Synergistic approach of Multi-Energy Models for a European Optimal Energy System Management Tool

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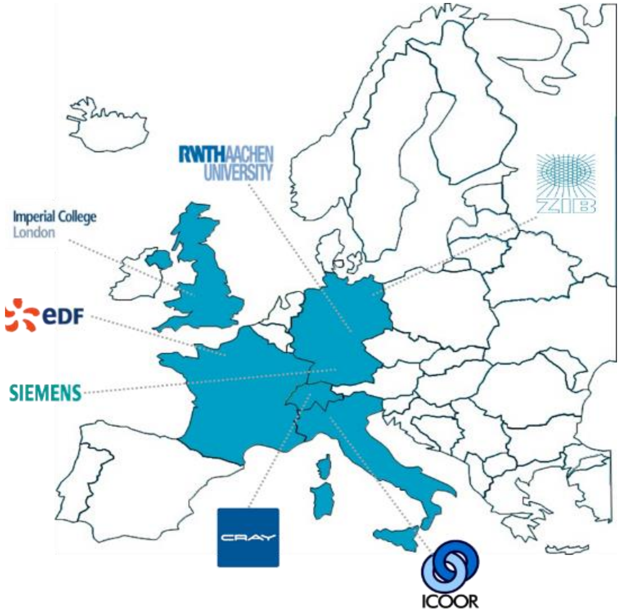
Content

- Overview of plan4res
- Transmission planning under uncertainty
- Option value of flexibility for transmission planning
- ESO/DSO operational challenge: whole-system approach
- Summary

plan4res Consortium

Nov 2017 to Oct 2020

- ÉLECTRICITÉ DE FRANCE SA (EDF)
- IMPERIAL COLLEGE LONDON (IMPERIAL)
- SIEMENS AG, CORPORATE TECHNOLOGY (SIEMENS)
- CRAY COMPUTER GMBH (CRAY)
- ZUSE INSTITUTE BERLIN (ZIB)
- RWTH AACHEN UNIVERSITY (RWTH)
- CONSORZIO INTERUNIVERSITARIO PER L'OPTTIMIZZAZIONE E LA RICERCA OPERATIVA (ICOOR)

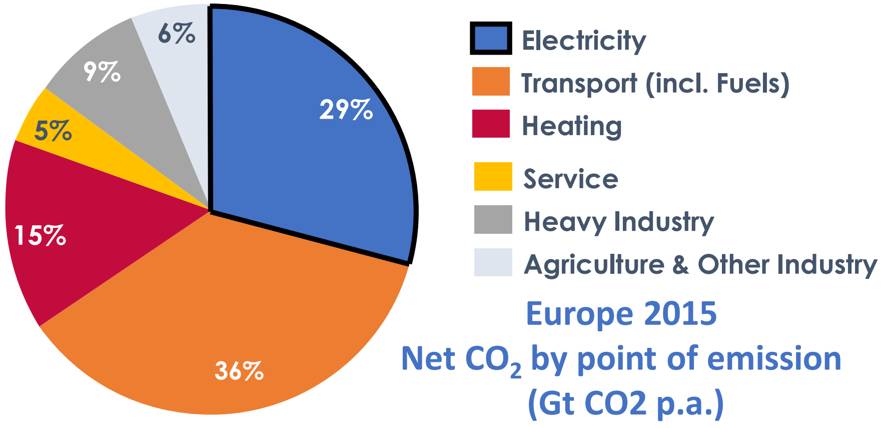


plan4res storyline

Facing European targets for reduction of greenhouse gas emissions while maintaining high quality of supply and low cost

⇒ Electricity : Increase share of renewable energy sources

⇒ Other Energies : move uses to low emission energy sources

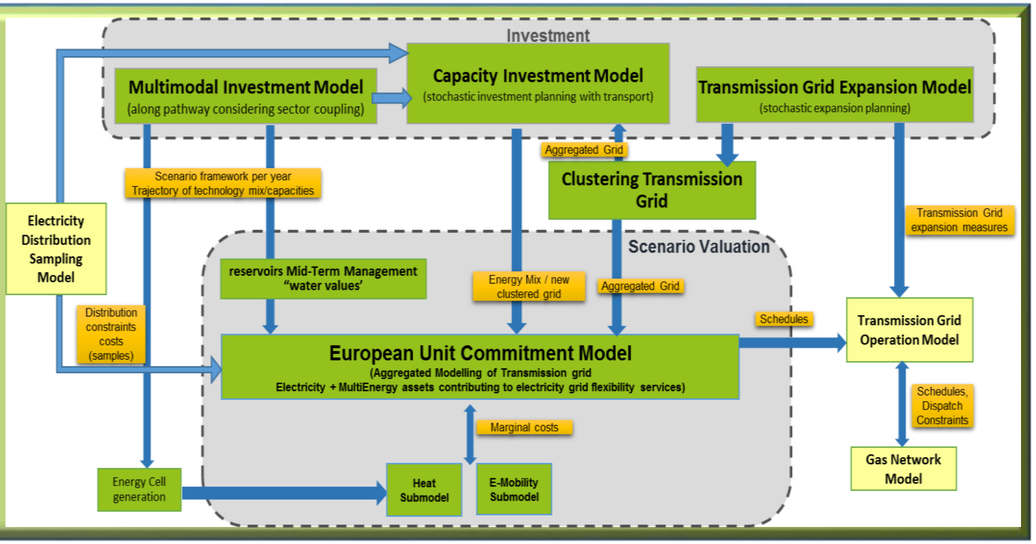


- **Optimise balance between new investments and optimum use of existing assets**
- **Maximise use of all (both traditional and emerging) flexibilities**

plan4res will provide : the **integrated representation of the system** which is necessary in order to simulate the energy system expansion and operation thus helping Europe to achieve its objectives with the lowest cost

Main objectives

- An ***end-to-end planning and operation tool,*** composed of a set of optimization models based on an ***integrated modelling*** of the pan-European Energy System,
- an efficient ***IT platform***
- and "***state-of-the-art" solution algorithms***



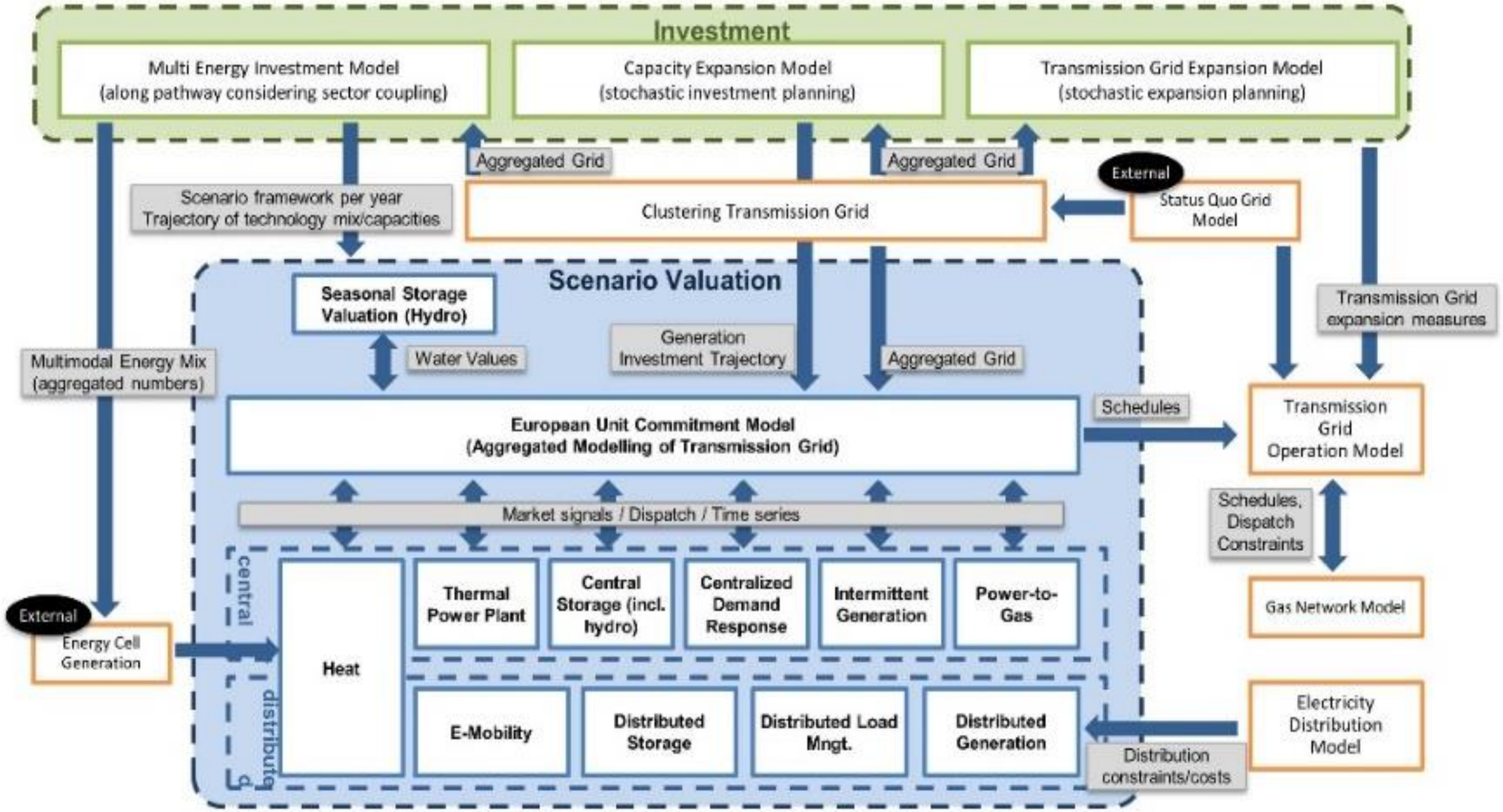
A **set of public data,**
European Scale, 2015 to 2050

3 **case studies** highlighting adequacy and relevance :
-Sector coupling : which energy mix for achieving COP 21?
-Cost of RES integration, value of flexibility, climate change
-Transmission expansion.

An integrated modelling

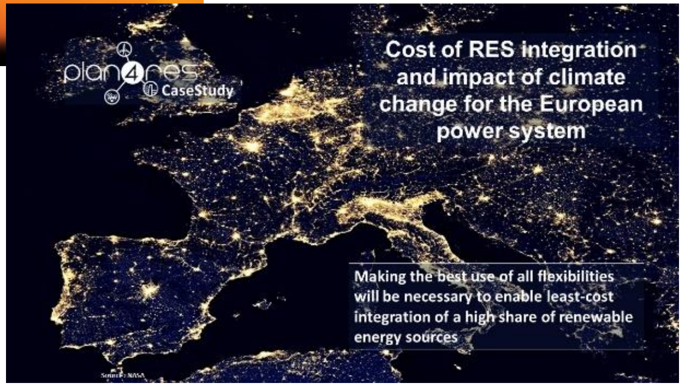
End-to-end planning and operation tool: set of optimization models based on an integrated modelling of the pan-European Energy System

- **Investment layer**: Determine investment decisions
- **Scenario valuation**: Evaluate investment decisions, operations planning
- **Analysis/additional tools**: Evaluate impact on electricity & gas grid



3 Case studies to highlight the tool's adequacy and relevance

- **Sector coupling: which energy mix for achieving COP 21?**
  - Based on a Multi-modal European energy concept for achieving COP 21
  - with perfect foresight, considering sector coupling of electricity, heat & cold, traffic, fuel/gas; and coupling to gas grids
- **Strategic development of the pan-European transmission network**
  - without perfect foresight and considering long-term uncertainties
- **Assessing cost of RES integration, value of flexibilities and impact of climate change for the European electricity system**



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Transmission planning

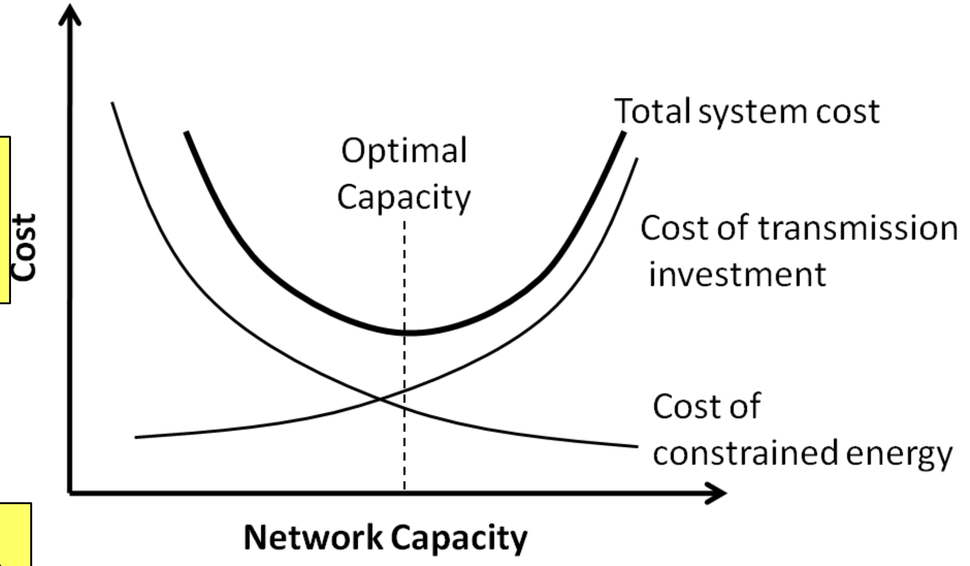
- Question: **where, when and how much capacity to build**?
- In thermal-dominated systems, transmission planning is driven by the need to meet peak demand with sufficient reliability.
- In systems with intermittent energy sources, transmission planning is driven by cost-benefit considerations

max{social welfare} = min{total cost}

- The future system evolution is affected by significant uncertainty:
  - **Short-term Uncertainties** (operational timescale)
  - **Long-Term Uncertainties** (investment timescale)
    - Location, size and technology of new generation plants
    - Investment costs of novel technologies (e.g. storage)
    - Long-term demand growth due to electrification of transport and heat
    - Long-term price trends (e.g. coal, gas, CO2)

Data-driven statistical models

Described via scenario trees



Why it is important?

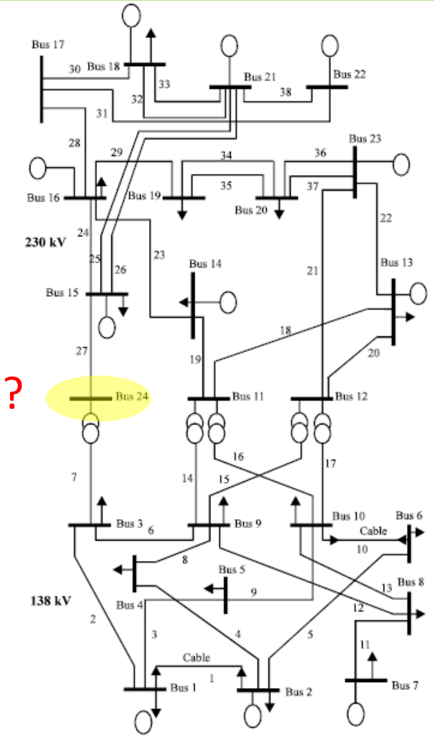
- **Capital decisions in power systems are largely irreversible. This creates the risk of inefficient investment (stranded assets).**
- **There is learning regarding future developments (inter-temporal resolution of uncertainty).**
- **The planner can exert managerial flexibility in his decision making; 'Fit-and-forget' vs. 'Wait-and-see'.**

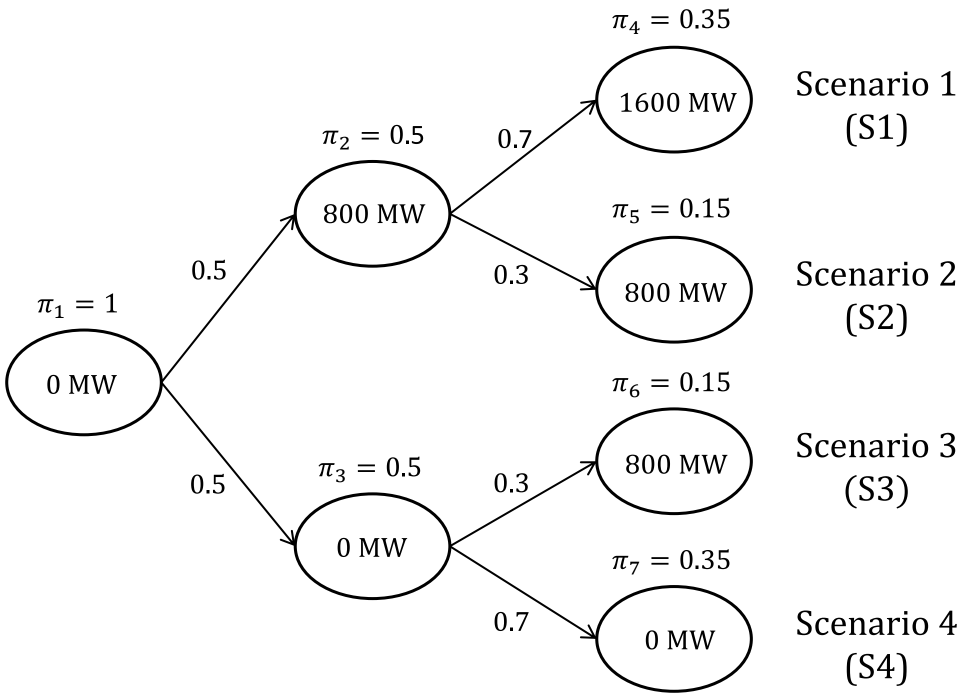
Planning-under-uncertainty optimisation frameworks are fundamental for identifying **openings for strategic action**

IEEE-RTS case study/1

IEEE-RTS:

- 24 buses
- 39 lines
- 28 generators
- 5 typical weeks (peak, winter, spring, summer, autumn) of 168 hours





We test three different models:

•**D-I**: Deterministic planning model where all asset types are allowed.

•**S-I**: Stochastic planning model where only investment in line reinforcements is allowed.

•**S-II**: Stochastic planning model where investment in all asset types is allowed.

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IEEE-RTS case study/2

Available assets for investment are shown below:

Table I
Transmission Line Reinforcement Options

Asset Type	Reinforcement Capacity [MW]	Annualized Capital Cost [£/year]	Build Time
Option A	200	1,500,000	1 epoch
Option B	400	2,500,000	1 epoch

Table II
Alternative Investment Options

Asset Type	Annualized Capital Cost [£/year]	Build Time
Phase-shifter	600,000	0 epochs
Storage device	15,000,000	0 epochs

QB maximum shift angle: 30°
Storage Charge/Discharge rate: 400MW
Storage Energy Capacity: 1600 MWh

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Deterministic and Stochastic Planning

Storage is sub-optimal under full knowledge of the future

		Investment Decisions			Costs (£m)					
		Epoch 1	Epoch2	Epoch 3	IC	OC	TC	E{IC}	E{OC}	E{TC}
D - I	S1	A (3-9), B (3-24), B (15-24)	A (3-9), PS (3-9), PS (11-14)	PS (15-16)	91.3	4957.4	5048.8	44.9	5603.8	5648.7
	S2	A (3-9), A (3-24), A (15-24)	PS (11-14)	-	52.9	5267.7	5320.6			
	S3	-	A (3-9), A (3-24), A (15-24)	PS (9-12), PS (10-12), PS (11-13)	33.6	5834.9	5868.6			
	S4	-	-	-	0.0	6295.1	6295.1			
S - I	S1	B (3-24)	A (1-3), A (3-9), A (14-16), B (15-16), B (15-24)	-	87.6	5078.7	5166.3	57.4	5665.9	5723.3
	S2	B (3-24)	A (1-3), A (3-9), A (14-16), B (15-16), B (15-24)	-	87.6	5336.5	5424.1			
	S3	B (3-24)	-	-	27.2	5897.1	5924.4			
	S4	B (3-24)	-	-	27.2	6295.1	6322.3			
S - II	S1	-	A (3-9), B (3-24), B (15-24), PS (12-13), PS (16-19), STOR (24)	PS (3-9), PS (8-9), PS (16-17)	149.2	5009.9	5159.1	79.6	5626.1	5705.7
	S2	-	A (3-9), B (3-24), B (15-24), PS (12-13), PS (16-19), STOR (24)	PS (9-11), PS (10-12)	147.6	5253.7	5401.3			
	S3	-	A (3-24)	PS (9-11), PS (13-23)	12.9	5875.4	5888.3			
	S4	-	A (3-24)	-	9.5	6295.1	6304.6			

Conservative first-stage commitments to conventional reinforcements

Ability to invest in storage defers long-term commitments to second stage (conditional on high-growth scenarios)

Option Value of Flexible Assets

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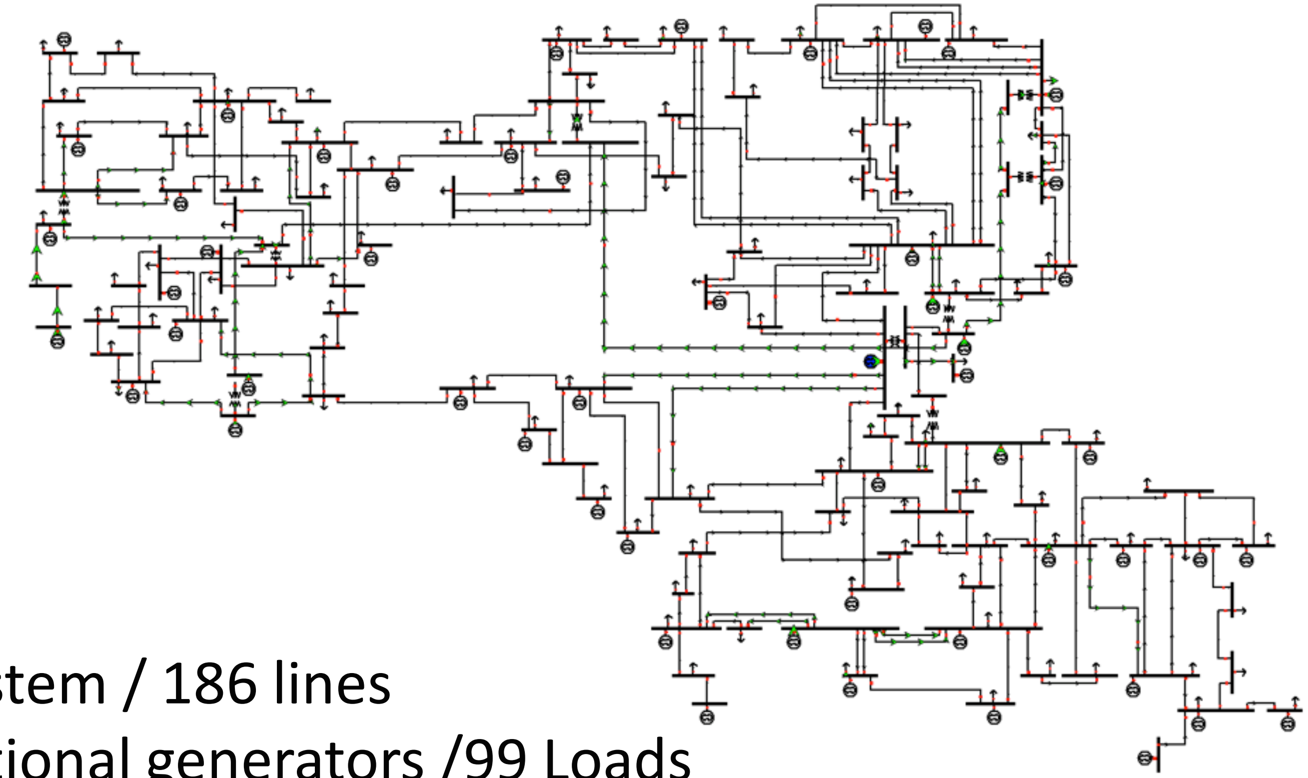
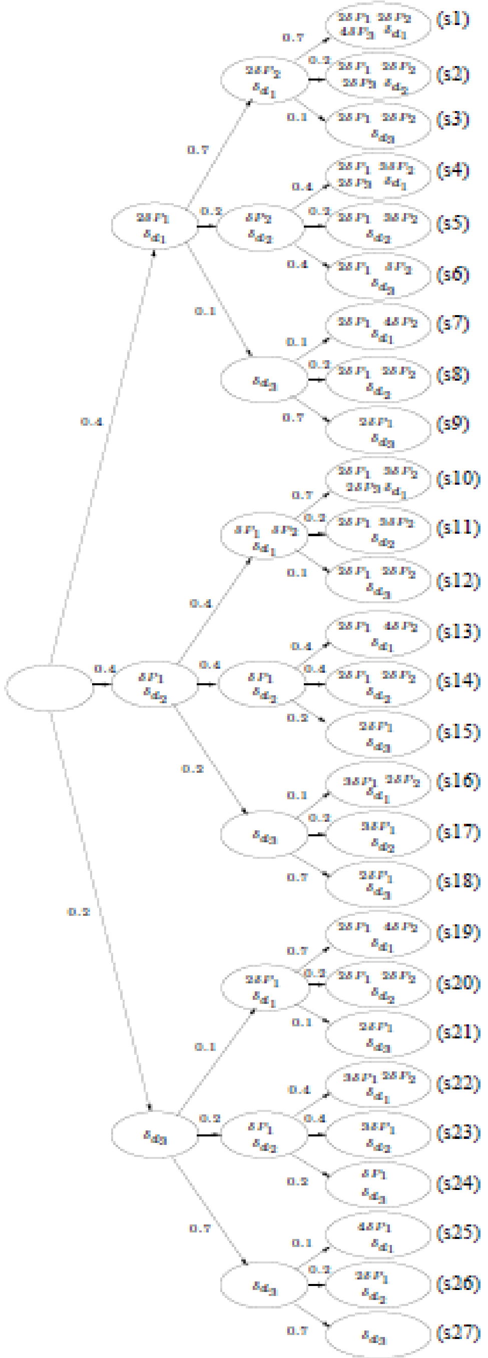
IEEE-118 case study





- 118 bus system / 186 lines
- 54 Conventional generators /99 Loads
- Tree with 27 scenarios, 40 nodes, 4 stages
- 3 candidate storage technologies, 3 candidate line types

Investment options

w	Reinforcement Capacity [MW]	$c_{\ell,w}$ \$/(MW km yr)	$\kappa_{\ell,w}$ \$/(km yr)	$\gamma_{\ell,w}$
A	200	76	91200	$1, \forall\ell$
B	400	76	121600	$1, \forall\ell$

Technology	Bus
Pumped Storage Hydro (PSH):	38, 63, 64, 65, 68, 81
Compressed Air Energy Storage (CAES):	12, 38, 63, 64, 65, 68, 81, 117
Lithium Ion Batteries (LI-ION):	26, 63, 68, 69, 80, 89, 116, 117

Technology	κ^H (\$/yr)	$\overline{\eta}$ (MWh)	$\underline{h}$ (MW)	ρ^e	γ^H
PSH	8,100,000	1000	250	0.8	2
CAES	290,175	360	15	0.7	1
LI-ION	1,547,600	20	5	0.92	0

Deterministic and Stochastic planning

Deterministic solutions for different scenarios

	Epochs			Cost ($m)		
ς	1	2	3	IC	OC	TC
1	S(2; 63, 64)	A(97) S(2; 63 − 65, 68, 117)	A(93, 95, 96) S(2; 38, 63 − 65, 68, 117)	177	13940	14117
9	–	S(2; 117)	A(93, 94) S(2; 63)	68	14876	14944
19	S(2; 63, 117)	S(2; 63, 64)	A(93, 104), B(97) S(2; 63, 64)	128	14800	14928
27	S(2; 117)	–	–	3	15803	15806

Stochastic solution

NBD	Epochs			Costs ($m)		
ς	2	3	4	IC	OC	TC
1	S(2; 63, 64)	A(93, 95, 96, 97) S(2; 38, 63 − 65, 68)	–	142	13999	14141
2	″	″	–	142	14146	14288
3	″	″	S(3; 117)	145	14341	14486
4	″	A(93, 95, 97) S(2; 63, 64)	–	106	14250	14356
5	″	″	S(3; 117)	109	14445	14554
6	″	″	″	109	14584	14693
7	″	A(93, 94, 97) S(2; 64)	″	109	14645	14754
8	″	″	″	109	14697	14806
9	″	″	″	109	14877	14986
10	S(2; 63)	A(93, 95, 97) B(97) S(2; 63, 64)	–	104	14390	14494
11	″	″	–	104	14588	14692
12	″	″	S(3; 117)	107	14718	14825
13	″	A(93, 97) S(2; 63, 64)	–	72	14789	14861
14	″	″	S(3; 117)	75	14858	14933
15	″	″	″	75	15062	15137
16	″	A(93) S(2; 63), S(3; 117)	–	44	15086	15130
17	″	″	–	44	15192	15236
18	″	″	–	44	15335	15379
19	–	A(93, 104) B(97) S(2; 63, 64)	–	117	14823	14940
20	–	″	–	117	14994	15111
21	–	″	S(3; 117)	120	15197	15317
22	–	A(93, 97) S(2; 63), S(3; 117)	–	74	15131	15205
23	–	″	–	74	15334	15408
24	–	″	–	74	15470	15544
25	–	S(2; 63), S(3; 117)	S(3; 63)	12	15619	15631
26	–	″	–	8	15609	15617
27	–	″	–	8	15804	15812

Ability to invest in storage (flexibility) defers long-term commitments to second stage (conditional on high-growth scenarios)

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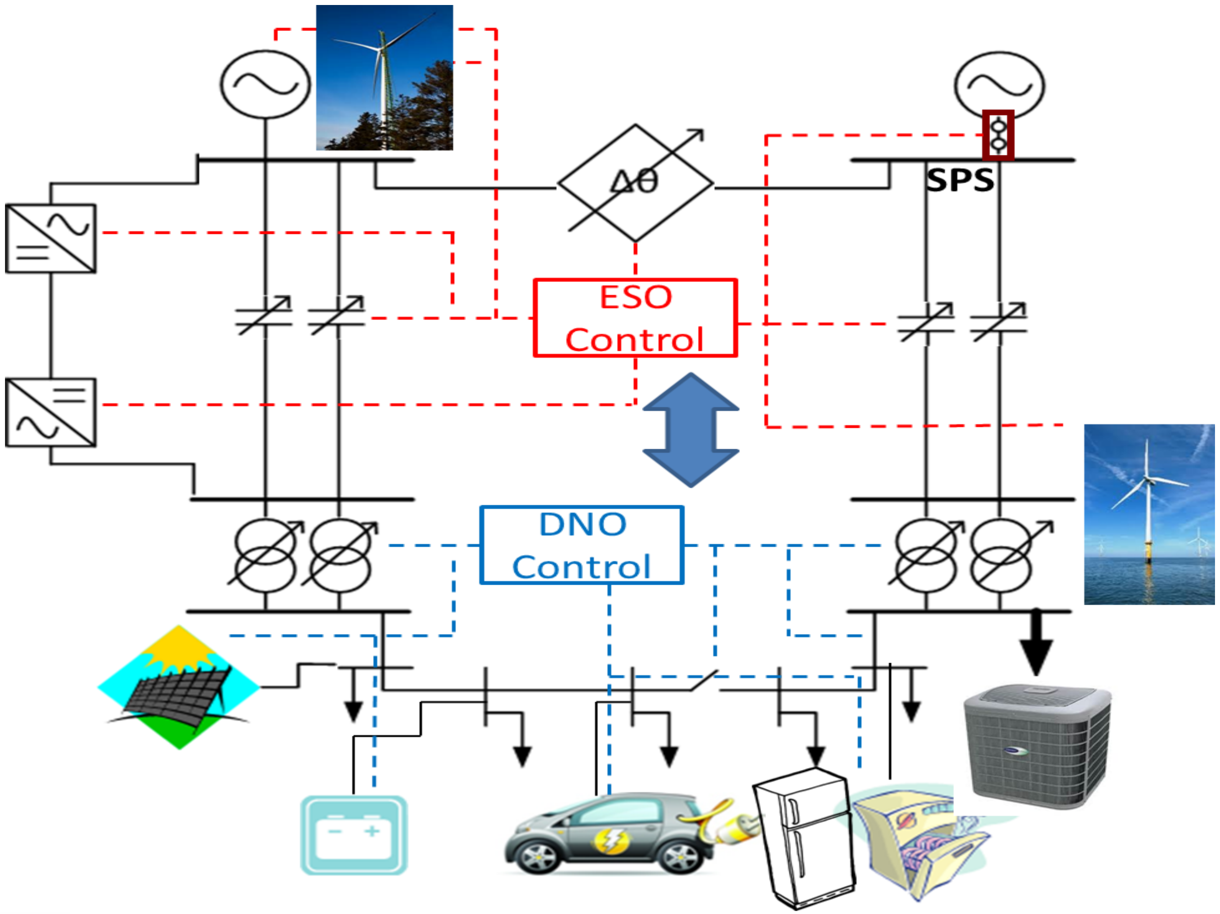
ESO/DSO Operational challenge

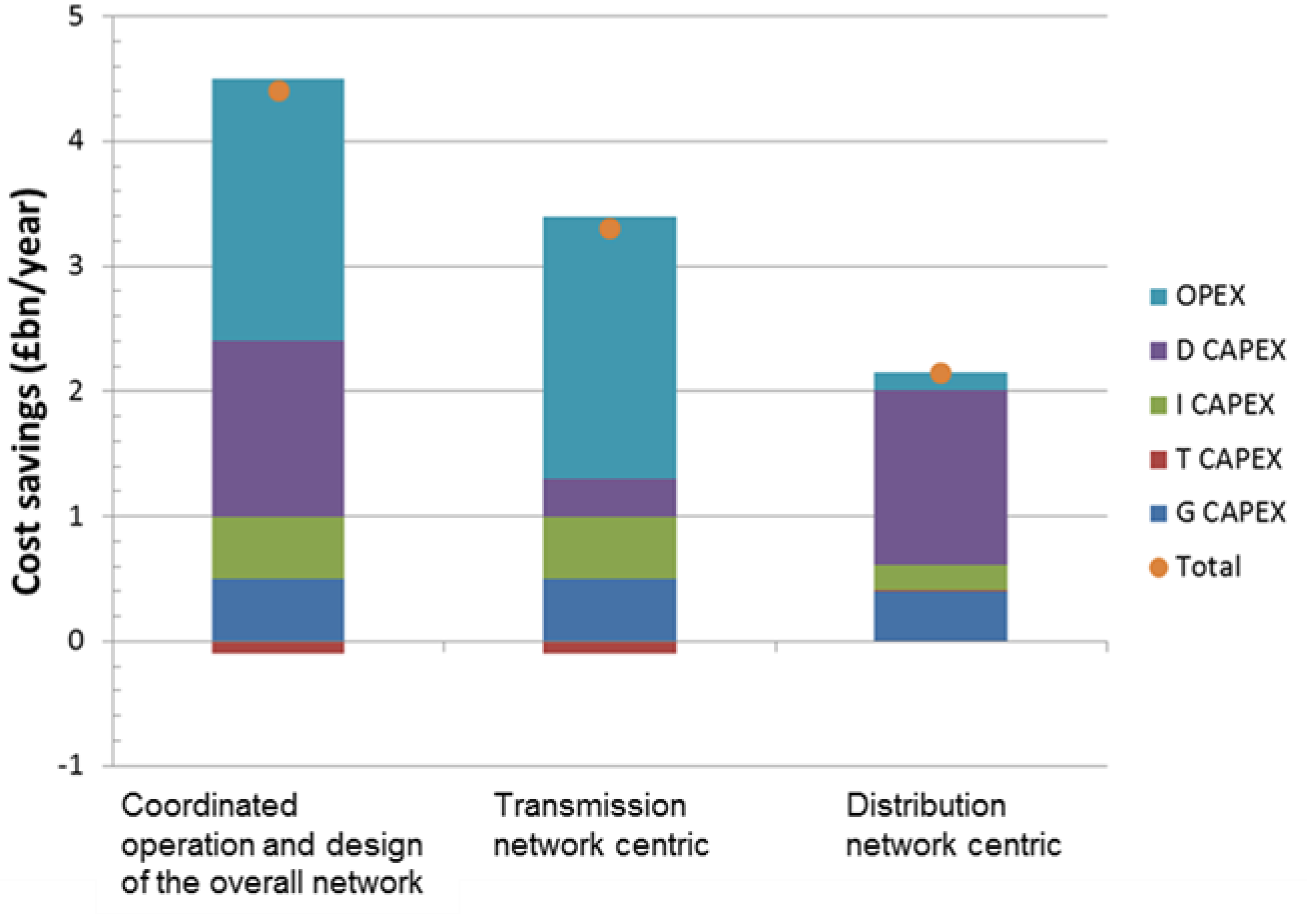


Paradigm shift in delivering security of supply: ***from redundancy in assets to intelligence***

Source of control: ***from Transmission to Distribution: business case for DNO/ESO***

Complexity, Market, Regulation

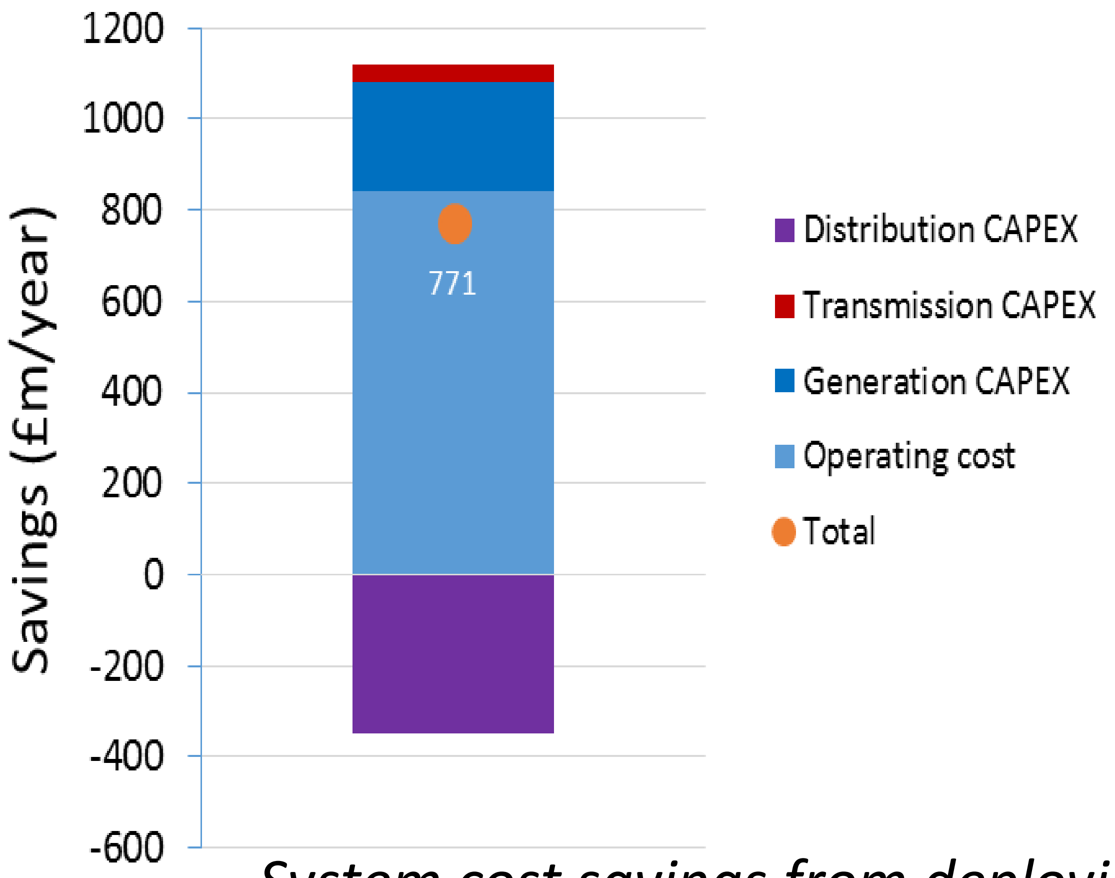
Potential GB benefits of alternative operation and design models /1



Source: Imperial's modelling analysis

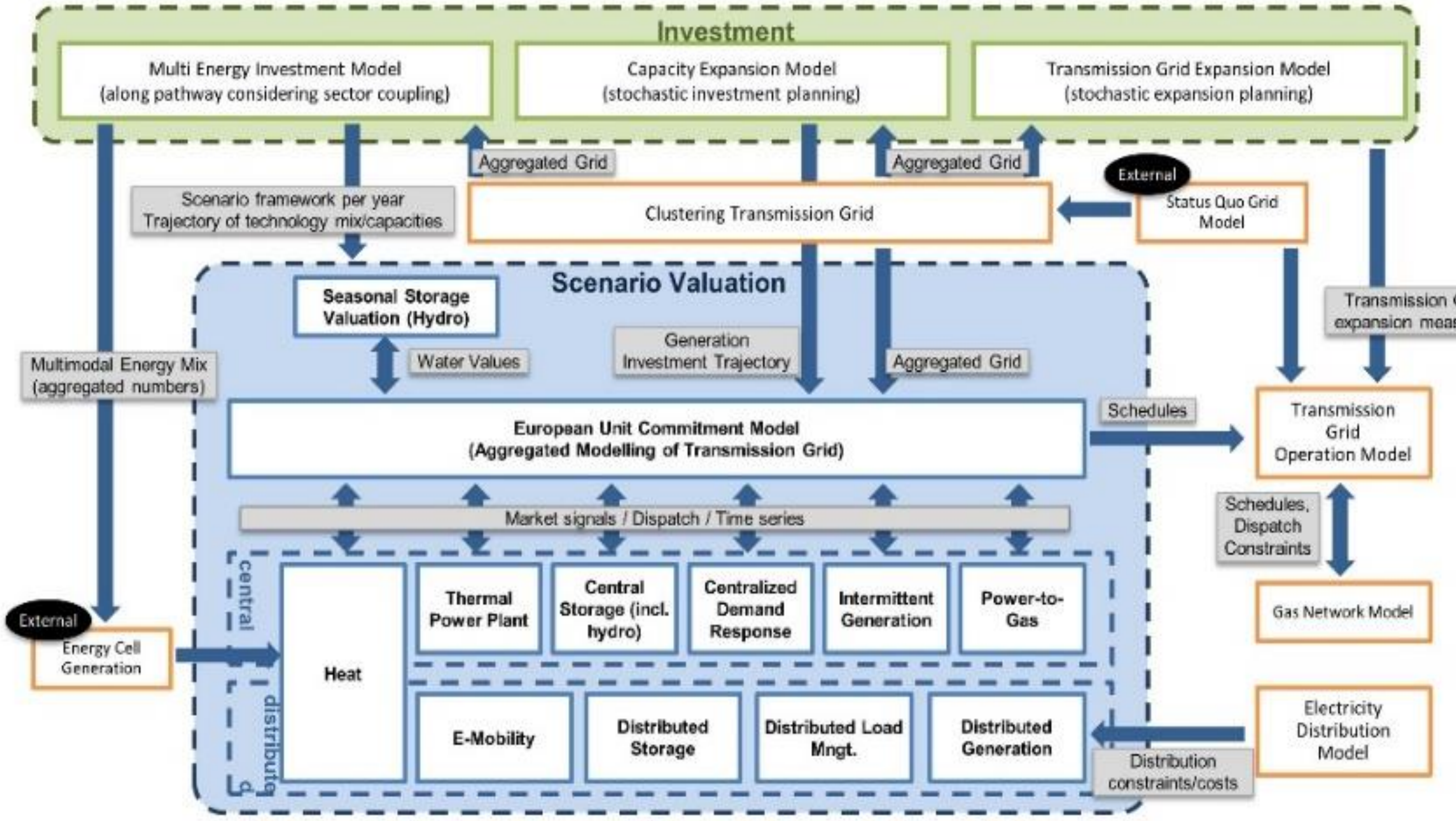
- Coordinated TSO/DSO allows the flexibility to be used optimally for minimising the whole-system costs
- How to achieve the whole-system optimisation?
- What will be the role of DSO to achieve that?
- Key challenges:
  - Visibility of DER
  - Controllability of DER
  - Local network constraints

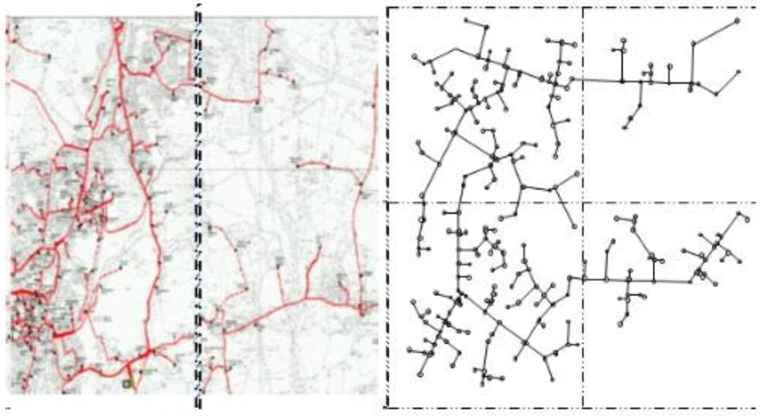
Potential benefits of alternative operation and design models/2



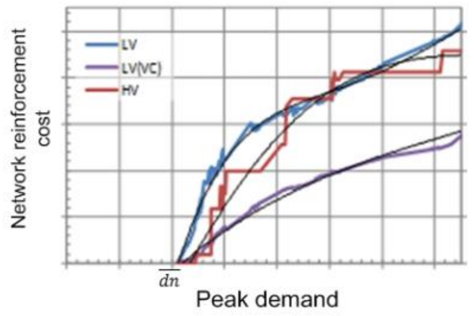
System cost savings from deploying demand-side flexibility based on a whole-system rather than a DSO-centric approach

Integration of distribution network models



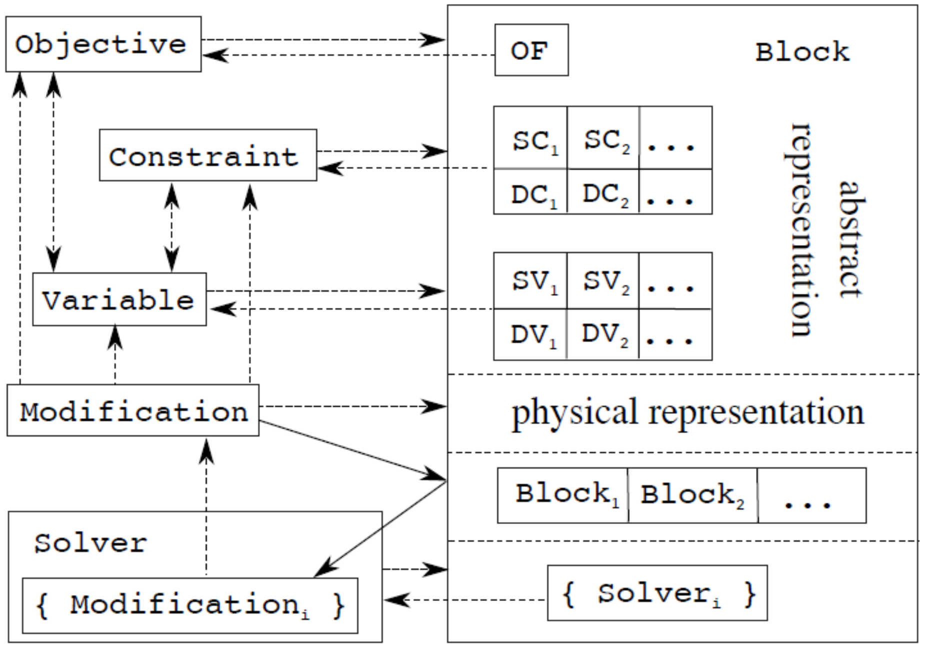


(a) Real network (b) Representative network



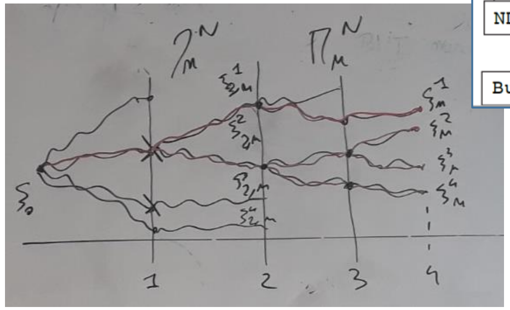
An IT platform for efficient implementation

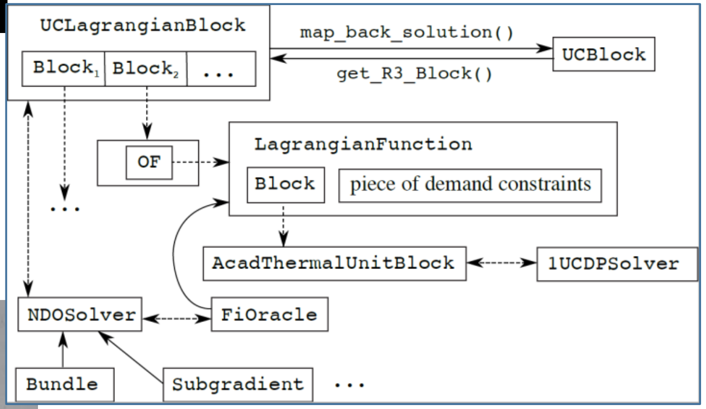
- ***A modelling system* for *structured problems***
  - set of C++ classes
  - explicitly supporting nested structures
  - allows exploiting specialised solvers
  - manages dynamic changes
  - Deals with parallelization
  - Includes various State-of-the art optimization algorithms (bilevel, bundle…)



Solving algorithms

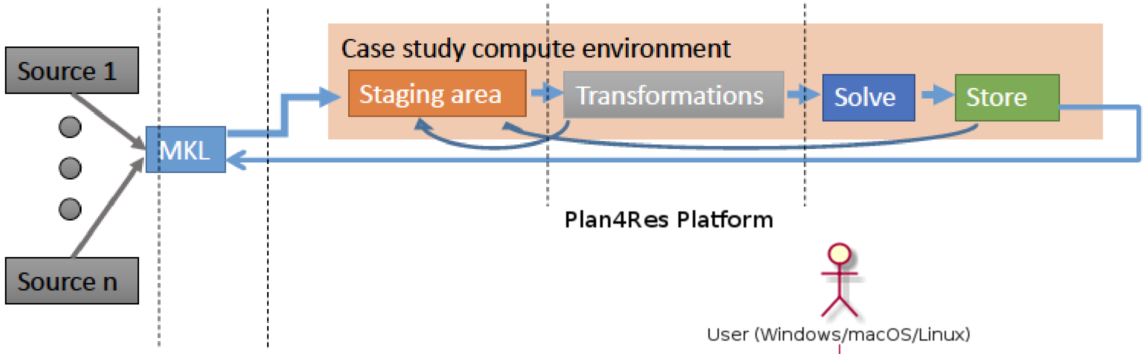
- The latest SCIP release for large-scale MIP problems
- StOpt, an open-source stochastic optimization library for large seasonal storage problems
- NDOSolver/FiOracle, for solving problems induced by decomposition algorithms

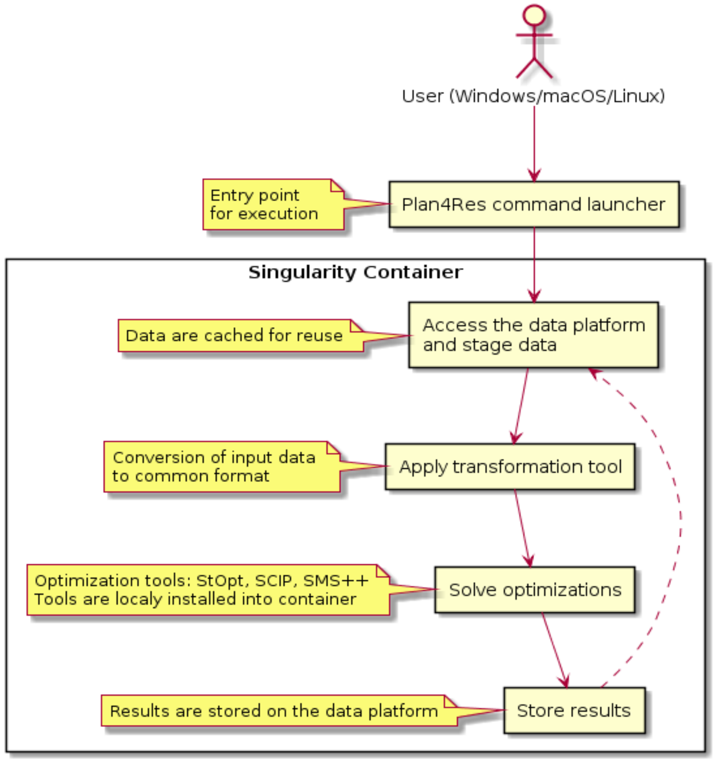




An IT platform for efficient implementation

- **Workflow**
  - Collects data from several sources
  - Executes tools and models
- **Containerized Compute Environment**
  - Same executables run everywhere
  - No dependency issues
  - Add-on software (license restricted) can be locally added in a standardized way
  - Directory structure layout predefined so software can rely on it cross-site
- **Parallelisation embedded**





Summary

- Increased uncertainty in future requires increased system flexibility to deal with operational and planning uncertainty
- Flexibility has an option value as it enables strategic decisions to adapt with long-term uncertainty in planning
- Stochastic optimisation application
- Flexibility will shift to distribution
- TSO-DSO coordination to maximise the value of distributed flexibility
- Integrated whole-energy system modelling application
- Efficient optimisation approaches to solve large-scale problems
- Comprehensive studies to be carried out in the last year of the project

Thank you

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Questions?

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