OpenMod Africa

plan4res

The plan4res modelling suite

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- Scope of Model
- Optimisation Methods

Scope of Model

The plan4res electricity system modelling suite

a Stochastic Power System model composed of 3 embedded layers:

- ***The Capacity expansion model computes the optimal mix on a given year***
  - ✓ electric generation plants,
  - ✓ Short term storages (batteries….),
  - ✓ interconnection capacities
- ***The seasonal storage valuation model computes the optimal strategy for seasonal storages***
  - ✓ For Hydro reservoirs
  - ✓ And also all other 'seasonal' flexibilities such as Seasonal Demand response
- ***The European unit commitment (EUC) model computes the optimal dispatch:***
  - ✓ Supply power demand and ancillary services
  - ✓ Minimal inertia in the system
  - ✓ Maximum transmission and distribution capacities between clusters
  - ✓ Technical (including dynamic) constraints of all assets

Plan4res is based on the SMS++ optimisation and modelling framework

[The SMS++ Project]

The SMS++ Project

A Structured Modeling System for mathematical models

Main characteristics

❑ Adaptable Geography perimeter

- Europe or lower perimeter
- Subcountry representation is possible

❑ Uncertainties:

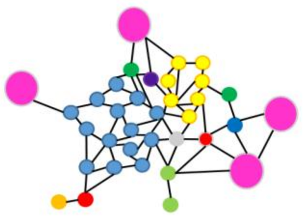
- Electricity demand
- RES profiles (PV, Wind, RoR…)
- Inflows
- Failures of traditional plants

❑ Modular Time horizon and granularity

- Typically 1 yr. with hourly granularity

❑ Modular Grid

- Regions and interconnections
- Regions can be:
  - Countries
  - Groups of countries
  - Sub country regions



❑ Power plants

- Operational decision of power plants based on their specific fuel costs
- Technical constraints (ramping, min up-/downtimes,…)

❑ Storages

- Hydro storages including complex cascaded systems
- Battery storages

❑ Intermittent generation

- Generation of wind, solar, run of river based on meteorological profiles

❑ E-mobility

- Storage capability of electric vehicles (vehicle-to-grid, power-to-vehicle)
- Limitation of storage availability by driving profiles

❑ Demand Response

- Load shifting of a given energy consumption during a sub-period
- Load curtailment based on a given potential (e.g. during one year)

Thermal power plants

- Constraints
  - Minimum and maximum power
  - Ramping rate limits
  - Minimum up and down times
  - Simple constraints between active power and reserves
  - Simple modelling of inertia and system services
- Cost functions
  - Convex quadratic or piecewise linear (cutting plane model)
  - Start up costs

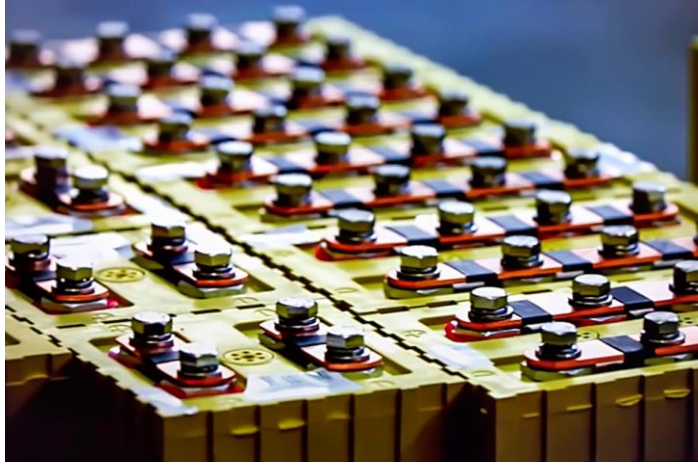
Intermittent Generation

- Constraints
  - Maximum power depending on uncertainty scenarios
  - Ramping rate limits
  - Simple constraints between active power and reserves
  - Simple modelling of inertia and system services
- Cost functions
  - Linear (usually no cost)

Seasonal storage

- Constraints
  - Minimum and maximum volume of the reservoir
  - Minimum and maximum power injections
  - For each turbine, minimum and maximum ow rate of water
  - Power is given as a function of ow rate by a concave cutting plane model
  - Ramping rate limits on ow rates
  - Simple constraints between active power and reserves
- Valleys can be modeled
  - Valley are modeled as a graph with arcs connecting the reservoirs
  - For each arc, uphill and downhill ow delays
  - But requires extensions to pre-processing
- Cost functions are provided by the Seasonal Storage Valuation (SSV) as a Cutting plan model

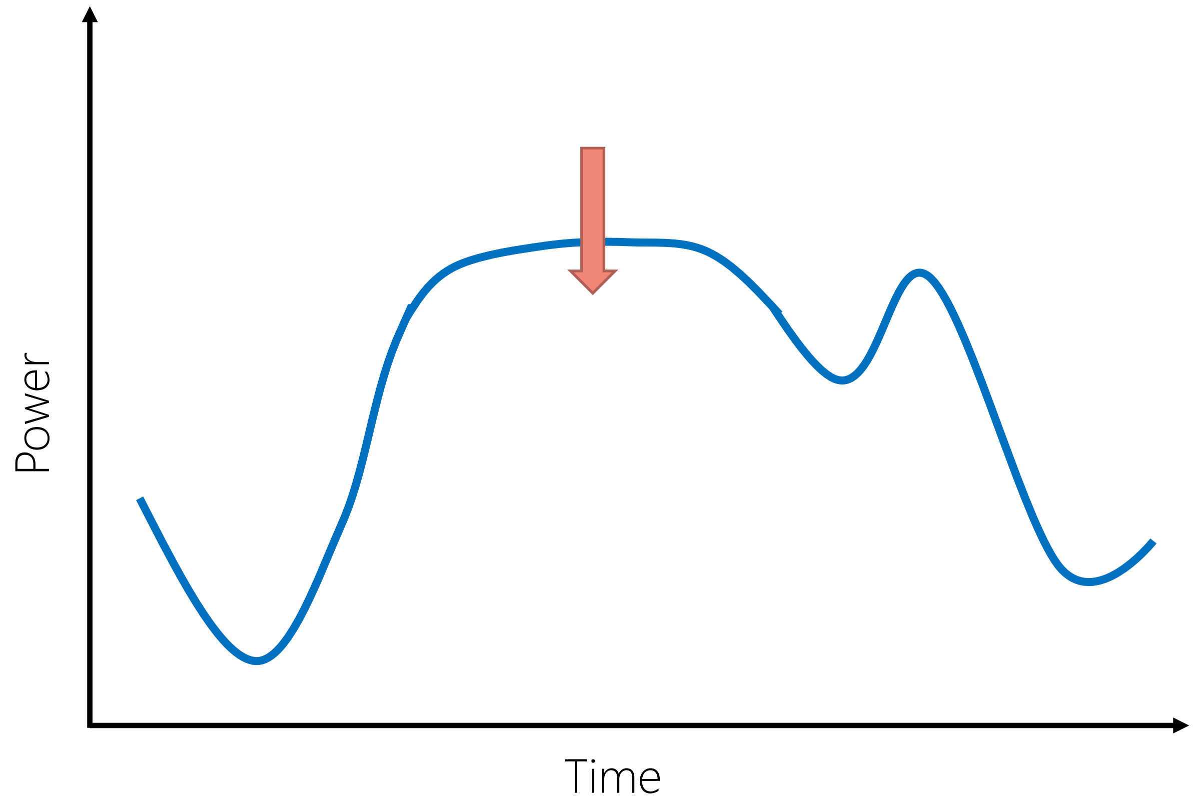
Short term storage



- Constraints
  - Minimum and maximum volume of the storage
  - Minimum and maximum injected power into the grid
  - Ramping rate limits
  - Potentially different injection and withdrawing efficiency ratio
  - Simple constraints between active power and reserves
  - Simple modelling of inertia and system services (eg for hydro)
- Cost functions
  - Linear costs

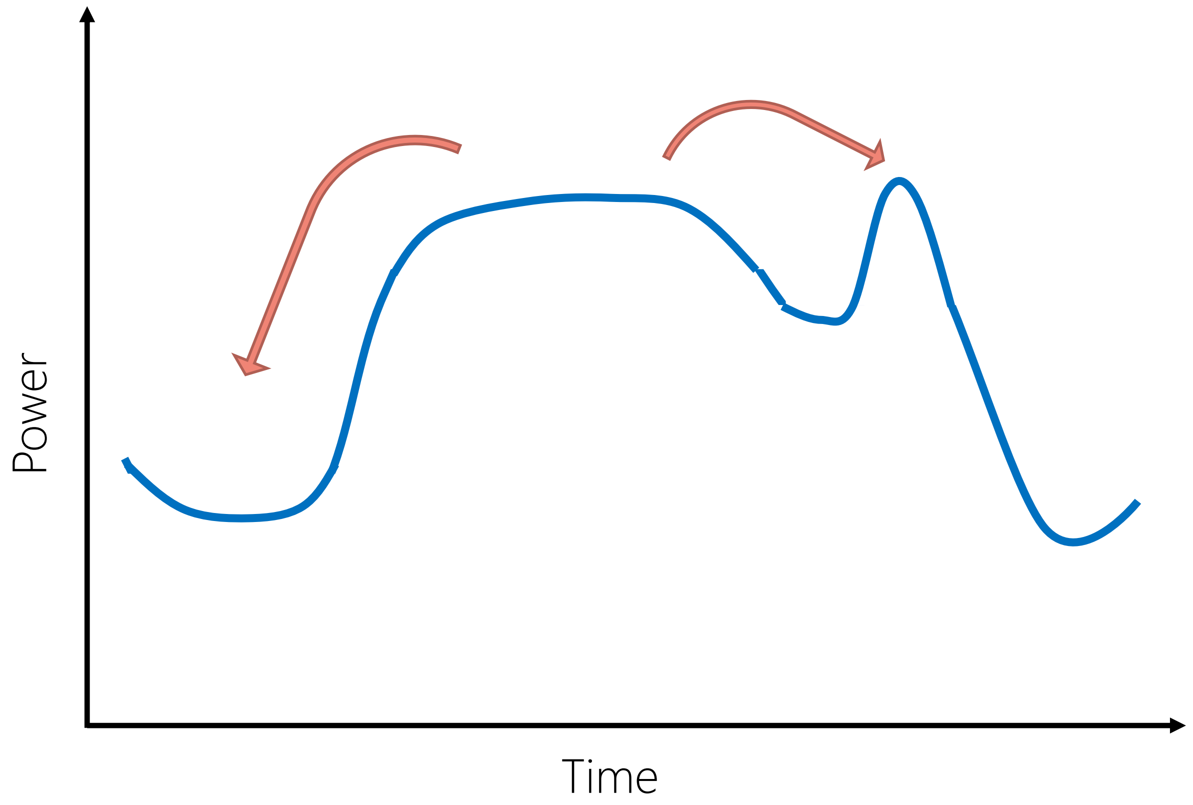
Demand Response : Load curtailment

- Load curtailment Ex: Mid-term contracts (for instance annual contracts) between utilities and consumers, where each consumer agrees to reduce his consumption when this is required by the utility
  - Energy storage that can be optimized over the whole mid-term horizon as a seasonal storage



Demand Response : Load Shifting

- Load shifting (Ex: Appliances with fixed energy needs on a given period allowing some flexibility on the load profile e.g. EV battery)
  - Data: a reference consumption signal with a given energy consumption on a given period
  - The flexible profile (to be optimally chosen) should
    - in terms of energy: consume the same energy as the reference prole on the given period
    - in terms power: not deviate to much from the reference prole



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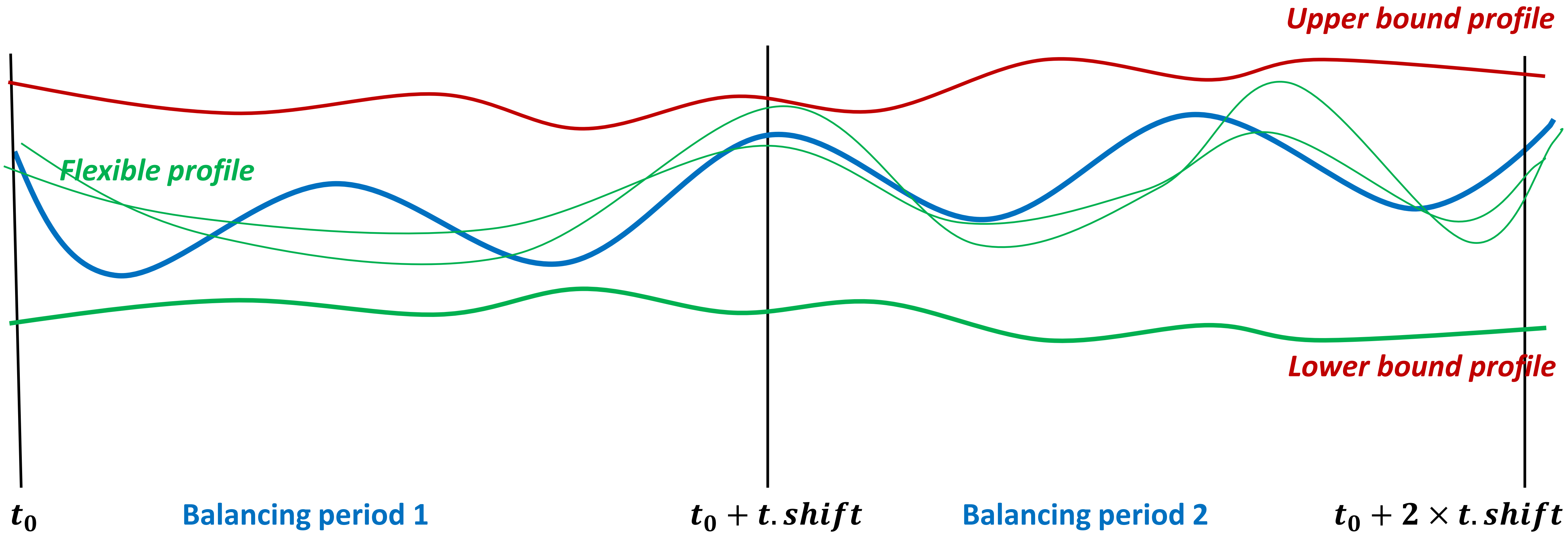
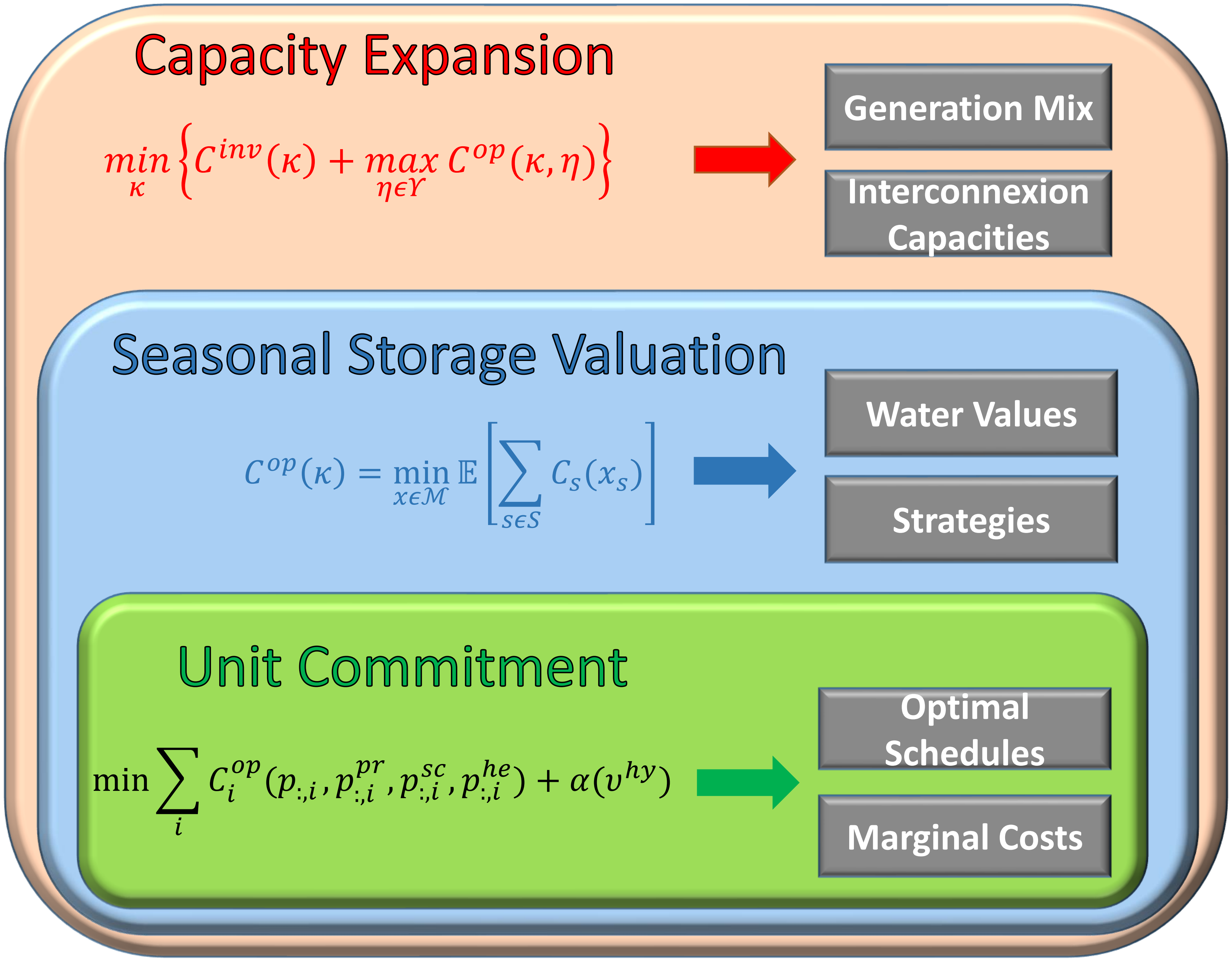
Modelling load shifting



Optimisation Problems

- **The Capacity expansion model** computes the optimal mix:
  - ✓ *electric generation plants,*
  - ✓ *storages,*
  - ✓ *interconnection capacities between clusters*
  - ✓ *distribution grid capacities,*
- **The seasonal storage valuation model** computes the operation strategies for seasonal storages:
  - ✓ *For Hydro reservoirs*
  - ✓ *And also all other 'seasonal' flexibilities such as Demand response*
- **The European unit commitment model** computes the optimal operation schedule for all the assets dealing with constraints:
  - ✓ *Supply power demand and ancillary services*
  - ✓ *Minimal inertia in the system*
  - ✓ *Maximum transmission and distribution capacities between clusters*
  - ✓ *Technical constraints of all assets*



Unit Commitment

Compute dispatch for all assets on a short-term horizon (eg. 1 week)

$$\min \sum_i C_i^{op}(p_{:,i}, p_{:,i}^{pr}, p_{:,i}^{sc}) + \alpha(v^{hy})$$

C_i^{op}: Operational costs of unit i subject to it‘s operational variables

$p_{t,i}, p_{t,i}^{pr}, p_{t,i}^{sc}$: Provision of power, primary/secondary reserve by unit i in timestep t submitted to dynamic constraints

α: Approximation of the value of seasonal storages

v^{hy}: Storage level

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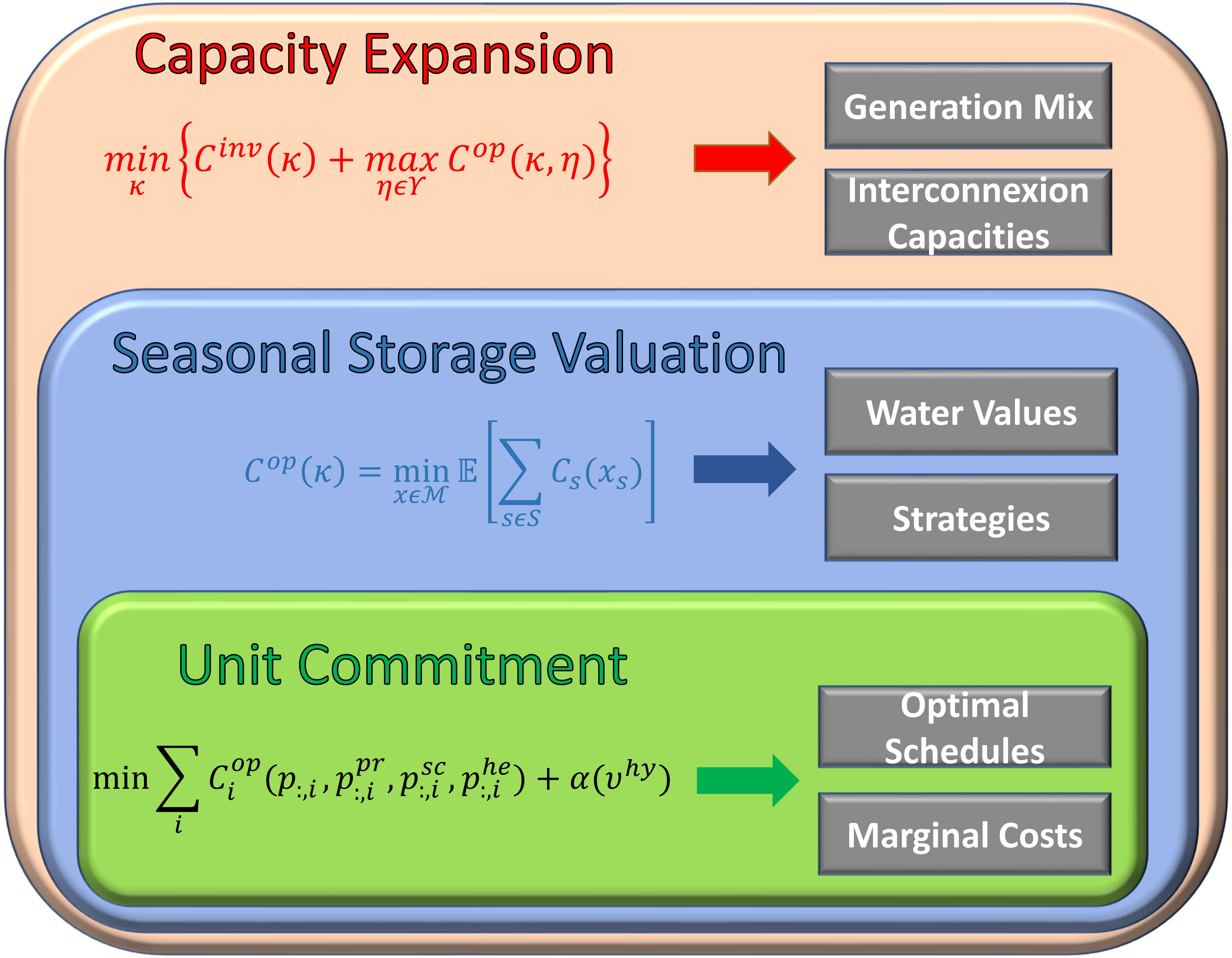

Seasonal Storage Valuation

Compute strategies for managing seasonal storage on a mid-term horizon (eg 1 year)

$$C^{op}(\kappa) = \min_{x \epsilon \mathcal{M}} \mathbb{E}\left[\sum_{s \epsilon S} C_s(x_s)\right]$$

$\boldsymbol{C^{op}(\kappa)}$: Operational costs depending on investment decisions κ

$\boldsymbol{C_s}$: Operational costs on sub-period s

$\boldsymbol{\mathcal{M}}$: Feasible set associated with operation decisions

$\boldsymbol{S}$: Set of sub-periods (e.g. weeks)

$\boldsymbol{x}$: Operation decisions on sub-period s

$\boldsymbol{\kappa}$: Investment decisions taken by capacity expansion model

- **The Capacity expansion model** computes the optimal mix:
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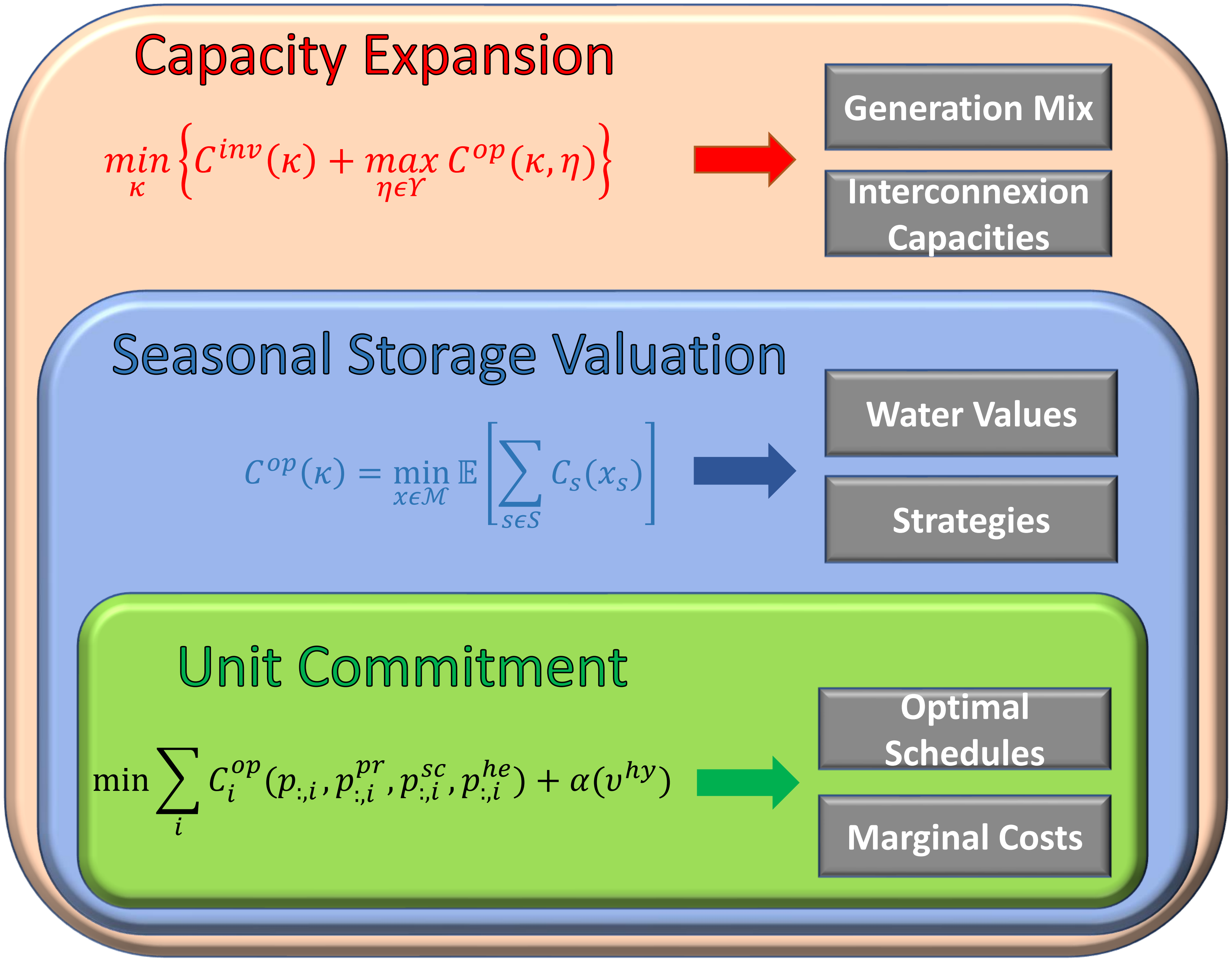


Capacity Expansion

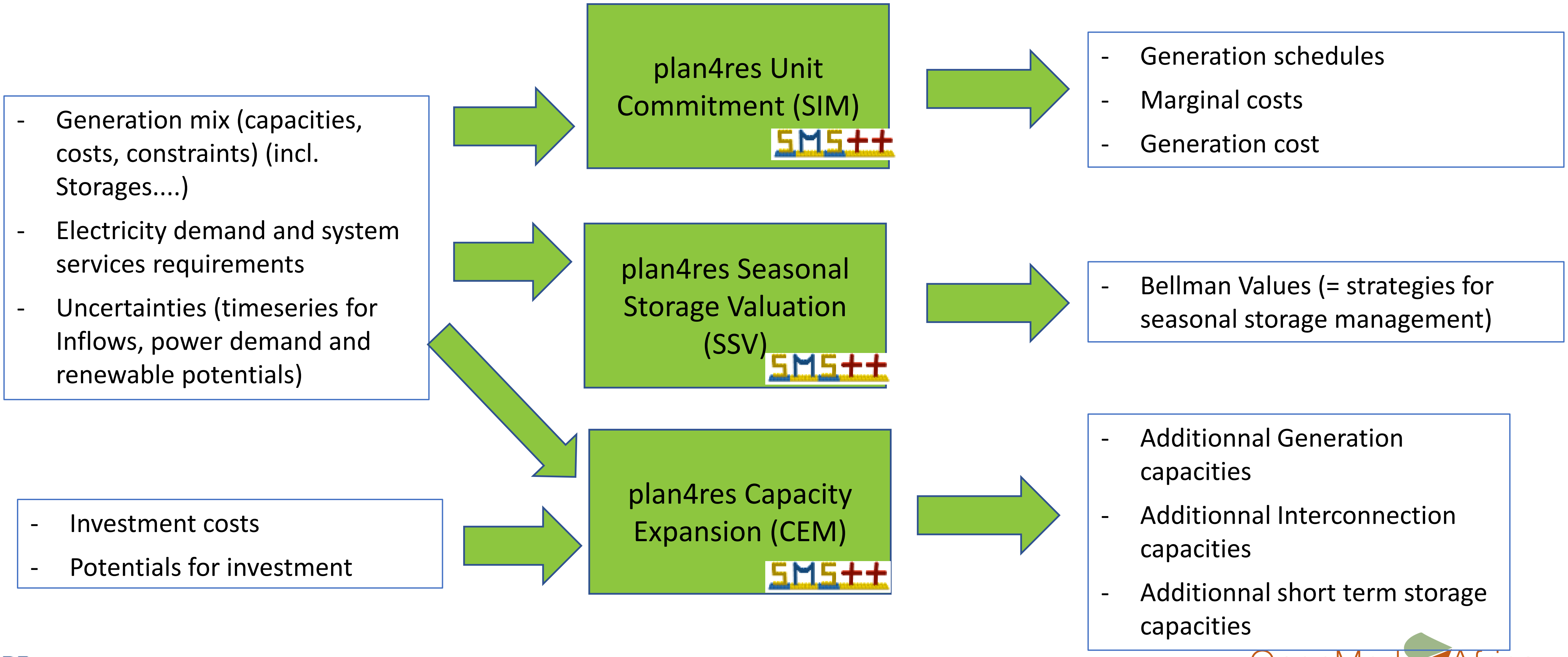
Design the optimal generation, transmission and distribution mix for a given long-term horizon (eg. 2050)

$$\min_{\kappa}\left\{C^{inv}(\kappa) + min \underset{\eta\epsilon\Upsilon}{E} C^{op}(\kappa,\eta)\right\}$$

$\boldsymbol{\kappa}$: Investment decisions (generation assets, transmission)
$\boldsymbol{\Upsilon}$: Set of uncertainty scenarios
$\boldsymbol{C^{inv}}$: Costs induced by installing capacitiy κ
$\boldsymbol{C^{op}}$: Expected operational costs with given capacity κ

Inputs and Outputs

Inputs and Outputs



Input Format: excel and csv files

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[Data format and linkages – africaenergymodels.net]

			MW	MW	€/MWh	€/MW/yr	MW	MW	€/MW
Zone	Name	NumberUnits	MaxPower	MinPower	VariableCost	FixedCost	MaxAddedCapacity	MaxRetCapacity	InvestmentCost
Baltics	Biomass|w/ CCS	1	140.00	0	42.7947925	64350	0	0	9704850
Benelux	Biomass|w/ CCS	1	6 596.00	0	42.7947925	64350	1000	0	9704850
Britain	Biomass|w/ CCS	1	7 107.00	0	42.7947925	64350	2000	0	9704850
Denmark	Biomass|w/ CCS	1	3 018.00	0	42.7947925	64350	0	0	9704850
EasternEu	Biomass|w/ CCS	1	23 701.00	0	42.7947925	64350	2000	0	9704850
Finland	Biomass|w/ CCS	1	10.00	0	42.7947925	6			
Germany	Biomass|w/ CCS	1	23 431.00	0	42.7947925	6			
Iberia	Biomass|w/ CCS	1	8 439.00	0	42.7947925	6			
Norway	Biomass|w/ CCS	1	278.00	0	42.7947925	6			
Balkans	Biomass|w/o CCS	1	346.162174	0	38.304	4			
Baltics	Biomass|w/o CCS	1	390.834754	0	38.304	4			
Benelux	Biomass|w/o CCS	1	674.853699	0	38.304	4			
Britain	Biomass|w/o CCS	1	1876.66987	0	38.304	4			

								MW	MW	€/MW
Name	Type	Direction	StartLine	EndLine	MaxPowerFlow	MinPowerFlow	Impedance	MaxAddedCapacity	MaxRetCapacity	InvestmentCost
Denmark>Germany	AC	Bidirectior	Denmark	Germany	3100	-3100	0	10000	0	2142500
Denmark>Norway	AC	Bidirectior	Denmark	Norway	1700	-1700	0	10000	0	2142500
Denmark>Sweden	AC	Bidirectior	Denmark	Sweden	2440	-2440	0	10000	0	2142500
Finland>Sweden	AC	Bidirectior	Finland	Sweden	1950	-2250	0	10000	0	2142500
France>Germany	AC	Bidirectior	France	Germany	9547.99513	-8260	0	10000	0	2142500
France>Italy	AC	Bidirectior	France	Italy	866	-1160	0	10000	0	2142500
France>Switzerland	AC	Bidirectior	France	Switzerlan	3200	-1100	0	10000	0	2142500
Germany>Norway	AC	Bidirectior	Germany	Norway	1444	-1444	0	10000	0	2142500
Germany>Sweden	AC	Bidirectior	Germany	Sweden	353.958333	-610	0	10000	0	2142500
								0000	0	2142500
								0000	0	2142500

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0	1	[illegible]	0	[illegible]	0	[illegible]	[illegible]	1	0	[illegible]	0.1	0.1		[illegible]

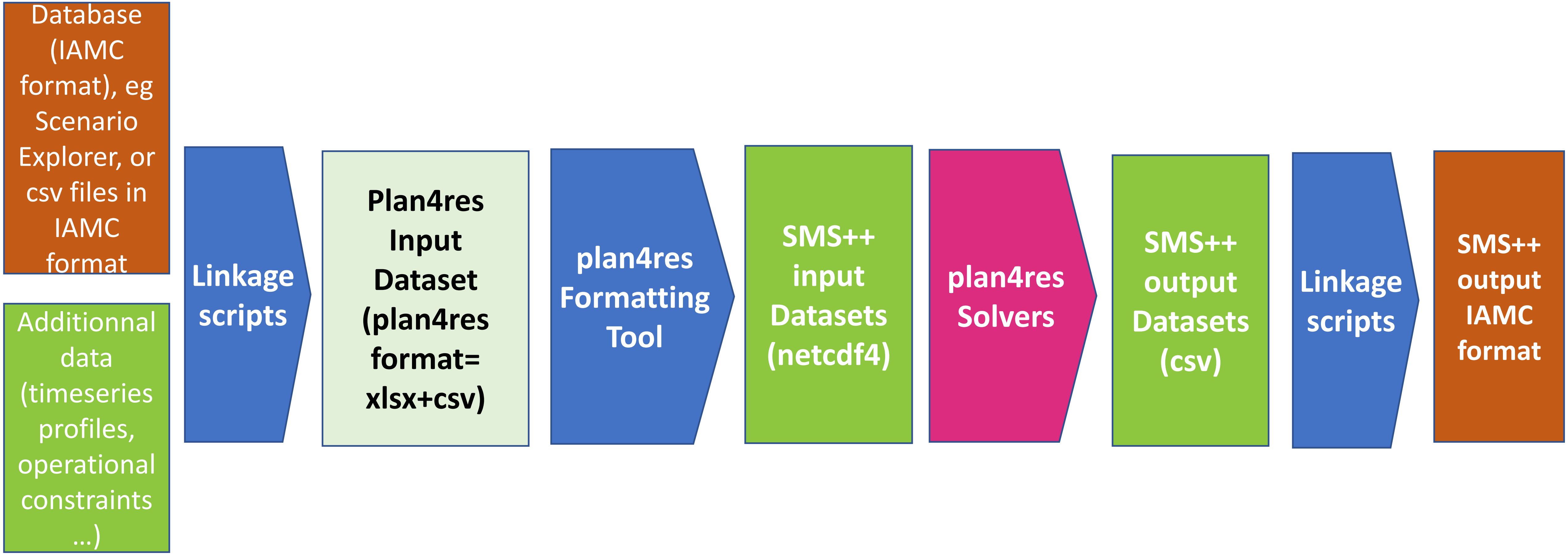
Output Format: csv files

[Data format and linkages – africaenergymodels.net](africaenergymodels.net)

	A	BZ	CA	CK	CL	
1	Timestep	Hydro|Run of River_Italy_0	Hydro|Run of River_Norway_0	Solar|PV_France_0	Solar|PV_Germany_0	So
2	0	8924.261003	9384.602202	0	0	
3	1	8924.261003	9384.602202	0	0	
4	2	8924.261003	9384.602202	0	0	
5	3	8924.261003	9384.602202	0	0	
6	4	8924.261003	9384.602202	0	1264.439101	
7	5	8924.261003	9384.602202	436.4834276	7767.268764	2
8	6	8924.261003	9384.602202	5565.163702	18785.95236	
9	7	8924.261003	9384.602202	16259.00768	28178.92854	2
10	8	0	9384.602202	32081.53193	43352.19775	4
11	9	8924.261003	9384.602202	47685.81447	50758.1982	4
12	10	0	9384.602202	59252.6253	50938.83236	5
13	11	0	9384.602202	66127.23928	54190.24719	
14	12	0	9384.602202	69946.46927	65028.29663	7
15	13	8924.261003	9384.602202	68964.38156	61776.8818	5
16	14	8924.261003	9384.602202	60671.19644	53828.97888	
17	15	8924.261003	9384.602202	44193.94704	55635.32045	5
18	16	8924.261003	9384.602202	28917.02708	43171.56359	
19	17	8924.261003	9384.602202	16259.00768	32333.51416	4
20	18	8924.261003	9384.602202	8293.185124	17340.8791	2

Design of the tool

plan4res design



plan4res design

- Plan4res is composed of:
  - Linkage scripts: from and to IAMC format (python)
  - Formatting tool:
    - Creates NetCDF4 SMS++ inputs
    - C++ version available in the container
    - Currently being rewritten in python
  - Plan4res Solvers
    - Written in C++ based on SMS++

https://gitlab.com/smspp/smspp-project

Main modules:

- ucblock_solver
- sddpsolver
- investmentsolver

Plan4res solving modules

- 3 modules
  - ucblock_solver: solves a deterministic unit commitment problem (usually on 1 week)
  - sddp_solver:
    - Compute bellman values
    - Solves a serie of unit commitments on a sequence of periods, with bellman values as input
  - Investment_solves
    - Compute optimal investments
    - Simulates (= solves series of unit commitment problems on all periods, for all scenarios)

https://gitlab.com/smspp/smspp-project

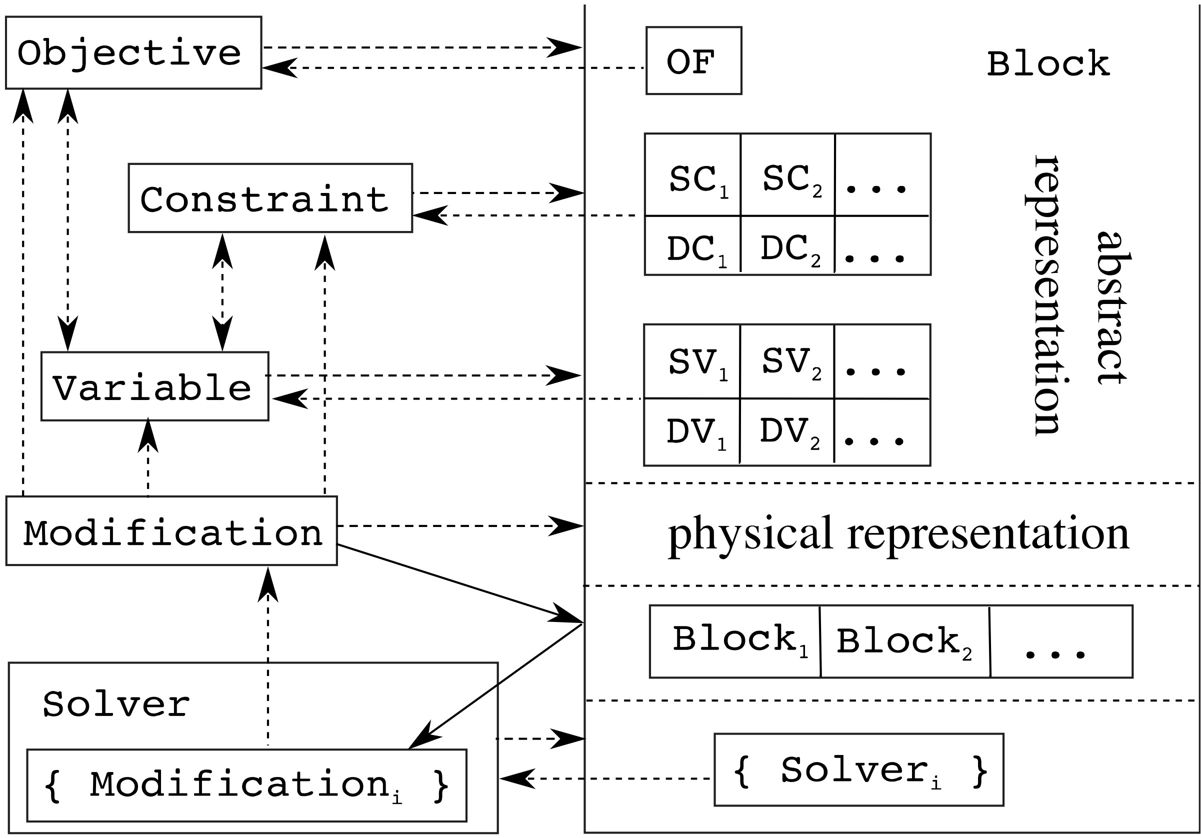
Plan4res solving modules

- The 3 modules are implemeted with the SMS++ framework (developped by University of Pisa)
- They are available within a container (developped by HPE)
- Can run on any platform (Unix, Windows, Mac)
- Includes parallelisation
- Installation process:
  - Download container: git clone –recursive https://gitlab.com/cerl/plan4res/p4r-env.git
  - Install container: bin/p4r
  - Install solvers:
    - CPLEX or equivalent
    - StOpt: : bin/p4r add-on stopt
  - Install SMS++: bin/p4r add-on sms++

https://gitlab.com/smspp/smspp-project

Modelling with SMS++

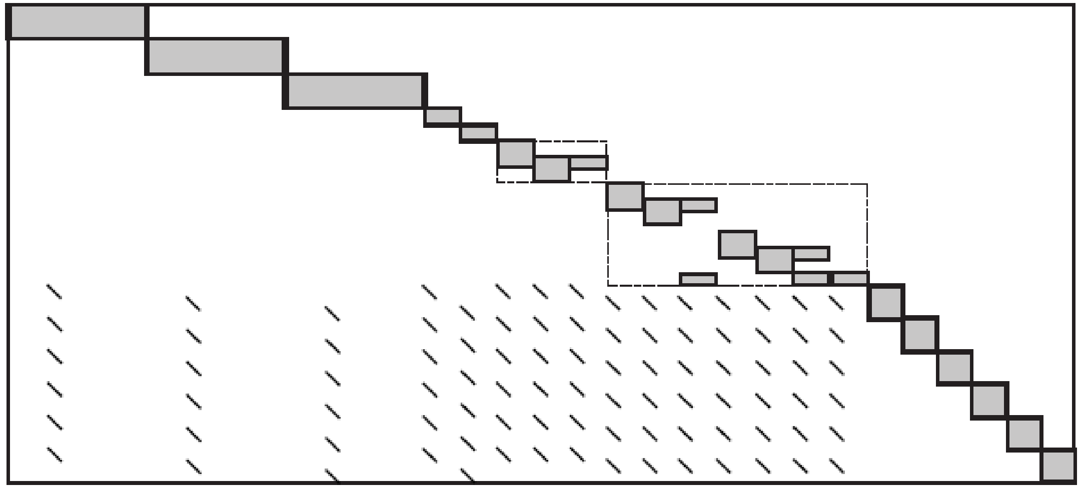
- **SMS++ is a set of C++ classes implementing a modelling system that:**
- allows exploiting specialised solvers
- manages all types of dynamic changes in the model
- Explicitely handles reformulation/restriction/relaxation
- does parallel from the start
- should be able to deal with almost anything (bilevel, PDE,..)
- ***Includes specialized blocks for energy system modelling***



Modelling with SMS++

Nested decompositions at different time horizons

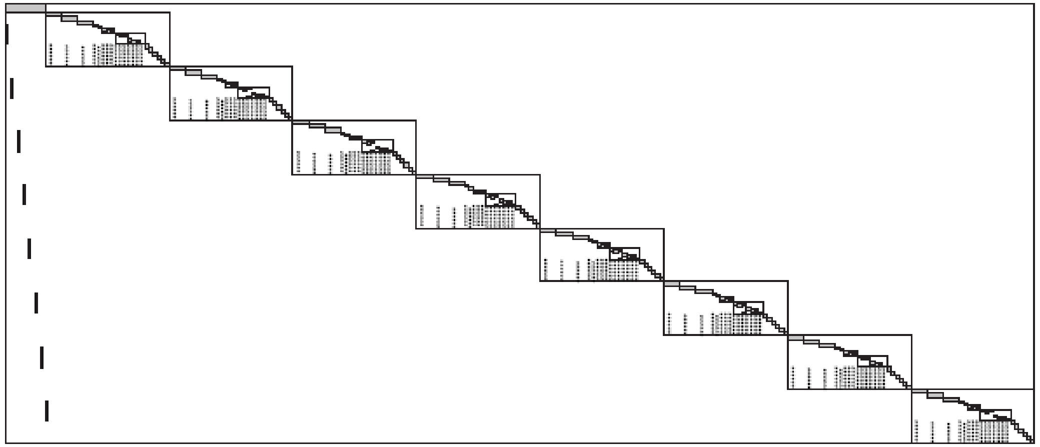
- Schedule a set of generating units to satisfy the demand at each node of the transmission network at each time instant of the horizon (24h)



- Several types of almost independent blocks + linking constraints
- Perfect structure for Lagrangian relaxation[1,2]

[1] Borghetti, F., Lacalandra, Nucci "Lagrangian Heuristics Based on Disaggregated Bundle Methods [...]", *IEEE TPWRS*, 2003
[2] Scuzziato, Finardi, F. "Comparing Spatial and Scenario Decomposition for Stochastic [...]" *IEEE Trans. Sust. En.*, 2018

- Manage water levels in reservoirs considering uncertainties (inflows, temperatures, demands, ...) to minimize costs over the time horizon

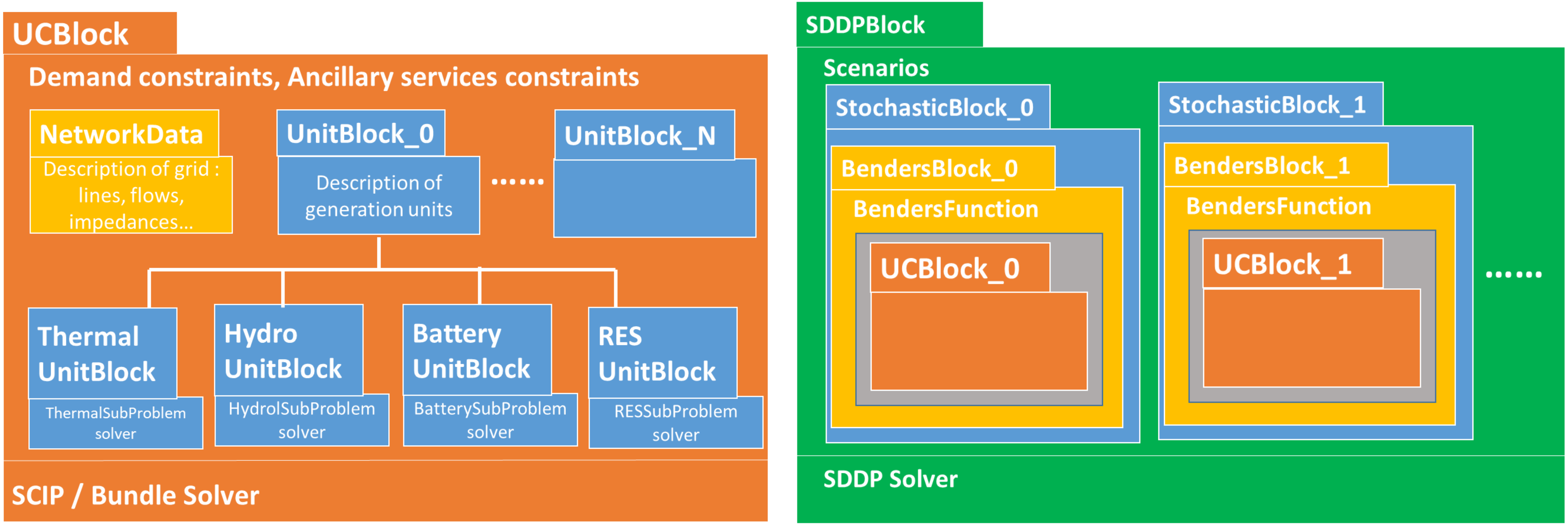


- Very large size, nested structure
- Perfect structure for Stochastic Dual Dynamic Programming[3,4] with multiple EUC inside

[3] Pereira, Pinto "Multi-stage stochastic optimization applied to energy planning" *Math. Prog.*, 1991
[4] van-Ackooij, Warin "On conditional cuts for Stochastic Dual Dynamic Programming" arXiv:1704.06205, 2017

Source: A. Frangioni, Uni Pisa

The Seasonal Storage Valuation and Unit Commitment in SMS++



- Plan4res documentation: [OM4A-Training-Material/plan4res-Training-Material]
- Plan4res gitub (containing all that is necessary for installing and running planRres): plan4res
- SMS++: https://gitlab.com/smspp/smspp-project
- Plan4res on zenodo: https://zenodo.org/communities/plan4res

https://zenodo.org/communities/openentrance

Thank you