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eeh power systems laboratory

EMPA
Materials Science & Technology

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4th Generation District Heating Technologies and Systems

3RD INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND
4TH GENERATION DISTRICT HEATING

The Influence of Participation in Ancillary Service Markets on Optimal Energy Hub Operation

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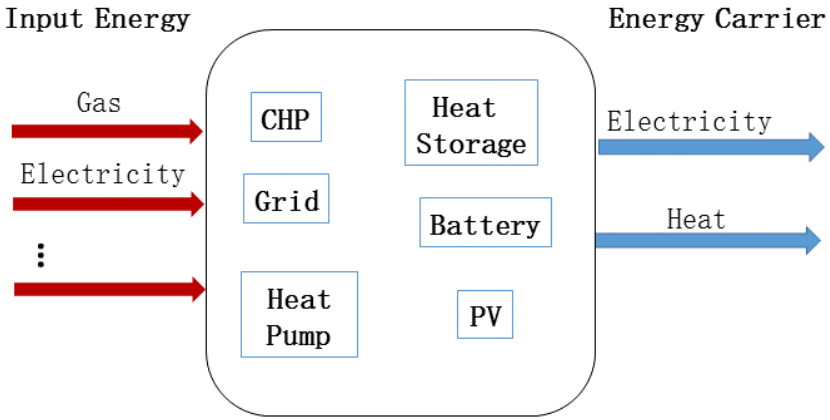
Copenhagen, 12.09.2017

Outline

- Introduction – Energy Hubs, Ancillary Services and Goal
- Model – Assumptions and Objective Function
- Evaluation – Assessment of Stochastic Modelling
- Case Studies – Parameter Sensitivity Analysis
- Conclusion
- Outlook

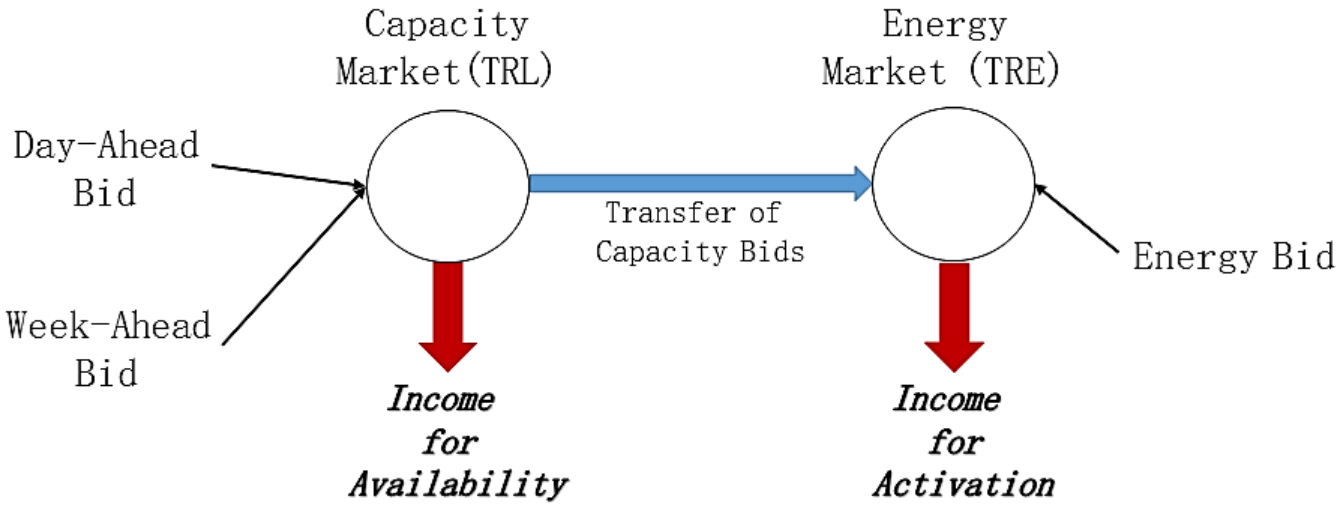
Introduction – Energy Hubs (EH)

- Conceptual approach to describe District Multi Energy Systems (DMES)



Introduction – Ancillary Services (AS)

- Tertiary Control Reserve



Source: *Survey on Ancillary Services Procurement, Balancing Market Design 2015, ENTSO-E, 2016*

Introduction – Goal

- Model development to include AS in the EH modelling tool
- Model development that determines the optimal bidding strategy
- Investigation of important parameters that affect the EH operation
- Investigation of possible profitable scenarios under AS participation

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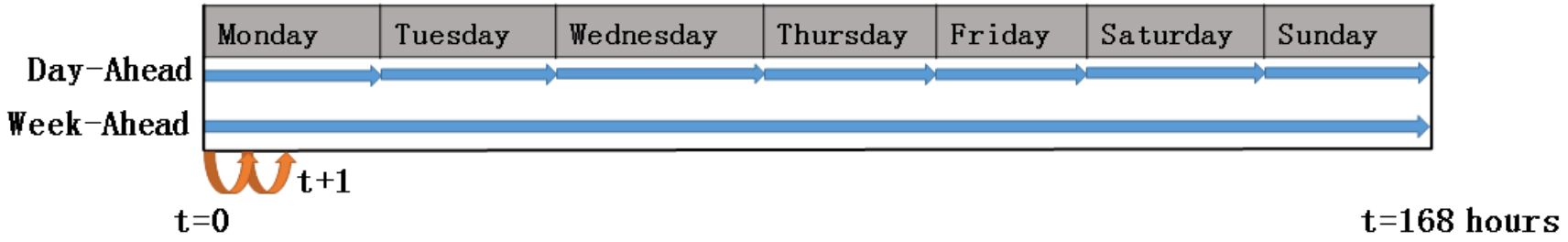
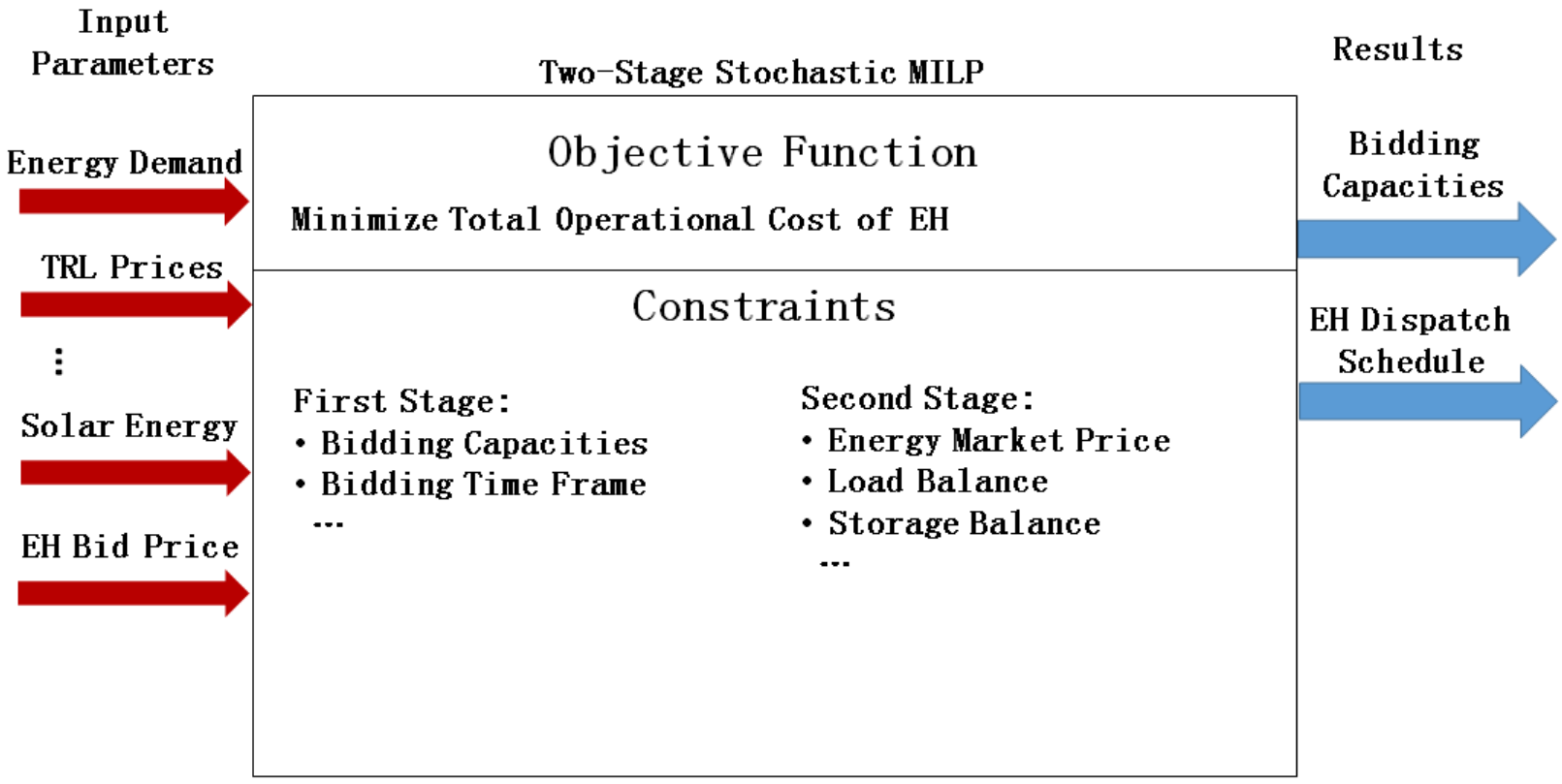
Model – Products and Time Frame

- Positive and Negative TRL
- Week-ahead and Day-ahead products
- Optimization horizon: 1 week
- Simulation horizon: 1 year



Model – MILP



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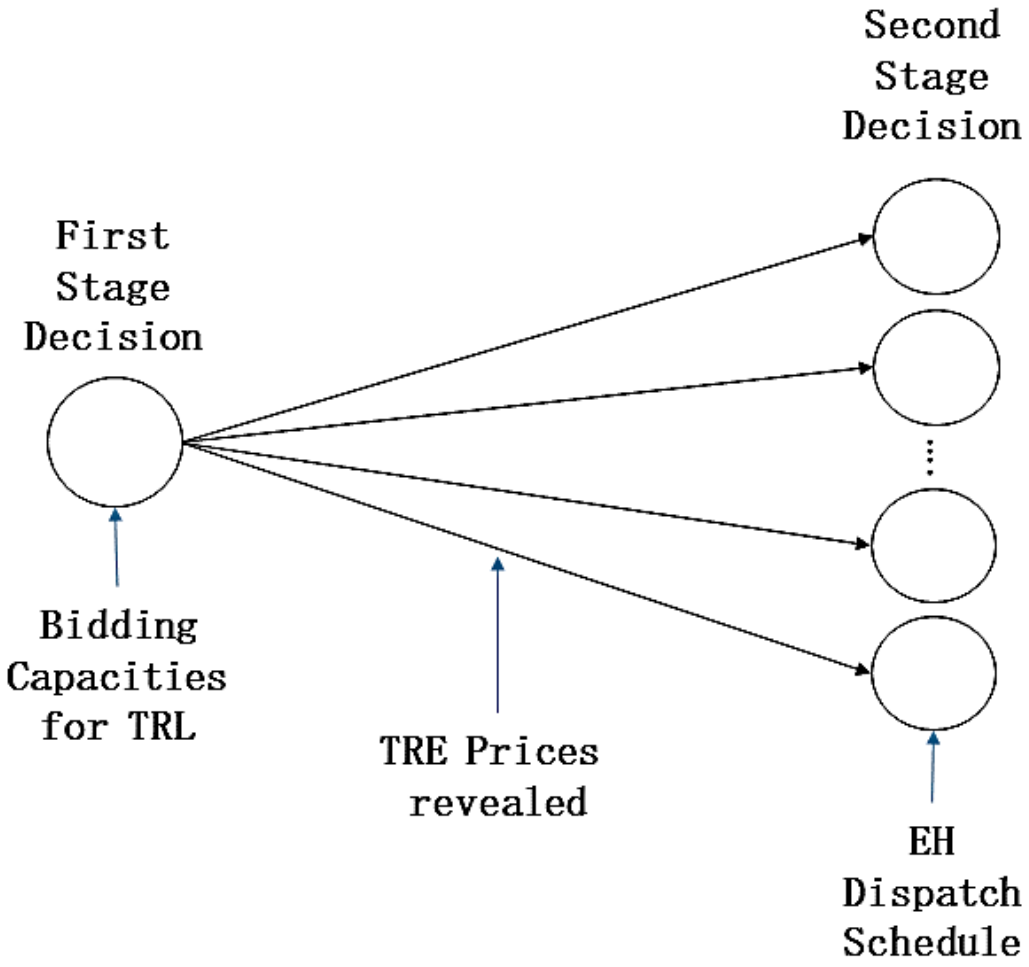
Model – Two-Stage Stochastic MILP



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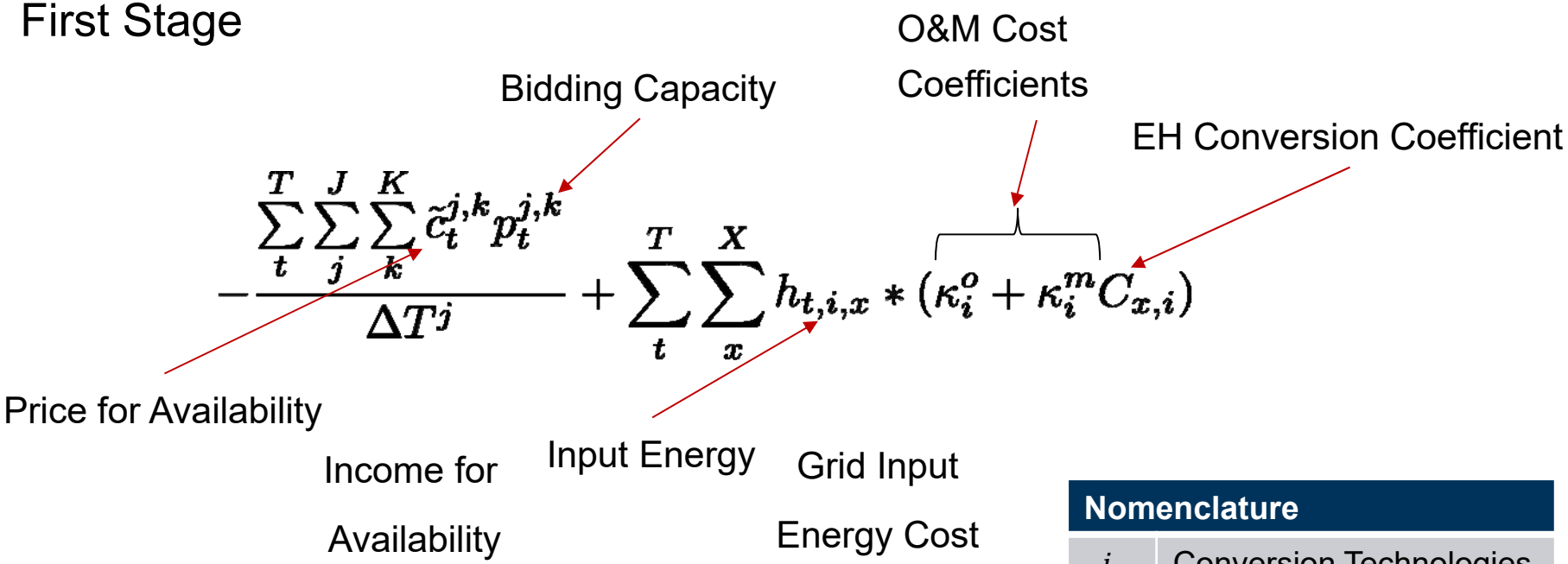
Model – Objective Function (Total Cost)

First Stage



Nomenclature	
i	Conversion Technologies
j	Week or Day Ahead
k	Positive or Negative
t	Time
x	Energy Carrier

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Model – Objective Function (Total Cost)

Second Stage

Price for Energy

Binary Activation Variable

$$\frac{1}{s}\sum_{s}^{S}\left(\sum_{i}^{I}\sum_{t}^{T}\sum_{x}^{X}(\kappa_i^o+\kappa_i^m C_{x,i})h_{t,i,x,s}-\sum_{t}^{T}\sum_{j}^{J}\widehat{c}^{j,k}\alpha_{t,s}^{j,k}p_t^{j,k}\right)$$

Cost of Operation

Income from Activation

Nomenclature	
i	Conversion Technologies
j	Week or Day Ahead
k	Positive or Negative
t	Time
x	Energy Carrier
s	Scenarios

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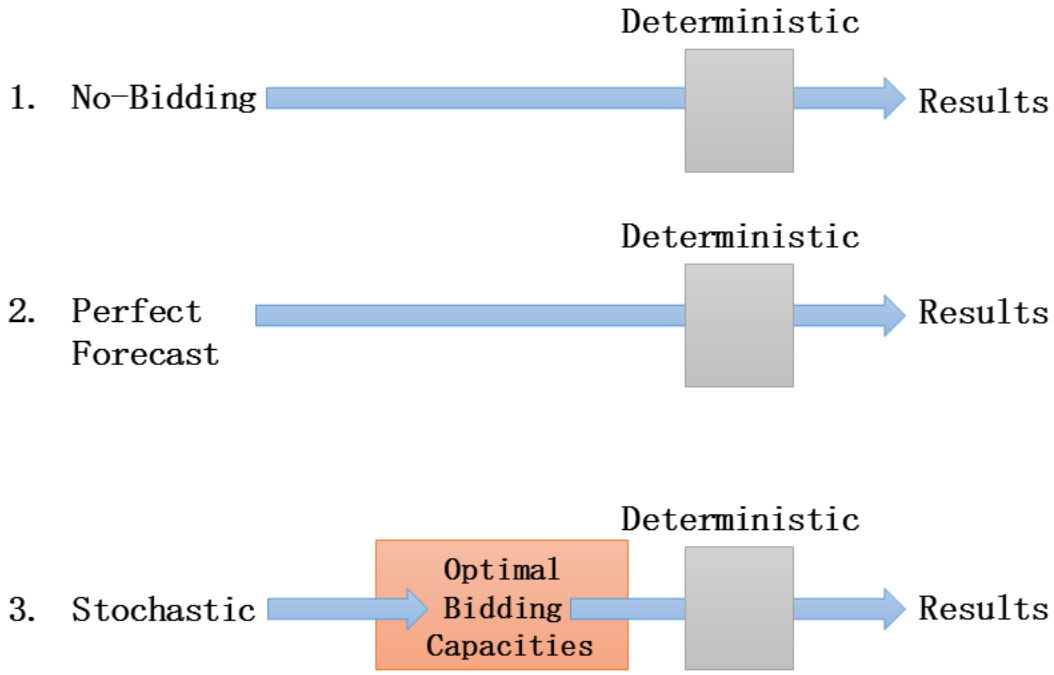
Evaluation – Base Case Comparison

- Definition of Base Case

- Comparison of three different versions of Base Case:



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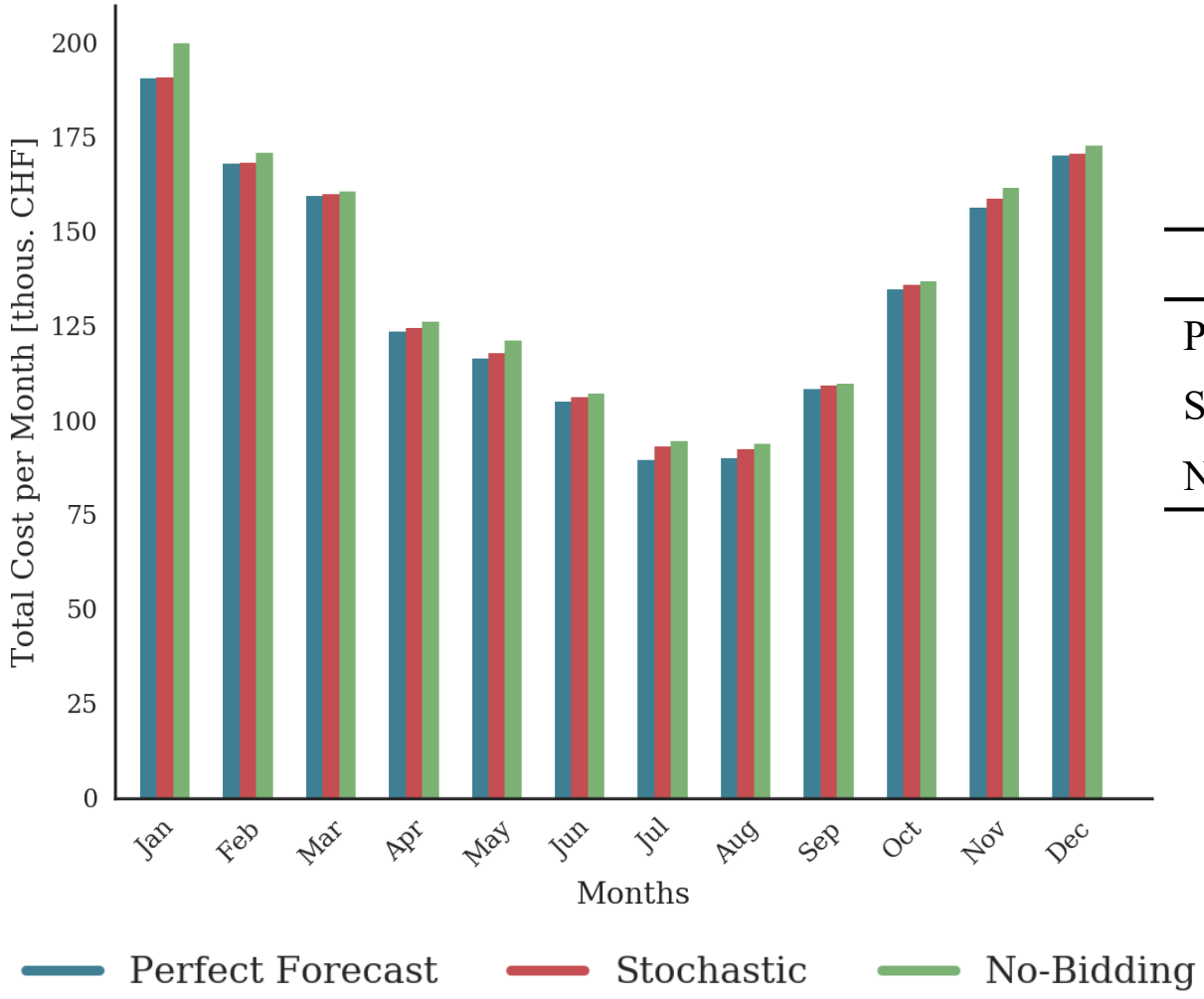
Evaluation – Total Cost



Total Cost [thous. CHF]	
Perfect Forecast	1,612
Stochastic	1,627
No-Bidding	1,655

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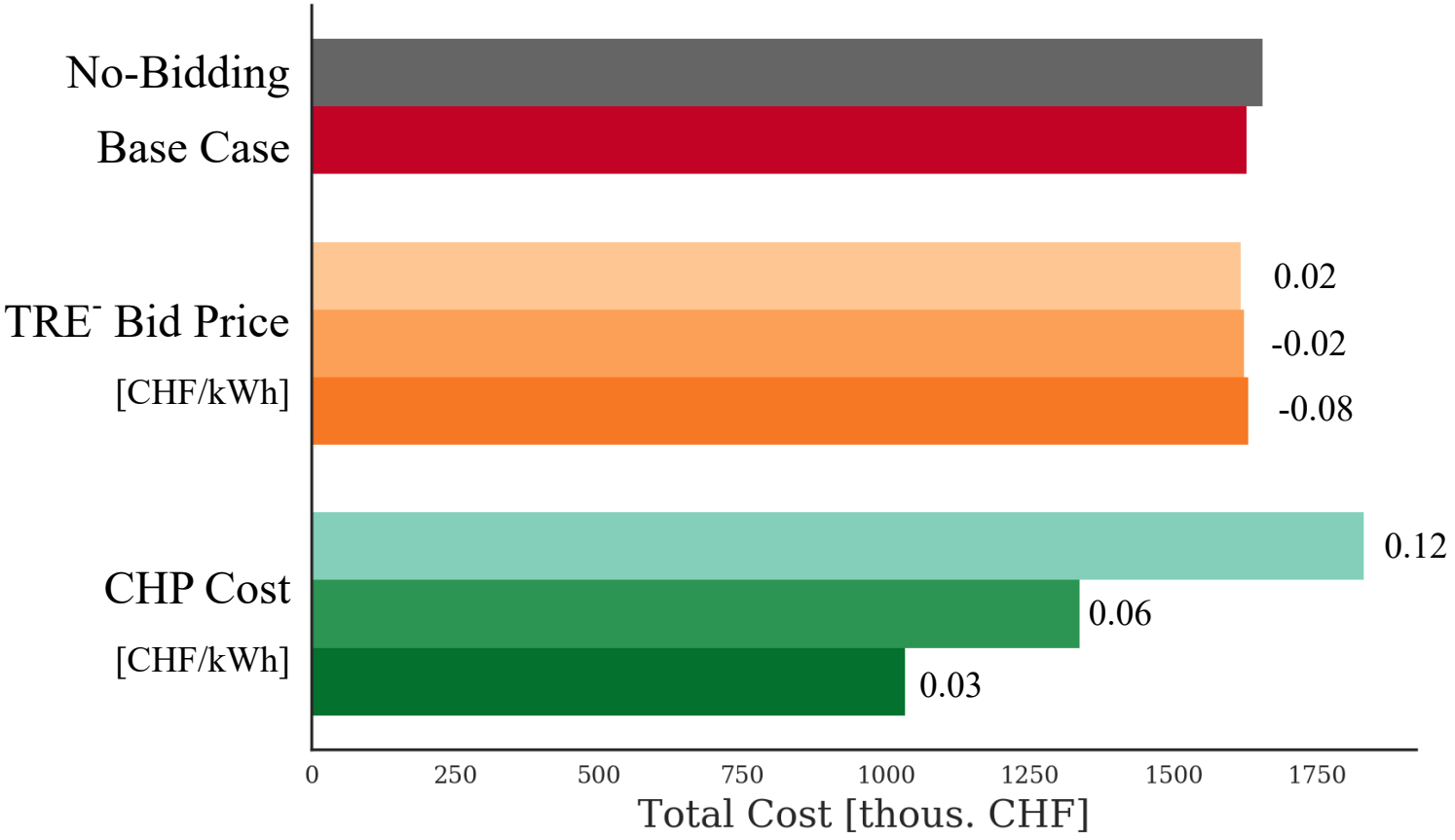
Case Studies – Parameter Sensitivity Analysis

Case	Modified Parameter	New Value	Base Case Value	Unit
1		0.03		
2	CHP Operating Cost	0.06	0.09	CHF/kWh
3		0.12		
4		-0.08		
5	TRE^{-} Bid Price	-0.02	0.08	CHF/kWh
6		0.02		

Case Studies – Total Cost



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Conclusion

- Model is capable of determining the optimal bidding strategy of the EH
- Modeling evaluation shows that the uncertainty is captured well
- Case Studies show Parameter Sensitivity
- Small Margin for Profit

Outlook

- Model is extendable to include Primary, Secondary Control Reserve and Control Pooling
- Design Optimization
- Capacity Market Uncertainty

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Thank you for your attention!

Model (4/7) – Assumptions

- Capacity bid always accepted
- All bidding decisions at the beginning of the week
- No minimum bid size considered
- Energy provision every hour
- Perfect knowledge of EH demand and solar energy input

Model (7/7) – Uncertainty

- Time series of the TRE prices

$$c_{1,s}^{m,pos} \dots c_{T,s}^{m,pos}, \qquad c_{1,s}^{m,neg} \dots c_{T,s}^{m,neg}$$

- Scenario generation
  - Decorrelation technique
  - ARIMA model

Nomenclature	
$c_{t,s}^{m,pos}$	TRE⁺ Market Scenario Price
$c_{t,s}^{m,neg}$	TRE⁻ Market Scenario Price

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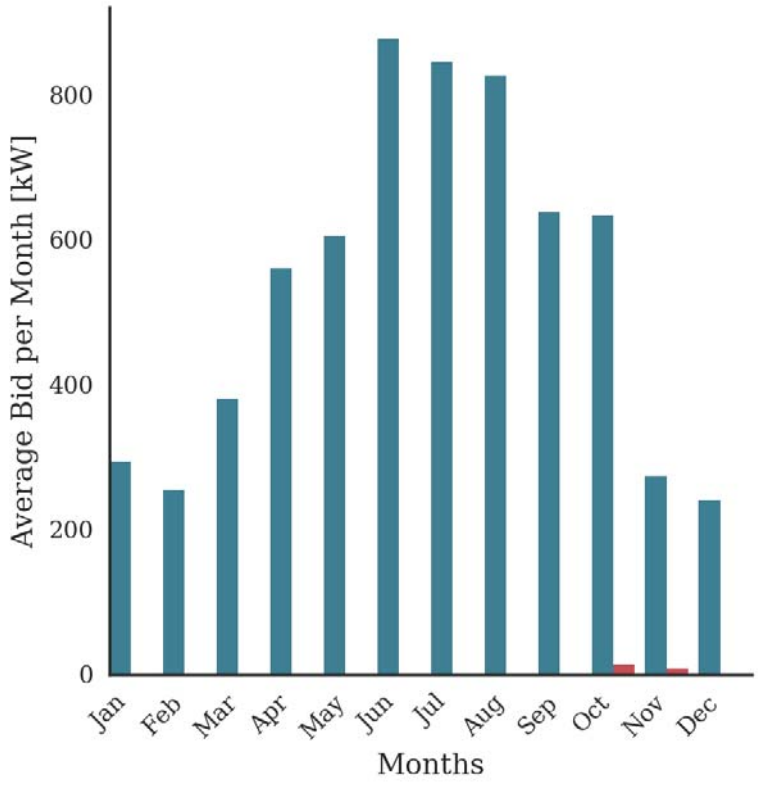
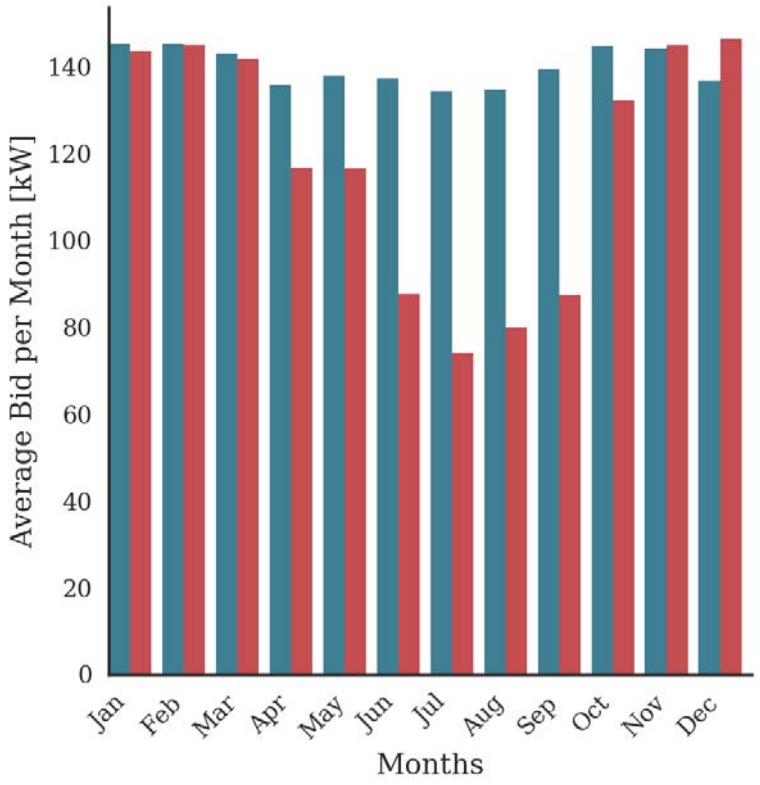
Evaluation – Day-Ahead, Average Bid Size

Positive Control



Negative Control



Perfect Forecast Stochastic

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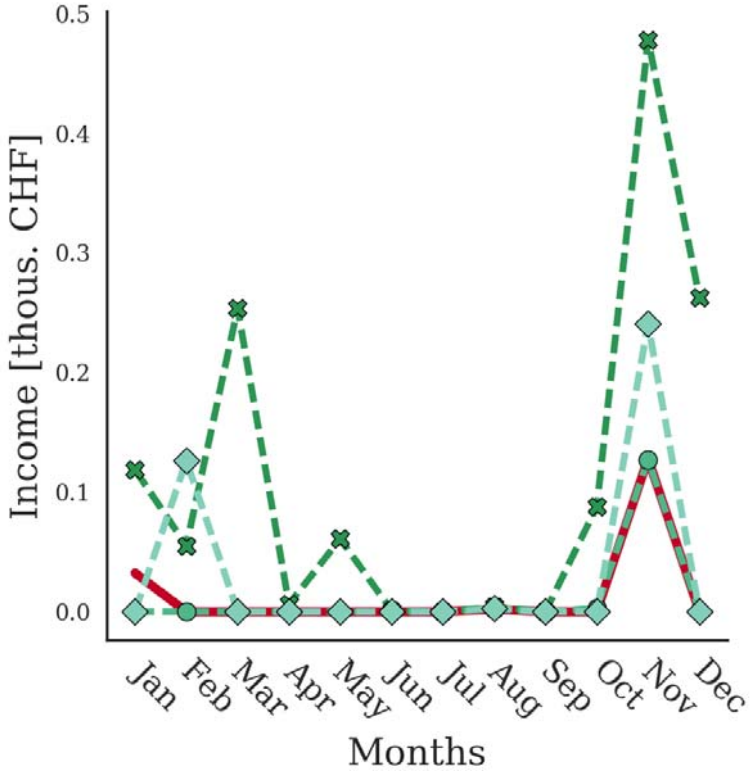
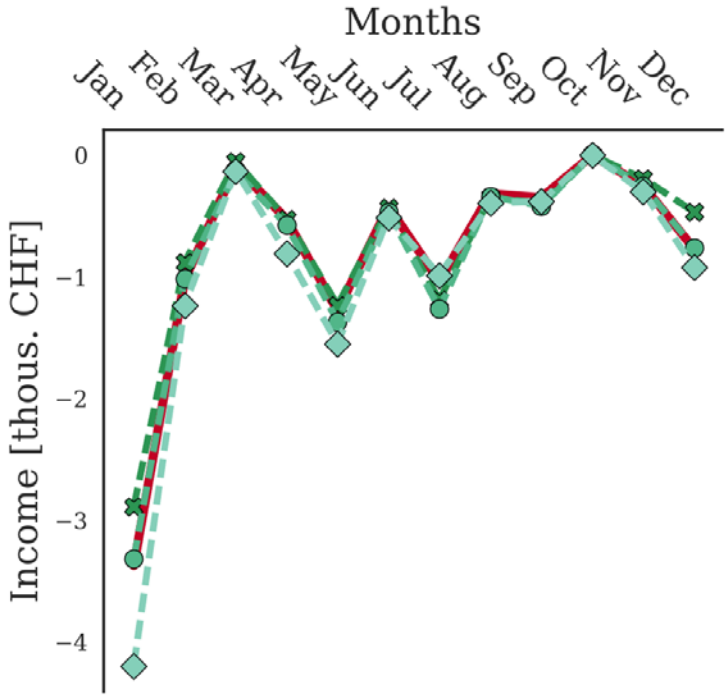
Case Studies – CHP Cost, Activation Income

Positive Control

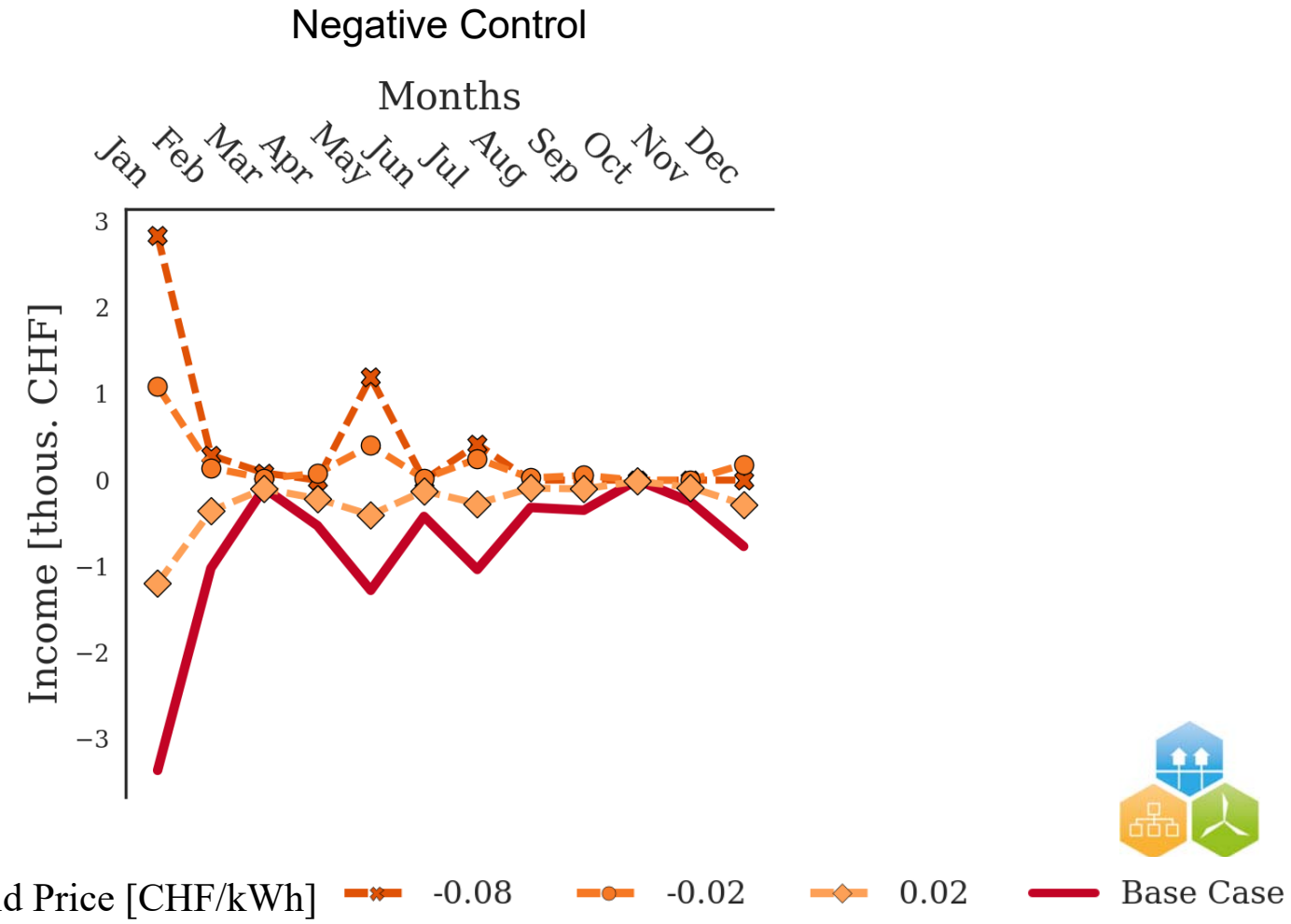


Negative Control

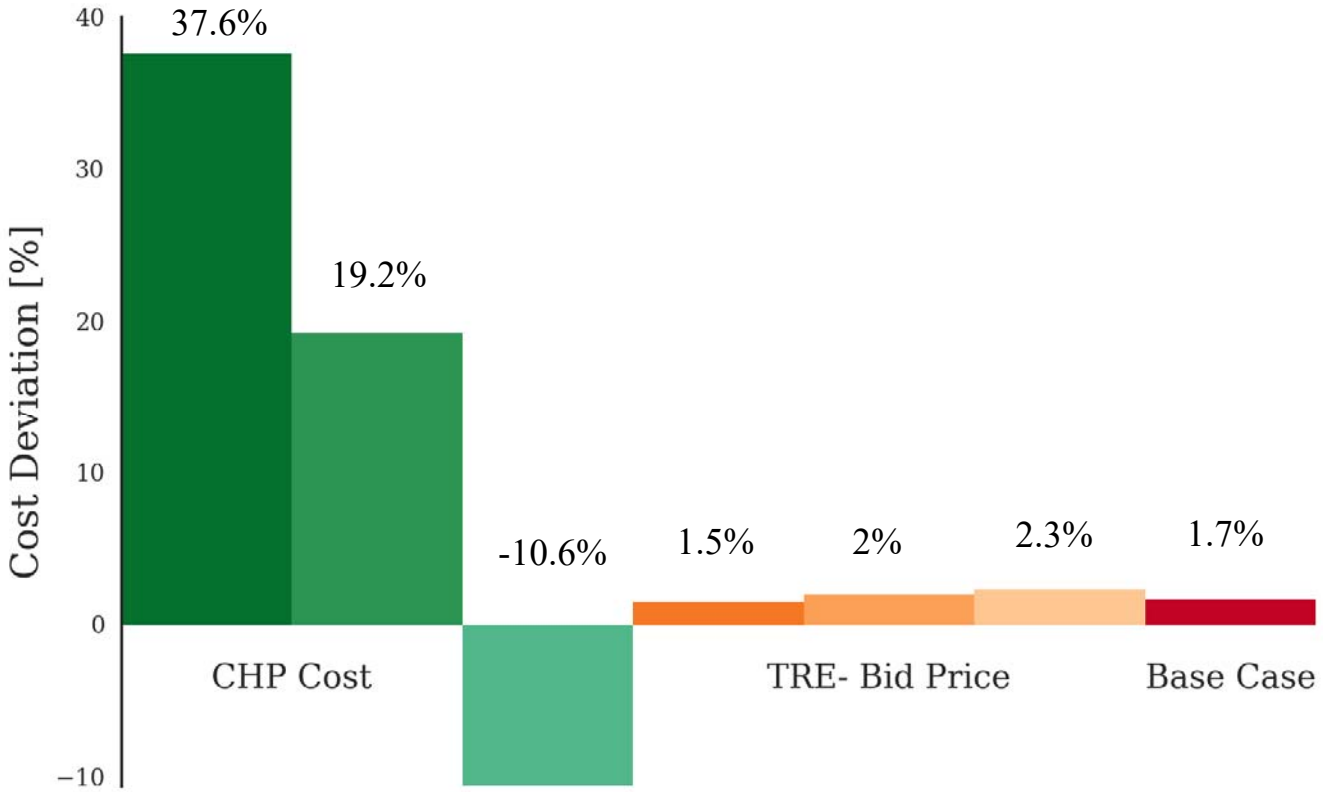


CHP Cost [CHF/kWh] 0.03 0.06 0.12 Base Case

Case Studies – TRE⁻ Bid Price, Activation Income



Case Studies – Cost Deviation from No-Bidding



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Conclusion

- Model is capable of determining the income of TRL for EH
  - Negative Control Bids are more frequent
  - Day-Ahead Products are preferable
- Case Studies show Parameter Sensitivity
  - CHP cost has a great influence
  - TRE^- bid price is important for frequency of activation
- Small Margin for Profit

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Ancillary Services (AS) in Switzerland

- Frequency Control
- Voltage Support
- Compensation of active power losses
- Black Start and island operation capability
- System coordination
- Operational measurement

Frequency Control

Capacity			
	PRL	***SRL***	***TRL***
Procurement Scheme	Market	Market	Market
Minimum Bid size (MW)	1	5	5
Product Resolution (time)	Week(s)	Week(s)	Day(s)
Distance to Real Time of Auction	Day(s)	Day(s)	Day(s)
Settlement Rule	Pay as Bid	Pay as Bid	Pay as Bid
Cost Recovery Scheme	Grid Users	Grid Users	Grid Users
Monitoring	Real Time	Real Time	Real Time
Product	Symmetric	Symmetric	Asymmetric
Tender Period	Weekly	Weekly	Weekly or Daily
Capacity Provider	Generators + Load + Pump Storage units pumping		

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Frequency Control

Energy			
	PRL	***SRL***	***TRL***
Procurement Scheme	-	-	Market
Activation Rule	-	Pro-Rata	Merit Order
Minimum Bid size (MW)	-	-	5
Product Resolution (time)	-	-	Hour or Blocks
Distance to Real Time of Auction	-	-	Hour or Blocks
Settlement Rule	-	Hybrid	Pay as Bid
Cost Recovery Scheme	-	BRP	BRP
Monitoring	-	Ex Post Check	Ex Post Check
Product	Symmetric	Symmetric	Daily Tenders for 4h-Blocks
Activation Time	30s	5m	15m
Partially Activated Product	-	-	No
Volume of Control Power Required (MW)	+/- 74	+/-400	-450,-300
Link	Control Signal	Control Signal	Email, Call
Remuneration of Energy	-	According to Spot Market Price	For 4-h Block Offer and Energy Used

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Model – Definition of Bidding Capacities

$$p_t^{j,k} = p_t^{g,k} + p_t^{st,k} \quad for \quad k = positive \tag{1}$$

$$p_t^{j,k} = p_t^{st,k} \quad for \quad k = negative \tag{2}$$

- $p_t^{st,k}$: Bidding Capacity Storage
- $p_t^{g,k}$: Bidding Capacity from Generating Units

Nomenclature	
i	Conversion Technologies
j	Week or Day Ahead
k	Positive or Negative
t	Time
x	Energy Carrier

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Model – First Stage Constraints

- Product Time Frame

$$p_t^{j,k} = p_{t+1}^{j,k} \quad for \quad mod(t, 168) \neq 0, \quad j = w$$

$$p_t^{j,k} = p_{t+1}^{j,k} \quad for \quad mod(mod(t, 24), 4) \neq 0, \quad j = d$$

- Minimum Bid Size

$$p_t^{j,k} \leq \beta_t^{j,k} * M$$

$$p_t^{j,k} \geq \beta_t^{j,k} * \underline{p}^{j,k}$$

Nomenclature	
i	Conversion Technologies
j	Week or Day Ahead
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x	Energy Carrier

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Model – Second Stage Constraints

- Positive Control

$$p_t^{g,k} \leq \sum_i^I (h_i^N - h_{t,i,x,s} C_{x,i})$$

$$p_t^{st,k} \leq \Omega_{t,s,x}^{soc} - \Omega_x^N * \underline{\omega}$$

- Negative Control

$$p_{t,x}^{st,k} \leq \Omega_x^N - \Omega_{t,s,x}^{soc}$$

Nomenclature	
i	Conversion Technologies
j	Week or Day Ahead
k	Positive or Negative
t	Time
x	Energy Carrier

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Model – Energy Market Constraints

- Positive Control

$$\alpha_{t,s}^{j,k} = \begin{cases} 1, & \text{if} \quad \widehat{c}^{j,k} \leq c_{t,s}^{m,k} \\ 0, & \text{otherwise} \end{cases}$$

- Negative Control

$$\alpha_{t,s}^{j,k} = \begin{cases} 1, & \text{if} \quad \widehat{c}^{j,k} * c_{t,s}^{m,k} > 0 \quad and \quad \left|\widehat{c}^{j,k}\right| \leq \left|c_{t,s}^{m,k}\right| \\ 0, & \text{if} \quad \widehat{c}^{j,k} * c_{t,s}^{m,k} > 0 \quad and \quad \left|\widehat{c}^{j,k}\right| \geq \left|c_{t,s}^{m,k}\right| \\ 1, & \text{if} \quad \widehat{c}^{j,k} * c_{t,s}^{m,k} < 0 \quad and \quad \widehat{c}^{j,k} > 0 \\ 0, & \text{if} \quad \widehat{c}^{j,k} * c_{t,s}^{m,k} < 0 \quad and \quad \widehat{c}^{j,k} < 0 \\ 0, & \text{if} \quad \widehat{c}^{j,k} * c_{t,s}^{m,k} = 0 \end{cases}$$

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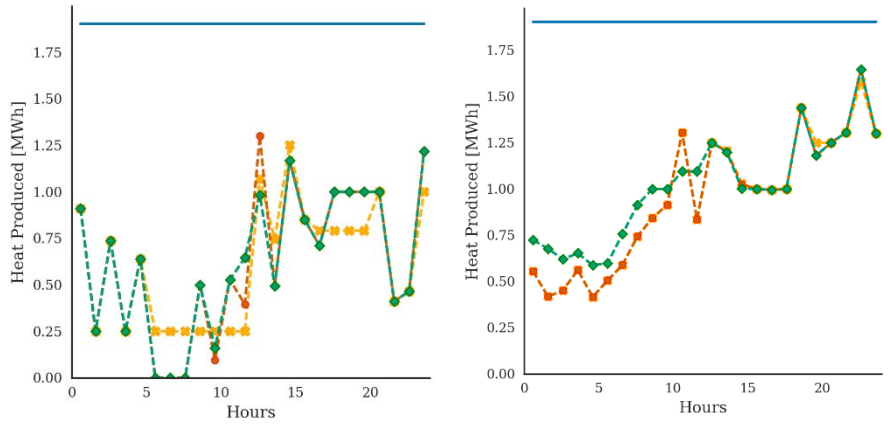
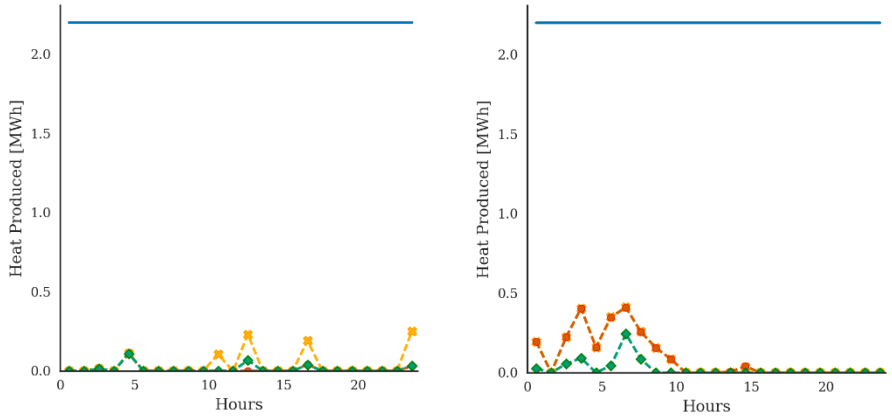
Evaluation - Results

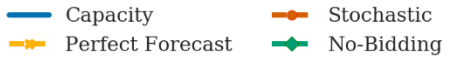
Day 310 | Day 359

CHP



Heat Pump





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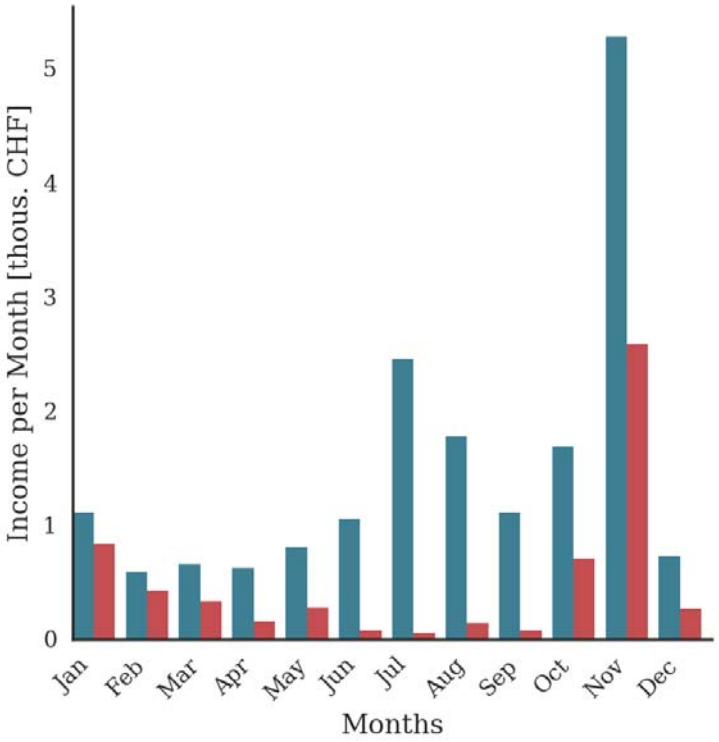
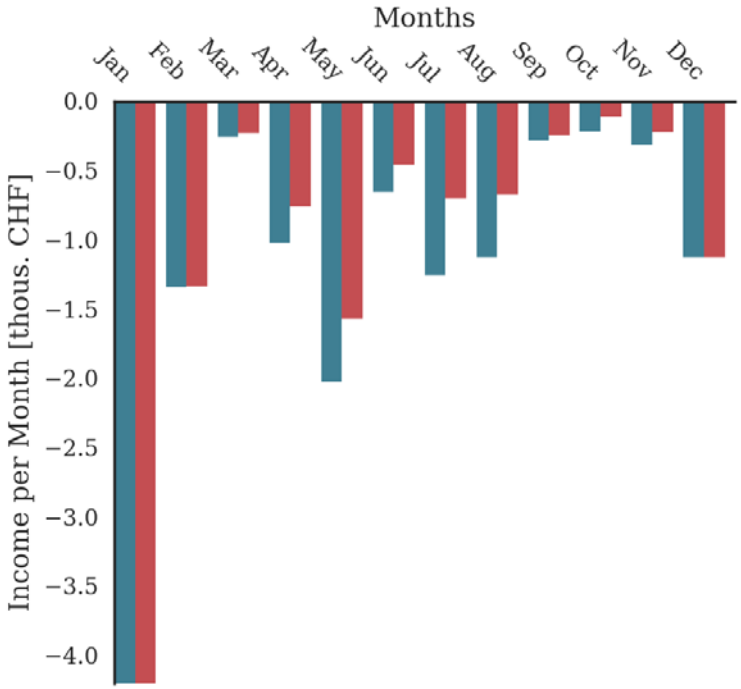
Evaluation- Results



Availability Income



Activation Income

Perfect Forecast Stochastic

Evaluation- Results

Total Avail. Income [thous. CHF]	
Perfect Forecast	17.8
Stochastic	5.9
No-Bidding	0

Availability Income

Total Activ. Income [thous. CHF]	
Perfect Forecast	-14.4
Stochastic	-12.2
No-Bidding	0

Activation Income

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Evaluation

Period From 07.11.2016
Until 07.11.2016
Time 08 - 12
SHOW

• Period: 07.11.2016 - 07.11.2016

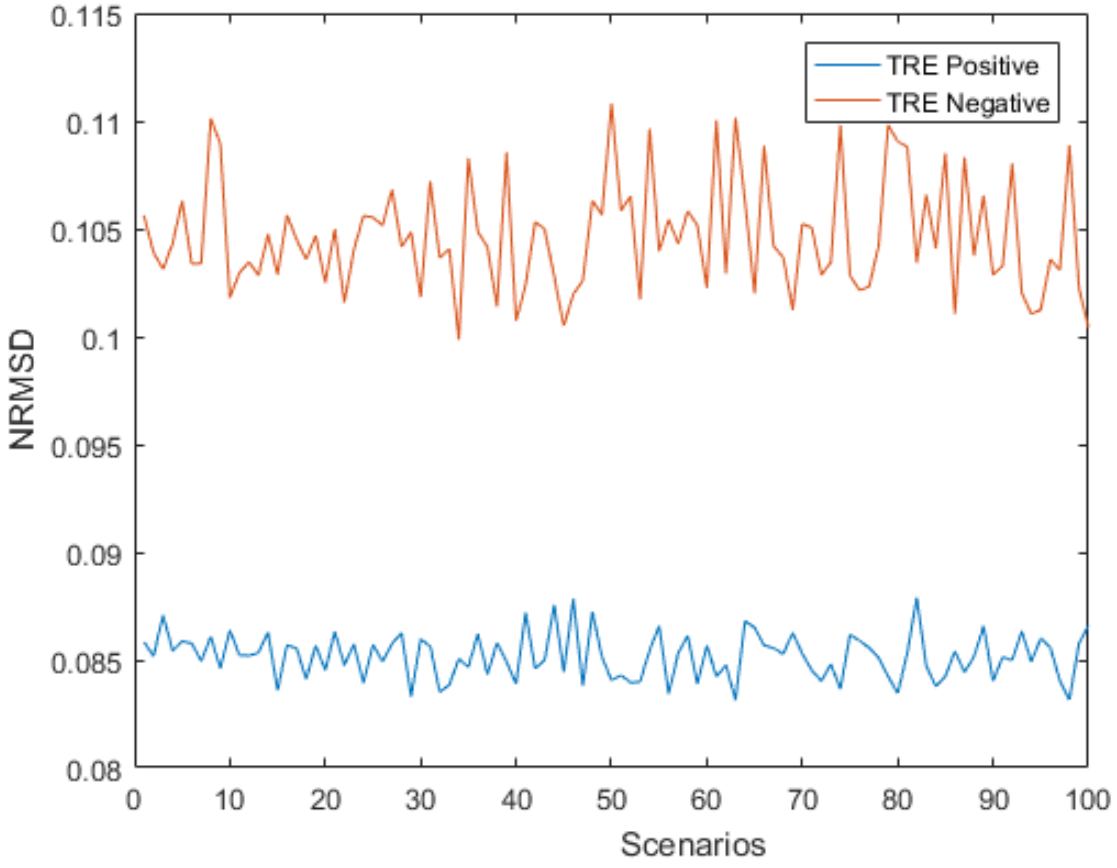
Date	Time	Description	Power offered MW	Power allocated MW	Price CHF/MW
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	15.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	7	7	19.08
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	37.80
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	38.80
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	39.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	39.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	48.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	48.44
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	50.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	55.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	58.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	85.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	89.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	100	5	100.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	130.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	30	30	130.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	145.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	156.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	180.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	35	30	199.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	200.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	80	40	235.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	300.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	25	0	1'000.00
07.11.2016	08:00 - 12:00	TRL+_s_08-12	20	0	1'000.00

Power Positive
Period From 06.11.2016
Until 06.11.2016
Time 08 - 12
SHOW

• Period: 06.11.2016 - 06.11.2016

Date	Time	Description	Power offered MW	Power allocated MW	Price CHF/MW
06.11.2016	08:00 - 12:00	TRL+_s_08-12	100	90	1.80
06.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	2.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	2.30
06.11.2016	08:00 - 12:00	TRL+_s_08-12	100	59	2.32
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	9	2.43
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	10	2.70
06.11.2016	08:00 - 12:00	TRL+_s_08-12	15	15	2.80
06.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	3.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	30	30	3.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	3.20
06.11.2016	08:00 - 12:00	TRL+_s_08-12	20	20	3.20
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	3.50
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	3.60
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	3.60
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	3.70
06.11.2016	08:00 - 12:00	TRL+_s_08-12	5	5	3.89
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	4.80
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	8.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	5	0	20.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	20.10
06.11.2016	08:00 - 12:00	TRL+_s_08-12	50	0	38.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	5	0	50.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	8	0	51.00
06.11.2016	08:00 - 12:00	TRL+_s_08-12	10	0	145.00

Scenario Forecast



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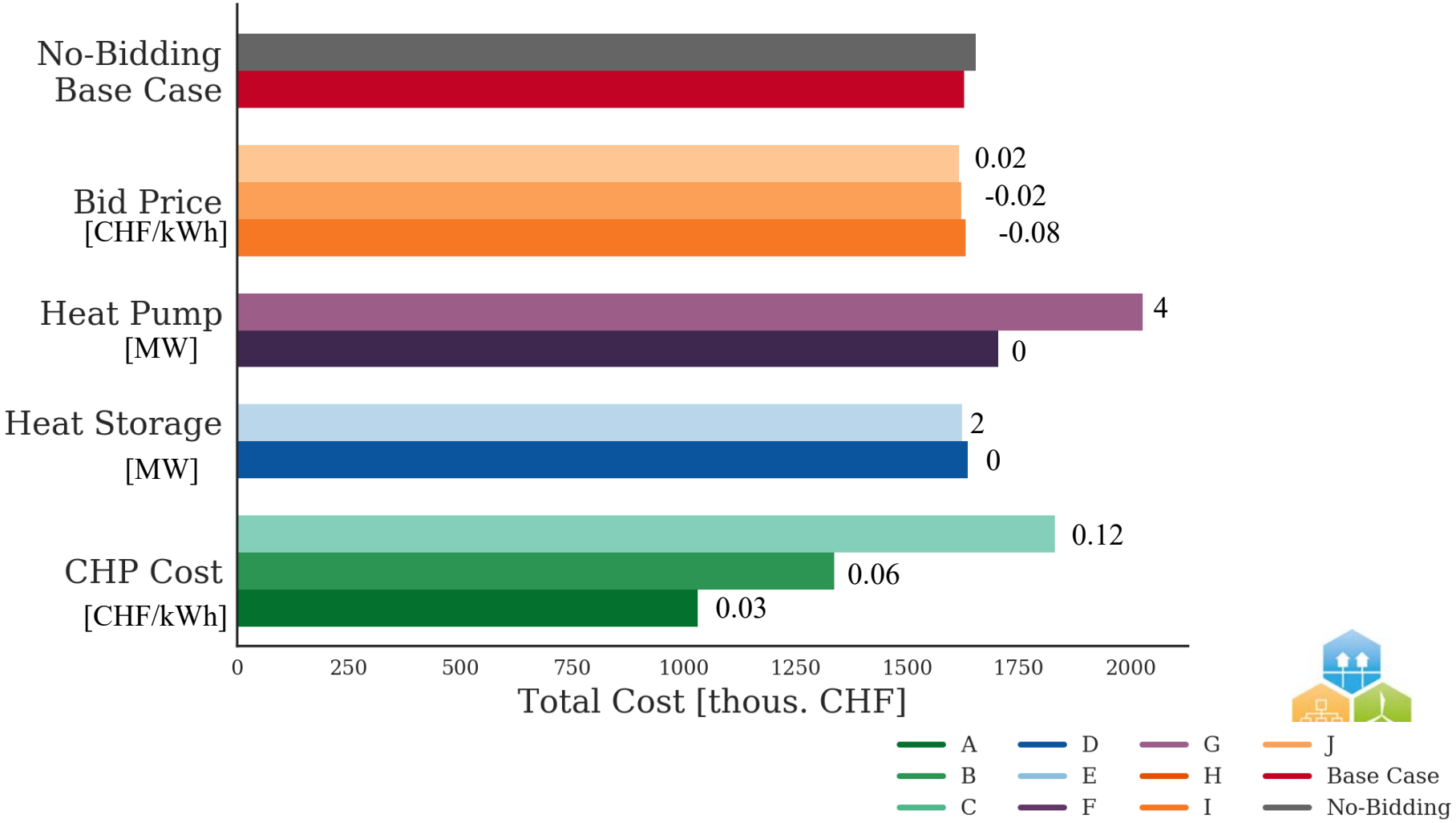
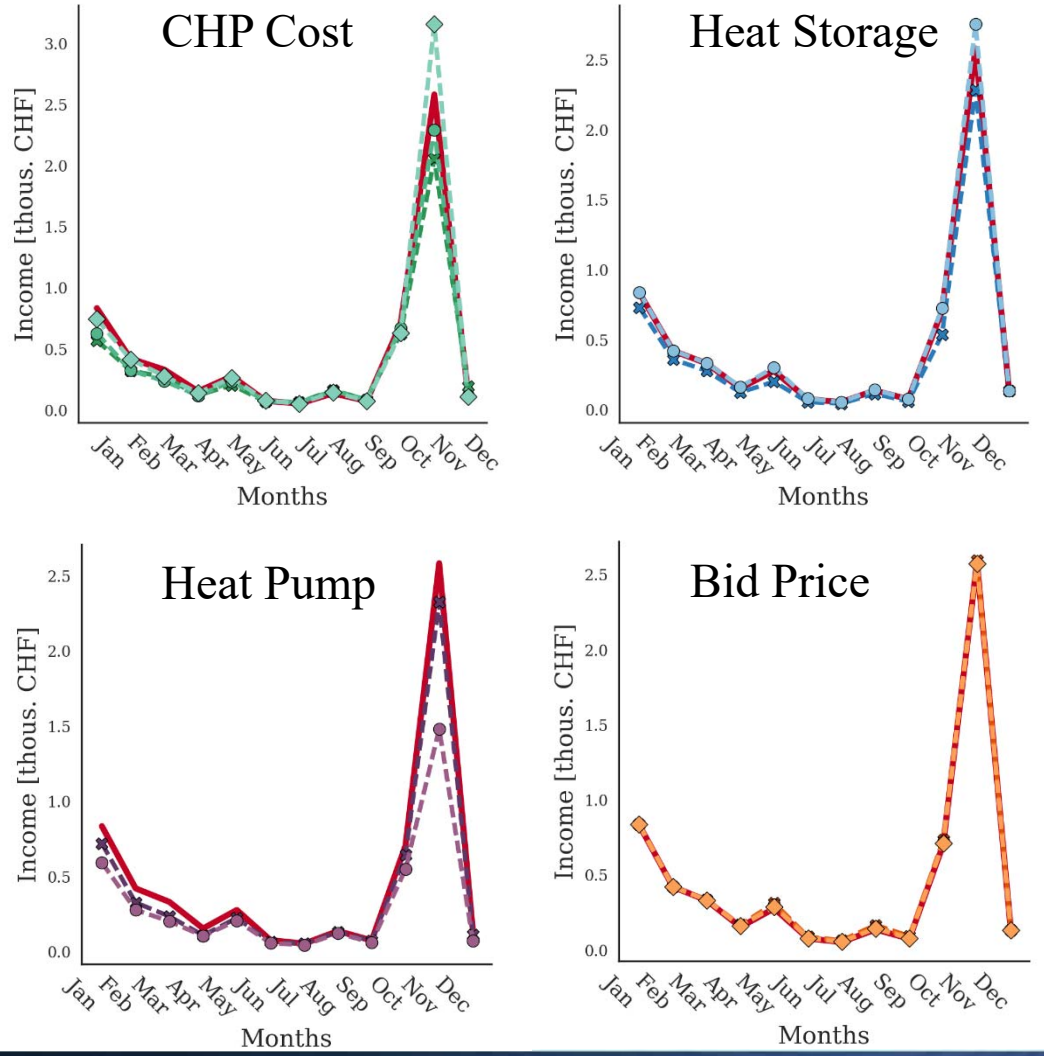
Case Studies – Parameter Sensitivity Analysis

Case	Modified Parameter	New Value	Base Case Value	Unit
A		0.03		
B	CHP Operating Cost	0.06	0.09	CHF/kWh
C		0.12		
D	Heat Storage Capacity	0	1	MWh
E		2		
F	Heat Pump Capacity	0	2.2	MW
G		4		
H		-0.08		
I	TRE^{-} Bid Price	-0.02	0.08	CHF/kWh
J		0.02		

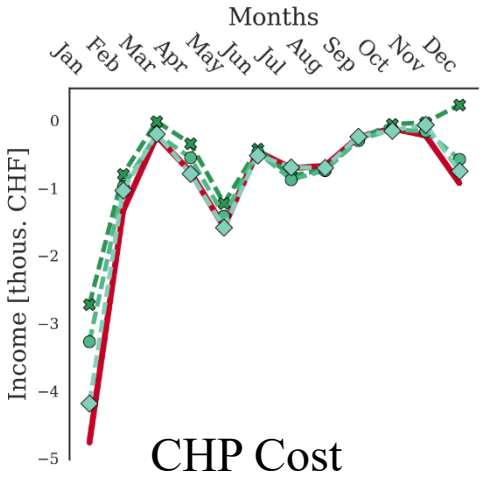
Case Studies – Total Cost



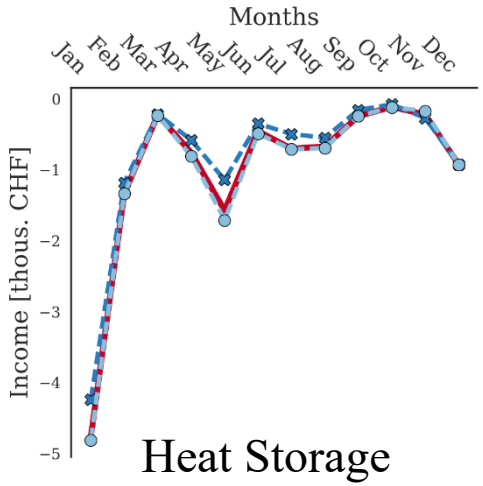
Case Studies – Availability Income



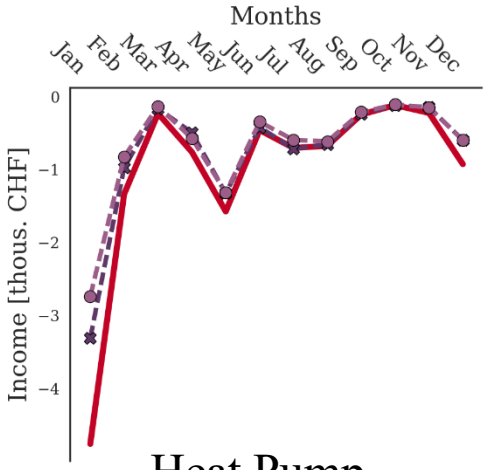
Case Studies – Activation Income



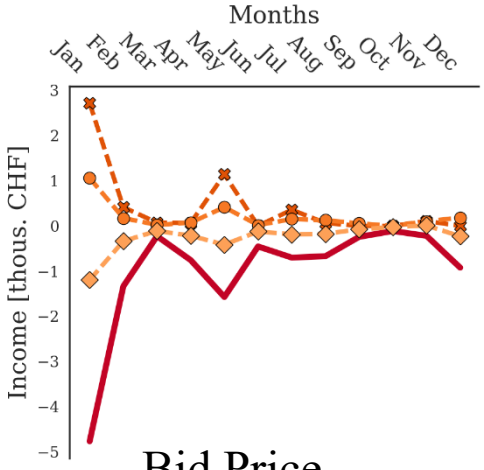
CHP Cost



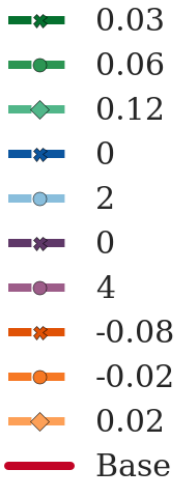
Heat Storage



Heat Pump

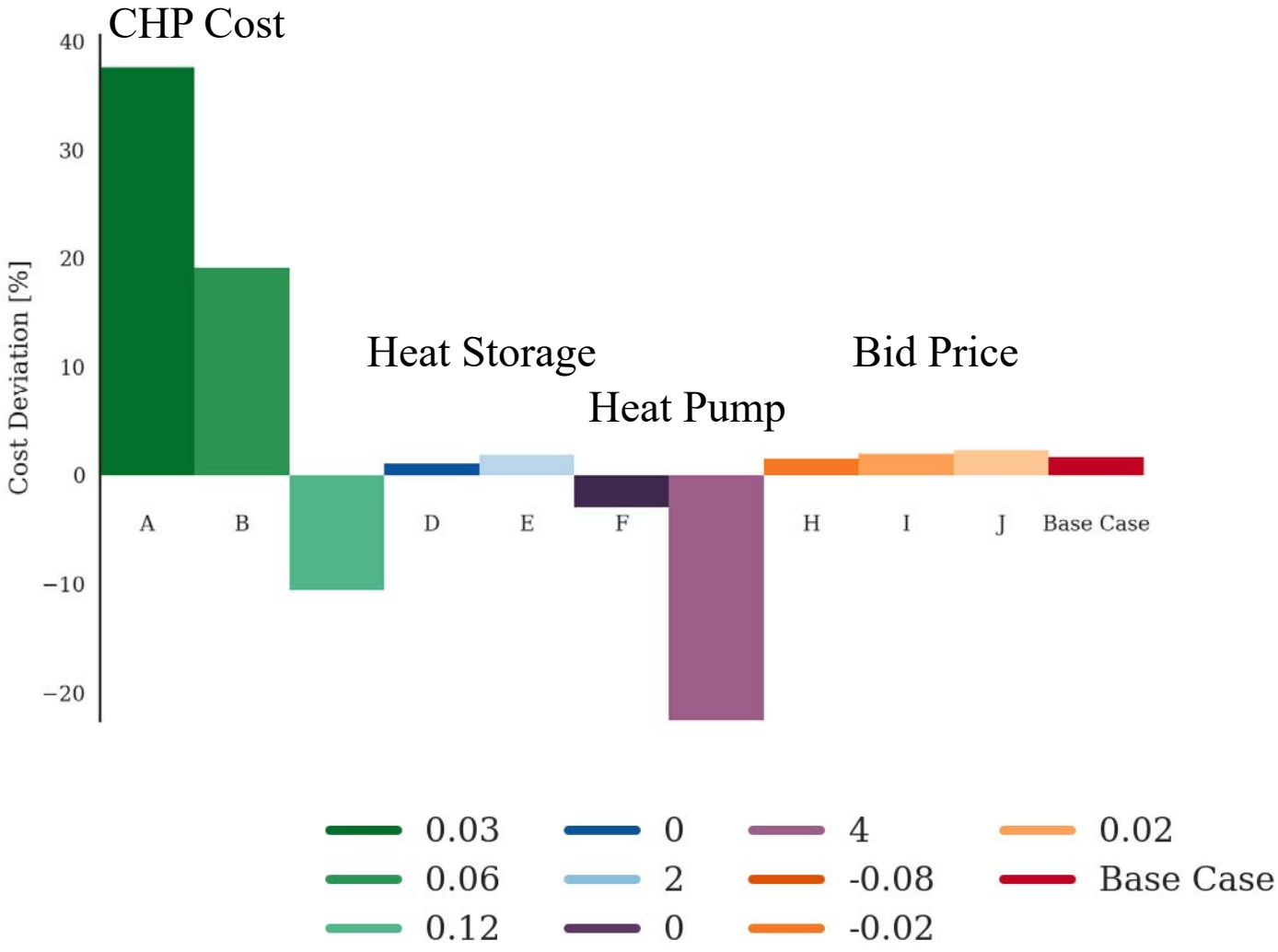


Bid Price



Case Studies – Cost Deviation from No-Bidding

Case	Cost Deviation to No-Bidding (%)
A	37.6
B	19.2
C	-10.6
D	1.1
E	1.9
F	-3
G	-22.5
H	1.5
I	2
J	2.3
Base Case	1.7



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A low-carbon heating and cooling strategy

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The Influence of Participation in Ancillary Service Markets on Optimal Energy Hub Operation

Foteini Rafaela Tsaousi

12/09/2017

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