



Analyzing the Effects of a European Co-optimized Day-Ahead Energy and Reserve Market Coupling

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Outline

1. **PROBLEM DESCRIPTION**

Context - Why Co-optimization?

2. **MARKET CLEARING MODEL**

Modules and Structure

3. **MARKET STUDIES**

Study Parameters

Offer Formulation

Results



01

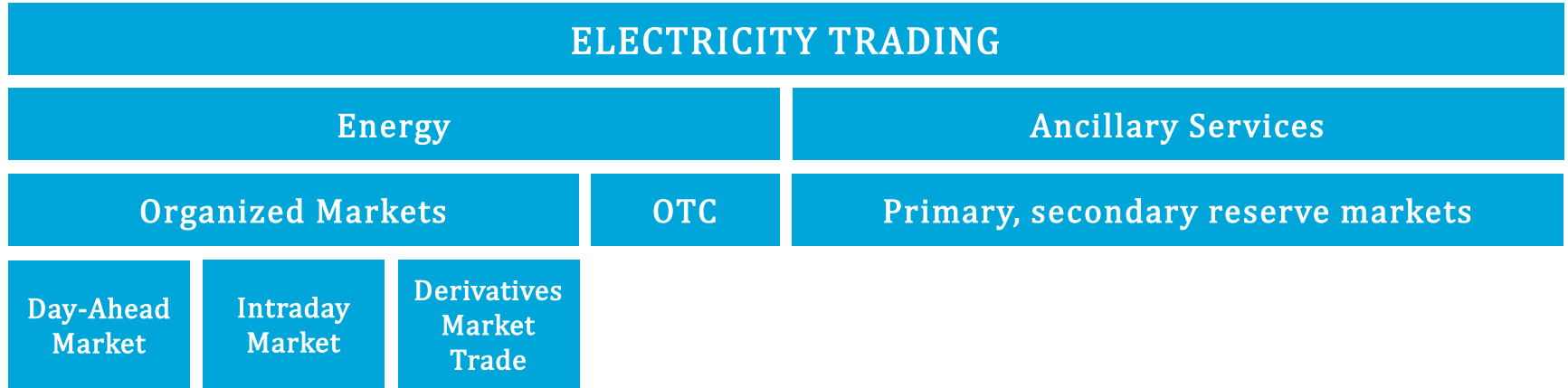
Context





Electricity Trading

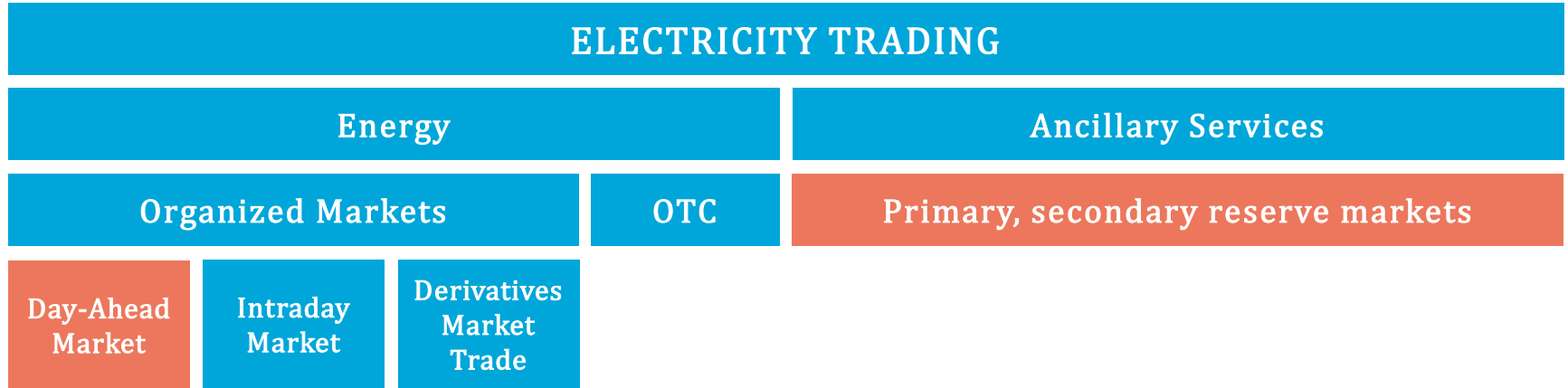
Variety of Mechanisms





Electricity Trading

Variety of Mechanisms



Electricity Trading

Variety of Mechanisms

Day-Ahead Market

PRICE COUPLING OF REGIONS

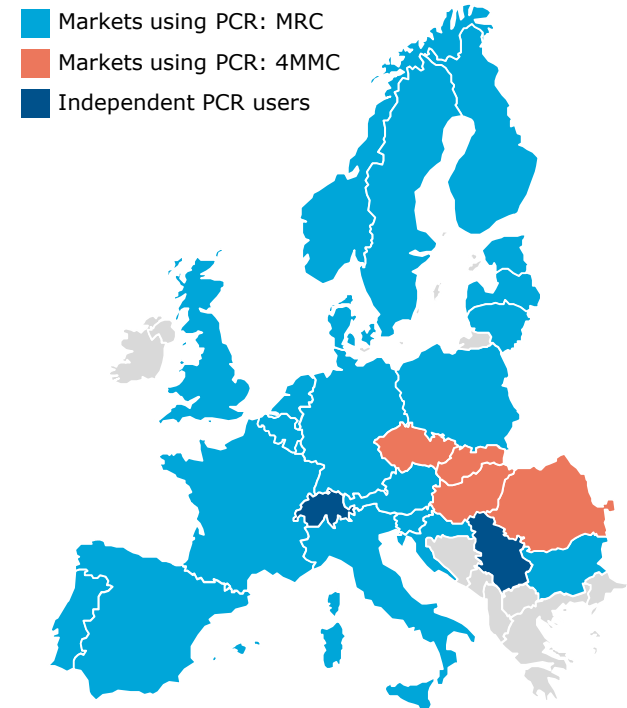
Initiative of 7 power exchanges: EPEX SPOT, GME, Nord Pool, OMIE, OPCOM, OTE, TGE

Single price coupling algorithm: EUPHEMIA

For day-ahead power market since 2014

Main benefits:

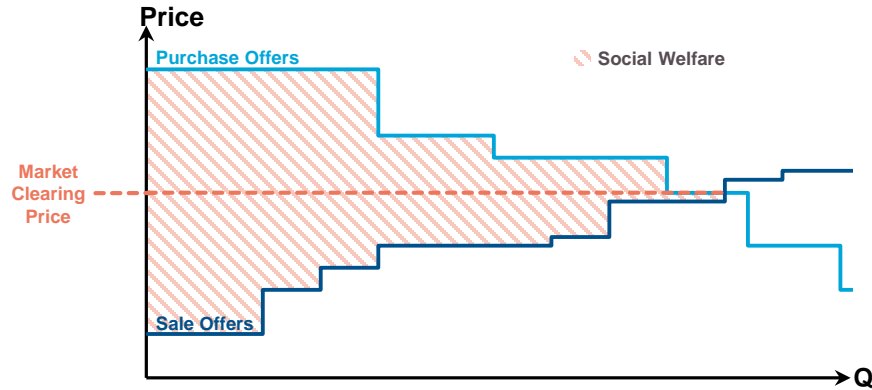
- Demand/supply orders not confined territorially
- Improves market liquidity
- Eliminates need for market players to acquire transmission capacity rights for cross-border exchange



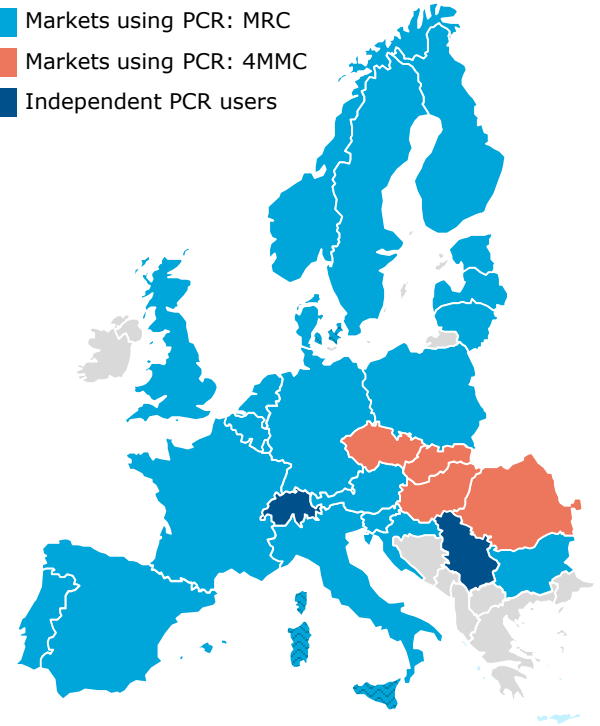
Electricity Trading

Variety of Mechanisms

Day-Ahead Market

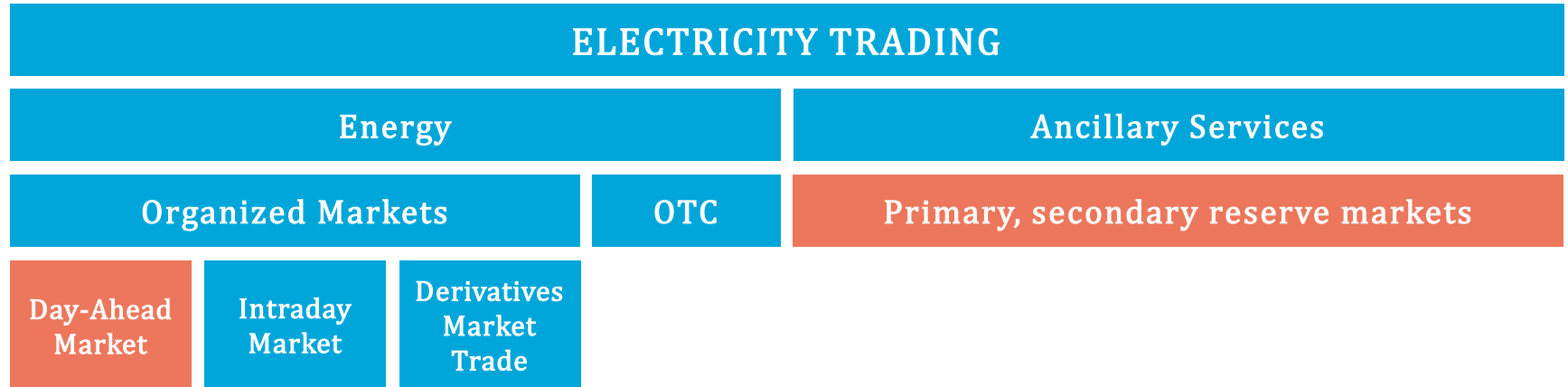


- Markets using PCR: MRC
- Markets using PCR: 4MMC
- Independent PCR users



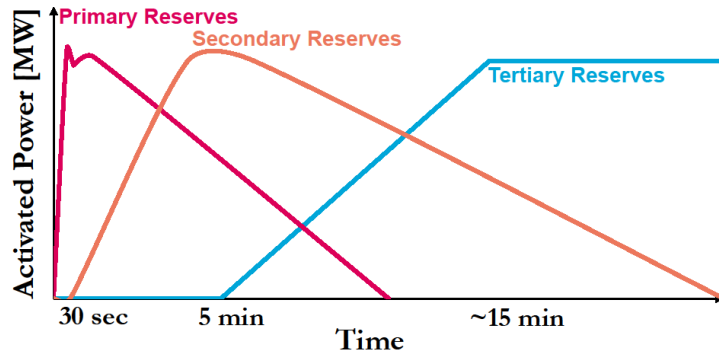
Electricity Trading

Variety of Mechanisms



Electricity Trading

Variety of Mechanisms



Primary, secondary reserve markets

Frequency Containment Reserves (FCR or primary reserves) react within seconds of system imbalance, maintain frequency within certain secure range

Automated Frequency Restoration Reserves (aFRR or secondary reserves) react within seconds to minutes to replace FCR and resolve frequency to reference level

Manual Frequency Restoration Reserves (mFRR or tertiary reserves) have a similar goal to aFRR, but react slower

Replacement Reserves (RR, included in tertiary reserves) are activated in case of severe imbalance to free up FRR reserves within minutes to hours

Electricity Trading

Variety of Mechanisms



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Electricity Trading

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Why Co-optimization?

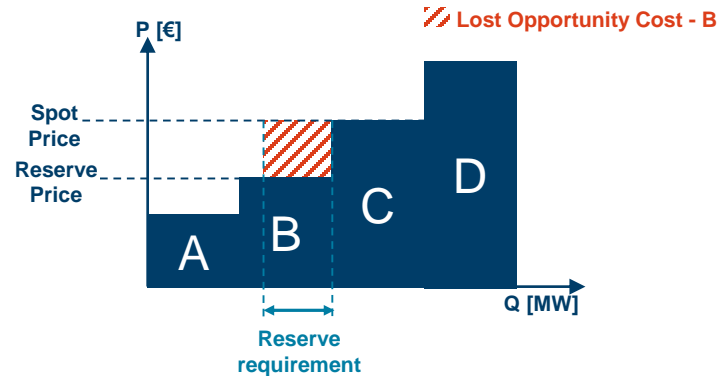
CURRENT MARKET ISSUES

For Market Actors

Must decide between selling energy or reserves without knowing the prices beforehand

Amount sold on first market no longer available for secondary markets

→ Can lead to a lost opportunity cost



For TSOs

Must decide to assign transmission capacity to energy or reserves

Amount reserved on first market no longer available for further markets



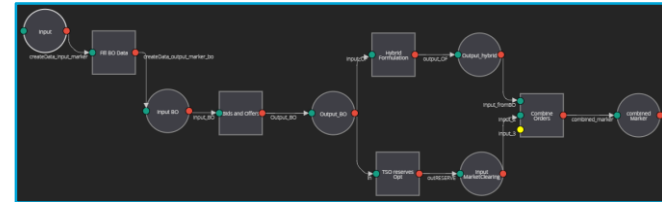
02

Model Development



PROtotyping Markets and Energy Transmission for a Harmonized and Efficient Use of the System

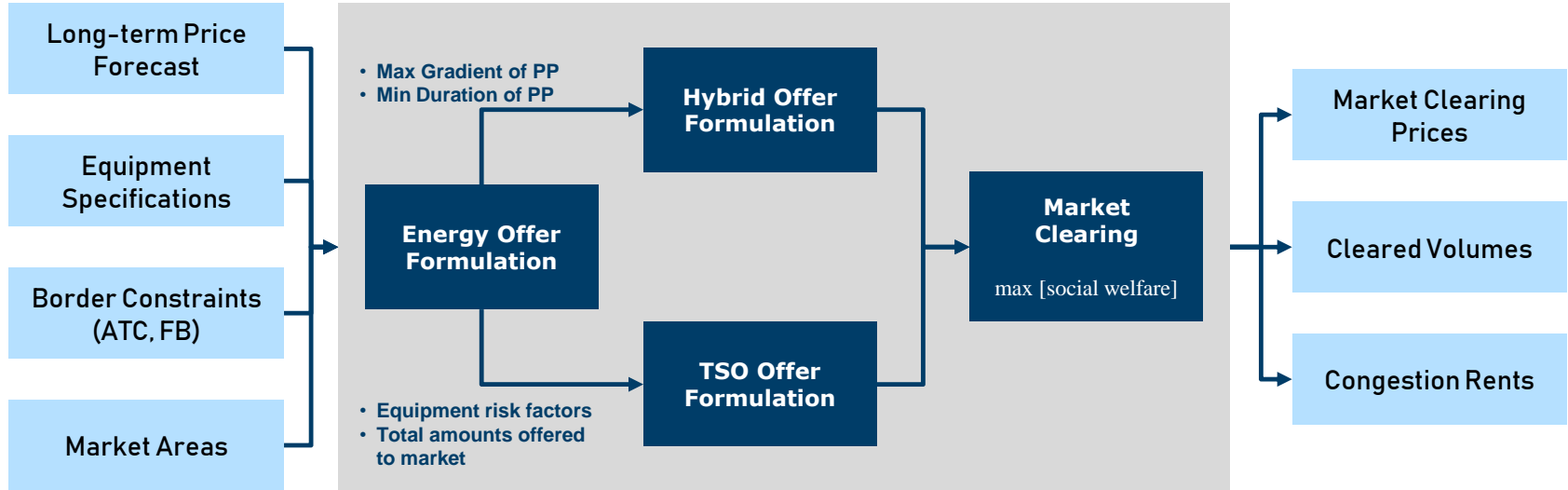
- Integrated platform designed for simulating energy systems
- Used to carry out prospective studies on market architectures and quantify impacts
- Flexible prototyping tools:
 - Scripts (Python)
 - Data models
 - Toolboxes
 - Time series
 - Optimization (GLPK, Xpress solvers)
 - Data visualization
 - Workflow development



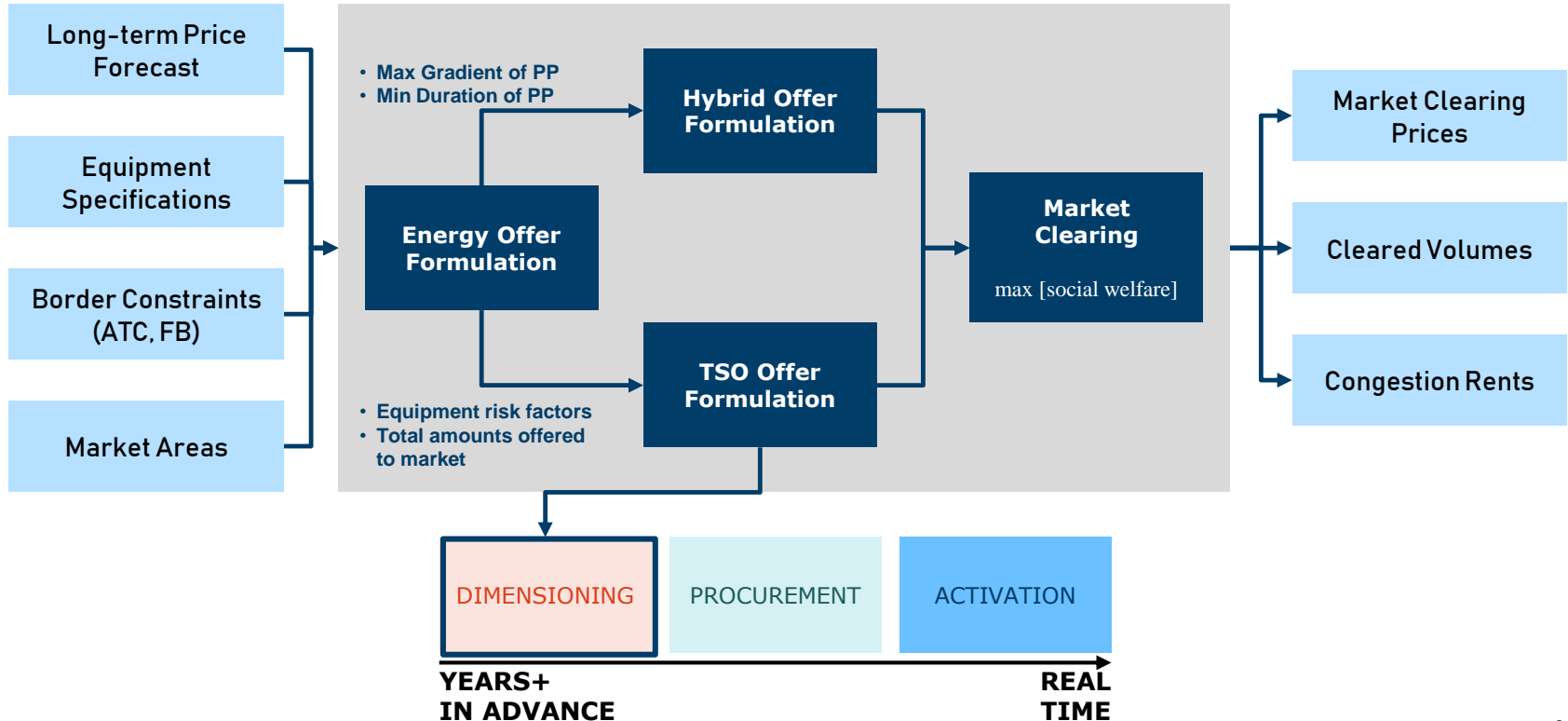
```

main.py *
5  #-- Access to the output marker
6  OUTPUT_LIST = API_IO.Outputs
7  if len(OUTPUT_LIST)>1:
8      raise Exception('Too many outputs markers')
9  if len(OUTPUT_LIST)<1:
10     raise Exception('An output marker must be selected')
11  output_marker = OUTPUT_LIST[0].Marker
12
13  #-- Create a new MarketArea named "marketarea_name"
14  new_marketarea = output_marker.MarketArea.CreateInstance("marketarea_name")
15
  
```

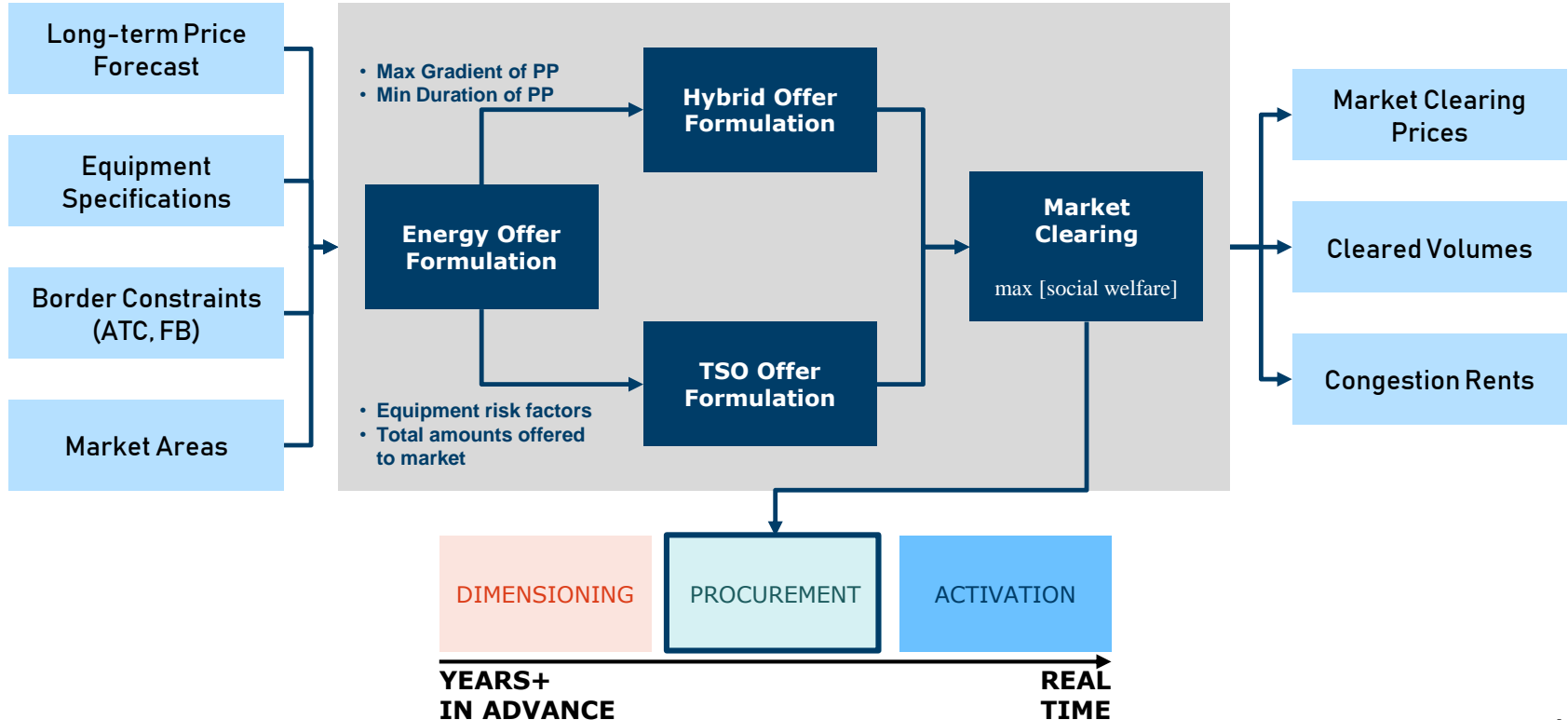
Model Methodology



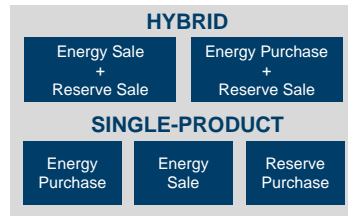
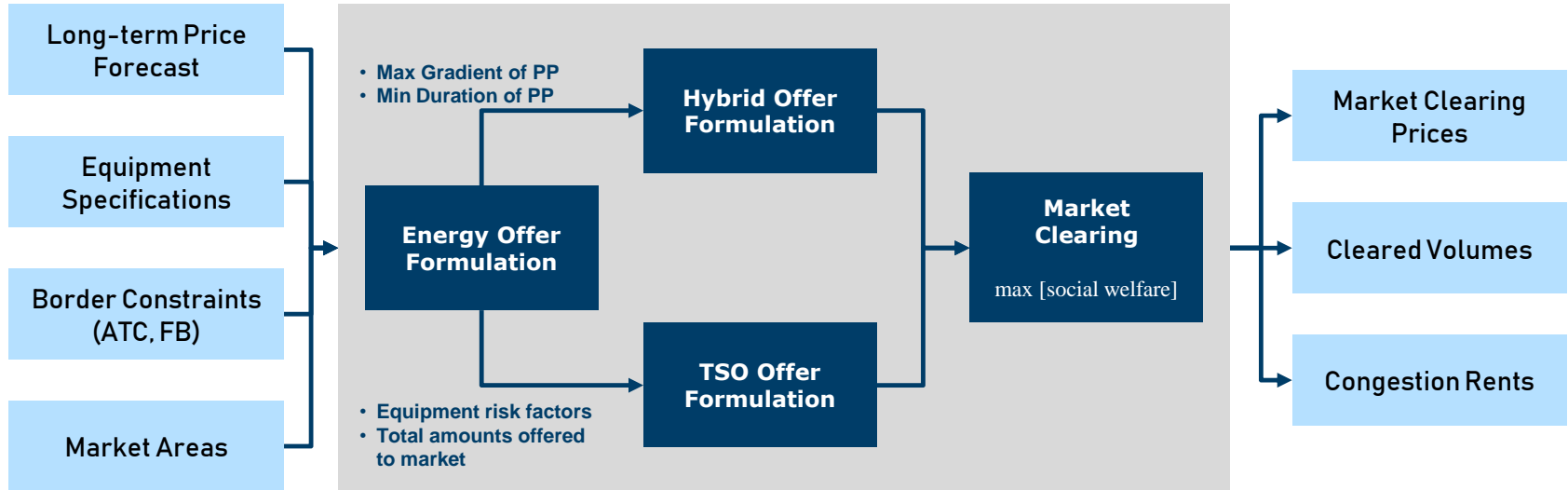
Model Methodology



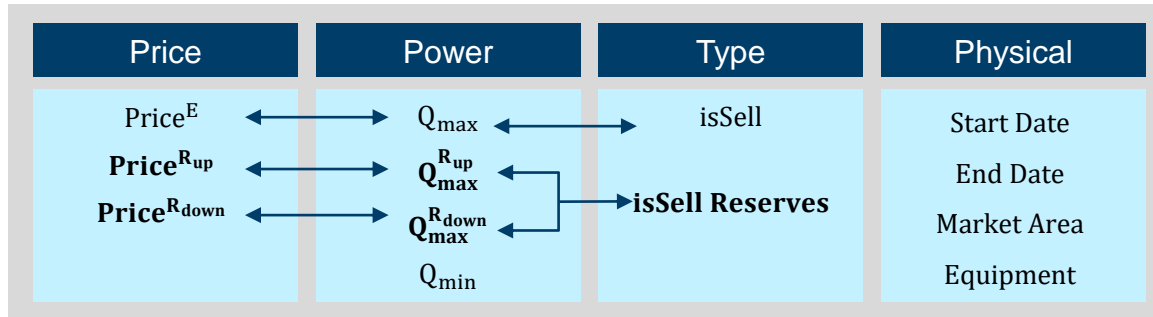
Model Methodology



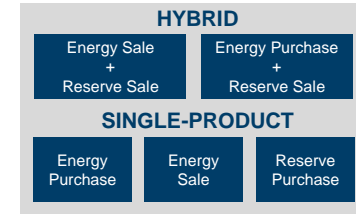
Model Methodology



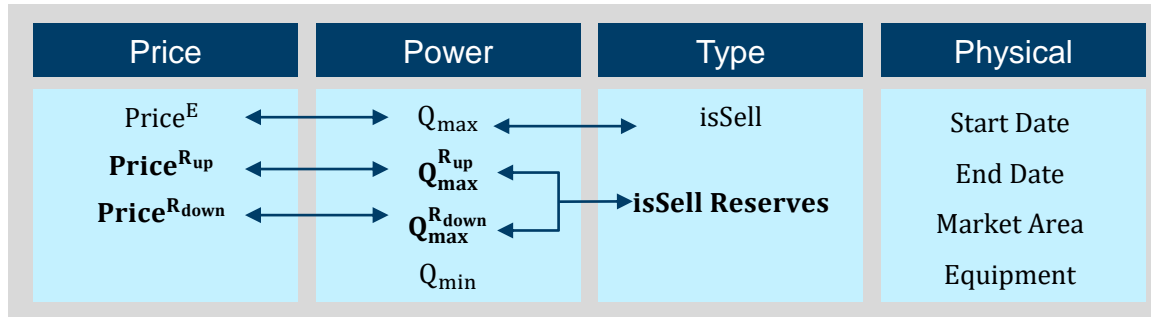
Order Properties



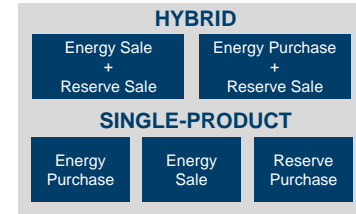
For 5 Offer Types:



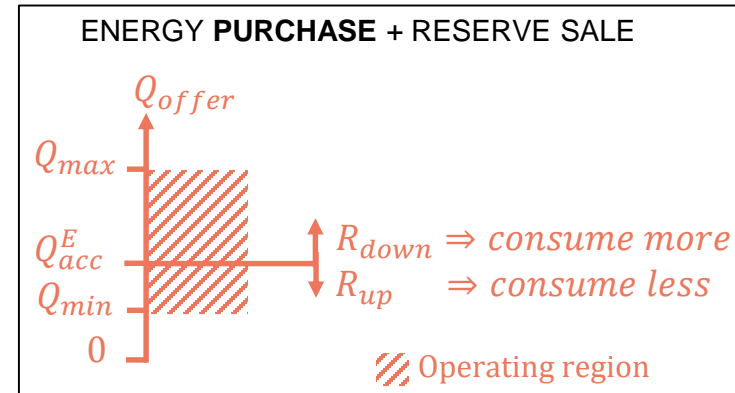
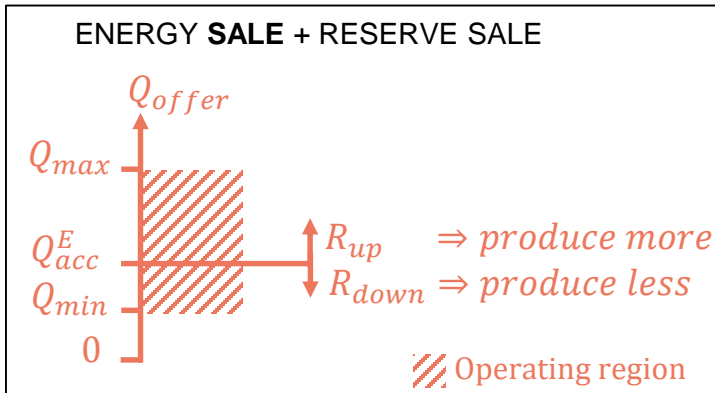
Order Properties



For 5 Offer Types:



TOTAL AMOUNT OF POWER/CAPACITY ACCEPTED IS WITHIN RANGE OFFERED





03

Market Studies





Why Co-optimization?

CURRENT MARKET ISSUES

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Why Co-optimization?

CURRENT MARKET ISSUES

For Market Actors

Must decide between selling energy or reserves without knowing the prices beforehand

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→ Can lead to a lost opportunity cost

➤ **NO LOST OPPORTUNITY COST WITH CO-OPTIMIZATION**

For TSOs

Must decide to assign transmission capacity to energy or reserves

Amount reserved on first market no longer available for further markets

➤ **CURRENT KEY AREA OF STUDY**

Market Studies

Context

- **AT A EUROPEAN LEVEL, MARKET DESIGNS FOR OPTIMAL CROSS-BORDER RESERVE EXCHANGE ARE UNDER DISCUSSION**
- **MARKET SEQUENCE (SEQUENTIAL VS. SIMULTANEOUS)**
- **METHODOLOGY FOR IMPLEMENTATION OF CO-OPTIMIZATION**
 - 1) Reserves before Energy
 - 2) Energy before Reserves
 - 3) Co-optimization

Market Studies

Context

- **AT A EUROPEAN LEVEL, MARKET DESIGNS FOR OPTIMAL CROSS-BORDER RESERVE EXCHANGE ARE UNDER DISCUSSION**
- **MARKET SEQUENCE (SEQUENTIAL VS. SIMULTANEOUS)**
- **METHODOLOGY FOR IMPLEMENTATION OF CO-OPTIMIZATION**
 - 1) Reserves before Energy
 - 2) Energy before Reserves
 - 3) Co-optimization
 - a) Full Co-optimization with hybrid offers → **POTENTIALLY COMPUTATIONALLY EXPENSIVE**
 - b) Sequential optimization of energy before reserves
 - Keeping cross-border capacities from full co-optimization
 - c) Sequential optimization of reserves before energy
 - Keeping cross-border capacities from full co-optimization

Market Studies

Case Descriptions

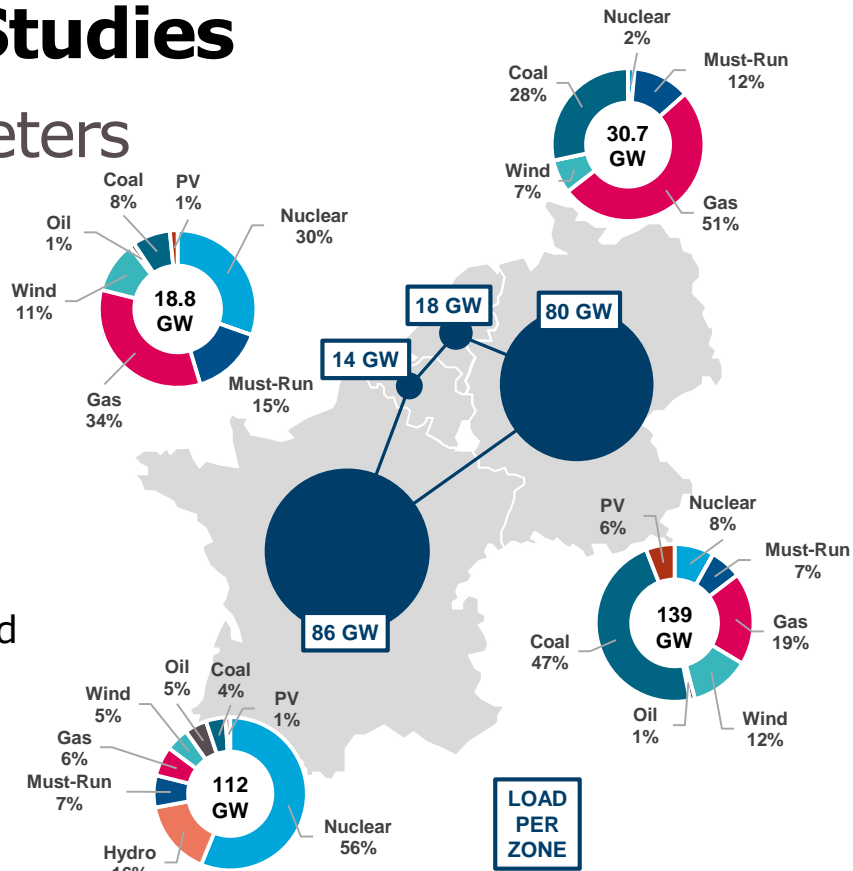
		First Product		Second Product	
		Product	Border Constraints	Product	Border Constraints
1	Base	Full Cooptimization			
2	E1 Base	Energy	Max Border Constraint	Reserves	Remaining Capacity
3	R1 Base	Reserves	Max Border Constraint	Energy	Remaining Capacity
4	E1 No Coopt	Energy	95%* Max Border Constraint	Reserves	Remaining Capacity
5	R1 No Coopt	Reserves	5%* Max Border Constraint	Energy	Remaining Capacity
6	E1 Pre-Coopt	Energy	Cleared Energy (from Cooptimization)	Reserves	Remaining Capacity
7	R1 Pre-Coopt	Reserves	Cleared Reserves (from Cooptimization)	Energy	Remaining Capacity

*Current Foreseen Market Convention

Market Studies

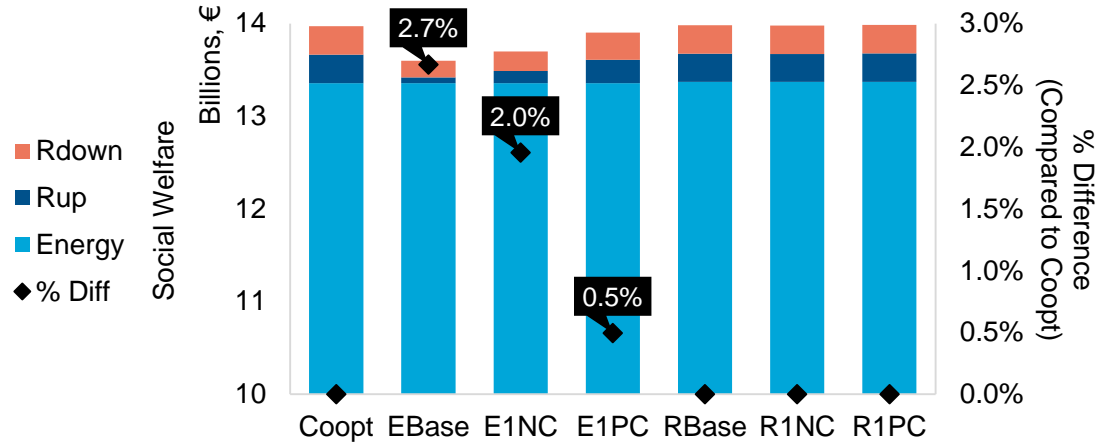
Parameters

Region	CWE (before DE/AT split)
Border Constraints	Flow-based
Timeframe	1 day (performed on several days)
Indicators	Cross-border capacities utilized Social Welfare Congestion rents Market clearing prices



Social Welfare

02 March 2017

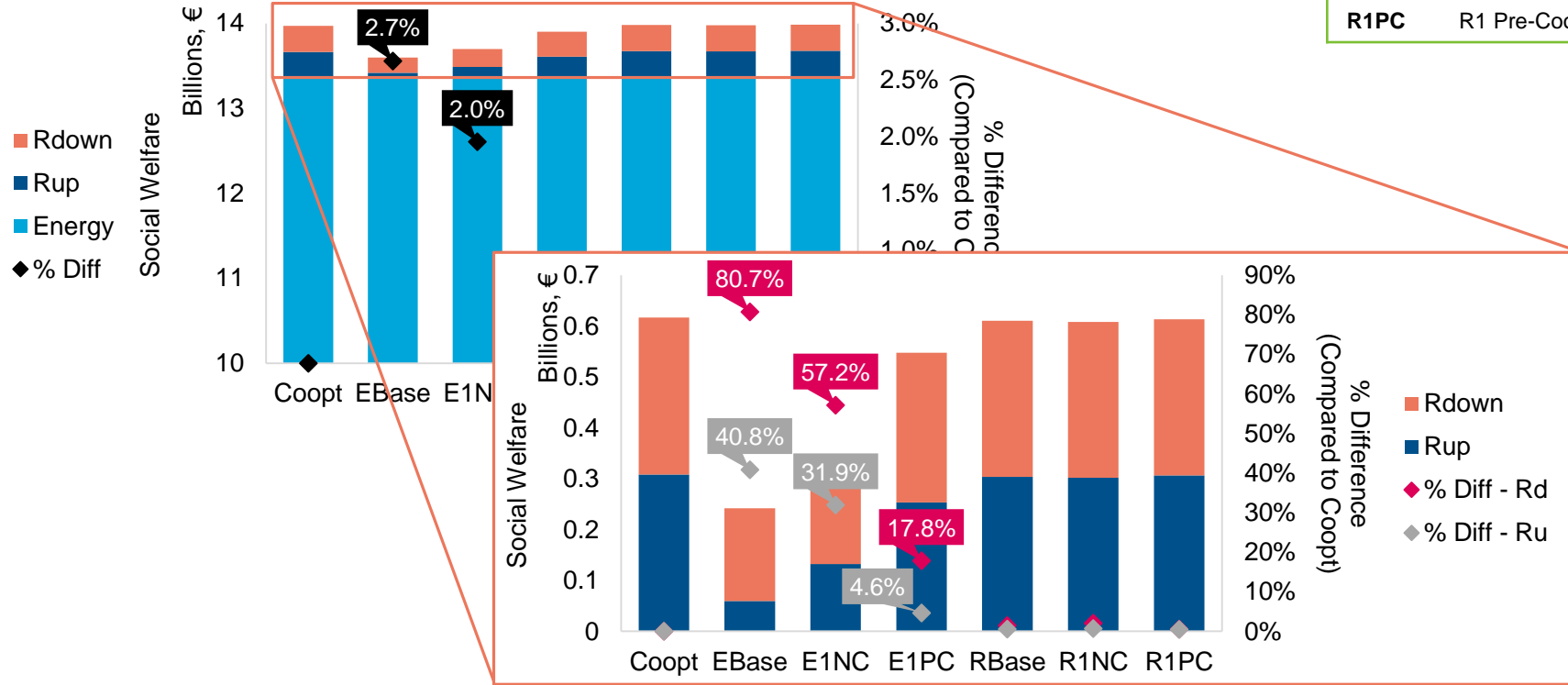


E1NC	E1 No Coopt
R1NC	R1 No Coopt
E1PC	E1 Pre-Coopt
R1PC	R1 Pre-Coopt

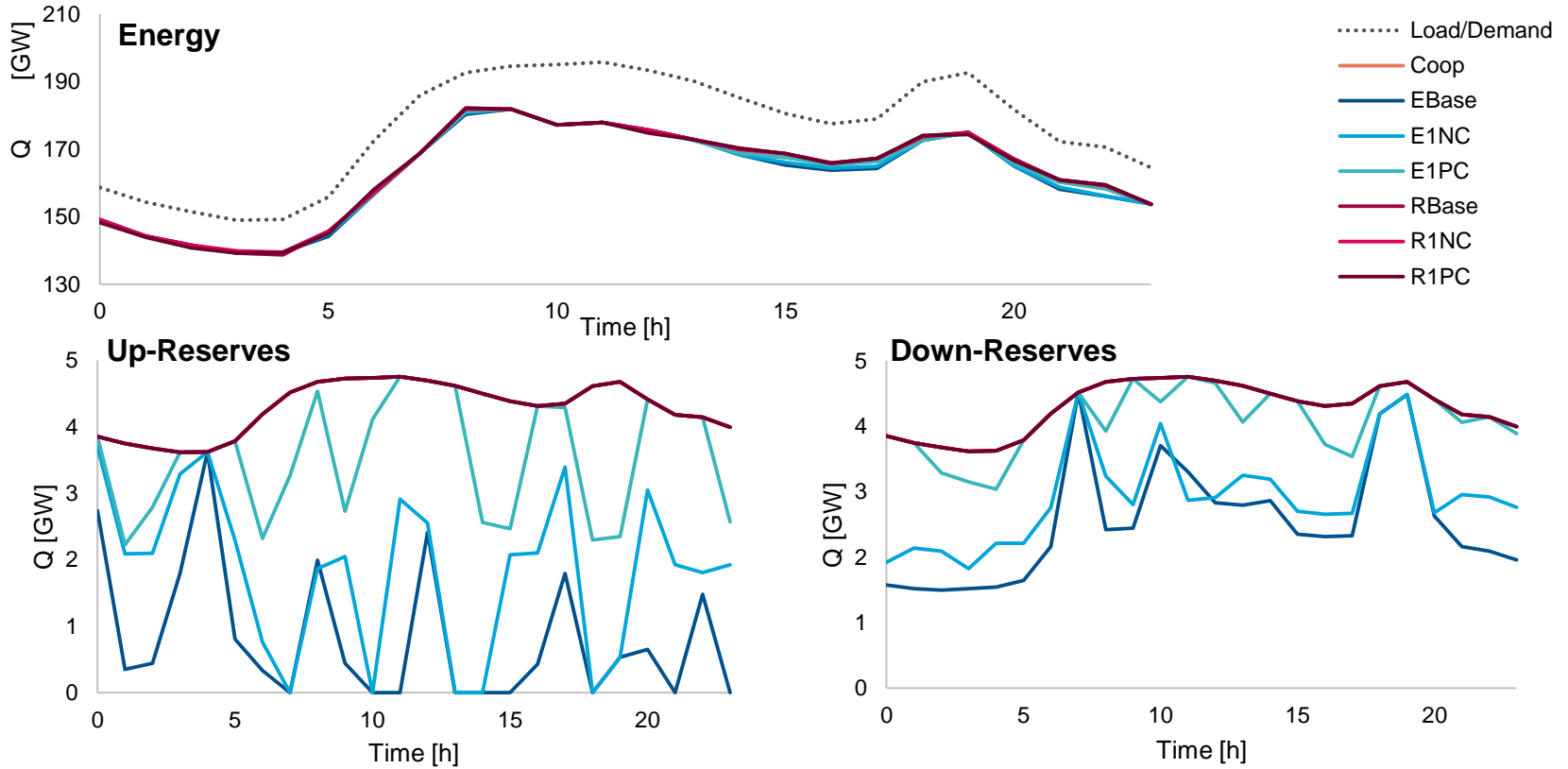
Social Welfare

02 March 2017

E1NC	E1 No Coopt
R1NC	R1 No Coopt
E1PC	E1 Pre-Coopt
R1PC	R1 Pre-Coopt

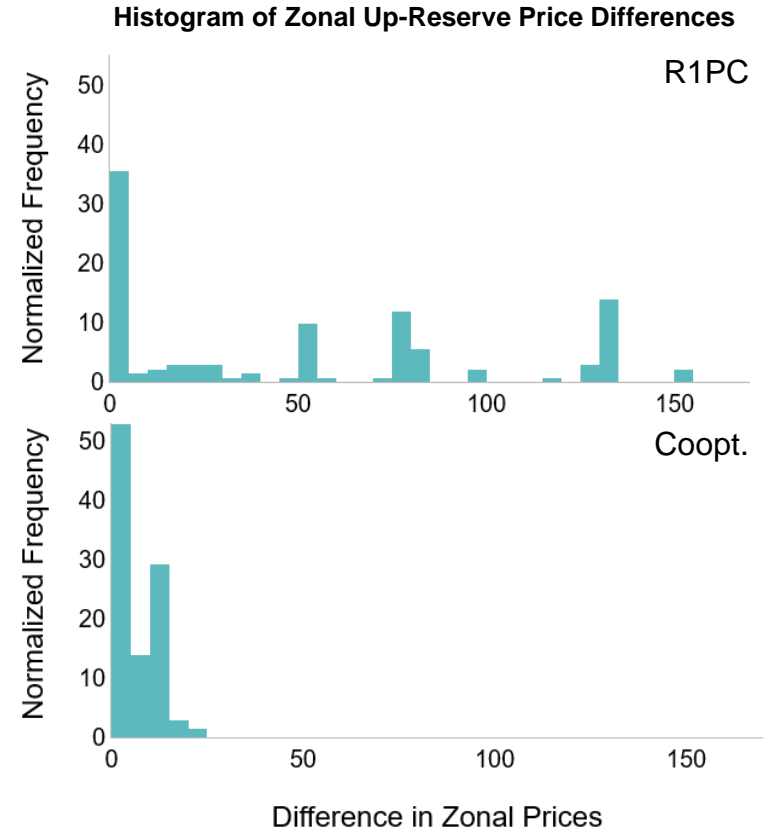
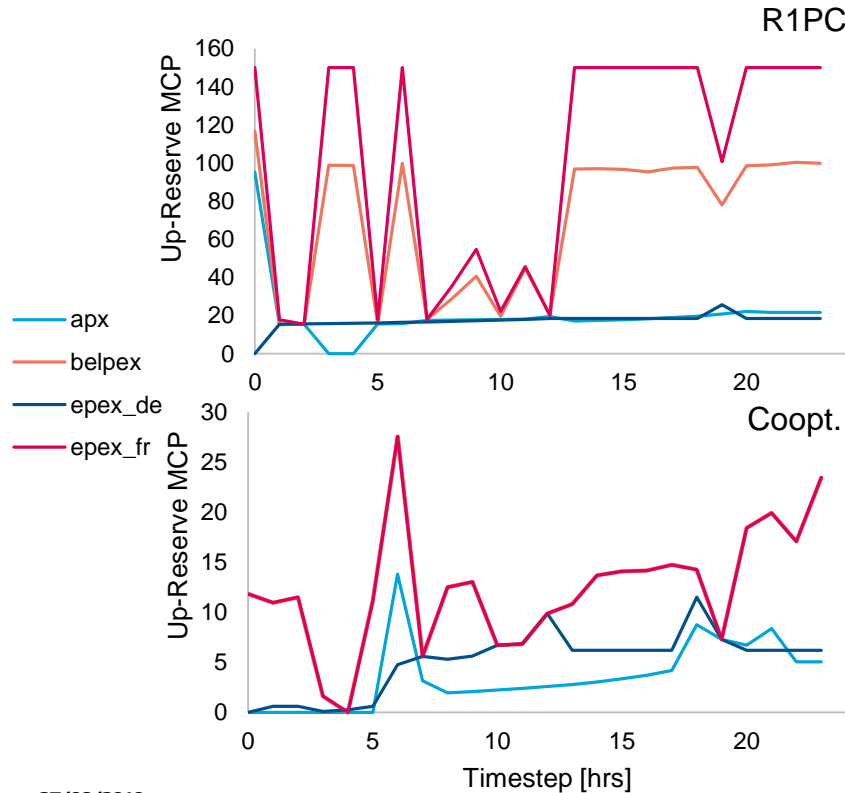


Amount Cleared – 02 Mar 2017 – FB





Results – Reserve 1st Markets



Conclusions

- 1. COOPTIMIZATION REPRESENTS THE IDEAL SOLUTION**
- 2. CLEARING ENERGY FIRST GIVES A SIGNIFICANT DECREASE IN THE RESERVE WELFARE**
- 3. CLEARING RESERVES FIRST LEADS TO A LOST OPPORTUNITY COST FOR CERTAIN ACTORS**



Appendix



References

- P. Sores, D. Divenyi, B. Polgari, D. Raisz, And A. Sleisz, "Day-ahead Market Structures For Co-optimized Energy And Reserve Allocation," In *2015 12th International Conference On The European Energy Market (EEM)*, Lisbon, Portugal, 2015, Pp. 1–5.
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- EUPHEMIA Public Description: PCR Market Coupling Algorithm. 1.5. EPEX SPOT–GME–NordPool–OMIE–OPCOM–OTE–TGE. Dec. 2016. url: <https://www.nordpoolspot.com/globalassets/download-center/pcr/euphemia-public-documentation.pdf>
- ENTSO-E WGAS, "Survey on Ancillary Services Procurement, Balancing Market Design 2016." 03-Oct-2017.



Model Limits and Caveats

SAME OFFERS FOR ALL CASES

In reality, market players include a price premium due to the risk of a lost opportunity cost, which is not taken into account in this study

ALL CAPACITY ON FIRST MARKET

In reality, market players would reserve some capacity for the second market

FEWER OFFERS (~2500+)

No increase in computational time for this study

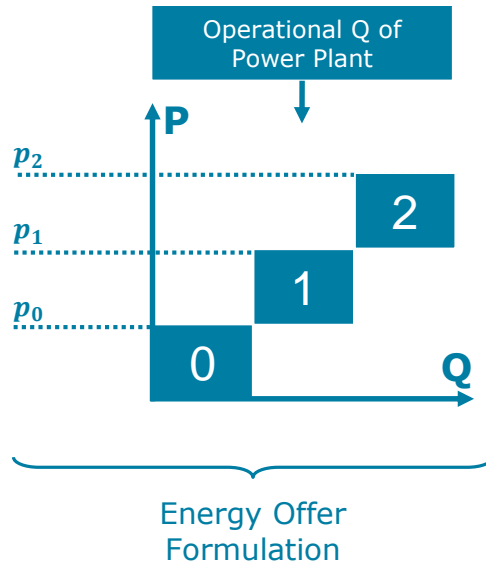
ALL ENERGY SOLD ON DAY-AHEAD MARKET

Not modelling OTC, etc.

Hybrid Offer Formulation

The energy offer formulation separately optimizes the profit of each equipment based on different price curves (some optimistic, some pessimistic) taking into account the technical parameters

→ **This creates an offer for each price curve**

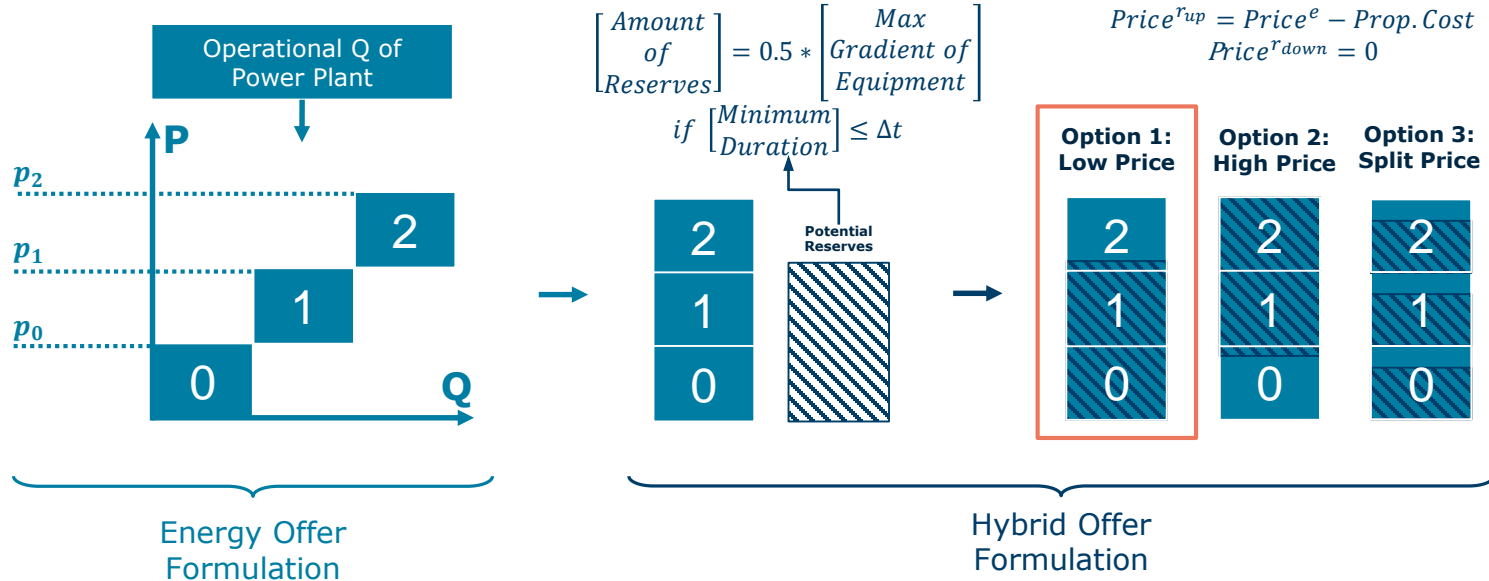


Hybrid Offer Formulation

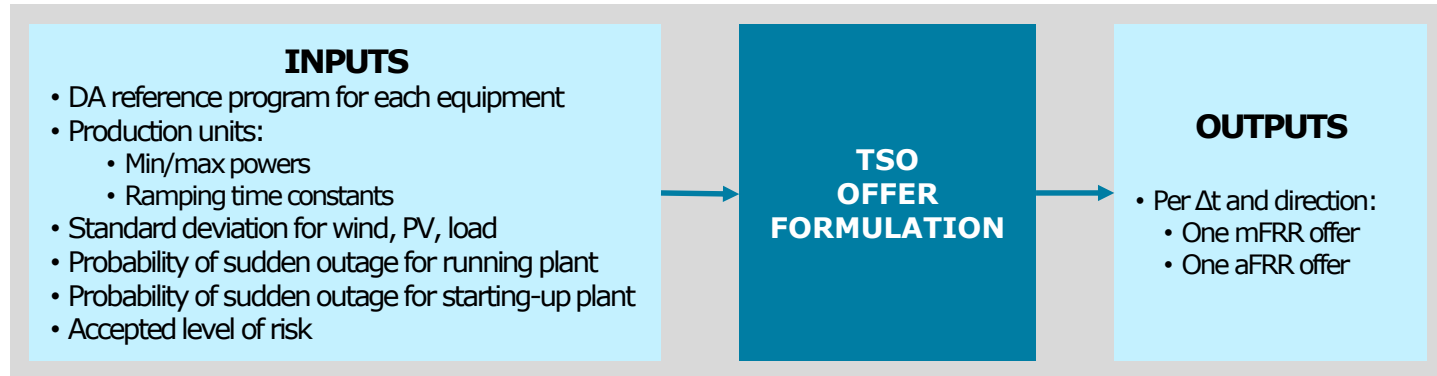
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The calculated reserve amount for each equipment can be split up into these offers 3 different ways



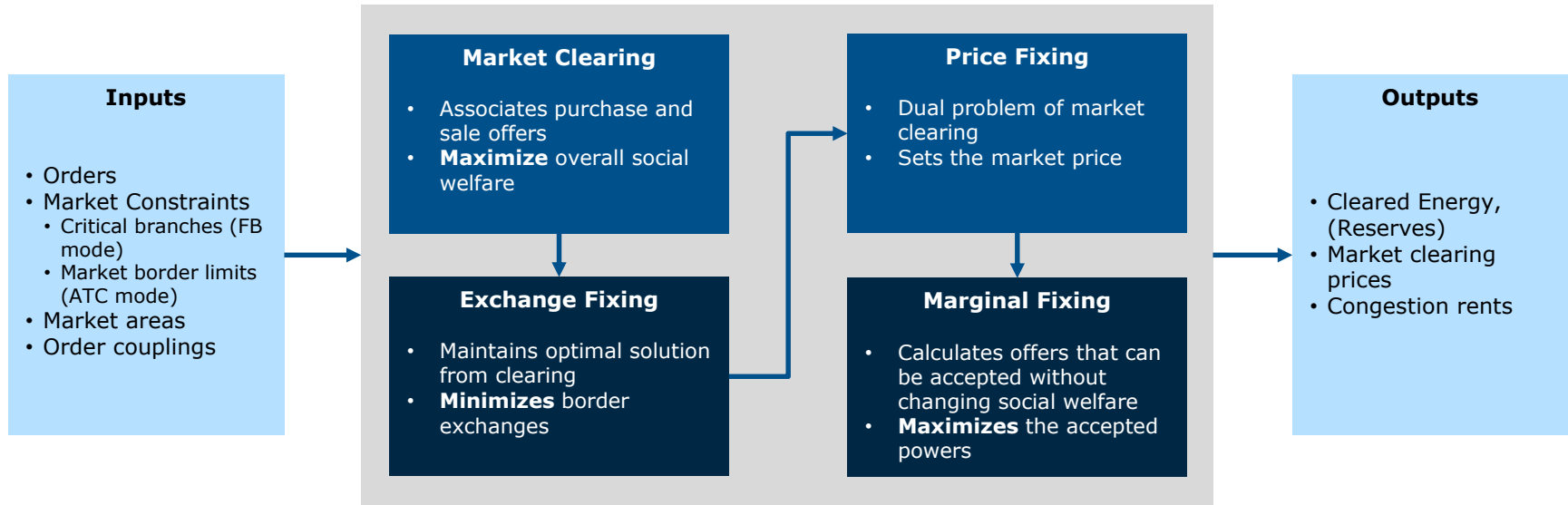
TSO Offer Formulation



Note: Secondary control amount defined according to ENTSO-E formula

Clearing Model Development

Modules





Market Clearing

Constraints

Market Clearing
Exchange Fixing
Price Fixing
Marginal Fixing

1. **EVERYTHING SOLD IS PURCHASED**

Ensured across all zones connected by a common market border

2. **TOTAL AMOUNT OF POWER/CAPACITY ACCEPTED IS WITHIN RANGE OFFERED**

Ensured for each order

3. **BORDER CONSTRAINTS**

ATC – Ensured for each market border

Flow-based – Ensured for each critical branch