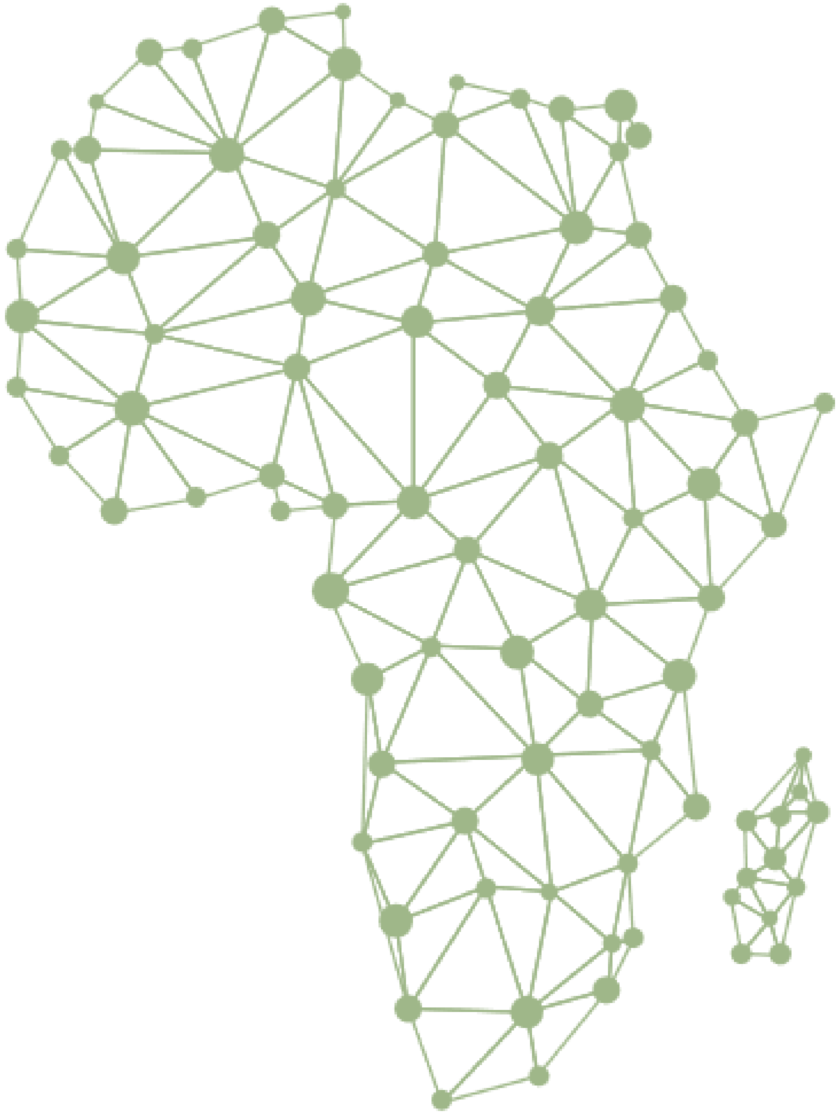

OpenMod Africa

plan4res

plan4res workshop Madrid

Sandrine Charousset,
EDF

June, 19, 2024

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OpenMod Africa

plan4res

The model

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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

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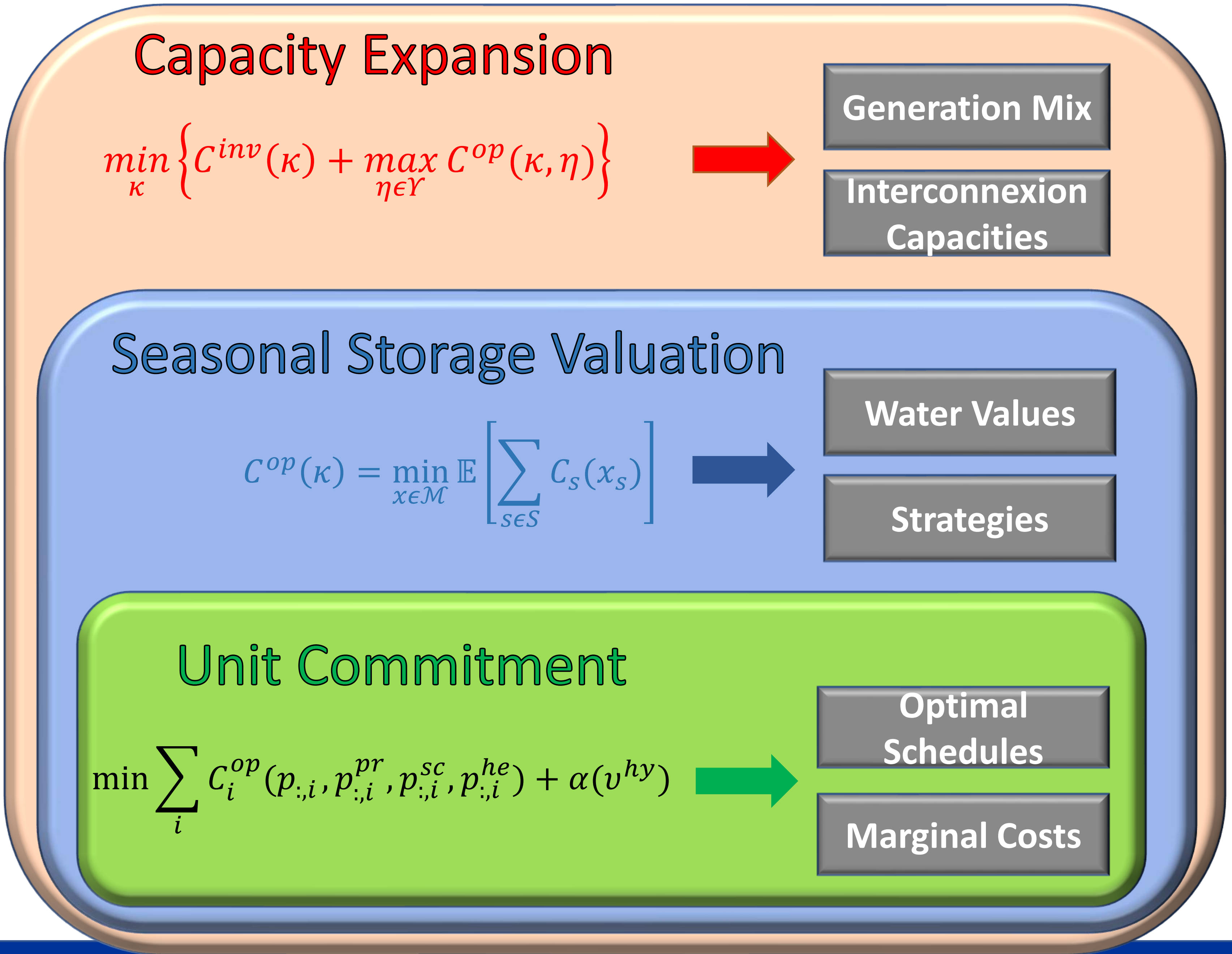
- **The Capacity expansion model** computes the optimal mix:
  - ✓ *electric generation plants,*
  - ✓ *storages,*
  - ✓ *interconnection capacities between clusters*
  - ✓ *distribution grid capacities,*
- **The seasonal storage valuation model** computes the operation strategies for seasonal storages:
  - ✓ *For Hydro reservoirs*
  - ✓ *And also all other 'seasonal' flexibilities such as Demand response*
- **The 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*



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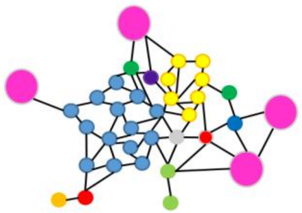
Main characteristics

- ## 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)

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Inputs and Outputs

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Inputs and Outputs

- Generation mix (capacities, costs, constraints) (incl. Storages....)
- Electricity demand and system services rqrts
- Uncertainties

- Investment costs
- Potentials for investment

plan4res Unit Commitment

- Generation schedules
- Marginal costs
- Generation cost

plan4res Seasonal Storage Valuation

- Bellman Values (= strategies for seasonal storage management)

plan4res Capacity Expansion

- Invested Generation capacities
- Invested Interconnection capacities
- Invested short term storage capacities

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Design of the tool

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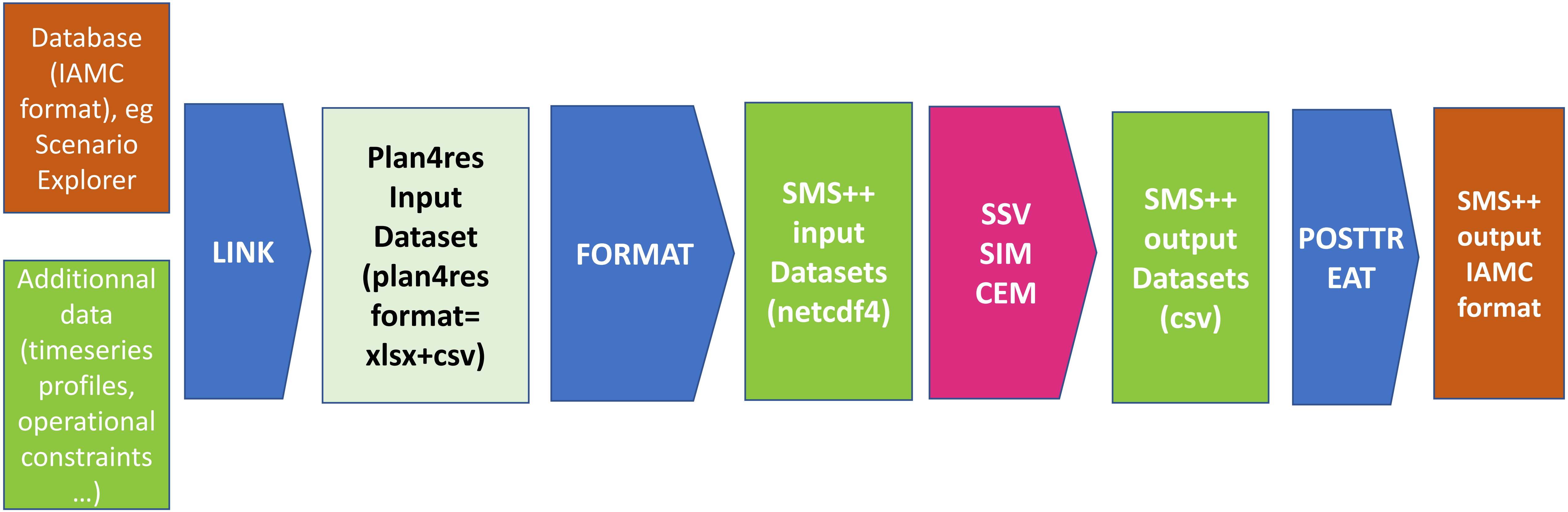
plan4res design



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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

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OpenMod Africa

plan4res

Main modules:

- ucblock_solver
- sddpsolver
- investmentsolver

SMS++

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Plan4res solving modules

- 3 modules
  - *(ucblock_solver: solves a short term 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_solver
    - Compute optimal investments
    - Simulates (= solves series of unit commitment problems on all periods, for all scenarios)

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

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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), but more adapted to Linux
- Includes parallelisation

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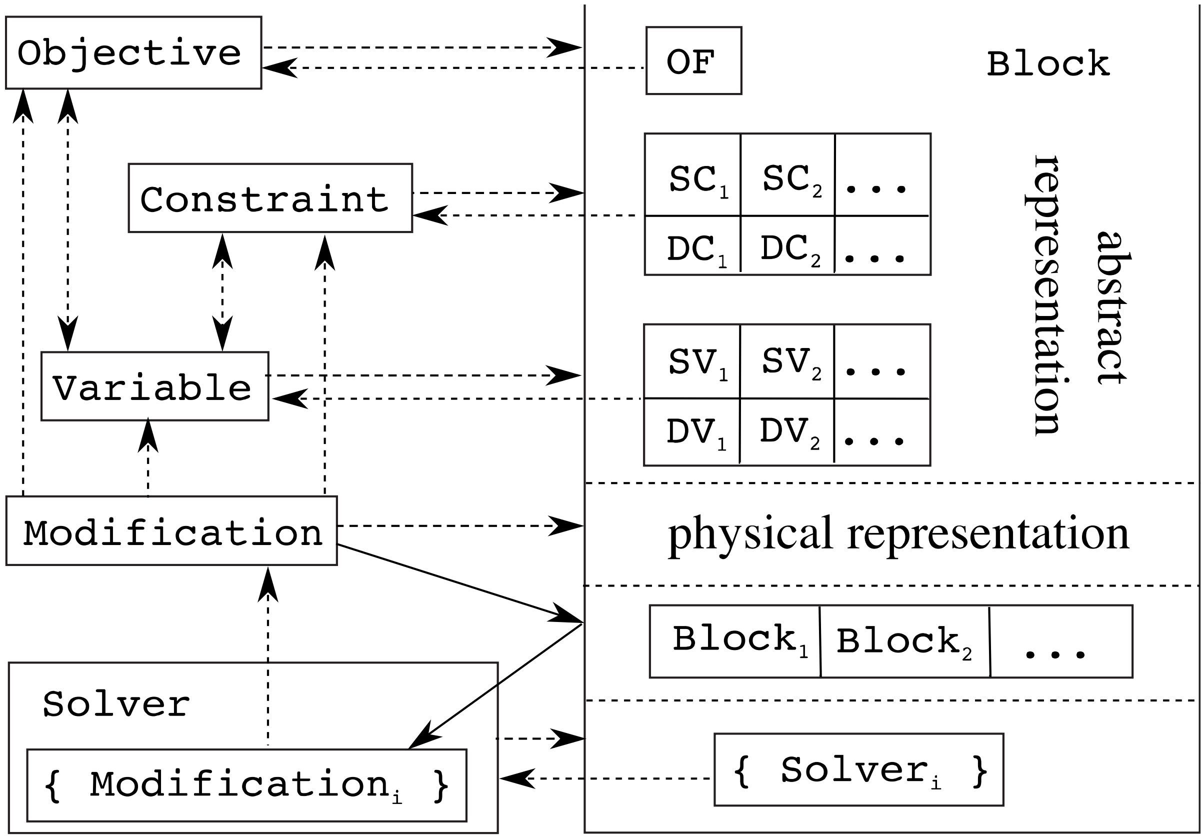
Modelling with SMS++

- 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***

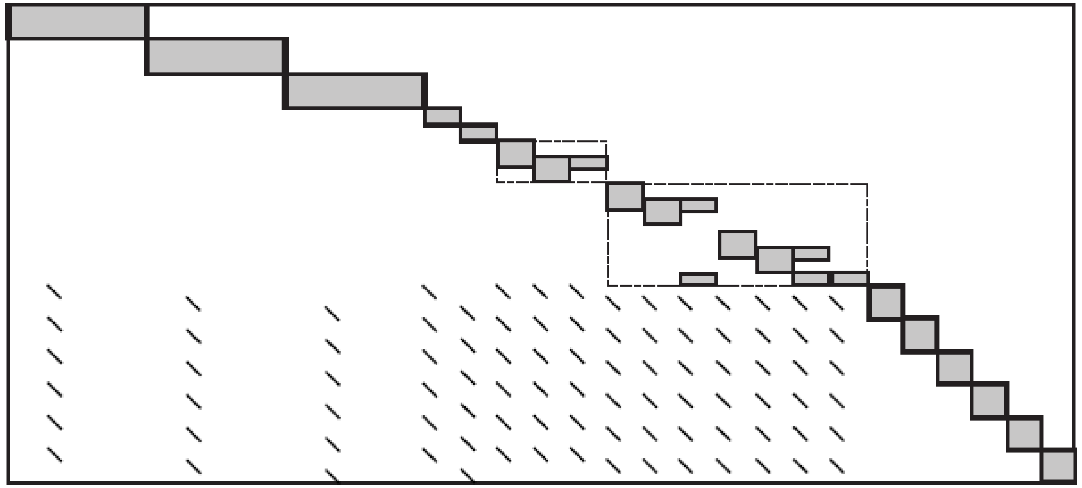


nework Programme for Research and Innovation no. 101118123

Modelling with SMS++

Nested decompositions at different time horizons

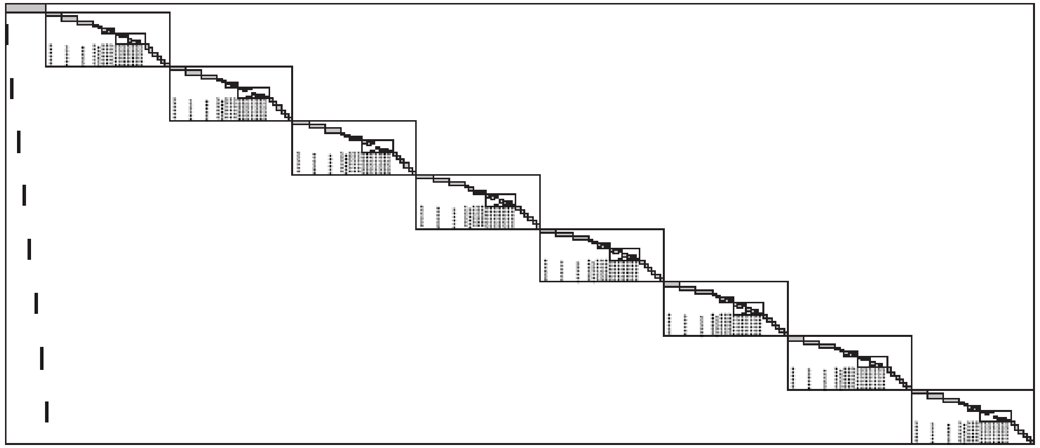
- Schedule a set of generating units to satisfy the demand at each node of the transmission network at each time instant of the horizon (24h)



- 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

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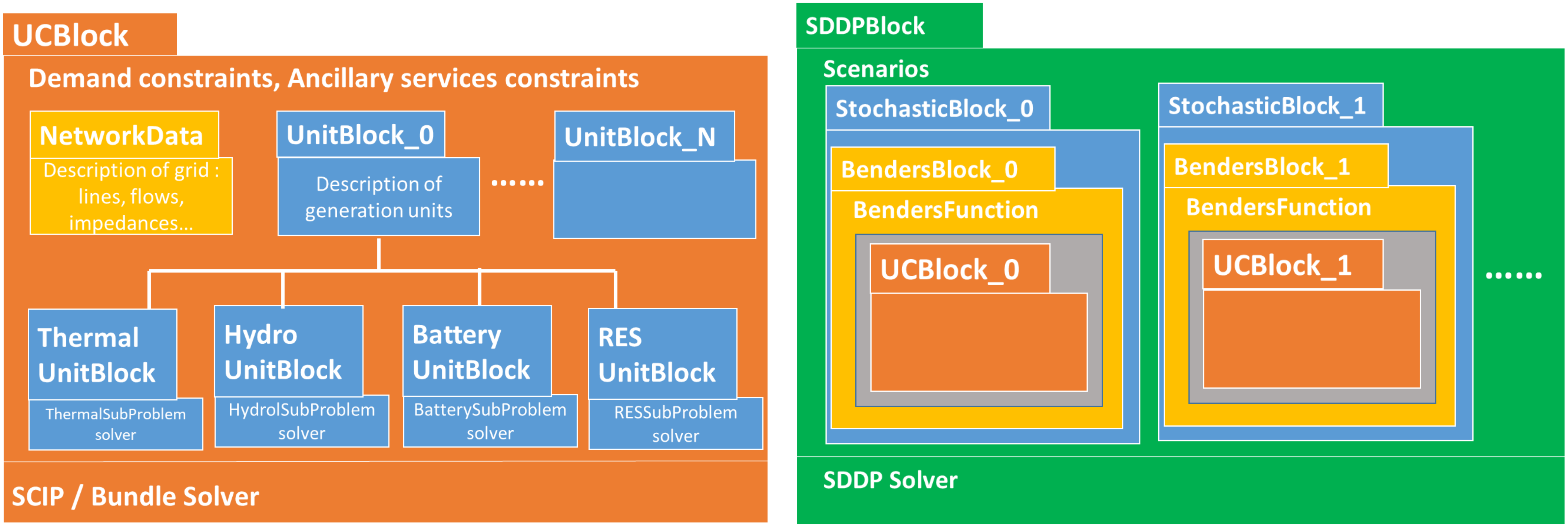
The Seasonal Storage Valuation and Unit Commitment in SMS++



Installation recap

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Plan4res structure

plan4res is composed of the following pieces:

- **The p4r-env container :** https://gitlab.com/cerl/plan4res/p4r-env
- **The SMS++ modelling and optimization library :** https://gitlab.com/smspp
- **The plan4res python linkage, pre/post processing, visualisation scripts :** https://github.com/openENTRANCE/plan4res-scripts
- **Launching scripts, documentation, example of datasets :** https://github.com/openENTRANCE/plan4res

Installing plan4res requires installing each piece

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Installing p4r-env

p4r-env is the main container

It includes:

- A full linux installation (currently debian:bullseye)
- All dependences required by of SMS++ (in particular boost, eigen, netcdf-C++, see https://gitlab.com/smspp/smspp#getting-started)
- Python3 and all packages needed by the plan4res python scripts

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Installing p4r-env in windows

Requirements:

- Windows 7 pro 64bit SP1 or higher
- powershell 3.0 or higher
- CPU must support hardware virtualization (which may require beeing enabled in the BIOS)

Procedure:

- Install Git for Windows (use default settings) https://git-for-windows.github.io/
- Install VirtualBox and Extension Pack https://www.virtualbox.org/wiki/Downloads
- Install Vagrant https://www.vagrantup.com/downloads.html
- (Optional) Install Vagrant Manager http://vagrantmanager.com/downloads/

Vagrant and VirtualBox allow to emulate a UNIX system on the windows computer

See **https://gitlab.com/cerl/plan4res/p4r-env#windows**

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Installing p4r-env in windows

Commands for windows installation:

- Run Git Bash
- Within Git Bash:
    - git clone --recursive https://gitlab.com/cerl/plan4res/p4r-env
    - cd p4r-env
    - Edit Vagrantfile to give more memory….
    - git config submodule.recurse true
    - vagrant plugin install vagrant-proxyconf
    - vagrant up
    - vagrant halt

Creates structure p4r-env

Starts the container (first time downloads image)

Stops the container

You can set the RAM and CPU allocated to the VM by editing parameters `vb.cpus` and `vb.memory` in file p4r-env\Vagrantfile. We advise setting at least **4096 Mb of RAM**!

See https://gitlab.com/cerl/plan4res/p4r-env#windows

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Installing p4r-env in linux

Commands for linux installation:

- Create a directory (install_dir)
  - ➢ mkdir install_dir
- Download p4r-env:
  - ➢ git clone --recursive https://gitlab.com/cerl/plan4res/p4r-env
  - ➢ cd p4r-env
  - ➢ *(if you are using OpenMPI, edit config/plan4res.conf => change MPICH to OpenMPI – see next slide)*
  - ➢ bin/p4r
  - ➢ exit

Creates structure p4r-env

Starts the container (first time downloads image)

Stops the container

See **https://gitlab.com/cerl/plan4res/p4r-env#linux**

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Adaptations of p4r-env to local needs

If your system allows parallelisation

- Check mpi version :

  mpiexec –version

- 2 versions of the container are available depending on MPI installation: openMPI and MPICH

  Default version of the container is for MPICH

  To change to openMPI:

  - **edit file p4r-env/config/plan4res.conf**
  - **change value of P4R_MPI_IMP:**
    - **Instead of** **P4R_MPI_IMP=${P4R_MPI_IMP:-"MPICH"}**
    - **Write:** **P4R_MPI_IMP=${P4R_MPI_IMP:-“OpenMPI"}**

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Adaptations of p4r-env to local needs

To prevent download of SIF image each time you run bin/p4r (or any Launch)

- **edit file p4r-env/config/plan4res.conf**
- **change value of P4R_SINGULARITY_IMAGE_PRESERVE:**
  - **Instead of**

P4R_SINGULARITY_IMAGE_PRESERVE=${P4R_SINGULARITY_IMAGE_PRESERVE:-0}

  - **Write**

P4R_SINGULARITY_IMAGE_PRESERVE=1

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Installing SMS++ in p4r-env

Requirements:

- You must have a linux installer of CPLEX (even if installing on a windows machine!!)
  => cplex_studioXXXX.bin (XXXX depends on the version of CPLEX)

Procedure (for academics to get free version of CPLEX):

- Go to IBM ILOG CPLEX Optimization Studio: https://www.ibm.com/products/ilog-cplex-optimization-studio
- click "Try it free" =>You will be asked for create an account as an academic or use an already existing one, then you will be directed to the download page
- Download the LINUX version of the installer bin (cplex_studioXXX.bin)

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Installing SMS++ in p4r-env

For Windows users, if necessary:
Edit *install_dir\p4r-env\scripts\add-ons\sms++*: replace 3 instances of `make -j$(getconf _NPROCESSORS_ONLN)` with `make –j1`.

Commands :

- Commands are launched from the directory p4r-env
- Install StOpt (stochastic optimization library)
  - (bin/p4r add-on stopt uninstall)
  - bin/p4r add-on stopt
- Install SMS++
  - (bin/p4r add-on sms++ uninstall)
  - bin/p4r add-on sms++ CPLEX=<Your-CPLEX-Linux-Installer.bin>

Always install before SMS++

only if old install already exists

Install sms++ executables in p4r-env

See https://gitlab.com/cerl/plan4res/p4r-env#p4r-env

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Installing the python scripts in p4r-env

Commands (You are still located in the directory p4r-env)

- cd scripts
- mkdir python
- cd python
- git clone https://github.com/openENTRANCE/openentrance.git
- git clone https://github.com/openENTRANCE/plan4res-scripts.git

Install Open ENTRANCE nomenclature

Install linkage, pre/post-treatment and visualisation scripts

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Get documentation, config files and launch scripts

- From your install_DIR
- git clone https://github.com/openENTRANCE/plan4res.git
- Copy launch scripts plan4res/run* to p4r-env
- Copy the sub-dir plan4res/include to p4r-env/scripts/
- Copy the datasets in ExampleData to p4r-env/data/local/

Creates plan4res dir in Install_Dir, populated with…. (see next slide)

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Plan4res input data

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What do we need ?

- to be specified in settingsCreateInputPlan4res_xx.yml

- Yearly data:
  - Electricity demand (Final Energy|Electricity)
  - Interconnections (Network|Electricity|Maximum Flow)
  - Installed Capacities (Capacity|Electricity|)
  - Costs (Variable Cost (incl. Fuel Cost)|Electricity|)
- Hourly Timeseries

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The IAMC file as converted from GENeSYS-MOD inputs and outputs

Example in
https://github.com/openENTRANCE/plan4res/tree/main/ExampleData/mini/IAMC

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Plan4res datasets

- Main files:
  - Regions: ZP_ZonePartition
  - Demand: ZV_ZoneValues
  - Interconnections: IN_Interconnections
  - Thermal Power: TU_ThermalUnits
  - Hydro Réservoirs: SS_SeasonalStorage
  - Renewable Power: RES_RenewableUnits
  - Storage: STS_ShortTermStorage
- TimeSeries:
  - Demand Profiles
  - Inflows
  - Renewable load factors
  - …

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Example in
https://github.com/openENTRANCE/plan4res/tree/main/ExampleData/mini/csv_simul

https://github.com/openENTRANCE/plan4res/tree/main/ExampleData/mini/csv_invest

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Creating the Plan4res datasets

CreateInputPlan4res.py

runCREATE.sh

Usage: from p4r-env,

./runCREATE.sh NAMEDATASET simul → Dataset for simulation

or

./runCREATE.sh NAMEDATASET invest → Dataset for investment optimisation

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SMS++ datasets

- Main files:
  - InvestmentBlock.nc4 → Describes the investment optimisation problem
  - SDDP_Block.nc4 → Describes the problem on 1 year
  - Block_$i.nc4 → Describes the short term problems and the power system

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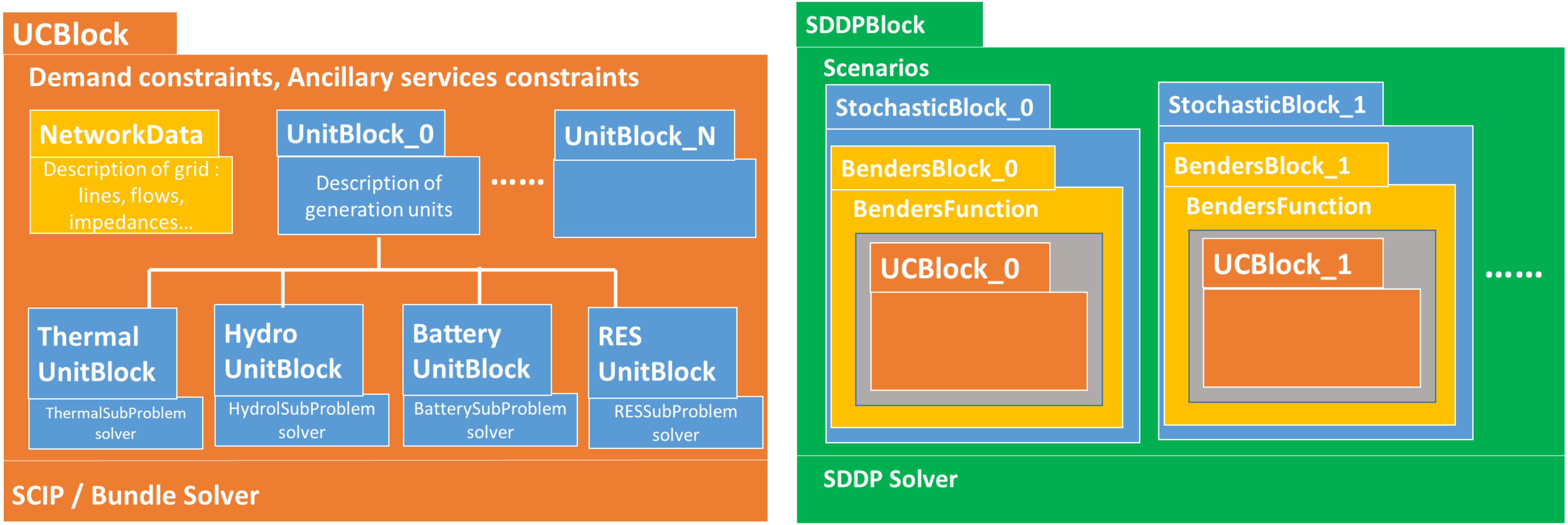
The Seasonal Storage Valuation and Unit Commitment in SMS++



Example in
https://github.com/openENTRANCE/plan4res/tree/main/ExampleData/mini/nc4_simul

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Creating the netCDF files

format.py

runFORMAT.sh

Usage: from p4r-env,

./runFORMAT.sh NAMEDATASET simul → Dataset for simulation

or

./runCREATE.sh NAMEDATASET optim → Dataset for computing bellman values

or

./runCREATE.sh NAMEDATASET invest → Dataset for investment optimisation

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Running the models

- 3 solvers available:
  - SDDP → Computes Bellman values
  - Simulation → Computes schedules of all units
  - Investment → Computes a more adapted power mix

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Running the SDDP

runSSV.sh

Usage: from p4r-env,

./runSSV.sh NAMEDATASET

BellmanValuesOUT

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Running the Simulation

runSIM.sh

Usage: from p4r-env,

./runSIM.sh NAMEDATASET

ActivePower
MarginalCosts
Flows
…..

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Running the Investment

runCEM.sh

Usage: from p4r-env,

./runCEL.sh NAMEDATASET

SolutionOUT.csv
And all results of simulation

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