, comm, region, region, year, slice)	$eqTradeFlowUp_{t1,c,r,r,y,s}$	
meqTradeFlowLo(trade, comm, region, region, year, slice)	$eqTradeFlowLo_{t1,c,r,r,y,s}$	
meqExportRowLo(expp, comm, region, year, slice)	$eqExportRowLo_{e,c,r,y,s}$	
meqImportRowUp(imp, comm, region, year, slice)	$eqImportRowUp_{i,c,r,y,s}$	
meqImportRowLo(imp, comm, region, year, slice)	$eqImportRowLo_{i,c,r,y,s}$	
meqTradeCapFlow(trade, comm, year, slice)	$eqTradeCapFlow_{t1,c,y,s}$	
meqBalLo(comm, region, year, slice)	$eqBalLo_{c,r,y,s}$	
meqBalUp(comm, region, year, slice)	$eqBalUp_{c,r,y,s}$	
meqBalFx(comm, region, year, slice)	$eqBalFx_{c,r,y,s}$	
meqLECActivity(tech, region, year)	$eqLECActivity_{t,r,y}$	
mTechAct2AInp(tech, comm, region, year, slice)	$Act2AInp^{Tech}{}_{t,c,r,y,s}$	
mTechCap2AInp(tech, comm, region, year, slice)	$Cap2AInp^{Tech}{}_{t,c,r,y,s}$	
mTechNCap2AInp(tech, comm, region, year, slice)	$NCap2AInp^{Tech}{}_{t,c,r,y,s}$	
mTechCinp2AInp(tech, comm, comm, region, year, slice)	$Cinp2AInp^{Tech}{}_{t,c,c,r,y,s}$	
mTechCout2AInp(tech, comm, comm, region, year, slice)	$Cout2AInp^{Tech}{}_{t,c,c,r,y,s}$	
mTechAct2AOut(tech, comm, region, year, slice)	$Act2AOut^{Tech}{}_{t,c,r,y,s}$	
mTechCap2AOut(tech, comm, region, year, slice)	$Cap2AOut^{Tech}{}_{t,c,r,y,s}$	
mTechNCap2AOut(tech, comm, region, year, slice)	$NCap2AOut^{Tech}{}_{t,c,r,y,s}$	
mTechCinp2AOut(tech, comm, comm, region, year, slice)	$Cinp2AOut^{Tech}{}_{t,c,c,r,y,s}$	
mTechCout2AOut(tech, comm, comm, region, year, slice)	$Cout2AOut^{Tech}{}_{t,c,c,r,y,s}$	
mLECRegion(region)	$LECRegion_r$	

Parameters

Name	**Alias**	**Description**
ordYear(year)	$ordYear_y$	ord year for GLPK
cardYear(year)	$cardYear_y$	card year for GLPK
pPeriodLen(year)	$PeriodLen_y$	Length of perios for milestone year
pSliceShare(slice)	$SliceShare_s$	Share of slice
pAggregateFactor(comm, comm)	$AggregateFactor_{c,c}$	Aggregation factor of commodities
pTechOlife(tech, region)	$Olife^{Tech}_{t,r}$	Operational life of technologies

pTechCinp2ginp(tech, comm, region, year, slice)	$Cinp2ginp^{Tech}_{t,c,r,y,s}$	Multiplier that transforms commodity input into group input
pTechGinp2use(tech, group, region, year, slice)	$Ginp2use^{Tech}_{t,g,r,y,s}$	Multiplier that transforms group input into use
pTechCinp2use(tech, comm, region, year, slice)	$Cinp2use^{Tech}_{t,c,r,y,s}$	Multiplier that transforms commodity input to use
pTechUse2cact(tech, comm, region, year, slice)	$Use2cact^{Tech}_{t,c,r,y,s}$	Multiplier that transforms use to commodity activity
pTechCact2cout(tech, comm, region, year, slice)	$Cact2cout^{Tech}_{t,c,r,y,s}$	Multiplier that transforms commodity activity to commodity output
pTechEmisComm(tech, comm)	$EmisComm^{Tech}_{t,c}$	Combustion factor for input commodity (from 0 to 1)
pTechAct2AInp(tech, comm, region, year, slice)	$Act2AInp^{Tech}_{t,c,r,y,s}$	Multiplier to activity to calculate aux-commodity input
pTechCap2AInp(tech, comm, region, year, slice)	$Cap2AInp^{Tech}_{t,c,r,y,s}$	Multiplier to capacity to calculate aux-commodity input
pTechNCap2AInp(tech, comm, region, year, slice)	$NCap2AInp^{Tech}_{t,c,r,y,s}$	Multiplier to new-capacity to calculate aux-commodity input
pTechCinp2AInp(tech, comm, comm, region, year, slice)	$Cinp2AInp^{Tech}_{t,c,c,r,y,s}$	Multiplier to commodity-input to calculate aux-commodity input
pTechCout2AInp(tech, comm, comm, region, year, slice)	$Cout2AInp^{Tech}_{t,c,c,r,y,s}$	Multiplier to commodity-output to calculate aux-commodity input
pTechAct2AOut(tech, comm, region, year, slice)	$Act2AOut^{Tech}_{t,c,r,y,s}$	Multiplier to activity to calculate aux-commodity output
pTechCap2AOut(tech, comm, region, year, slice)	$Cap2AOut^{Tech}_{t,c,r,y,s}$	Multiplier to capacity to calculate aux-commodity output
pTechNCap2AOut(tech, comm, region, year, slice)	$NCap2AOut^{Tech}_{t,c,r,y,s}$	Multiplier to new capacity to calculate aux-commodity output
pTechCinp2AOut(tech, comm, comm, region, year, slice)	$Cinp2AOut^{Tech}_{t,c,c,r,y,s}$	Multiplier to commodity to calculate aux-commodity output
pTechCout2AOut(tech, comm, comm, region, year, slice)	$Cout2AOut^{Tech}_{t,c,c,r,y,s}$	Multiplier to commodity-output to calculate aux-commodity input
pTechFixom(tech, region, year)	$Fixom^{Tech}_{t,r,y}$	Fixed Operating and maintenance (O&M) costs (per unit of capacity)
pTechVarom(tech, region, year, slice)	$Varom^{Tech}_{t,r,y,s}$	Variable O&M costs (per unit of acticity)
pTechInvcost(tech, region, year)	$Invcost^{Tech}_{t,r,y}$	Investment costs (per unit of capacity)
pTechEac(tech, region, year)	$Eac^{Tech}_{t,r,y}$	Eac coefficient for investment costs (per unit of capacity)
pTechShareLo(tech, comm, region, year, slice)	$ShareLo^{Tech}_{t,c,r,y,s}$	Lower bound for share of the commodity in total group input or output
pTechShareUp(tech, comm, region, year, slice)	$ShareUp^{Tech}_{t,c,r,y,s}$	Upper bound for share of the commodity in total group input or output
pTechAfLo(tech, region, year, slice)	$AfLo^{Tech}_{t,r,y,s}$	Lower bound for activity for each slice
pTechAfUp(tech, region, year, slice)	$AfUp^{Tech}_{t,r,y,s}$	Upper bound for activity for each slice
pTechRampUp(tech, region, year, slice)	$RampUp^{Tech}_{t,r,y,s}$	Ramp Up for activity for each slice
pTechRampDown(tech, region, year, slice)	$RampDown^{Tech}_{t,r,y,s}$	Ramp Down for activity for each slice
pTechAfsLo(tech, region, year, slice)	$AfsLo^{Tech}_{t,r,y,s}$	Lower bound for activity for sum over slices
pTechAfsUp(tech, region, year, slice)	$AfsUp^{Tech}_{t,r,y,s}$	Upper bound for activity for sum over slices
pTechAfcLo(tech, comm, region, year, slice)	$AfcLo^{Tech}_{t,c,r,y,s}$	Lower bound for commodity output
pTechAfcUp(tech, comm, region, year, slice)	$AfcUp^{Tech}_{t,c,r,y,s}$	Upper bound for commodity output
pTechStock(tech, region, year)	$Stock^{Tech}_{t,r,y}$	Technology capacity stock
pTechCap2act(tech)	$Cap2act^{Tech}_{t}$	Technology capacity units to activity units conversion factor

pTechCvarom(tech, comm, region, year, slice)	$Cvarom^{Tech}_{t,c,r,y,s}$	Commodity-specific variable costs (per unit of commodity input or output)
pTechAvarom(tech, comm, region, year, slice)	$Avarom^{Tech}_{t,c,r,y,s}$	Auxilary Commodity-specific variable costs (per unit of commodity input or ou
pDiscount(region, year)	$Discount_{r,y}$	Discount rate (can be region and year specific)
pDiscountFactor(region, year)	$DiscountFactor_{r,y}$	Discount factor (cumulative)
pDiscountFactorMileStone(region, year)	$DiscountFactorMileStone_{r,y}$	Discount factor (cumulative) sum for MileStone
pSupCost(sup, comm, region, year, slice)	$Cost^{Sup}_{s1,c,r,y,s}$	Costs of supply (price per unit)
pSupAvaUp(sup, comm, region, year, slice)	$AvaUp^{Sup}_{s1,c,r,y,s}$	Upper bound for supply
pSupAvaLo(sup, comm, region, year, slice)	$AvaLo^{Sup}_{s1,c,r,y,s}$	Lower bound for supply
pSupReserveUp(sup, comm, region)	$ReserveUp^{Sup}_{s1,c,r}$	Total supply reserve by region Up
pSupReserveLo(sup, comm, region)	$ReserveLo^{Sup}_{s1,c,r}$	Total supply reserve by region Lo
pDemand(dem, comm, region, year, slice)	$^{Demand}_{d,c,r,y,s}$	Exogenous demand
pEmissionFactor(comm, comm)	$EmissionFactor_{c,c}$	Emission factor
pDummyImportCost(comm, region, year, slice)	$ImportCost^{Dummy}_{c,r,y,s}$	Dummy costs parameters (for debugging)
pDummyExportCost(comm, region, year, slice)	$ExportCost^{Dummy}_{c,r,y,s}$	Dummy costs parameters (for debuging)
pTaxCostInp(comm, region, year, slice)	$CostInp^{Tax}_{c,r,y,s}$	Commodity taxes for input
pTaxCostOut(comm, region, year, slice)	$CostOut^{Tax}_{c,r,y,s}$	Commodity taxes for output
pTaxCostBal(comm, region, year, slice)	$CostBal^{Tax}_{c,r,y,s}$	Commodity taxes for balance
pSubCostInp(comm, region, year, slice)	$SubCostInp_{c,r,y,s}$	Commodity subsidies for input
pSubCostOut(comm, region, year, slice)	$SubCostOut_{c,r,y,s}$	Commodity subsidies for output
pSubCostBal(comm, region, year, slice)	$SubCostBal_{c,r,y,s}$	Commodity subsidies for balance
pStorageInpEff(stg, comm, region, year, slice)	$InpEff^{Storage}_{st1,c,r,y,s}$	Storage input efficiency
pStorageOutEff(stg, comm, region, year, slice)	$OutEff^{Storage}_{st1,c,r,y,s}$	Storage output efficiency
pStorageStgEff(stg, comm, region, year, slice)	$StgEff^{Storage}_{st1,c,r,y,s}$	Storage time-efficiency (annual)
pStorageStock(stg, region, year)	$Stock^{Storage}_{st1,r,y}$	Storage capacity stock
pStorageOlife(stg, region)	$Olife^{Storage}_{st1,r}$	Storage operational life
pStorageCostStore(stg, region, year, slice)	$CostStore^{Storage}_{st1,r,y,s}$	Storing costs per stored amount (annual)
pStorageCostInp(stg, region, year, slice)	$CostInp^{Storage}_{st1,r,y,s}$	Storage input costs
pStorageCostOut(stg, region, year, slice)	$CostOut^{Storage}_{st1,r,y,s}$	Storage output costs
pStorageFixom(stg, region, year)	$Fixom^{Storage}_{st1,r,y}$	Storage fixed O&M costs
pStorageInvcost(stg, region, year)	$Invcost^{Storage}_{st1,r,y}$	Storage investment costs
pStorageEac(stg, region, year)	$Eac^{Storage}_{st1,r,y}$	
pStorageCap2stg(stg)	$Cap2stg^{Storage}_{st1}$	Storage capacity units to activity units conversion factor

pStorageAfLo(stg, region, year, slice)	$AfLo^{Storage}_{st1,r,y,s}$	Storage capacity lower bound (minimum charge level)
pStorageAfUp(stg, region, year, slice)	$AfUp^{Storage}_{st1,r,y,s}$	Storage capacity upper bound (maximum charge level)
pStorageCinpUp(stg, comm, region, year, slice)	$CinpUp^{Storage}_{st1,c,r,y,s}$	Storage input upper bound
pStorageCinpLo(stg, comm, region, year, slice)	$CinpLo^{Storage}_{st1,c,r,y,s}$	Storage input lower bound
pStorageCoutUp(stg, comm, region, year, slice)	$CoutUp^{Storage}_{st1,c,r,y,s}$	Storage output upper bound
pStorageCoutLo(stg, comm, region, year, slice)	$CoutLo^{Storage}_{st1,c,r,y,s}$	Storage output lower bound
pStorageNCap2Stg(stg, comm, region, year, slice)	$NCap2Stg^{Storage}_{st1,c,r,y,s}$	Initial storage charging for new investment
pStorageCharge(stg, comm, region, year, slice)	$Charge^{Storage}_{st1,c,r,y,s}$	Initial storage charging for stock
pStorageStg2AInp(stg, comm, region, year, slice)	$Stg2AInp^{Storage}_{st1,c,r,y,s}$	Storage accumulated volume to auxilary input
pStorageStg2AOut(stg, comm, region, year, slice)	$Stg2AOut^{Storage}_{st1,c,r,y,s}$	Storage accumulated volume output
pStorageCinp2AInp(stg, comm, region, year, slice)	$Cinp2AInp^{Storage}_{st1,c,r,y,s}$	Storage input to auxilary input coefficient
pStorageCinp2AOut(stg, comm, region, year, slice)	$Cinp2AOut^{Storage}_{st1,c,r,y,s}$	Storage input to auxilary output coefficient
pStorageCout2AInp(stg, comm, region, year, slice)	$Cout2AInp^{Storage}_{st1,c,r,y,s}$	Storage output to auxilary input coefficient
pStorageCout2AOut(stg, comm, region, year, slice)	$Cout2AOut^{Storage}_{st1,c,r,y,s}$	Storage output to auxilary output coefficient
pStorageCap2AInp(stg, comm, region, year, slice)	$Cap2AInp^{Storage}_{st1,c,r,y,s}$	Storage capacity to auxilary input coefficient
pStorageCap2AOut(stg, comm, region, year, slice)	$Cap2AOut^{Storage}_{st1,c,r,y,s}$	Storage capacity to auxilary output coefficient
pStorageNCap2AInp(stg, comm, region, year, slice)	$NCap2AInp^{Storage}_{st1,c,r,y,s}$	Storage new capacity to auxilary input coefficient
pStorageNCap2AOut(stg, comm, region, year, slice)	$NCap2AOut^{Storage}_{st1,c,r,y,s}$	Storage new capacity to auxilary output coefficient
pTradeIrEff(trade, region, region, year, slice)	$IrEff^{Trade}_{t1,r,r,y,s}$	Inter-regional trade efficiency
pTradeIrUp(trade, region, region, year, slice)	$IrUp^{Trade}_{t1,r,r,y,s}$	Upper bound on trade flow
pTradeIrLo(trade, region, region, year, slice)	$IrLo^{Trade}_{t1,r,r,y,s}$	Lower bound on trade flow
pTradeIrCost(trade, region, region, year, slice)	$IrCost^{Trade}_{t1,r,r,y,s}$	Costs of trade flow
pTradeIrMarkup(trade, region, region, year, slice)	$IrMarkup^{Trade}_{t1,r,r,y,s}$	Markup of trade flow
pTradeIrCsrc2Ainp(trade, comm, region, region, year, slice)	$IrCsrc2Ainp^{Trade}_{t1,c,r,r,y,s}$	Auxiliary input commodity in source region
pTradeIrCsrc2Aout(trade, comm, region, region, year, slice)	$IrCsrc2Aout^{Trade}_{t1,c,r,r,y,s}$	Auxiliary output commodity in source region
pTradeIrCdst2Ainp(trade, comm, region, region, year, slice)	$IrCdst2Ainp^{Trade}_{t1,c,r,r,y,s}$	Auxiliary input commodity in destination region
pTradeIrCdst2Aout(trade, comm, region, region, year, slice)	$IrCdst2Aout^{Trade}_{t1,c,r,r,y,s}$	Auxiliary output commodity in destination region
pExportRowRes(expp)	$ExportRowRes_{e}$	Upper bound on accumulated export to ROW
pExportRowUp(expp, region, year, slice)	$ExportRowUp_{e,r,y,s}$	Upper bound on export to ROW
pExportRowLo(expp, region, year, slice)	$ExportRowLo_{e,r,y,s}$	Lower bound on export to ROW
pExportRowPrice(expp, region, year, slice)	$ExportRowPrice_{e,r,y,s}$	Export prices to ROW
pImportRowRes(imp)	$ImportRowRes_{i}$	Upper bound on accumulated import to ROW

pImportRowUp(imp, region, year, slice)	$ImportRowUp_{i,r,y,s}$	Upper bount on import from ROW
pImportRowLo(imp, region, year, slice)	$ImportRowLo_{i,r,y,s}$	Lower bound on import from ROW
pImportRowPrice(imp, region, year, slice)	$ImportRowPrice_{i,r,y,s}$	Import prices from ROW
pTradeStock(trade, year)	$Stock^{Trade}_{t1,y}$	
pTradeOlife(trade)	$Olife^{Trade}_{t1}$	
pTradeInvcost(trade, region, year)	$Invcost^{Trade}_{t1,r,y}$	
pTradeEac(trade, region, year)	$Eac^{Trade}_{t1,r,y}$	
pTradeCap2Act(trade)	$Cap2Act^{Trade}_{t1}$	
pWeather(weather, region, year, slice)	$^{Weather}_{wth1,r,y,s}$	
pSupWeatherUp(weather, sup)	$WeatherUp^{Sup}_{wth1,s1}$	
pSupWeatherLo(weather, sup)	$WeatherLo^{Sup}_{wth1,s1}$	
pTechWeatherAfLo(weather, tech)	$WeatherAfLo^{Tech}_{wth1,t}$	
pTechWeatherAfUp(weather, tech)	$WeatherAfUp^{Tech}_{wth1,t}$	
pTechWeatherAfsLo(weather, tech)	$WeatherAfsLo^{Tech}_{wth1,t}$	
pTechWeatherAfsUp(weather, tech)	$WeatherAfsUp^{Tech}_{wth1,t}$	
pTechWeatherAfcLo(weather, tech, comm)	$WeatherAfcLo^{Tech}_{wth1,t,c}$	
pTechWeatherAfcUp(weather, tech, comm)	$WeatherAfcUp^{Tech}_{wth1,t,c}$	
pStorageWeatherAfLo(weather, stg)	$WeatherAfLo^{Storage}_{wth1,st1}$	
pStorageWeatherAfUp(weather, stg)	$WeatherAfUp^{Storage}_{wth1,st1}$	
pStorageWeatherCinpUp(weather, stg)	$WeatherCinpUp^{Storage}_{wth1,st1}$	
pStorageWeatherCinpLo(weather, stg)	$WeatherCinpLo^{Storage}_{wth1,st1}$	
pStorageWeatherCoutUp(weather, stg)	$WeatherCoutUp^{Storage}_{wth1,st1}$	
pStorageWeatherCoutLo(weather, stg)	$WeatherCoutLo^{Storage}_{wth1,st1}$	
pLECLoACT(region)	$LECLoACT_r$	

Variables

Name	Alias	Description
vTechInv(tech, region, year)	$\mathbf{Inv}^{\mathbf{Tech}}_{t,r,y}$	Overnight investment costs
vTechEac(tech, region, year)	$\mathbf{Eac}^{\mathbf{Tech}}_{t,r,y}$	Annualized investment costs
vTechOMCost(tech, region, year)	$\mathbf{OMCost}^{\mathbf{Tech}}_{t,r,y}$	Sum of all operational costs is equal vTechFixom + vTechVarom (AVarom + CVarom + ActVarom)

vSupCost(sup, region, year)	$\mathbf{Cost}^{\mathbf{Sup}}{}_{s1,r,y}$	Supply costs
vEmsFuelTot(comm, region, year, slice)	$\mathbf{EmsFuelTot}_{c,r,y,s}$	Total fuel emissions
vBalance(comm, region, year, slice)	$\mathbf{Balance}_{c,r,y,s}$	Net commodity balance
vTotalCost(region, year)	$\mathbf{TotalCost}_{r,y}$	Regional annual total costs
vObjective	**Objective**	Objective costs
vTaxCost(comm, region, year)	$\mathbf{Cost}^{\mathbf{Tax}}{}_{c,r,y}$	Total tax levies (tax costs)
vSubsCost(comm, region, year)	$\mathbf{Cost}^{\mathbf{Subs}}{}_{c,r,y}$	Total subsidies (for substraction from costs)
vAggOut(comm, region, year, slice)	$\mathbf{AggOut}_{c,r,y,s}$	Aggregated commodity output
vStorageOMCost(stg, region, year)	$\mathbf{OMCost}^{\mathbf{Storage}}{}_{st1,r,y}$	Storage O&M costs
vTradeCost(region, year)	$\mathbf{Cost}^{\mathbf{Trade}}{}_{r,y}$	Total trade costs
vTradeRowCost(region, year)	$\mathbf{RowCost}^{\mathbf{Trade}}{}_{r,y}$	Trade with ROW costs
vTradeIrCost(region, year)	$\mathbf{IrCost}^{\mathbf{Trade}}{}_{r,y}$	Interregional trade costs

Positive variables

Name	Alias	Description
vTechNewCap(tech, region, year)	$\mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,y}$	New capacity
vTechRetiredStock(tech, region, year)	$\mathbf{RetiredStock}^{\mathbf{Tech}}{}_{t,r,y}$	Early retired capacity
vTechRetiredNewCap(tech, region, year, year)	$\mathbf{RetiredNewCap}^{\mathbf{Tech}}{}_{t,r,y,y}$	Early retired capacity
vTechCap(tech, region, year)	$\mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y}$	Total capacity of the technology
vTechAct(tech, region, year, slice)	$\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s}$	Activity level of technology
vTechInp(tech, comm, region, year, slice)	$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s}$	Input level
vTechOut(tech, comm, region, year, slice)	$\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s}$	Output level
vTechAInp(tech, comm, region, year, slice)	$\mathbf{AInp}^{\mathbf{Tech}}{}_{t,c,r,y,s}$	Auxiliary commodity input
vTechAOut(tech, comm, region, year, slice)	$\mathbf{AOut}^{\mathbf{Tech}}{}_{t,c,r,y,s}$	Auxiliary commodity output
vSupOut(sup, comm, region, year, slice)	$\mathbf{Out}^{\mathbf{Sup}}{}_{s1,c,r,y,s}$	Output of supply
vSupReserve(sup, comm, region)	$\mathbf{Reserve}^{\mathbf{Sup}}{}_{s1,c,r}$	Total supply reserve
vDemInp(comm, region, year, slice)	$\mathbf{Inp}^{\mathbf{Dem}}{}_{c,r,y,s}$	Input to demand
vOutTot(comm, region, year, slice)	$\mathbf{OutTot}_{c,r,y,s}$	Total commodity output (consumption is not counted)
vInpTot(comm, region, year, slice)	$\mathbf{InpTot}_{c,r,y,s}$	Total commodity input
vInp2Lo(comm, region, year, slice, slice)	$\mathbf{Inp2Lo}_{c,r,y,s,s}$	Desagregation of slices for input parent to (grand)child
vOut2Lo(comm, region, year, slice, slice)	$\mathbf{Out2Lo}_{c,r,y,s,s}$	Desagregation of slices for output parent to (grand)child
vSupOutTot(comm, region, year, slice)	$\mathbf{OutTot}^{\mathbf{Sup}}{}_{c,r,y,s}$	Total commodity supply

vTechInpTot(comm, region, year, slice)	$\mathbf{InpTot}^{\mathbf{Tech}}{}_{c,r,y,s}$	Total commodity input to technologies
vTechOutTot(comm, region, year, slice)	$\mathbf{OutTot}^{\mathbf{Tech}}{}_{c,r,y,s}$	Total commodity output from technologies
vStorageInpTot(comm, region, year, slice)	$\mathbf{InpTot}^{\mathbf{Storage}}{}_{c,r,y,s}$	Total commodity input to storages
vStorageOutTot(comm, region, year, slice)	$\mathbf{OutTot}^{\mathbf{Storage}}{}_{c,r,y,s}$	Total commodity output from storages
vStorageAInp(stg, comm, region, year, slice)	$\mathbf{AInp}^{\mathbf{Storage}}{}_{st1,c,r,y,s}$	Aux-commodity input to storage
vStorageAOut(stg, comm, region, year, slice)	$\mathbf{AOut}^{\mathbf{Storage}}{}_{st1,c,r,y,s}$	Aux-commodity input from storage
vDummyImport(comm, region, year, slice)	$\mathbf{Import}^{\mathbf{Dummy}}{}_{c,r,y,s}$	Dummy import (for debugging)
vDummyExport(comm, region, year, slice)	$\mathbf{Export}^{\mathbf{Dummy}}{}_{c,r,y,s}$	Dummy export (for debugging)
vStorageInp(stg, comm, region, year, slice)	$\mathbf{Inp}^{\mathbf{Storage}}{}_{st1,c,r,y,s}$	Storage input
vStorageOut(stg, comm, region, year, slice)	$\mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,s}$	Storage output
vStorageStore(stg, comm, region, year, slice)	$\mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s}$	Storage accumulated level
vStorageInv(stg, region, year)	$\mathbf{Inv}^{\mathbf{Storage}}{}_{st1,r,y}$	Storage technology investments
vStorageEac(stg, region, year)	$\mathbf{Eac}^{\mathbf{Storage}}{}_{st1,r,y}$	Storage technology EAC investments
vStorageCap(stg, region, year)	$\mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y}$	Storage capacity
vStorageNewCap(stg, region, year)	$\mathbf{NewCap}^{\mathbf{Storage}}{}_{st1,r,y}$	Storage new capacity
vImport(comm, region, year, slice)	$\mathbf{Import}_{c,r,y,s}$	Total regional import (Ir + ROW)
vExport(comm, region, year, slice)	$\mathbf{Export}_{c,r,y,s}$	Total regional export (Ir + ROW)
vTradeIr(trade, comm, region, region, year, slice)	$\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,r,r,y,s}$	Total physical trade flows between regions
vTradeIrAInp(trade, comm, region, year, slice)	$\mathbf{IrAInp}^{\mathbf{Trade}}{}_{t1,c,r,y,s}$	Trade auxilari input
vTradeIrAInpTot(comm, region, year, slice)	$\mathbf{IrAInpTot}^{\mathbf{Trade}}{}_{c,r,y,s}$	Trade total auxilari input
vTradeIrAOut(trade, comm, region, year, slice)	$\mathbf{IrAOut}^{\mathbf{Trade}}{}_{t1,c,r,y,s}$	Trade auxilari output
vTradeIrAOutTot(comm, region, year, slice)	$\mathbf{IrAOutTot}^{\mathbf{Trade}}{}_{c,r,y,s}$	Trade auxilari output
vExportRowAccumulated(expp, comm)	$\mathbf{ExportRowAccumulated}_{e,c}$	Accumulated export to ROW
vExportRow(expp, comm, region, year, slice)	$\mathbf{ExportRow}_{e,c,r,y,s}$	Export to ROW
vImportRowAccumulated(imp, comm)	$\mathbf{ImportRowAccumulated}_{i,c}$	Accumulated import from ROW
vImportRow(imp, comm, region, year, slice)	$\mathbf{ImportRow}_{i,c,r,y,s}$	Import from ROW
vTradeCap(trade, year)	$\mathbf{Cap}^{\mathbf{Trade}}{}_{t1,y}$	
vTradeInv(trade, region, year)	$\mathbf{Inv}^{\mathbf{Trade}}{}_{t1,r,y}$	
vTradeEac(trade, region, year)	$\mathbf{Eac}^{\mathbf{Trade}}{}_{t1,r,y}$	
vTradeNewCap(trade, year)	$\mathbf{NewCap}^{\mathbf{Trade}}{}_{t1,y}$	
vTotalUserCosts(region, year)	$\mathbf{TotalUserCosts}_{r,y}$	

Equations

Technology

Activity Input & Output

Technology input to output
eqTechSng2Sng$_{t,r,c,cp,y,s}$

$$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} * Cinp2use^{Tech}_{t,c,r,y,s} = \frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s}}{Use2cact^{Tech}_{t,cp,r,y,s} * Cact2cout^{Tech}_{t,cp,r,y,s}} \tag{1}$$

Technology group input to output
eqTechGrp2Sng$_{t,r,g,cp,y,s}$

$$Ginp2use^{Tech}_{t,g,r,y,s} * \sum_{c} \left(\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} * Cinp2ginp^{Tech}_{t,c,r,y,s} \right) = \frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s}}{Use2cact^{Tech}_{t,cp,r,y,s} * Cact2cout^{Tech}_{t,cp,r,y,s}} \tag{2}$$

Technology input to group output
eqTechSng2Grp$_{t,r,c,gp,y,s}$

$$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} * Cinp2use^{Tech}_{t,c,r,y,s} = \sum_{cp} \left(\frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s}}{Use2cact^{Tech}_{t,cp,r,y,s} * Cact2cout^{Tech}_{t,cp,r,y,s}} \right) \tag{3}$$

Technology group input to group output
eqTechGrp2Grp$_{t,r,g,gp,y,s}$

$$Ginp2use^{Tech}_{t,g,r,y,s} * \sum_{c} \left(\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} * Cinp2ginp^{Tech}_{t,c,r,y,s} \right) = \sum_{cp} \left(\frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s}}{Use2cact^{Tech}_{t,cp,r,y,s} * Cact2cout^{Tech}_{t,cp,r,y,s}} \right) \tag{4}$$

Shares for grouped commodities

Technology lower bound on input share
eqTechShareInpLo$_{t,r,g,c,y,s}$

$$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} \geq ShareLo^{Tech}_{t,c,r,y,s} * \sum_{cp} \left(\mathbf{Inp}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \tag{5}$$

Technology upper bound on input share

$eqTechShareInpUp_{t,r,g,c,y,s}$

$$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} \leq ShareUp^{Tech}_{t,c,r,y,s} * \sum_{cp} \left(\mathbf{Inp}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \tag{6}$$

Technology lower bound on output share

$eqTechShareOutLo_{t,r,g,c,y,s}$

$$\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s} \geq ShareLo^{Tech}_{t,c,r,y,s} * \sum_{cp} \left(\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \tag{7}$$

Technology upper bound on output share

$eqTechShareOutUp_{t,r,g,c,y,s}$

$$\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s} \leq ShareUp^{Tech}_{t,c,r,y,s} * \sum_{cp} \left(\mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \tag{8}$$

Auxiliary input & output

Technology auxiliary commodity input

$eqTechAInp_{t,c,r,y,s}$

$$\begin{aligned} \mathbf{AInp}^{\mathbf{Tech}}{}_{t,c,r,y,s} &= \left(\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} * Act2AInp^{Tech}_{t,c,r,y,s} \right) \\ &+ \left(\mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * Cap2AInp^{Tech}_{t,c,r,y,s} \right) \\ &+ \left(\mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,y} * NCap2AInp^{Tech}_{t,c,r,y,s} \right) + \sum_{cp} \left(Cinp2AInp^{Tech}_{t,c,cp,r,y,s} * \mathbf{Inp}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) + \sum_{cp} \left(Cout2AInp^{Tech}_{t,c,cp,r,y,s} * \mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \end{aligned} \tag{9}$$

Technology auxiliary commodity output

$eqTechAOut_{t,c,r,y,s}$

$$\begin{aligned} \mathbf{AOut}^{\mathbf{Tech}}{}_{t,c,r,y,s} &= \left(\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} * Act2AOut^{Tech}_{t,c,r,y,s} \right) \\ &+ \left(\mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * Cap2AOut^{Tech}_{t,c,r,y,s} \right) \\ &+ \left(\mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,y} * NCap2AOut^{Tech}_{t,c,r,y,s} \right) + \sum_{cp} \left(Cinp2AOut^{Tech}_{t,c,cp,r,y,s} * \mathbf{Inp}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) + \sum_{cp} \left(Cout2AOut^{Tech}_{t,c,cp,r,y,s} * \mathbf{Out}^{\mathbf{Tech}}{}_{t,cp,r,y,s} \right) \end{aligned} \tag{10}$$

Availability

Technology availability factor lower bound
eqTechAfLo$_{t,r,y,s}$

$$AfLo^{Tech}_{t,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfLo^{Tech}_{wth1,t} * {}^{Weather}_{wth1,r,y,s} \right) \leq \mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} \tag{11}$$

Technology availability factor upper bound
eqTechAfUp$_{t,r,y,s}$

$$\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} \leq AfUp^{Tech}_{t,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfUp^{Tech}_{wth1,t} * {}^{Weather}_{wth1,r,y,s} \right) \tag{12}$$

Technology availability factor for sum lower bound
eqTechAfsLo$_{t,r,y,s}$

$$AfsLo^{Tech}_{t,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfsLo^{Tech}_{wth1,t} * {}^{Weather}_{wth1,r,y,s} \right) \leq \sum_{sp} \left(\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,sp} \right) \tag{13}$$

Technology availability factor for sum upper bound
eqTechAfsUp$_{t,r,y,s}$

$$\sum_{sp} \left(\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,sp} \right) \leq AfsUp^{Tech}_{t,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfsUp^{Tech}_{wth1,t} * {}^{Weather}_{wth1,r,y,s} \right) \tag{14}$$

Technology ramp up factor
eqTechRampUp$_{t,r,y,s}$

$$\frac{\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s}}{SliceShare_{s}} - \sum_{sp} \left(\frac{\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,sp}}{SliceShare_{sp}} \right) \leq \frac{SliceShare_{s} * 365 * 24 * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y}}{RampUp^{Tech}_{t,r,y,s}} \tag{15}$$

Technology ramp down factor
eqTechRampDown$_{t,r,y,s}$

$$\sum_{sp} \left(\frac{\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,sp}}{SliceShare_{sp}} \right) - \frac{\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s}}{SliceShare_{s}} \leq \frac{SliceShare_{s} * 365 * 24 * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y}}{RampDown^{Tech}_{t,r,y,s}} \tag{16}$$

Activity and output

Technology activity to commodity output
eqTechActSng$_{t,c,r,y,s}$

$$\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} = \frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s}}{Cact2cout^{Tech}_{t,c,r,y,s}} \tag{17}$$

Technology activity to group output
eqTechActGrp$_{t,g,r,y,s}$

$$\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s} = \sum_{c} \left(\frac{\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s}}{Cact2cout^{Tech}_{t,c,r,y,s}} \right) \tag{18}$$

Availability commodity factor

Technology commodity availability factor lower bound
eqTechAfcOutLo$_{t,r,c,y,s}$

$$Cact2cout^{Tech}_{t,c,r,y,s} * AfcLo^{Tech}_{t,c,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfcLo^{Tech}_{wth1,t,c} * {}^{Weather}_{wth1,r,y,s} \right) \leq \mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s} \tag{19}$$

Technology commodity availability factor upper bound
eqTechAfcOutUp$_{t,r,c,y,s}$

$$\mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s} \leq Cact2cout^{Tech}_{t,c,r,y,s} * AfcUp^{Tech}_{t,c,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * \prod_{wth1} \left(WeatherAfcUp^{Tech}_{wth1,t,c} * {}^{Weather}_{wth1,r,y,s} \right) \tag{20}$$

Technology commodity availability factor lower bound
eqTechAfcInpLo$_{t,r,c,y,s}$

$$AfcLo^{Tech}_{t,c,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfcLo^{Tech}_{wth1,t,c} * {}^{Weather}_{wth1,r,y,s} \right) \leq \mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} \tag{21}$$

Technology commodity availability factor upper bound
eqTechAfcInpUp$_{t,r,c,y,s}$

$$\mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s} \leq AfcUp^{Tech}_{t,c,r,y,s} * Cap2act^{Tech}_{t} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} * SliceShare_{s} * \prod_{wth1} \left(WeatherAfcUp^{Tech}_{wth1,t,c} * {}^{Weather}_{wth1,r,y,s} \right) \tag{22}$$

Capacity and costs equations

Technology capacity
eqTechCap$_{t,r,y}$

$$\mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} = Stock^{Tech}_{t,r,y} - \mathbf{RetiredStock}^{\mathbf{Tech}}{}_{t,r,y} + \sum_{yp}\left(\mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,yp}\right) - \sum_{yp}\left(\sum_{ye}\left(\mathbf{RetiredNewCap}^{\mathbf{Tech}}{}_{t,r,yp,ye}\right)\right) \tag{23}$$

Stock retired eqution
eqTechRetiredNewCap$_{t,r,y}$

$$\sum_{yp}\left(\mathbf{RetiredNewCap}^{\mathbf{Tech}}{}_{t,r,y,yp}\right) \leq \mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,y} \tag{24}$$

Stock retired eqution
eqTechRetiredStock$_{t,r,y}$

$$\mathbf{RetiredStock}^{\mathbf{Tech}}{}_{t,r,y} \leq Stock^{Tech}_{t,r,y} \tag{25}$$

Technology Equivalent Annual Cost (EAC)
eqTechEac$_{t,r,y}$

$$\mathbf{Eac}^{\mathbf{Tech}}{}_{t,r,y} = \sum_{yp}\left(Eac^{Tech}_{t,r,yp} * \left(\mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,yp} - \sum_{ye}\left(\mathbf{RetiredNewCap}^{\mathbf{Tech}}{}_{t,r,yp,ye}\right)\right)\right) \tag{26}$$

Technology investment costs
eqTechInv$_{t,r,y}$

$$\mathbf{Inv}^{\mathbf{Tech}}{}_{t,r,y} = Invcost^{Tech}_{t,r,y} * \mathbf{NewCap}^{\mathbf{Tech}}{}_{t,r,y} \tag{27}$$

Technology O&M costs
eqTechOMCost$_{t,r,y}$

$$\begin{aligned}\mathbf{OMCost}^{\mathbf{Tech}}{}_{t,r,y} = {} & Fixom^{Tech}_{t,r,y} * \mathbf{Cap}^{\mathbf{Tech}}{}_{t,r,y} + \sum_{s}\left(Varom^{Tech}_{t,r,y,s} * \mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s}\right) \\ & + \sum_{s}\left(\sum_{c}\left(Cvarom^{Tech}_{t,c,r,y,s} * \mathbf{Inp}^{\mathbf{Tech}}{}_{t,c,r,y,s}\right)\right) + \sum_{s}\left(\sum_{c}\left(Cvarom^{Tech}_{t,c,r,y,s} * \mathbf{Out}^{\mathbf{Tech}}{}_{t,c,r,y,s}\right)\right) \\ & + \sum_{s}\left(\sum_{c}\left(Avarom^{Tech}_{t,c,r,y,s} * \mathbf{AOut}^{\mathbf{Tech}}{}_{t,c,r,y,s}\right)\right) + \sum_{s}\left(\sum_{c}\left(Avarom^{Tech}_{t,c,r,y,s} * \mathbf{AInp}^{\mathbf{Tech}}{}_{t,c,r,y,s}\right)\right)\end{aligned} \tag{28}$$

Supply

Supply availability upper bound
eqSupAvaUp$_{s1,c,r,y,s}$

$$\mathbf{Out^{Sup}}_{s1,c,r,y,s} \leq AvaUp^{Sup}_{s1,c,r,y,s} * \prod_{wth1} \left(WeatherUp^{Sup}_{wth1,s1} * {}^{Weather}_{wth1,r,y,s} \right) \tag{29}$$

Supply availability lower bound
eqSupAvaLo$_{s1,c,r,y,s}$

$$\mathbf{Out^{Sup}}_{s1,c,r,y,s} \geq AvaLo^{Sup}_{s1,c,r,y,s} * \prod_{wth1} \left(WeatherLo^{Sup}_{wth1,s1} * {}^{Weather}_{wth1,r,y,s} \right) \tag{30}$$

Total supply of each commodity
eqSupTotal$_{s1,c,r}$

$$\mathbf{Reserve^{Sup}}_{s1,c,r} = \sum_{y,s} \left(PeriodLen_y * \mathbf{Out^{Sup}}_{s1,c,r,y,s} \right) \tag{31}$$

Total supply vs reserve check
eqSupReserveUp$_{s1,c,r}$

$$ReserveUp^{Sup}_{s1,c,r} \geq \mathbf{Reserve^{Sup}}_{s1,c,r} \tag{32}$$

Total supply vs reserve check
eqSupReserveLo$_{s1,c,r}$

$$\mathbf{Reserve^{Sup}}_{s1,c,r} \geq ReserveLo^{Sup}_{s1,c,r} \tag{33}$$

Total supply costs
eqSupCost$_{s1,r,y}$

$$\mathbf{Cost^{Sup}}_{s1,r,y} = \sum_{c,s} \left(Cost^{Sup}_{s1,c,r,y,s} * \mathbf{Out^{Sup}}_{s1,c,r,y,s} \right) \tag{34}$$

Demand

Demand equation
eqDemInp$_{c,r,y,s}$

$$\mathbf{Inp^{Dem}}_{c,r,y,s} = \sum_{d} \left({}^{Demand}_{d,c,r,y,s} \right) \tag{35}$$

Emission & Aggregated commodity

Aggregating commodity output
eqAggOut$_{c,r,y,s}$

$$\mathbf{AggOut}_{c,r,y,s} = \sum_{cp} \left(AggregateFactor_{c,cp} * \sum_{sp} (\mathbf{OutTot}_{cp,r,y,sp}) \right) \tag{36}$$

Emissions from commodity consumption (i.e. fuels combustion)
eqEmsFuelTot$_{c,r,y,s}$

$$\mathbf{EmsFuelTot}_{c,r,y,s} = \sum_{cp} \left(EmissionFactor_{c,cp} * \sum_{t} \left(EmisComm_{t,cp}^{Tech} * \sum_{sp} \left(\mathbf{Inp^{Tech}}_{t,cp,r,y,sp} \right) \right) \right) \tag{37}$$

Storage

Input & Output

Storage equation
eqStorageAInp$_{st1,c,r,y,s}$

$$\begin{aligned} \mathbf{AInp^{Storage}}_{st1,c,r,y,s} = & \sum_{cp} \left(Stg2AInp_{st1,c,r,y,s}^{Storage} * \mathbf{Store^{Storage}}_{st1,cp,r,y,s} \right) + \sum_{cp} \left(Cinp2AInp_{st1,c,r,y,s}^{Storage} * \mathbf{Inp^{Storage}}_{st1,cp,r,y,s} \right) \\ & + \sum_{cp} \left(Cout2AInp_{st1,c,r,y,s}^{Storage} * \mathbf{Out^{Storage}}_{st1,cp,r,y,s} \right) + \sum_{cp} \left(Cap2AInp_{st1,c,r,y,s}^{Storage} * \mathbf{Cap^{Storage}}_{st1,r,y} \right) \\ & + \sum_{cp} \left(NCap2AInp_{st1,c,r,y,s}^{Storage} * \mathbf{NewCap^{Storage}}_{st1,r,y} \right) \end{aligned} \tag{38}$$

Storage availability factor lower
eqStorageAOut$_{st1,c,r,y,s}$

$$\begin{aligned} \mathbf{AOut^{Storage}}_{st1,c,r,y,s} = & \sum_{cp} \left(Stg2AOut_{st1,c,r,y,s}^{Storage} * \mathbf{Store^{Storage}}_{st1,cp,r,y,s} \right) + \sum_{cp} \left(Cinp2AOut_{st1,c,r,y,s}^{Storage} * \mathbf{Inp^{Storage}}_{st1,cp,r,y,s} \right) \\ & + \sum_{cp} \left(Cout2AOut_{st1,c,r,y,s}^{Storage} * \mathbf{Out^{Storage}}_{st1,cp,r,y,s} \right) + \sum_{cp} \left(Cap2AOut_{st1,c,r,y,s}^{Storage} * \mathbf{Cap^{Storage}}_{st1,r,y} \right) \\ & + \sum_{cp} \left(NCap2AOut_{st1,c,r,y,s}^{Storage} * \mathbf{NewCap^{Storage}}_{st1,r,y} \right) \end{aligned} \tag{39}$$

Storage availability factor upper

$eqStorageStore_{st1,c,r,y,s}$

$$\begin{aligned}\mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s} &= Charge^{Storage}_{st1,c,r,y,s} + \left(NCap2Stg^{Storage}_{st1,c,r,y,s} * \mathbf{NewCap}^{\mathbf{Storage}}{}_{st1,r,y}\right) + \sum_{sp}\left(InpEff^{Storage}_{st1,c,r,y,sp} * \mathbf{Inp}^{\mathbf{Storage}}{}_{st1,c,r,y,sp}\right) \\ &+ \sum_{sp}\left(\left(StgEff^{Storage\ \ SliceShare_s}_{st1,c,r,y,s}\right) * \mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,sp}\right) - \sum_{sp}\left(\frac{\mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,sp}}{OutEff^{Storage}_{st1,c,r,y,sp}}\right)\end{aligned} \tag{40}$$

Storage input less Stote

$eqStorageAfLo_{st1,c,r,y,s}$

$$\mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \geq AfLo^{Storage}_{st1,r,y,s} * Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * \prod_{wth1}\left(WeatherAfLo^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{41}$$

$eqStorageAfUp_{st1,c,r,y,s}$

$$\mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \leq AfUp^{Storage}_{st1,r,y,s} * Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * \prod_{wth1}\left(WeatherAfUp^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{42}$$

$eqStorageClean_{st1,c,r,y,s}$

$$\frac{\mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,s}}{OutEff^{Storage}_{st1,c,r,y,s}} \leq \mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \tag{43}$$

$eqStorageInpUp_{st1,c,r,y,s}$

$$\mathbf{Inp}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \leq Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * CinpUp^{Storage}_{st1,c,r,y,s} * SliceShare_s * \prod_{wth1}\left(WeatherCinpUp^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{44}$$

$eqStorageInpLo_{st1,c,r,y,s}$

$$\mathbf{Inp}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \geq Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * CinpLo^{Storage}_{st1,c,r,y,s} * SliceShare_s * \prod_{wth1}\left(WeatherCinpLo^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{45}$$

$eqStorageOutUp_{st1,c,r,y,s}$

$$\mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \leq Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * CoutUp^{Storage}_{st1,c,r,y,s} * SliceShare_s * \prod_{wth1}\left(WeatherCoutUp^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{46}$$

$eqStorageOutLo_{st1,c,r,y,s}$

$$\mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \geq Cap2stg^{Storage}_{st1} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} * CoutLo^{Storage}_{st1,c,r,y,s} * SliceShare_s * \prod_{wth1}\left(WeatherCoutLo^{Storage}_{wth1,st1} * {}^{Weather}_{wth1,r,y,s}\right) \tag{47}$$

Capacity and costs for storage

Storage capacity

eqStorageCap$_{st1,r,y}$

$$\mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} = Stock^{Storage}_{st1,r,y} + \sum_{yp} \left(\mathbf{NewCap}^{\mathbf{Storage}}{}_{st1,r,yp} \right) \tag{48}$$

Storage investments

eqStorageInv$_{st1,r,y}$

$$\mathbf{Inv}^{\mathbf{Storage}}{}_{st1,r,y} = Invcost^{Storage}_{st1,r,y} * \mathbf{NewCap}^{\mathbf{Storage}}{}_{st1,r,y} \tag{49}$$

eqStorageEac$_{st1,r,y}$

$$\mathbf{Eac}^{\mathbf{Storage}}{}_{st1,r,y} = \sum_{yp} \left(Eac^{Storage}_{st1,r,yp} * \mathbf{NewCap}^{\mathbf{Storage}}{}_{st1,r,yp} \right) \tag{50}$$

Storage total costs

eqStorageCost$_{st1,r,y}$

$$\begin{aligned} &\mathbf{OMCost}^{\mathbf{Storage}}{}_{st1,r,y} \\ &= Fixom^{Storage}_{st1,r,y} * \mathbf{Cap}^{\mathbf{Storage}}{}_{st1,r,y} \\ &\quad + \sum_{c} \left(\sum_{s} \left(CostInp^{Storage}_{st1,r,y,s} * \mathbf{Inp}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \right) + \sum_{s} \left(CostOut^{Storage}_{st1,r,y,s} * \mathbf{Out}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \right) + \sum_{s} \left(CostStore^{Storage}_{st1,r,y,s} * \mathbf{Store}^{\mathbf{Storage}}{}_{st1,c,r,y,s} \right) \right) \end{aligned} \tag{51}$$

Interregional and ROW Trade

Flow

Import equation

eqImport$_{c,dst,y,s}$

$$\mathbf{Import}_{c,dst,y,s} = \sum_{sp} \left(\sum_{t1} \left(\sum_{src} \left(IrEff^{Trade}_{t1,src,dst,y,sp} * \mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,src,dst,y,sp} \right) \right) \right) + \sum_{sp} \left(\sum_{i} \left(\mathbf{ImportRow}_{i,c,dst,y,sp} \right) \right) \tag{52}$$

Export equation

eqExport$_{c,src,y,s}$

$$\mathbf{Export}_{c,src,y,s} = \sum_{sp}\left(\sum_{t1}\left(\sum_{dst}\left(\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,src,dst,y,sp}\right)\right)\right) + \sum_{sp}\left(\sum_{e}\left(\mathbf{ExportRow}_{e,c,src,y,sp}\right)\right) \tag{53}$$

Trade upper bound
eqTradeFlowUp$_{t1,c,src,dst,y,s}$

$$\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,src,dst,y,s} \leq IrUp^{Trade}_{t1,src,dst,y,s} \tag{54}$$

Trade lower bound
eqTradeFlowLo$_{t1,c,src,dst,y,s}$

$$\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,src,dst,y,s} \geq IrLo^{Trade}_{t1,src,dst,y,s} \tag{55}$$

Total trade costs
eqCostTrade$_{r,y}$

$$\mathbf{Cost}^{\mathbf{Trade}}{}_{r,y} = \mathbf{RowCost}^{\mathbf{Trade}}{}_{r,y} + \mathbf{IrCost}^{\mathbf{Trade}}{}_{r,y} \tag{56}$$

Costs of trade with the Rest of the World (ROW)
eqCostRowTrade$_{r,y}$

$$\mathbf{RowCost}^{\mathbf{Trade}}{}_{r,y} = \sum_{i,c,s}\left(ImportRowPrice_{i,r,y,s} * \mathbf{ImportRow}_{i,c,r,y,s}\right) - \sum_{e,c,s}\left(ExportRowPrice_{e,r,y,s} * \mathbf{ExportRow}_{e,c,r,y,s}\right) \tag{57}$$

Costs of import
eqCostIrTrade$_{r,y}$

$$\begin{aligned}\mathbf{IrCost}^{\mathbf{Trade}}{}_{r,y} = &\sum_{t1}\left(\mathbf{Eac}^{\mathbf{Trade}}{}_{t1,r,y}\right) + \sum_{t1,src}\left(\sum_{c}\left(\sum_{s}\left(\left(\left(IrCost^{Trade}_{t1,src,r,y,s} + IrMarkup^{Trade}_{t1,src,r,y,s}\right) * \mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,src,r,y,s}\right)\right)\right)\right) \\ &- \sum_{t1,dst}\left(\sum_{c}\left(\sum_{s}\left(\left(IrMarkup^{Trade}_{t1,r,dst,y,s} * \mathbf{Ir}^{\mathbf{Trade}}{}_{t1,c,r,dst,y,s}\right)\right)\right)\right)\end{aligned} \tag{58}$$

Export to ROW upper bound
eqExportRowUp$_{e,c,r,y,s}$

$$\mathbf{ExportRow}_{e,c,r,y,s} \leq ExportRowUp_{e,r,y,s} \tag{59}$$

Export to ROW lower bound

$eqExportRowLo_{e,c,r,y,s}$

$$\mathbf{ExportRow}_{e,c,r,y,s} \geq ExportRowLo_{e,r,y,s} \tag{60}$$

Cumulative export to ROW
$eqExportRowCumulative_{e,c}$

$$\mathbf{ExportRowAccumulated}_{e,c} = \sum_{r,y,s} \left(PeriodLen_y * \mathbf{ExportRow}_{e,c,r,y,s} \right) \tag{61}$$

Accumulated export to ROW upper bound
$eqExportRowResUp_{e,c}$

$$\mathbf{ExportRowAccumulated}_{e,c} \leq ExportRowRes_e \tag{62}$$

Import from ROW upper bound
$eqImportRowUp_{i,c,r,y,s}$

$$\mathbf{ImportRow}_{i,c,r,y,s} \leq ImportRowUp_{i,r,y,s} \tag{63}$$

Import of ROW lower bound
$eqImportRowLo_{i,c,r,y,s}$

$$\mathbf{ImportRow}_{i,c,r,y,s} \geq ImportRowLo_{i,r,y,s} \tag{64}$$

Accumulated import from ROW
$eqImportRowAccumulated_{i,c}$

$$\mathbf{ImportRowAccumulated}_{i,c} = \sum_{r,y,s} \left(PeriodLen_y * \mathbf{ImportRow}_{i,c,r,y,s} \right) \tag{65}$$

Accumulated import from ROW upper bound
$eqImportRowResUp_{i,c}$

$$\mathbf{ImportRowAccumulated}_{i,c} \leq ImportRowRes_i \tag{66}$$

$eqTradeCapFlow_{t1,c,y,s}$

$$SliceShare_s * Cap2Act_{t1}^{Trade} * \mathbf{Cap^{Trade}}_{t1,y} \geq \sum_{src,dst} \left(\mathbf{Ir^{Trade}}_{t1,c,src,dst,y,s} \right) \tag{67}$$

$eqTradeCap_{t1,y}$

$$\mathbf{Cap}^{\mathbf{Trade}}{}_{t1,y} = Stock^{Trade}_{t1,y} + \sum_{yp} \left(\mathbf{NewCap}^{\mathbf{Trade}}{}_{t1,yp} \right) \tag{68}$$

$eqTradeInv_{t1,r,y}$

$$\mathbf{Inv}^{\mathbf{Trade}}{}_{t1,r,y} = Invcost^{Trade}_{t1,r,y} * \mathbf{NewCap}^{\mathbf{Trade}}{}_{t1,y} \tag{69}$$

$eqTradeEac_{t1,r,y}$

$$\mathbf{Eac}^{\mathbf{Trade}}{}_{t1,r,y} = \sum_{yp} \left(Eac^{Trade}_{t1,r,yp} * \mathbf{NewCap}^{\mathbf{Trade}}{}_{t1,yp} \right) \tag{70}$$

Trade IR capacity equations

Auxiliary input & output equations

Trade auxiliary commodity input
$eqTradeIrAInp_{t1,c,r,y,s}$

$$\mathbf{IrAInp}^{\mathbf{Trade}}{}_{t1,c,r,y,s} = \sum_{dst} \left(IrCsrc2Ainp^{Trade}_{t1,c,r,dst,y,s} * \sum_{cp} \left(\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,cp,r,dst,y,s} \right) \right) + \sum_{src} \left(IrCdst2Ainp^{Trade}_{t1,c,src,r,y,s} * \sum_{cp} \left(\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,cp,src,r,y,s} \right) \right) \tag{71}$$

Trade auxiliary commodity output
$eqTradeIrAOut_{t1,c,r,y,s}$

$$\mathbf{IrAOut}^{\mathbf{Trade}}{}_{t1,c,r,y,s} = \sum_{dst} \left(IrCsrc2Aout^{Trade}_{t1,c,r,dst,y,s} * \sum_{cp} \left(\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,cp,r,dst,y,s} \right) \right) + \sum_{src} \left(IrCdst2Aout^{Trade}_{t1,c,src,r,y,s} * \sum_{cp} \left(\mathbf{Ir}^{\mathbf{Trade}}{}_{t1,cp,src,r,y,s} \right) \right) \tag{72}$$

Trade auxiliary commodity input
$eqTradeIrAInpTot_{c,r,y,s}$

$$\mathbf{IrAInpTot}^{\mathbf{Trade}}{}_{c,r,y,s} = \sum_{t1,sp} \left(\mathbf{IrAInp}^{\mathbf{Trade}}{}_{t1,c,r,y,sp} \right) \tag{73}$$

Trade auxiliary commodity output
$eqTradeIrAOutTot_{c,r,y,s}$

$$\mathbf{IrAOutTot}^{\mathbf{Trade}}{}_{c,r,y,s} = \sum_{t1,sp} \left(\mathbf{IrAOut}^{\mathbf{Trade}}{}_{t1,c,r,y,sp} \right) \tag{74}$$

Balance equations & dummy import & export

PRODUCTION ¡= CONSUMPTION commodity balance
eqBalLo$_{c,r,y,s}$

$$\mathbf{Balance}_{c,r,y,s} \geq 0 \tag{75}$$

PRODUCTION ¿= CONSUMPTION commodity balance
eqBalUp$_{c,r,y,s}$

$$\mathbf{Balance}_{c,r,y,s} \leq 0 \tag{76}$$

PRODUCTION = CONSUMPTION commodity balance
eqBalFx$_{c,r,y,s}$

$$\mathbf{Balance}_{c,r,y,s} = 0 \tag{77}$$

Commodity balance
eqBal$_{c,r,y,s}$

$$\mathbf{Balance}_{c,r,y,s} = \mathbf{OutTot}_{c,r,y,s} - \mathbf{InpTot}_{c,r,y,s} \tag{78}$$

Total commodity output
eqOutTot$_{c,r,y,s}$

$$\begin{aligned}\mathbf{OutTot}_{c,r,y,s} = {} & \mathbf{Import}^{\mathbf{Dummy}}{}_{c,r,y,s} + \mathbf{OutTot}^{\mathbf{Sup}}{}_{c,r,y,s} + \mathbf{EmsFuelTot}_{c,r,y,s} + \mathbf{AggOut}_{c,r,y,s} + \mathbf{OutTot}^{\mathbf{Tech}}{}_{c,r,y,s} \\ & + \mathbf{OutTot}^{\mathbf{Storage}}{}_{c,r,y,s} + \mathbf{Import}_{c,r,y,s} + \mathbf{IrAOutTot}^{\mathbf{Trade}}{}_{c,r,y,s} + \sum_{sp} (\mathbf{Out2Lo}_{c,r,y,sp,s})\end{aligned} \tag{79}$$

Total commodity input
eqOut2Lo$_{c,r,y,s}$

$$\begin{aligned}\sum_{sp} (\mathbf{Out2Lo}_{c,r,y,s,sp}) = {} & \mathbf{OutTot}^{\mathbf{Sup}}{}_{c,r,y,s} + \mathbf{EmsFuelTot}_{c,r,y,s} + \mathbf{AggOut}_{c,r,y,s} + \mathbf{OutTot}^{\mathbf{Tech}}{}_{c,r,y,s} \\ & + \mathbf{OutTot}^{\mathbf{Storage}}{}_{c,r,y,s} + \mathbf{Import}_{c,r,y,s} + \mathbf{IrAOutTot}^{\mathbf{Trade}}{}_{c,r,y,s}\end{aligned} \tag{80}$$

From coomodity slice to lo level
eqInpTot$_{c,r,y,s}$

$$\mathbf{InpTot}_{c,r,y,s} = \mathbf{Inp^{Dem}}_{c,r,y,s} + \mathbf{Export^{Dummy}}_{c,r,y,s} + \mathbf{InpTot^{Tech}}_{c,r,y,s} + \mathbf{InpTot^{Storage}}_{c,r,y,s} + \mathbf{Export}_{c,r,y,s} + \mathbf{IrAInpTot^{Trade}}_{c,r,y,s} + \sum_{sp} \left(\mathbf{Inp2Lo}_{c,r,y,sp,s}\right) \tag{81}$$

From coomodity slice to lo level
eqInp2Lo$_{c,r,y,s}$

$$\sum_{sp} \left(\mathbf{Inp2Lo}_{c,r,y,s,sp}\right) = \mathbf{InpTot^{Tech}}_{c,r,y,s} + \mathbf{InpTot^{Storage}}_{c,r,y,s} + \mathbf{Export}_{c,r,y,s} + \mathbf{IrAInpTot^{Trade}}_{c,r,y,s} \tag{82}$$

Supply total output
eqSupOutTot$_{c,r,y,s}$

$$\mathbf{OutTot^{Sup}}_{c,r,y,s} = \sum_{s1} \left(\sum_{sp} \left(\mathbf{Out^{Sup}}_{s1,c,r,y,sp} \right) \right) \tag{83}$$

Technology total input
eqTechInpTot$_{c,r,y,s}$

$$\mathbf{InpTot^{Tech}}_{c,r,y,s} = \sum_{t} \left(\sum_{sp} \left(\mathbf{Inp^{Tech}}_{t,c,r,y,sp} \right) \right) + \sum_{t} \left(\sum_{sp} \left(\mathbf{AInp^{Tech}}_{t,c,r,y,sp} \right) \right) \tag{84}$$

Technology total output
eqTechOutTot$_{c,r,y,s}$

$$\mathbf{OutTot^{Tech}}_{c,r,y,s} = \sum_{t} \left(\sum_{sp} \left(\mathbf{Out^{Tech}}_{t,c,r,y,sp} \right) \right) + \sum_{t} \left(\sum_{sp} \left(\mathbf{AOut^{Tech}}_{t,c,r,y,sp} \right) \right) \tag{85}$$

Storage total input
eqStorageInpTot$_{c,r,y,s}$

$$\mathbf{InpTot^{Storage}}_{c,r,y,s} = \sum_{st1} \left(\mathbf{Inp^{Storage}}_{st1,c,r,y,s} \right) + \sum_{st1} \left(\mathbf{AInp^{Storage}}_{st1,c,r,y,s} \right) \tag{86}$$

Storage total output
eqStorageOutTot$_{c,r,y,s}$

$$\mathbf{OutTot^{Storage}}_{c,r,y,s} = \sum_{st1} \left(\mathbf{Out^{Storage}}_{st1,c,r,y,s} \right) + \sum_{st1} \left(\mathbf{AOut^{Storage}}_{st1,c,r,y,s} \right) \tag{87}$$

Objective and aggregated costs equations

Total costs

eqCost$_{r,y}$

$$\begin{aligned}\mathbf{TotalCost}_{r,y} = &\sum_{t}\left(\mathbf{Eac}^{\mathbf{Tech}}{}_{t,r,y}\right) + \sum_{t}\left(\mathbf{OMCost}^{\mathbf{Tech}}{}_{t,r,y}\right) + \sum_{s1}\left(\mathbf{Cost}^{\mathbf{Sup}}{}_{s1,r,y}\right) + \sum_{c,s}\left(ImportCost^{Dummy}_{c,r,y,s} * \mathbf{Import}^{\mathbf{Dummy}}{}_{c,r,y,s}\right) \\ &+ \sum_{c,s}\left(ExportCost^{Dummy}_{c,r,y,s} * \mathbf{Export}^{\mathbf{Dummy}}{}_{c,r,y,s}\right) + \sum_{c}\left(\mathbf{Cost}^{\mathbf{Tax}}{}_{c,r,y}\right) - \sum_{c}\left(\mathbf{Cost}^{\mathbf{Subs}}{}_{c,r,y}\right) \\ &+ \sum_{st1}\left(\mathbf{OMCost}^{\mathbf{Storage}}{}_{st1,r,y}\right) + \sum_{st1}\left(\mathbf{Eac}^{\mathbf{Storage}}{}_{st1,r,y}\right) + \mathbf{Cost}^{\mathbf{Trade}}{}_{r,y} + \mathbf{TotalUserCosts}_{r,y}\end{aligned} \tag{88}$$

Commodity taxes

eqTaxCost$_{c,r,y}$

$$\mathbf{Cost}^{\mathbf{Tax}}{}_{c,r,y} = \sum_{s}\left(CostOut^{Tax}_{c,r,y,s} * \mathbf{OutTot}_{c,r,y,s}\right) + \sum_{s}\left(CostInp^{Tax}_{c,r,y,s} * \mathbf{InpTot}_{c,r,y,s}\right) + \sum_{s}\left(CostBal^{Tax}_{c,r,y,s} * \mathbf{Balance}_{c,r,y,s}\right) \tag{89}$$

Commodity subsidy

eqSubsCost$_{c,r,y}$

$$\mathbf{Cost}^{\mathbf{Subs}}{}_{c,r,y} = \sum_{s}\left(SubCostOut_{c,r,y,s} * \mathbf{OutTot}_{c,r,y,s}\right) + \sum_{s}\left(SubCostInp_{c,r,y,s} * \mathbf{InpTot}_{c,r,y,s}\right) + \sum_{s}\left(SubCostBal_{c,r,y,s} * \mathbf{Balance}_{c,r,y,s}\right) \tag{90}$$

Objective equation

eqObjective

$$\mathbf{Objective} = \sum_{r,y}\left(\mathbf{TotalCost}_{r,y} * DiscountFactorMileStone_{r,y}\right) \tag{91}$$

LEC equation

eqLECActivity$_{t,r,y}$

$$\sum_{s}\left(\mathbf{Act}^{\mathbf{Tech}}{}_{t,r,y,s}\right) \geq LECLoACT_{r} \tag{92}$$