

# OSeMOSYS-Pyomo Model Documentation

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# 1 General Description

This document describes the sets, parameters, variables, and equations of the OSeMOSYS-Pyomo model.

## 2 Sets

Set Name	Description
YEAR	y
TECHNOLOGY	t
TIMESLICE	l
FUEL	f
EMISSION	e
MODE_OF_OPERATION	m
REGION	r
SEASON	ls
DAYTYPE	ld
DAILYTIMEBRACKET	lh
STORAGE	

## 3 Parameters

Parameter Name	Description
p_YearSplit	Parameters are defined with a p in front of the name of each parameter
p_DiscountRate	[r] Region specific value for the discount rate, expressed in decimals (e.g. 0.05)
p_DaySplit	[lh,y] Length of one DailyTimeBracket in one specific day as a fraction of the year (e.g., when distinguishing between days and night: 12h/(24h*365d)).
p_Conversionsls	[ls,l] Binary parameter linking one TimeSlice to a certain Season. It has value 0 if the TimeSlice does not pertain to the specific season, 1 if it does.
p_Conversionld	[ld,l] Binary parameter linking one TimeSlice to a certain DayType. It has value 0 if the TimeSlice does not pertain to the specific DayType, 1 if it does.
p_Conversionlh	[lh,l] Binary parameter linking one TimeSlice to a certain DailyTimeBracket. It has value 0 if the TimeSlice does not pertain to the specific DailyTimeBracket, 1 if it does.
p_DaysInDayType	[ls,ld,y] Number of days for each day type, within one week (natural number, ranging from 1 to 7)
p_TradeRoute	[r,rr,f,y] Binary parameter defining the links between region r and region rr, to enable or disable trading of a specific commodity. It has value 1 when two regions are linked, 0 otherwise
p_DepreciationMethod	[r] Binary parameter defining the type of depreciation to be applied. It has value 1 for sinking fund depreciation, value 2 for straight-line depreciation.
p_DiscountRateIdv	[r,t] Technology and region specific value for the discount rate, expressed in decimals (e.g. 0.05). It is used for calculating the capital recovery factor (CRF).
p_DiscountFactor	[r,y] Discount factor for a specific year and region, calculated from the discount rate.
p_DiscountFactorMid	[r,y] Discount factor for a specific year and region, calculated from the discount rate.

<b>Parameter Name</b>	<b>Description</b>
p_SpecifiedAnnualDemand	SpecifiedAnnualDemand[r,f,y] - Total specified demand for the year, linked to a specific ‘time of use’ during the year.
p_SpecifiedDemandProfile	SpecifiedDemandProfile[r,f,l,y] - Annual fraction of energy-service or commodity demand that is required in each time slice. For each year, all the defined SpecifiedDemandProfile input values should sum up to 1.
p_AccumulatedAnnualDemand	AccumulatedAnnualDemand[r,f,y] - Accumulated Demand for a certain commodity in one specific year. It cannot be defined for a commodity if its SpecifiedAnnualDemand for the same year is already defined and vice versa.
p_CapacityToActivityUnit	CapacityToActivityUnit[r,t] - Conversion factor relating the energy that would be produced when one unit of capacity is fully used in one year.
p_CapacityFactor	CapacityFactor[r,t,l,y] - Capacity available per each TimeSlice expressed as a fraction of the total installed capacity, with values ranging from 0 to 1. It gives the possibility to account for forced outages.
p_AvailabilityFactor	AvailabilityFactor[r,t,y] - Maximum time a technology can run in the whole year, as a fraction of the year ranging from 0 to 1. It gives the possibility to account for planned outages.
p_OperationalLife	OperationalLife[r,t] - Useful lifetime of a technology, expressed in years.
p_ResidualCapacity	ResidualCapacity[r,t,y]- Remained capacity available from before the modelling period.
p_InputActivityRatio	InputActivityRatio[r,t,f,m,y] - Rate of use of a commodity by a technology, as a ratio of the rate of activity.
p_OutputActivityRatio	OutputActivityRatio[r,t,f,m,y] - Rate of commodity output from a technology, as a ratio of the rate of activity.
p_CapitalCost	CapitalCost[r,t,y]-Capital investment cost of a technology, per unit of capacity. \$/kW
p_VariableCost	VariableCost[r,t,m,y] - Cost of a technology for a given mode of operation (Variable O&M cost), per unit of activity \$/GJ
p_FixedCost	FixedCost[r,t,y] - Fixed O&M cost of a technology, per unit of capacity. \$/kW/yr
p_TechnologyToStorage	TechnologyToStorage[r,t,s,m] - Binary parameter linking a technology to the storage facility it charges. It has value 1 if the technology and the storage facility are linked, 0 otherwise.
p_TechnologyFromStorage	TechnologyFromStorage[r,t,s,m] - Binary parameter linking a storage facility to the technology it feeds. It has value 1 if the technology and the storage facility are linked, 0 otherwise.
p_StorageLevelStart	StorageLevelStart[r,s] - Level of storage at the beginning of first modelled year, in units of activity.
p_StorageMaxChargeRate	StorageMaxChargeRate[r,s]-Maximum charging rate for the storage, in units of activity per year.
p_StorageMaxDischargeRate	StorageMaxDischargeRate[r,s] - Maximum discharging rate for the storage, in units of activity per year.
p_MinStorageCharge	MinStorageCharge[r,s,y] - It sets a lower bound to the amount of energy stored, as a fraction of the maximum, with a number ranging between 0 and 1. The storage facility cannot be emptied below this level.
p_OperationalLifeStorage	OperationalLifeStorage[r,s] - Useful lifetime of the storage facility.
p_CapitalCostStorage	CapitalCostStorage[r,s,y] - Investment costs of storage additions, defined per unit of storage capacity.
p_ResidualStorageCapacity	ResidualStorageCapacity[r,s,y] - Exogenously defined storage capacities.

Parameter Name	Description
p_CapacityOfOneTechnologyUnit	CapacityOfOneTechnologyUnit[r,t,y] - Capacity of one new unit of a technology. In case the user sets this parameter, the related technology will be installed only in batches of the specified capacity and the problem will turn into a Mixed Integer Linear Problem.
p_TotalAnnualMaxCapacity	TotalAnnualMaxCapacity[r,t,y] - Total maximum existing (residual plus cumulatively installed) capacity allowed for a technology in a specified year.
p_TotalAnnualMinCapacity	TotalAnnualMinCapacity[r,t,y] - Total minimum existing (residual plus cumulatively installed) capacity allowed for a technology in a specified year.
p_TotalAnnualMaxCapacityInvestment	TotalAnnualMaxCapacityInvestment[r,t,y]-Maximum capacity of a technology, expressed in power units.
p_TotalAnnualMinCapacityInvestment	TotalAnnualMinCapacityInvestment[r,t,y]-Minimum capacity of a technology, expressed in power units.
p_TotalTechnologyAnnualActivityUpperLimit	TotalTechnologyAnnualActivityUpperLimit[r,t,y]-Total maximum level of activity allowed for a technology in one year.
p_TotalTechnologyAnnualActivityLowerLimit	TotalTechnologyAnnualActivityLowerLimit[r,t,y] - Total minimum level of activity allowed for a technology in one year.
p_TotalTechnologyModelPeriodActivityUpperLimit	TotalTechnologyModelPeriodActivityUpperLimit[r,t]-Total maximum level of activity allowed for a technology in the entire modelled period.
p_TotalTechnologyModelPeriodActivityLowerLimit	TotalTechnologyModelPeriodActivityLowerLimit[r,t]-Total minimum level of activity allowed for a technology in the entire modelled period.
p_ReserveMarginTagTechnology	ReserveMarginTagTechnology[r,t,y] - Binary parameter tagging the technologies that are allowed to contribute to the reserve margin. It has value 1 for the technologies allowed, 0 otherwise.
p_ReserveMarginTagFuel	ReserveMarginTagFuel[r,f,y] Binary parameter tagging the fuels to which the reserve margin applies. It has value 1 if the reserve margin applies to the fuel, 0 otherwise.
p_ReserveMargin	ReserveMargin[r,y] Minimum level of the reserve margin required to be provided for all the tagged commodities, by the tagged technologies. If no reserve margin is required, the parameter will have value 1; if, for instance, 20% reserve margin is required, the parameter will have value 1.2.
p RETagTechnology	RETagTechnology[r,t,y] - Binary parameter tagging the renewable technologies that must contribute to reaching the indicated minimum renewable production target. It has value 1 for the technologies contributing, 0 otherwise.
p RETagFuel	RETagFuel[r,f,y] - Binary parameter tagging the fuels to which the renewable target applies to. It has value 1 if the target applies, 0 otherwise.
p REMinProductionTarget	REMinProductionTarget[r,y] - Minimum ratio of all renewable commodities tagged in the RETagCommodity parameter, to be produced by the technologies tagged with the RETechnology parameter.
p_EmissionActivityRatio	EmissionActivityRatio[r,t,e,m,y] - Emission factor of a technology per unit of activity, per mode of operation.
p_EmissionsPenalty	EmissionsPenalty[r,e,y] - Penalty per unit of emission.
p_AnnualExogenousEmission	AnnualExogenousEmission[r,e,y] It allows the user to account for additional annual emissions, on top of those computed endogenously by the model (e.g. emissions generated outside the region).

Parameter Name	Description
p_AnnualEmissionLimit	AnnualEmissionLimit[r,e,y] - Annual upper limit for a specific emission generated in the whole modelled region.
p_ModelPeriodExogenousEmission	ModelPeriodExogenousEmission[r,e] - It allows the user to account for additional emissions over the entire modelled period, on top of those computed endogenously by the model (e.g. generated outside the region).
p_ModelPeriodEmissionLimit	ModelPeriodEmissionLimit[r,e] Annual upper limit for a specific emission generated in the whole modelled region, over the entire modelled period.
p_CostoNoAsociado	Costo no asociado a la generacion
p_MinimumOperatingLoad	MinimunOperatingLoad[r,t,y] - Minimum load could operate a technology
p_Availability	De las unidades existentes cuales estan disponibles para instalar
p_NumberOfExistingUnits	Unidades que estan operando
p_CostoRecuperacion	Costo de re-invertir en una tecnologia
p_VidaUtilRecuperada	Vida Util despues de recuperadas
p_Mantenimiento	Periodo de mantenimiento en años
p_ExportPrice	Export price
p_MustRun	
p_MustRunTech	
p_MustRunFuel	

## 4 Variables

Variable Name	Description
v_RateOfDemand	RateOfDemand[r,l,f,y] $_{l=0}$ Intermediate variable. It represents the energy that would be demanded in one time slice l if the latter lasted the whole year. It is a function of the parameters SpecifiedAnnualDemand and SpecifiedDemandProfile. — Energy (per year)
v_Demand	Demand[r,l,f,y] $_{l=0}$ - Demand for one fuel in one time slice. Energy
v_RateOfStorageCharge	RateOfStorageCharge[r,s,ls,ld,lh,y] Intermediate variable. It represents the commodity that would be charged to the storage facility s in one time slice if the latter lasted the whole year. It is a function of the RateOfActivity and the parameter TechnologyToStorage. — Energy (per year)
v_RateOfStorageDischarge	RateOfStorageDischarge[r,s,ls,ld,lh,y] Intermediate variable. It represents the commodity that would be discharged from storage facility s in one time slice if the latter lasted the whole year. It is a function of the RateOfActivity and the parameter TechnologyFromStorage. Energy (per year)
v_NetChargeWithinYear	NetChargeWithinYear[r,s,ls,ld,lh,y] Net quantity of commodity charged to storage facility s in year y. It is a function of the RateOfStorageCharge and the RateOfStorageDischarge and it can be negative. Energy
v_NetChargeWithinDay	NetChargeWithinDay[r,s,ls,ld,lh,y] Net quantity of commodity charged to storage facility s in daytype ld. It is a function of the RateOfStorageCharge and the RateOfStorageDischarge and can be negative. Energy
v_StorageLevelYearStart	StorageLevelYearStart[r,s,y] $_{l=0}$ Level of stored commodity in storage facility s in the first time step of year y. Energy

<b>Variable Name</b>	<b>Description</b>
v_StorageLevelYearFinish	StorageLevelYearFinish[r,s,y] $_{\zeta=0}$ Level of stored commodity in storage facility s in the last time step of year y. Energy
v_StorageLevelSeasonStart	StorageLevelSeasonStart[r,s,ls,y] $_{\zeta=0}$ Level of stored commodity in storage facility s in the first time step of season ls. Energy
v_StorageLevelDayTypeStart	StorageLevelDayTypeStart[r,s,ls,ld,y] $_{\zeta=0}$ Level of stored commodity in storage facility s in the first time step of daytype ld. Energy
v_StorageLevelDayTypeFinish	StorageLevelDayTypeFinish[r,s,ls,ld,y] $_{\zeta=0}$ Level of stored commodity in storage facility s in the last time step of daytype ld. Energy
v_StorageLevel	StorageLowerLimit[r,s,y] $_{\zeta=0}$ Minimum allowed level of stored commodity in storage facility s, as a function of the storage capacity and the user-defined MinStorageCharge ratio. Energy
v_StorageLowerLimit	
v_StorageUpperLimit	StorageUpperLimit[r,s,y] $_{\zeta=0}$ Maximum allowed level of stored commodity in storage facility s. It corresponds to the total existing capacity of storage facility s (summing newly installed and pre-existing capacities). Energy
v_AccumulatedNewStorageCapacity	AccumulatedNewStorageCapacity[r,s,y] $_{\zeta=0}$ Cumulative capacity of newly installed storage from the beginning of the time domain to year y. Energy
v_NewStorageCapacity	NewStorageCapacity[r,s,y] $_{\zeta=0}$ Capacity of newly installed storage in year y. Energy
v_CapitalInvestmentStorage	CapitalInvestmentStorage[r,s,y] $_{\zeta=0}$ Undiscounted investment in new capacity for storage facility s. Derived from the NewStorageCapacity and the parameter CapitalCostStorage. Monetary units
v_DiscountedCapitalInvestmentStorage	DiscountedCapitalInvestmentStorage[r,s,y] $_{\zeta=0}$ Investment in new capacity for storage facility s, discounted through the parameter DiscountRate. Monetary units
v_SalvageValueStorage	SalvageValueStorage[r,s,y] $_{\zeta=0}$ Salvage value of storage facility s in year y, as a function of the parameters OperationalLifeStorage and DepreciationMethod. Monetary units
v_DiscountedSalvageValueStorage	DiscountedSalvageValueStorage[r,s,y] $_{\zeta=0}$ Salvage value of storage facility s, discounted through the parameter DiscountRate. Monetary units
v_TotalDiscountedStorageCost	TotalDiscountedStorageCost[r,s,y] $_{\zeta=0}$ Difference between the discounted capital investment in new storage facilities and the salvage value in year y. Monetary units
v_NumberOfNewTechnologyUnits	NumberOfNewTechnologyUnits[r,t,y] $_{\zeta=0}$ , integer Number of newly installed units of technology t in year y, as a function of the parameter CapacityOfOneTechnologyUnit. — No unit
v_NewCapacity	NewCapacity[r,t,y] $_{\zeta=0}$ Newly installed capacity of technology t in year y. Power
v_AccumulatedNewCapacity	AccumulatedNewCapacity[r,t,y] $_{\zeta=0}$ Cumulative newly installed capacity of technology t from the beginning of the time domain to year y. Power
v_TotalCapacityAnnual	TotalCapacityAnnual[r,t,y] $_{\zeta=0}$ - Total existing capacity of technology t in year y (sum of cumulative newly installed and pre-existing capacity). Power
v_RateOfActivity	RateOfActivity[r,l,t,m,y] $_{\zeta=0}$ Intermediate variable. It represents the activity of technology t in one mode of operation and in time slice l, if the latter lasted the whole year. — Energy (per year)
v_RateOfTotalActivity	RateOfTotalActivity[r,t,l,y] $_{\zeta=0}$ Sum of the RateOfActivity of a technology over the modes of operation. Energy (per year)

<b>Variable Name</b>	<b>Description</b>
v_TotalTechnologyAnnualActivity	TotalTechnologyAnnualActivity[r,t,y] $\zeta=0$ Total annual activity of technology t. Energy
v_TotalAnnualTechnologyActivityByMode	TotalAnnualTechnologyActivityByMode[r,t,m,y] $\zeta=0$ Annual activity of technology t in mode of operation m. Energy
v_TotalTechnologyModelPeriodActivity	TotalTechnologyModelPeriodActivity[r,t] Sum of the TotalTechnologyAnnualActivity over the years of the modelled period. Energy
v_RateOfProductionByTechnologyByMode	RateOfProductionByTechnologyByMode[r,l,t,m,f,y] $\zeta=0$ Intermediate variable. It represents the quantity of fuel f that technology t would produce in one mode of operation and in time slice l, if the latter lasted the whole year. It is a function of the variable RateOfActivity and the parameter OutputActivityRatio. Energy (per year)
v_RateOfProductionByTechnology	RateOfProductionByTechnology[r,l,t,f,y] $\zeta=0$ Sum of the RateOfProductionByTechnologyByMode over the modes of operation. Energy (per year)
v_ProductionByTechnology	ProductionByTechnology[r,l,t,f,y] $\zeta=0$ Production of fuel f by technology t in time slice l. Energy
v_ProductionByTechnologyAnnual	ProductionByTechnologyAnnual[r,t,f,y] $\zeta=0$ Annual production of fuel f by technology t. Energy
v_RateOfProduction	RateOfProduction[r,l,f,y] $\zeta=0$ Sum of the RateOfProductionByTechnology over all the technologies. Energy (per year)
v_Production	Production[r,l,f,y] $\zeta=0$ Total production of fuel f in time slice l. It is the sum of the ProductionByTechnology over all technologies. Energy
v_RateOfUseByTechnologyByMode	RateOfUseByTechnologyByMode[r,l,t,m,f,y] $\zeta=0$ Intermediate variable. It represents the quantity of fuel f that technology t would use in one mode of operation and in time slice l, if the latter lasted the whole year. It is the function of the variable RateOfActivity and the parameter InputActivityRatio. Energy (per year)
v_RateOfUseByTechnology	RateOfUseByTechnology[r,l,t,f,y] $\zeta=0$ Sum of the RateOfUseByTechnologyByMode over the modes of operation. Energy (per year)
v_RateOfUse	
v_UseByTechnologyAnnual	UseByTechnologyAnnual[r,t,f,y] $\zeta=0$ Annual use of fuel f by technology t. Energy
v_UseByTechnology	UseByTechnology[r,l,t,f,y] $\zeta=0$ Use of fuel f by technology t in time slice l. Energy
v_Use	Use[r,l,f,y] $\zeta=0$ Total use of fuel f in time slice l. It is the sum of the UseByTechnology over all technologies. Energy
v_Trade	Trade[r,rr,l,f,y] Quantity of fuel f traded between region r and rr in time slice l. Energy
v_TradeAnnual	TradeAnnual[r,rr,f,y] Annual quantity of fuel f traded between region r and rr. It is the sum of the variable Trade over all the time slices. Energy
v_ProductionAnnual	ProductionAnnual[r,f,y] $\zeta=0$ Total annual production of fuel f. It is the sum of the variable Production over all technologies. Energy
v_UseAnnual	UseAnnual[r,f,y] $\zeta=0$ Total annual use of fuel f. It is the sum of the variable Use over all technologies. Energy
v_CapitalInvestment	CapitalInvestment[r,t,y] $\zeta=0$ Undiscounted investment in new capacity of technology t. It is a function of the NewCapacity and the parameter CapitalCost. — Monetary units

<b>Variable Name</b>	<b>Description</b>
v_DiscountedCapitalInvestment	DiscountedCapitalInvestment[r,t,y] $\zeta=0$ Investment in new capacity of technology t, discounted through the parameter DiscountRate. Monetary units
v_SalvageValue	SalvageValue[r,t,y] $\zeta=0$ Salvage value of technology t in year y, as a function of the parameters OperationalLife and DepreciationMethod. Monetary units
v_DiscountedSalvageValue	DiscountedSalvageValue[r,t,y] $\zeta=0$ Salvage value of technology t, discounted through the parameter DiscountRate. Monetary units
v_OperatingCost	OperatingCost[r,t,y] $\zeta=0$ Undiscounted sum of the annual variable and fixed operating costs of technology t. Monetary units
v_DiscountedOperatingCost	DiscountedOperatingCost[r,t,y] $\zeta=0$ Annual OperatingCost of technology t, discounted through the parameter DiscountRate. Monetary units
v_AnnualVariableOperatingCost	AnnualVariableOperatingCost[r,t,y] $\zeta=0$ Annual variable operating cost of technology t. Derived from the TotalAnnualTechnologyActivityByMode and the parameter VariableCost. Monetary units
v_AnnualFixedOperatingCost	AnnualFixedOperatingCost[r,t,y] $\zeta=0$ Annual fixed operating cost of technology t. Derived from the TotalCapacityAnnual and the parameter FixedCost. Monetary units
v_TotalDiscountedCostByTechnology	TotalDiscountedCostByTechnology[r,t,y] $\zeta=0$ Difference between the sum of discounted operating cost / capital cost / emission penalties and the salvage value. Monetary units
v_TotalDiscountedCost	TotalDiscountedCost[r,y] $\zeta=0$ Sum of the TotalDiscountedCostByTechnology over all the technologies. Monetary units
v_ModelPeriodCostByRegion	ModelPeriodCostByRegion[r] $\zeta=0$ Sum of the TotalDiscountedCost over all modelled years. Monetary units
v_TotalCapacityInReserveMargin	TotalCapacityInReserveMargin[r,y] $\zeta=0$ Total available capacity of the technologies required to provide reserve margin. It is derived from the TotalCapacityAnnual and the parameter ReserveMarginTagTechnology. — Energy
v_DemandNeedingReserveMargin	DemandNeedingReserveMargin[r,l,y] $\zeta=0$ Quantity of fuel produced that is assigned to a target of reserve margin. Derived from the RateOfProduction and the parameter ReserveMarginTagFuel. Energy (per year)
v_TotalREProductionAnnual	TotalREProductionAnnual[r,y] Annual production by all technologies tagged as renewable in the model. Derived from the ProductionByTechnologyAnnual and the parameter RETagTechnology. Energy
v_RETTotalProductionOfTargetFuelAnnual	RETTotalProductionOfTargetFuelAnnual[r,y] Annual production of fuels tagged as renewable in the model. Derived from the RateOfProduction and the parameter RETagFuel. Energy
v_AnnualTechnologyEmissionByMode	AnnualTechnologyEmissionByMode[r,t,e,m,y] $\zeta=0$ Annual emission of agent e by technology t in mode of operation m. Derived from the RateOfActivity and the parameter EmissionActivityRatio. Quantity of emission
v_AnnualTechnologyEmission	AnnualTechnologyEmission[r,t,e,y] $\zeta=0$ Sum of the AnnualTechnologyEmissionByMode over the modes of operation. Quantity of emission
v_AnnualTechnologyEmissionPenalty	AnnualTechnologyEmissionPenaltyByEmission[r,t,e,y] $\zeta=0$ Undiscounted annual cost of emission e by technology t. It is a function of the AnnualTechnologyEmission and the parameter EmissionPenalty. Monetary units

Variable Name	Description
v_AnnualTechnologyEmissionsPenalty	AnnualTechnologyEmissionsPenalty[r,t,y] $\zeta=0$ Total undiscounted annual cost of all emissions generated by technology t. Sum of the AnnualTechnologyEmissionPenaltyByEmission over all the emitted agents. Monetary units
v_DiscountedTechnologyEmissionsPenalty	DiscountedTechnologyEmissionsPenalty[r,t,y] $\zeta=0$ Annual cost of emissions by technology t, discounted through the DiscountRate. Monetary units
v_AnnualEmissions	AnnualEmissions[r,e,y] $\zeta=0$ Sum of the AnnualTechnologyEmission over all technologies. Quantity of emission
v_ModelPeriodEmissions	ModelPeriodEmissions[r,e] $\zeta=0$ Total system emissions of agent e in the model period, accounting for both the emissions by technologies and the user defined ModelPeriodExogenousEmission. Quantity of emission
v_ConnectedUnits	ConnectedUnits[r,t,l,y] - Number of Conected Units in each TimeSlice
v_ResidualCapacity	"probando nueva capacidad residual
v_AccumulatedRecoveredUnits	
v_AccumulatedRecoveredCapacity	
v_AccumulatedRecoveredNewCapacity	
v_RecoveredExistingUnits	
v_RecoveredCapacity	
v_RecoveredNewCapacity	
v_Export	Exporting a commodity

## 5 Equations

The following constraints are defined in the model. Where available, the mathematical formulation is provided.

### 5.1 ObjectiveFunction

$$\sum_{r,y} \text{TotalDiscountedCost}_{r,y} \quad (1)$$

### 5.2 SpecifiedDemand\_EQ

$$\text{RateOfDemand}_{r,l,f,y} = \frac{\text{SpecifiedAnnualDemand}_{r,f,y} \cdot \text{SpecifiedDemandProfile}_{r,f,l,y}}{\text{YearSplit}_{l,y}} \quad (2)$$

### 5.3 CAa1\_TotalNewCapacity

$$\text{AccumulatedNewCapacity}_{r,t,y} = \sum_{yy \in YEAR: (y-yy < \text{OperationalLife}_{r,t}) \wedge (y-yy \geq 0)} \text{NewCapacity}_{r,t,yy} \quad (3)$$

### 5.4 CAa2\_TotalAnnualCapacity

$$\begin{aligned} \text{AccumulatedNewCapacity}_{r,t,y} + \text{ResidualCapacity}_{r,t,y} \\ = \text{TotalCapacityAnnual}_{r,t,y} \end{aligned} \quad (4)$$

### 5.5 CAa3\_TotalActivityOfEachTechnology

$$\sum_m \text{RateOfActivity}_{r,l,t,m,y} = \text{RateOfTotalActivity}_{r,l,y} \quad (5)$$

## 5.6 CAa4\_ConstraintCapacity

$$RateOfTotalActivity_{r,t,l,y} \leq TotalCapacityAnnual_{r,t,y} \cdot CapacityFactor_{r,t,l,y} \cdot CapacityToActivityUnit_{r,t} \quad (6)$$

## 5.7 CAa1n\_TotalResidualCapacity

$$ResidualCapacity_{r,t,y} = NumberOfExistingUnits_{r,t,y} \cdot CapacityOfOneTechnologyUnit_{r,t,y} \quad (7)$$

## 5.8 CAa5\_TotalNewCapacity

$$CapacityOfOneTechnologyUnit_{r,t,y} \cdot NumberOfNewTechnologyUnits_{r,t,y} \cdot Availability_{r,t,y} = NewCapacity_{r,t,y} \quad (8)$$

## 5.9 CAB1\_PlannedMaintenance

$$\sum_l RateOfTotalActivity_{r,t,l,y} \cdot YearSplit_{l,y} \leq \sum_l (TotalCapacityAnnual_{r,t,y} \cdot CapacityFactor_{r,t,l,y} \cdot YearSplit_{l,y} \cdot AvailabilityFactor_{r,t,y} \cdot CapacityToActivityUnit_{r,t}) \quad (9)$$

## 5.10 Recovered\_Existing\_Units

$$\begin{aligned} RecoveredExistingUnits_{r,t,y} \leq & NumberOfExistingUnits_{r,t,y-1} \\ & - NumberOfExistingUnits_{r,t,y} \\ & + RecoveredExistingUnits_{r,t,y} - VidaUtilRecuperada_{r,t} \end{aligned} \quad (10)$$

## 5.11 Accumulated\_Recovered\_Existing\_Units

$$AccumulatedRecoveredUnits_{r,t,y} = \sum_{yy \in YEAR: (y-yy < VidaUtilRecuperada_{r,t}) \wedge (y-yy \geq 0)} RecoveredExistingUnits_{r,t,yy} \quad (11)$$

## 5.12 Recovered\_Residual\_Aggregated

$$\begin{aligned} RecoveredCapacity_{r,t,y} \leq & ResidualCapacity_{r,t,y-1} \\ & - ResidualCapacity_{r,t,y} \\ & + RecoveredCapacity_{r,t,y} - VidaUtilRecuperada_{r,t} \end{aligned} \quad (12)$$

## 5.13 Accumulated\_Recovered\_Capacity

$$AccumulatedRecoveredCapacity_{r,t,y} = \sum_{yy \in YEAR: (y-yy < VidaUtilRecuperada_{r,t}) \wedge (y-yy \geq 0)} RecoveredCapacity_{r,t,yy} \quad (13)$$

## 5.14 Recovered\_New\_Capacity

$$RecoveredNewCapacity_{r,t,y} \leq NewCapacity_{r,t,y} - OperationalLife_{r,t} \quad (14)$$

## 5.15 Accumulated\_Recovered\_New\_Capacity

$$AccumulatedRecoveredNewCapacity_{r,t,y} = \sum_{yy \in YEAR: 0 \leq y-yy < VidaUtilRecuperada_{r,t}} RecoveredNewCapacity_{r,t,yy} \quad (15)$$

## 5.16 EBa1\_RateOfFuelProduction1

$$RateOfActivity_{r,l,t,m,y} \cdot OutputActivityRatio_{r,t,f,m,y} = RateOfProductionByTechnologyByMode_{r,l,t,m,f,y} \quad (16)$$

## 5.17 EBa2\_RateOfFuelProduction2

$$\sum_{m:OutputActivityRatio_{r,t,f,m,y} \neq 0} RateOfProductionByTechnologyByMode_{r,l,t,m,f,y} = RateOfProductionByTechnology_{r,l,t,f,y} \quad (17)$$

## 5.18 EBa3\_RateOfFuelProduction3

$$\sum_t RateOfProductionByTechnology_{r,l,t,f,y} = RateOfProduction_{r,l,f,y} \quad (18)$$

## 5.19 EBa4\_RateOfFuelUse1

$$RateOfActivity_{r,l,t,m,y} \cdot InputActivityRatio_{r,t,f,m,y} = RateOfUseByTechnologyByMode_{r,l,t,m,f,y} \quad (19)$$

## 5.20 EBa5\_RateOfFuelUse2

$$\sum_{m:InputActivityRatio_{r,t,f,m,y} \neq 0} RateOfUseByTechnologyByMode_{r,l,t,m,f,y} = RateOfUseByTechnology_{r,l,t,f,y} \quad (20)$$

## 5.21 EBa6\_RateOfFuelUse3

$$\sum_t RateOfUseByTechnology_{r,l,t,f,y} = RateOfUse_{r,l,f,y} \quad (21)$$

## 5.22 EBa7\_EnergyBalanceEachTS1

$$RateOfProduction_{r,l,f,y} \cdot YearSplit_{l,y} = Production_{r,l,f,y} \quad (22)$$

## 5.23 EBa8\_EnergyBalanceEachTS2

$$RateOfUse_{r,l,f,y} \cdot YearSplit_{l,y} = Use_{r,l,f,y} \quad (23)$$

## 5.24 EBa9\_EnergyBalanceEachTS3

$$RateOfDemand_{r,l,f,y} \cdot YearSplit_{l,y} = Demand_{r,l,f,y} \quad (24)$$

## 5.25 EBa10\_EnergyBalanceEachTS4

$$Trade_{r,rr,l,f,y} = - Trade_{rr,r,l,f,y} \quad (25)$$

## 5.26 EBa11\_EnergyBalanceEachTS5

$$\begin{aligned} Production_{r,l,f,y} &\geq Demand_{r,l,f,y} + Use_{r,l,f,y} \\ &+ \sum_{rr} Trade_{r,rr,l,f,y} \cdot TradeRoute_{r,rr,f,y} \\ &+ Export_{r,l,f,y} \end{aligned} \quad (26)$$

## 5.27 EBb1\_EnergyBalanceEachYear1

$$\sum_l Production_{r,l,f,y} = ProductionAnnual_{r,f,y} \quad (27)$$

### 5.28 EBb2\_EnergyBalanceEachYear2

$$\sum_l Use_{r,l,f,y} = UseAnnual_{r,f,y} \quad (28)$$

### 5.29 EBb3\_EnergyBalanceEachYear3

$$\sum_l Trade_{r,rr,l,f,y} = TradeAnnual_{r,rr,f,y} \quad (29)$$

### 5.30 EBb4\_EnergyBalanceEachYear4

$$\begin{aligned} ProductionAnnual_{r,f,y} &\geq UseAnnual_{r,f,y} \\ &+ \sum_{rr} TradeAnnual_{r,rr,f,y} \cdot TradeRoute_{r,rr,f,y} \\ &+ AccumulatedAnnualDemand_{r,f,y} \end{aligned} \quad (30)$$

### 5.31 Acc1\_FuelProductionByTechnology

$$RateOfProductionByTechnology_{r,l,t,f,y} \cdot YearSplit_{l,y} = ProductionByTechnology_{r,l,t,f,y} \quad (31)$$

### 5.32 Acc2\_FuelUseByTechnology

$$RateOfUseByTechnology_{r,l,t,f,y} \cdot YearSplit_{l,y} = UseByTechnology_{r,l,t,f,y} \quad (32)$$

### 5.33 Acc3\_AverageAnnualRateOfActivity

$$\sum_l RateOfActivity_{r,l,t,m,y} \cdot YearSplit_{l,y} = TotalAnnualTechnologyActivityByMode_{r,t,m,y} \quad (33)$$

### 5.34 Acc4\_ModelPeriodCostByRegion

$$\sum_y TotalDiscountedCost_{r,y} = ModelPeriodCostByRegion_r \quad (34)$$

### 5.35 S1\_RateOfStorageCharge

$$\begin{aligned} &\sum_{\substack{t,m,l: \\ TechnologyToStorage>0}} RateOfActivity_{r,l,t,m,y} \cdot TechnologyToStorage_{r,t,s,m} \\ &\cdot Conversionls_{l,ls} \cdot Conversionld_{l,ld} \cdot Conversionlh_{l,h} \\ &= RateOfStorageCharge_{r,s,ls,ld,h,y} \end{aligned} \quad (35)$$

### 5.36 S2\_RateOfStorageDischarge

$$\begin{aligned} &\sum_{\substack{t,m,l: \\ TechnologyFromStorage>0}} RateOfActivity_{r,l,t,m,y} \cdot TechnologyFromStorage_{r,t,s,m} \\ &\cdot Conversionls_{l,ls} \cdot Conversionld_{l,ld} \cdot Conversionlh_{l,h} \\ &= RateOfStorageDischarge_{r,s,ls,ld,h,y} \end{aligned} \quad (36)$$

### 5.37 S3\_NetChargeWithinYear

$$\begin{aligned} &\sum_l (RateOfStorageCharge_{r,s,ls,ld,h,y} - RateOfStorageDischarge_{r,s,ls,ld,h,y}) \\ &\cdot YearSplit_{l,y} \cdot Conversionls_{l,ls} \cdot Conversionld_{l,ld} \cdot Conversionlh_{l,h} \\ &= NetChargeWithinYear_{r,s,ls,ld,h,y} \end{aligned} \quad (37)$$

### 5.38 S4\_NetChargeWithinDay

$$(RateOfStorageCharge_{r,s,ls,ld,lh,y} - RateOfStorageDischarge_{r,s,ls,ld,lh,y}) \cdot DaySplit_{lh,y} = NetChargeWithinDay_{r,s,ls,ld,lh,y} \quad (38)$$

### 5.39 S5\_and\_S6\_StorageLevelYearStart

$$\begin{aligned} StorageLevelYearStart_{r,s,y-1} + \sum_{ls,ld,lh} NetChargeWithinYear_{r,s,ls,ld,lh,y-1} \\ = StorageLevelYearStart_{r,s,y} \end{aligned} \quad (39)$$

### 5.40 S7\_and\_S8\_StorageLevelYearFinish

$$\begin{aligned} StorageLevelYearStart_{r,s,y} + \sum_{ls,ld,lh} NetChargeWithinYear_{r,s,ls,ld,lh,y} \\ = StorageLevelYearFinish_{r,s,y} \end{aligned} \quad (40)$$

### 5.41 S9\_and\_S10\_StorageLevelSeasonStart

$$\begin{aligned} StorageLevelSeasonStart_{r,s,ls-1,y} + \sum_{ld,lh} NetChargeWithinYear_{r,s,ls-1,ld,lh,y} \\ = StorageLevelSeasonStart_{r,s,ls,y} \end{aligned} \quad (41)$$

### 5.42 S11\_and\_S12\_StorageLevelDayTypeStart

$$\begin{aligned} StorageLevelDayTypeStart_{r,s,ls,ld-1,y} + \sum_{lh} NetChargeWithinDay_{r,s,ls,ld-1,lh,y} \cdot DaysInDayType_{ls,ld-1,y} \\ = StorageLevelDayTypeStart_{r,s,ls,ld,y} \end{aligned} \quad (42)$$

### 5.43 S13\_and\_S14\_and\_S15\_StorageLevelDayTypeFinish

$$\begin{aligned} StorageLevelDayTypeFinish_{r,s,ls,ld+1,y} - \sum_{lh} NetChargeWithinDay_{r,s,ls,ld+1,lh,y} \cdot DaysInDayType_{ls,ld+1,y} \\ = StorageLevelDayTypeFinish_{r,s,ls,ld,y} \end{aligned} \quad (43)$$

### 5.44 S16\_StorageLevel

$$StorageLevel_{r,s,ls,ld,lh,y} = StorageLevelDayTypeStart_{r,s,ls,ld,y} \quad (44)$$

### 5.45 SC1\_LowerLimit\_BeginningOfDayTimeBracketOfFirstInstanceOfDayTypeInFirstV

$$\begin{aligned} 0 \leq StorageLevelDayTypeStart_{r,s,ls,ld,y} \\ + \sum_{lh:lh-lhlh>0} NetChargeWithinDay_{r,s,ls,ld,lh,lh,y} - StorageLowerLimit_{r,s,y} \end{aligned} \quad (45)$$

### 5.46 SC1\_UpperLimit\_BeginningOfDayTimeBracketOfFirstInstanceOfDayTypeInFirstV

$$\begin{aligned} StorageLevelDayTypeStart_{r,s,ls,ld,y} + \sum_{lh:lh-lhlh>0} NetChargeWithinDay_{r,s,ls,ld,lh,lh,y} \\ - StorageUpperLimit_{r,s,y} \leq 0 \end{aligned} \quad (46)$$

**5.47 SC2\_LowerLimit\_EndOfDayTimeBracketOfLastInstanceOfDayTypeInFirstWeekC**

$$\begin{aligned}
 0 &\leq StorageLevelDayTypeStart_{r,s,ls,ld,y} \\
 &- \sum_{lhlh:lh-lhlh<0} NetChargeWithinDay_{r,s,ls,ld-1,lhlh,y} \\
 &- StorageLowerLimit_{r,s,y}
 \end{aligned} \tag{47}$$

**5.48 SC2\_UpperLimit\_EndOfDayTimeBracketOfLastInstanceOfDayTypeInFirstWeekC**

$$\begin{aligned}
 StorageLevelDayTypeStart_{r,s,ls,ld,y} \\
 &- \sum_{lhlh:lh-lhlh<0} NetChargeWithinDay_{r,s,ls,ld-1,lhlh,y} \\
 &- StorageUpperLimit_{r,s,y} \leq 0
 \end{aligned} \tag{48}$$

**5.49 SC3\_LowerLimit\_EndOfDayTimeBracketOfLastInstanceOfDayTypeInLastWeekC**

$$\begin{aligned}
 0 &\leq StorageLevelDayTypeFinish_{r,s,ls,ld,y} \\
 &- \sum_{lhlh:lh-lhlh<0} NetChargeWithinDay_{r,s,ls,ld,lhlh,y} \\
 &- StorageLowerLimit_{r,s,y}
 \end{aligned} \tag{49}$$

**5.50 SC3\_UpperLimit\_EndOfDayTimeBracketOfLastInstanceOfDayTypeInLastWeekC**

$$\begin{aligned}
 StorageLevelDayTypeFinish_{r,s,ls,ld,y} \\
 &- \sum_{lhlh:lh-lhlh<0} NetChargeWithinDay_{r,s,ls,ld,lhlh,y} \\
 &- StorageUpperLimit_{r,s,y} \leq 0
 \end{aligned} \tag{50}$$

**5.51 SC4\_LowerLimit\_BeginningOfDayTimeBracketOfFirstInstanceOfDayTypeInLastW**

$$\begin{aligned}
 0 &\leq StorageLevelDayTypeFinish_{r,s,ls,ld-1,y} \\
 &+ \sum_{lhlh:lh-lhlh>0} NetChargeWithinDay_{r,s,ls,ld,lhlh,y} \\
 &- StorageUpperLimit_{r,s,y}
 \end{aligned} \tag{51}$$

**5.52 SC4\_UpperLimit\_BeginningOfDayTimeBracketOfFirstInstanceOfDayTypeInLastW**

$$\begin{aligned}
 StorageLevelDayTypeFinish_{r,s,ls,ld-1,y} \\
 &+ \sum_{lhlh:lh-lhlh>0} NetChargeWithinDay_{r,s,ls,ld,lhlh,y} \\
 &- StorageUpperLimit_{r,s,y} \leq 0
 \end{aligned} \tag{52}$$

**5.53 SC5\_MaxChargeConstraint**

$$RateOfStorageCharge_{r,s,ls,ld,lh,y} \leq StorageMaxChargeRate_{r,s} \tag{53}$$

**5.54 SC6\_MaxDischargeConstraint**

$$RateOfStorageDischarge_{r,s,ls,ld,lh,y} \leq StorageMaxDischargeRate_{r,s} \tag{54}$$

**5.55 SI1\_StorageUpperLimit**

$$AccumulatedNewStorageCapacity_{r,s,y} + ResidualStorageCapacity_{r,s,y} = StorageUpperLimit_{r,s,y} \tag{55}$$

## 5.56 SI2\_StorageLowerLimit

$$\text{MinStorageCharge}_{r,s,y} \cdot \text{StorageUpperLimit}_{r,s,y} = \text{StorageLowerLimit}_{r,s,y} \quad (56)$$

## 5.57 SI3\_TotalNewStorage

$$\sum_{\substack{yy \in YEAR: \\ (y - yy < \text{OperationalLifeStorage}_{r,s}) \\ \wedge (y - yy \geq 0)}} \text{NewStorageCapacity}_{r,s,yy} = \text{AccumulatedNewStorageCapacity}_{r,s,y} \quad (57)$$

## 5.58 SI4\_UndiscountedCapitalInvestmentStorage

$$\text{CapitalCostStorage}_{r,s,y} \cdot \text{NewStorageCapacity}_{r,s,y} = \text{CapitalInvestmentStorage}_{r,s,y} \quad (58)$$

## 5.59 SI5\_DiscountingCapitalInvestmentStorage

$$\frac{\text{CapitalInvestmentStorage}_{r,s,y}}{(1 + \text{DiscountRate}_r)^{y - \min(YEAR)}} = \text{DiscountedCapitalInvestmentStorage}_{r,s,y} \quad (59)$$

## 5.60 SI6\_SalvageValueStorageAtEndOfPeriod1

$$0 = \text{SalvageValueStorage}_{r,s,y} \quad (60)$$

## 5.61 SI7\_SalvageValueStorageAtEndOfPeriod2

$$\text{CapitalInvestmentStorage}_{r,s,y} \cdot \left(1 - \frac{\max(YEAR) - y + 1}{\text{OperationalLifeStorage}_{r,s}}\right) = \text{SalvageValueStorage}_{r,s,y} \quad (61)$$

## 5.62 SI8\_SalvageValueStorageAtEndOfPeriod3

$$\begin{aligned} & \text{CapitalInvestmentStorage}_{r,s,y} \\ & \cdot \left(1 - \frac{(1 + \text{DiscountRate}_r)^{\max(YEAR) - y + 1} - 1}{(1 + \text{DiscountRate}_r)^{\text{OperationalLifeStorage}_{r,s}} - 1}\right) = \text{SalvageValueStorage}_{r,s,y} \end{aligned} \quad (62)$$

## 5.63 SI9\_SalvageValueStorageDiscountedToStartYear

$$\frac{\text{SalvageValueStorage}_{r,s,y}}{(1 + \text{DiscountRate}_r)^{\max(YEAR) - \min(YEAR) + 1}} = \text{DiscountedSalvageValueStorage}_{r,s,y} \quad (63)$$

## 5.64 SI10\_TotalDiscountedCostByStorage

$$\text{DiscountedCapitalInvestmentStorage}_{r,s,y} - \text{DiscountedSalvageValueStorage}_{r,s,y} = \text{TotalDiscountedStorageCost}_{r,s,y} \quad (64)$$

## 5.65 CC1\_UndiscountedCapitalInvestment

$$\begin{aligned} \text{CapitalInvestment}_{r,t,y} = & \text{NewCapacity}_{r,t,y} \cdot \text{CapitalCost}_{r,t,y} \cdot \text{CRF}_{new} \cdot \text{PV}_{new} \\ & + \text{RecoveredCapacity}_{r,t,y} \cdot \text{CostoRecuperacion}_{r,t,y} \cdot \text{CRF}_{rec} \cdot \text{PV}_{rec} \\ & + \text{RecoveredNewCapacity}_{r,t,y} \cdot \text{CostoRecuperacion}_{r,t,y} \cdot \text{CRF}_{rec} \cdot \text{PV}_{rec} \\ & + \text{RecoveredExistingUnits}_{r,t,y} \cdot \text{CapacityOfOneTechnologyUnit}_{r,t,y_0} \\ & \cdot \text{CostoRecuperacion}_{r,t,y} \cdot \text{CRF}_{rec} \cdot \text{PV}_{rec} \end{aligned} \quad (65)$$

## 5.66 CC2\_DiscountingCapitalInvestment

$$\text{DiscountedCapitalInvestment}_{r,t,y} = \frac{\text{CapitalInvestment}_{r,t,y}}{\text{DiscountFactor}_{r,y}} \quad (66)$$

## 5.67 SV123\_SalvageValueAtEndOfPeriod1

$$\begin{aligned}
SalvageValue_{r,t,y} = & NewCapacity_{r,t,y} \cdot CapitalCost_{r,t,y} \cdot CRF_{new} \cdot PV_{new} \cdot f_{new} \\
& + RecoveredNewCapacity_{r,t,y} \cdot CostoRecuperacion_{r,t,y} \cdot CRF_{rec} \cdot PV_{rec} \cdot f_{rec} \\
& + RecoveredCapacity_{r,t,y} \cdot CostoRecuperacion_{r,t,y} \cdot CRF_{rec} \cdot PV_{rec} \cdot f_{rec} \\
& + RecoveredExistingUnits_{r,t,y} \cdot CapacityOfOneTechnologyUnit_{r,t,y_0} \\
& \cdot CostoRecuperacion_{r,t,y} \cdot CRF_{rec} \cdot PV_{rec} \cdot f_{rec}
\end{aligned} \tag{67}$$

## 5.68 SV4\_SalvageValueDiscountedToStarYear

$$DiscountedSalvageValue_{r,t,y} = \frac{SalvageValue_{r,t,y}}{(1 + DiscountRate_r)^{1+(y_L-y_0)}} \tag{68}$$

## 5.69 OC1\_OperatingCostVariable

$$\sum_{m: VariableCost_{r,t,m,y} \neq 0} TotalAnnualTechnologyActivityByMode_{r,t,m,y} \cdot VariableCost_{r,t,m,y} = AnnualVariableOperatingCost_{r,t,y} \tag{69}$$

## 5.70 OC2\_OperatingCostsFixedAnnual

$$TotalCapacityAnnual_{r,t,y} \cdot FixedCost_{r,t,y} = AnnualFixedOperatingCost_{r,t,y} \tag{70}$$

## 5.71 OC3\_OperatingCostsTotalAnnual

$$AnnualFixedOperatingCost_{r,t,y} + AnnualVariableOperatingCost_{r,t,y} = OperatingCost_{r,t,y} \tag{71}$$

## 5.72 OC4\_DiscountedOperatingCostsTotalAnnual

$$\frac{OperatingCost_{r,t,y}}{DiscountFactorMid_{r,y}} = DiscountedOperatingCost_{r,t,y} \tag{72}$$

## 5.73 TDC1\_TotalDiscountedCostByTechnology

$$\begin{aligned}
& DiscountedOperatingCost_{r,t,y} + DiscountedCapitalInvestment_{r,t,y} \\
& + DiscountedTechnologyEmissionsPenalty_{r,t,y} \\
& - DiscountedSalvageValue_{r,t,y} \\
& = TotalDiscountedCostByTechnology_{r,t,y}
\end{aligned} \tag{73}$$

## 5.74 TDC2\_TotalDiscountedCost

$$\begin{aligned}
& \sum_t TotalDiscountedCostByTechnology_{r,t,y} + \sum_s TotalDiscountedStorageCost_{r,s,y} \\
& = TotalDiscountedCost_{r,y}
\end{aligned} \tag{74}$$

## 5.75 TCC1\_TotalAnnualMaxCapacityConstraint

$$TotalCapacityAnnual_{r,t,y} \leq TotalAnnualMaxCapacity_{r,t,y} \tag{75}$$

## 5.76 TCC2\_TotalAnnualMinCapacityConstraint

$$TotalCapacityAnnual_{r,t,y} \geq TotalAnnualMinCapacity_{r,t,y} \tag{76}$$

## 5.77 NCC1\_TotalAnnualMaxNewCapacityConstraint

$$NewCapacity_{r,t,y} \leq TotalAnnualMaxCapacityInvestment_{r,t,y} \tag{77}$$

### 5.78 NCC2\_TotalAnnualMinNewCapacityConstraint

$$NewCapacity_{r,t,y} \geq TotalAnnualMinCapacityInvestment_{r,t,y} \quad (78)$$

### 5.79 AAC1\_TotalAnnualTechnologyActivity

$$\sum_l RateOfTotalActivity_{r,t,l,y} \cdot YearSplit_{l,y} = TotalTechnologyAnnualActivity_{r,t,y} \quad (79)$$

### 5.80 AAC2\_TotalAnnualTechnologyActivityUpperLimit

$$TotalTechnologyAnnualActivity_{r,t,y} \leq TotalTechnologyAnnualActivityUpperLimit_{r,t,y} \quad (80)$$

### 5.81 AAC3\_TotalAnnualTechnologyActivityLowerLimit

$$TotalTechnologyAnnualActivity_{r,t,y} \geq TotalTechnologyAnnualActivityLowerLimit_{r,t,y} \quad (81)$$

### 5.82 TAC1\_TotalModelHorizonTechnologyActivity

$$\sum_y TotalTechnologyAnnualActivity_{r,t,y} = TotalTechnologyModelPeriodActivity_{r,t} \quad (82)$$

### 5.83 TAC2\_TotalModelHorizonTechnologyActivityUpperLimit

$$TotalTechnologyModelPeriodActivity_{r,t} \leq TotalTechnologyModelPeriodActivityUpperLimit_{r,t} \quad (83)$$

### 5.84 TAC3\_TotalModelHorizonTechnologyActivityLowerLimit

$$TotalTechnologyModelPeriodActivity_{r,t} \geq TotalTechnologyModelPeriodActivityLowerLimit_{r,t} \quad (84)$$

### 5.85 RM3\_ReserveMargin\_Constraint

$$\begin{aligned} & \sum_{t,m,f:OutputActivityRatio \neq 0} RateOfActivity_{r,l,t,m,y} \cdot OutputActivityRatio_{r,t,f,m,y} \\ & \cdot ReserveMarginTagFuel_{r,f,y} \cdot ReserveMargin_{r,y} \\ & \leq \sum_t \left( \sum_{\substack{yy \in YEAR: \\ (y-yy < OperationalLife_{r,t}) \\ \wedge (y-yy \geq 0)}} NewCapacity_{r,t,yy} + ResidualCapacity_{r,t,y} \right) \\ & \cdot ReserveMarginTagTechnology_{r,t,y} \cdot CapacityToActivityUnit_{r,t} \end{aligned} \quad (85)$$

### 5.86 RE1\_FuelProductionByTechnologyAnnual

$$\sum_l ProductionByTechnology_{r,l,t,f,y} = ProductionByTechnologyAnnual_{r,t,f,y} \quad (86)$$

### 5.87 RE2\_TechIncluded

$$\sum_{t,f} ProductionByTechnologyAnnual_{r,t,f,y} \cdot RETagTechnology_{r,t,y} = TotalREProductionAnnual_{r,y} \quad (87)$$

### 5.88 RE3\_FuelIncluded

$$\sum_{l,f} RateOfProduction_{r,l,f,y} \cdot YearSplit_{l,y} \cdot RETagFuel_{r,f,y} = RETotalProductionOfTargetFuelAnnual_{r,y} \quad (88)$$

## 5.89 RE4\_EnergyConstraint

$$RETotalProductionOfTargetFuelAnnual_{r,y} \cdot REMinProductionTarget_{r,y} \leq TotalREProductionAnnual_{r,y} \quad (89)$$

## 5.90 RE5\_FuelUseByTechnologyAnnual

$$\sum_l RateOfUseByTechnology_{r,l,t,f,y} \cdot YearSplit_{l,y} = UseByTechnologyAnnual_{r,t,f,y} \quad (90)$$

## 5.91 E1\_AnnualEmissionProductionByMode

$$EmissionActivityRatio_{r,t,e,m,y} \cdot TotalAnnualTechnologyActivityByMode_{r,t,m,y} = AnnualTechnologyEmissionByMode_{r,t,e,m,y} \quad (91)$$

## 5.92 E2\_AnnualEmissionProduction

$$\sum_m AnnualTechnologyEmissionByMode_{r,t,e,m,y} = AnnualTechnologyEmission_{r,t,e,y} \quad (92)$$

## 5.93 E3\_EmissionsPenaltyByTechAndEmission

$$AnnualTechnologyEmission_{r,t,e,y} \cdot EmissionsPenalty_{r,e,y} = AnnualTechnologyEmissionPenaltyByEmission_{r,t,e,y} \quad (93)$$

## 5.94 E4\_EmissionsPenaltyByTechnology

$$\sum_e AnnualTechnologyEmissionPenaltyByEmission_{r,t,e,y} = AnnualTechnologyEmissionsPenalty_{r,t,y} \quad (94)$$

## 5.95 E5\_DiscountedEmissionsPenaltyByTechnology

$$\frac{AnnualTechnologyEmissionsPenalty_{r,t,y}}{DiscountFactorMid_{r,y}} = DiscountedTechnologyEmissionsPenalty_{r,t,y} \quad (95)$$

## 5.96 E6\_EmissionsAccounting1

$$\sum_t AnnualTechnologyEmission_{r,t,e,y} = AnnualEmissions_{r,e,y} \quad (96)$$

## 5.97 E7\_EmissionsAccounting2

$$\sum_y AnnualEmissions_{r,e,y} = ModelPeriodEmissions_{r,e} - ModelPeriodExogenousEmission_{r,e} \quad (97)$$

## 5.98 E8\_AnnualEmissionsLimit

$$AnnualEmissions_{r,e,y} + AnnualExogenousEmission_{r,e,y} \leq AnnualEmissionLimit_{r,e,y} \quad (98)$$

## 5.99 E9\_ModelPeriodEmissionsLimit

$$ModelPeriodEmissions_{r,e} \leq ModelPeriodEmissionLimit_{r,e} \quad (99)$$

## 5.100 Must\_Run

$$\begin{aligned} RateOfTotalActivity_{r,t,l,y} &\geq MustRunTech_{r,t,y} \cdot TotalCapacityAnnual_{r,t,y} \\ &\cdot CapacityFactor_{r,t,l,y} \cdot CapacityToActivityUnit_{r,t} \\ &\cdot AvailabilityFactor_{r,t,y} \end{aligned} \quad (100)$$