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# ECONOMIC MODELS

## FOR HYBRID ENERGY GRIDS IN SMART CITIES

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# OUTLINE

- Motivation
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  - Market Structure
- Business models
  - Methodology for design and evaluation
- Economic Models
  - Customers
  - Supply Companies
  - Distribution System Operators
- Conclusion & Outlook

# MOTIVATION

## Introduction

Major concepts of the OrPHEuS project:

- Hybrid point-of-view:

  Different energy networks are considered as one hybrid energy network via coupling technologies (e.g. CHP, heat pumps, …).

- Cooperative concept:

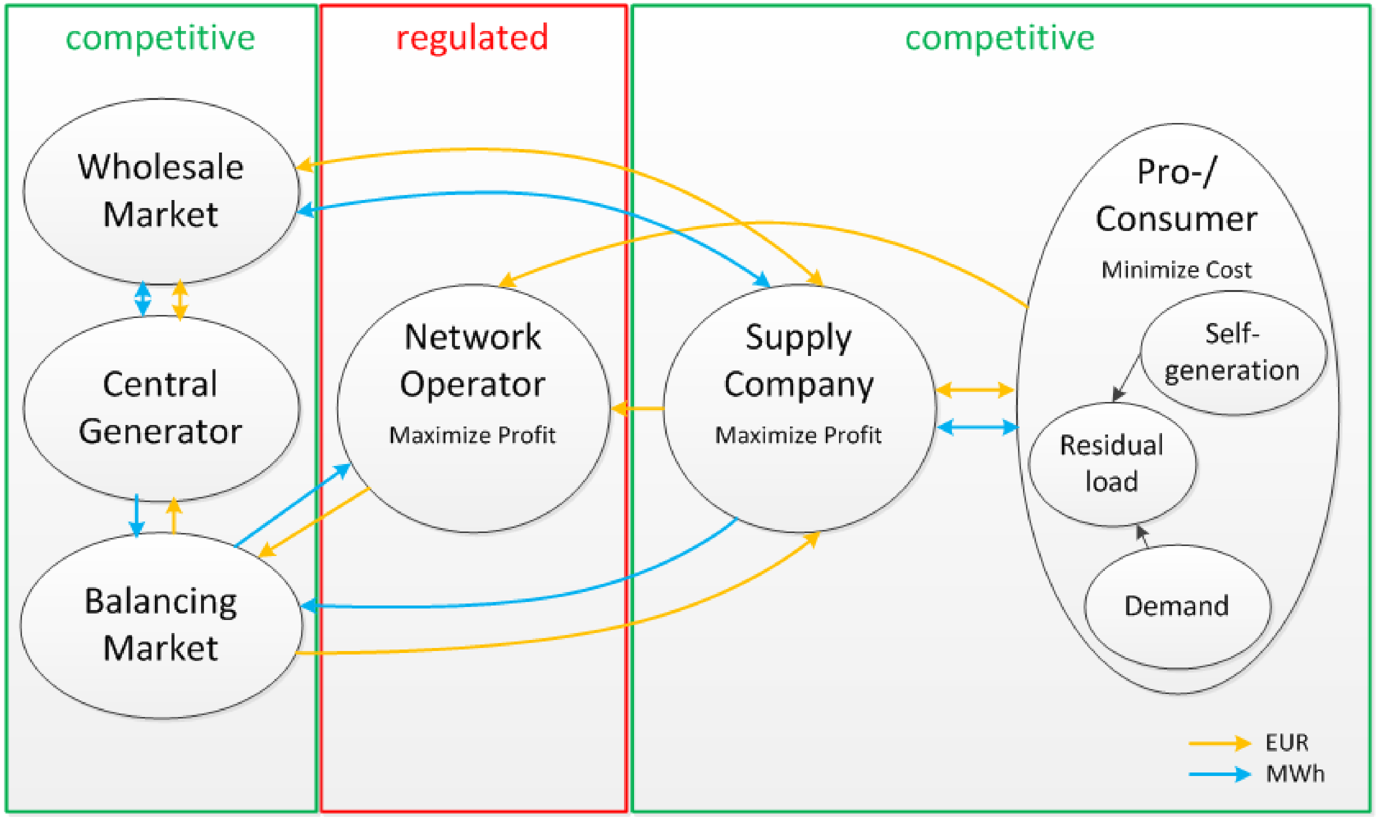
  Development of hybrid cooperative control strategies and corresponding business models among different market participants → Win-win situations

For the economic validation of new control strategies and business models a formal framework is required, capable of evaluating the (economic) benefits of each involved stakeholder.

→ Individual optimization problems for each market participants

# MOTIVATION

## Market structure and major interactions



# BUSINESS MODELS

## Methodology for design and evaluation

1. Definition Techno-Economic Set-up:
   - Involved market participants
   - Considered Technology Portfolio
   - Ownership structure of Technology Portfolio
   - Which technologies are controlled by control strategy?
   - Who operates the controller?
   - Operation mode of controller (cost-minimizing, network-friendly, CO2 reduction, …)
   - Tariff design
   - …
2. Economic Trade-Off analysis of default case vs. Alternative Business Model
   - Pareto-criterion
3. Robustness test
4. Business model replication and transferability

# ECONOMIC MODELS

## Customers

Objective: Minimize cost for meeting the demand for energy services

The model should

- consider multiple energy domains simultaneously and
- be flexibly adaptable to different technology portfolios
- and to different tariff types.

All quantities (demand $\boldsymbol{d}(t)$, (residual) load $\boldsymbol{q}(t)$, … in kWh/h) and prices (tariff $\boldsymbol{p}(t)$ in ct/kWh) are written as 3-dimensional vectors:

$$\mathbf{d}(t) := \begin{pmatrix} d^{El}(t) \\ d^{Gas}(t) \\ d^{Heat}(t) \end{pmatrix}, \quad \mathbf{q}(t) := \begin{pmatrix} q^{El}(t) \\ q^{Gas}(t) \\ q^{Heat}(t) \end{pmatrix}, \quad \mathbf{p}(t) := \begin{pmatrix} p^{El}(t) \\ p^{Gas}(t) \\ p^{Heat}(t) \end{pmatrix}.$$

# ECONOMIC MODELS

## Customers

Starting with a basic Standard (passive) Customer Model, the technology portfolio can be gradually extended by adding new terms and constraints in order to describe different customer types. E.g. adding a generation and a storage technology:

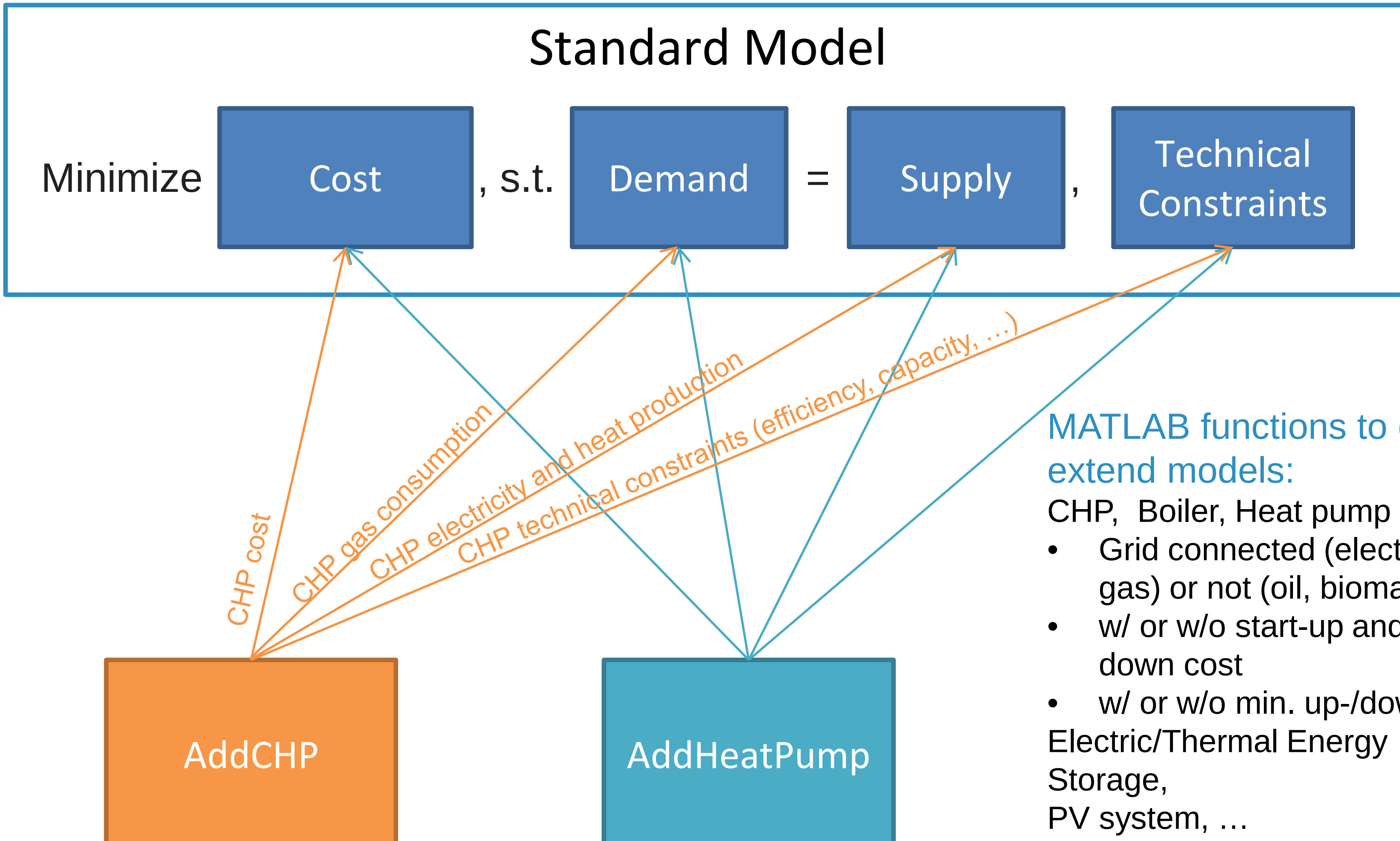
$$\begin{aligned}
\min\ & C \stackrel{!}{=} \sum_{k=1}^{N} \frac{1}{(1+r)^k} \cdot \sum_{t=1}^{8760} \mathbf{p}(t)^T \cdot \mathbf{q}(t) \\
\text{s.t.}\ & \mathbf{q}(t) = \mathbf{d}(t)
\end{aligned}$$

$\longrightarrow$

$$\begin{aligned}
\min\ & C \stackrel{!}{=} \mathbf{I}_{gen} + \mathbf{I}_{store} + \sum_{k=1}^{N} \frac{1}{(1+r)^k} \cdot \sum_{t=1}^{8760} \Big( \mathbf{p}(t)^T \cdot \mathbf{q}(t) \\
& \qquad + \mathbf{c}_{gen}(t)^T \cdot \mathbf{q}_{gen}(t) - \mathbf{p}_{feed}(t)^T \cdot \mathbf{q}_{feed}(t) \Big) \\
\text{s.t.}\ & \mathbf{q}(t) + \mathbf{q}_{gen}(t) + \mathbf{q}_{discharge}(t) = \mathbf{d}(t) + \mathbf{q}_{feed}(t) + \mathbf{q}_{charge}(t) \\
& \mathbf{SOC}(t) = (1 - \text{loss}_{standby}) \cdot \mathbf{SOC}(t-1) \\
& \qquad + \eta_{in} \cdot \mathbf{q}_{charge}(t) - \eta_{out}^{-1} \cdot \mathbf{q}_{discharge}(t) \\
& \mathbf{q}_{gen}(t) \leq \bar{\mathbf{q}}_{gen}, \\
& \underline{\mathbf{SOC}} \leq \mathbf{SOC}(t) \leq \overline{\mathbf{SOC}} \\
& \mathbf{q}_{charge}(t) \leq \bar{\mathbf{q}}_{charge} \\
& \mathbf{q}_{discharge}(t) \leq \bar{\mathbf{q}}_{discharge} \\
& \mathbf{q}(t), \mathbf{q}_{gen}(t), \mathbf{q}_{feed}(t), \mathbf{q}_{charge}(t), \mathbf{q}_{discharge}(t) \geq 0
\end{aligned}$$

# ECONOMIC MODELS

## Customers




MATLAB functions to quickly extend models:

CHP, Boiler, Heat pump

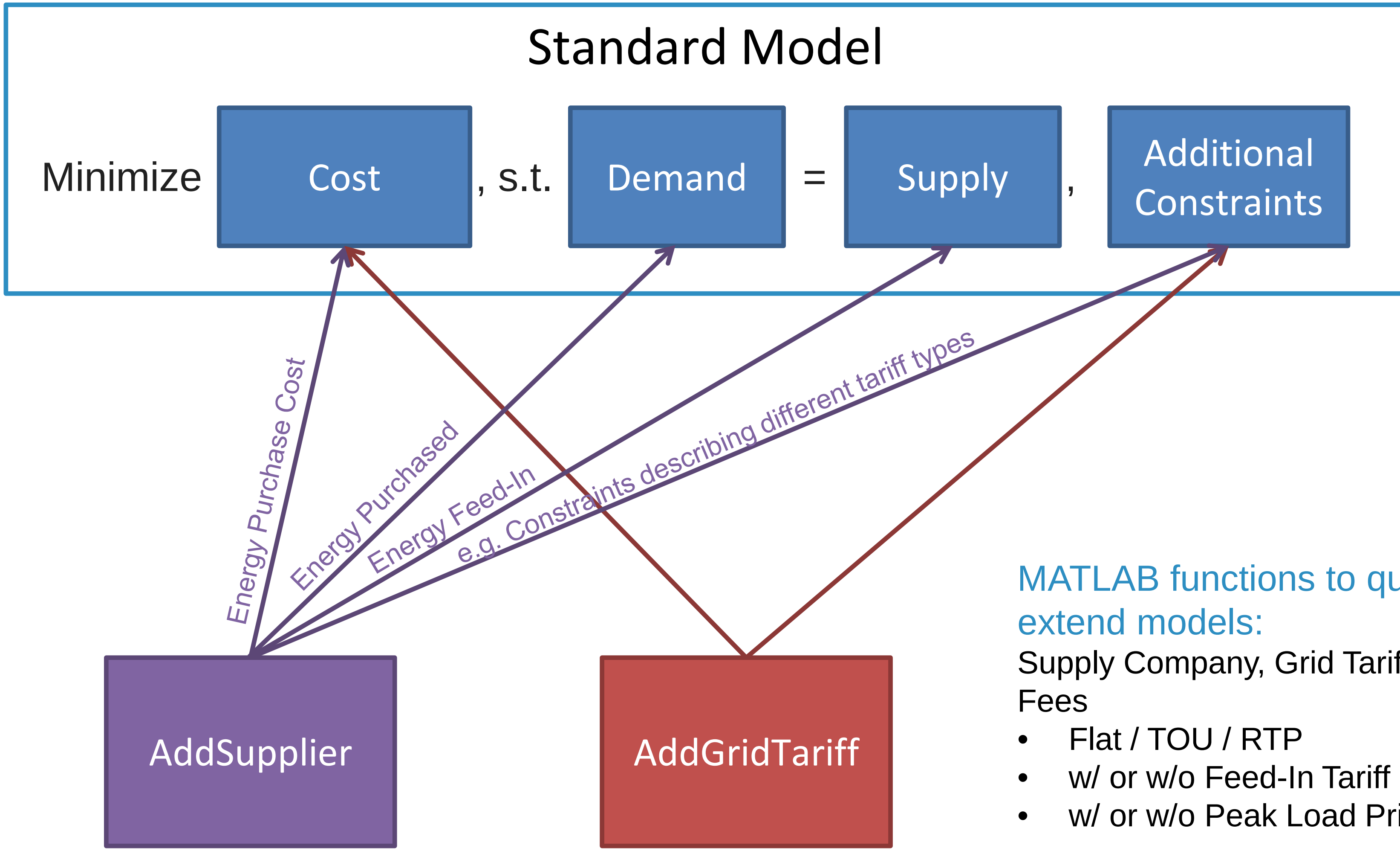
- Grid connected (electricity, gas) or not (oil, biomass)
- w/ or w/o start-up and shut-down cost
- w/ or w/o min. up-/downtime

Electric/Thermal Energy Storage,

PV system, …

# ECONOMIC MODELS

## Customers




MATLAB functions to quickly extend models:

Supply Company, Grid Tariff, Fees

- Flat / TOU / RTP
- w/ or w/o Feed-In Tariff
- w/ or w/o Peak Load Pricing

# ECONOMIC MODELS

## Supply Companies

Objective: Maximize Profit

Revenue:

- Energy retailed to customers (different customer groups with different tariffs)
- Wholesale market sales
- (Balancing markets)
- …

Cost:

- Energy purchased from wholesale market
  - Spot market
  - Futures
- Long-term contracts (e.g. gas)
- Cost for generation/storage/conversion (investment cost, fuel cost, …)
- Cost for balancing energy
- …

# ECONOMIC MODELS

## Supply Companies

Example optimization problem:

$$\max \Pi \overset{!}{=} -I_{gen} + \sum_{y=1}^{N} \frac{1}{(1+r)^y} \cdot \sum_{t=1}^{8760} \Big( \sum_{g \in G} \big(\mathbf{p}_{retail,g}(y,t)^T \cdot \sum_{k \in g} \mathbf{q}_{g,k}(y,t)\big) + \mathbf{p}_{spot,sell}(y,t)^T \cdot \mathbf{q}_{spot,sell}(y,t)$$

$$- \mathbf{c}_{gen}(y,t)^T \cdot \mathbf{q}_{gen}(y,t) - \mathbf{p}_{spot,buy}(y,t)^T \cdot \mathbf{q}_{spot,buy}(y,t)$$

$$- \mathbf{p}_{future}(y,t)^T \cdot \mathbf{q}_{future}(y,t) - \mathbf{p}_{bal}(y,t)^T \cdot \Delta\mathbf{q}(y,t) \Big)$$

$$\text{s.t.} \quad \mathbf{q}_{gen}(y,t) + \mathbf{q}_{future}(y,t) + \mathbf{q}_{spot,buy}(y,t) = \sum_{g \in G} \sum_{k \in g} \mathbf{q}_{scheduled,g,k}(y,t) + \mathbf{q}_{spot,sell}(y,t)$$

$$\Delta\mathbf{q}(y,t) = \sum_{g \in G} \sum_{k \in g} \big(\mathbf{q}_{g,k}(y,t) - \mathbf{q}_{scheduled,g,k}(y,t)\big)$$

$$\mathbf{q}_{gen}(y,t) \leq \bar{\mathbf{q}}_{gen}$$

Similar structure to customer model:

→ Various generation, conversion and energy storage technologies can be added.

→ More possibilities for energy procurement (different markets)

→ Different tariff types

# ECONOMIC MODELS

## Distribution System Operators

Objective: Maximize Profit

Revenue:

- Network charges for energy delivered to customers via network (different customer groups with different tariffs)

Cost:

- Investment cost (annual depreciation) and maintenance cost for assets (network components)

Important aspect: Regulation

Price-cap, revenue-cap
→ incentives for underinvestment

Rate-of-return, Cost-of-service

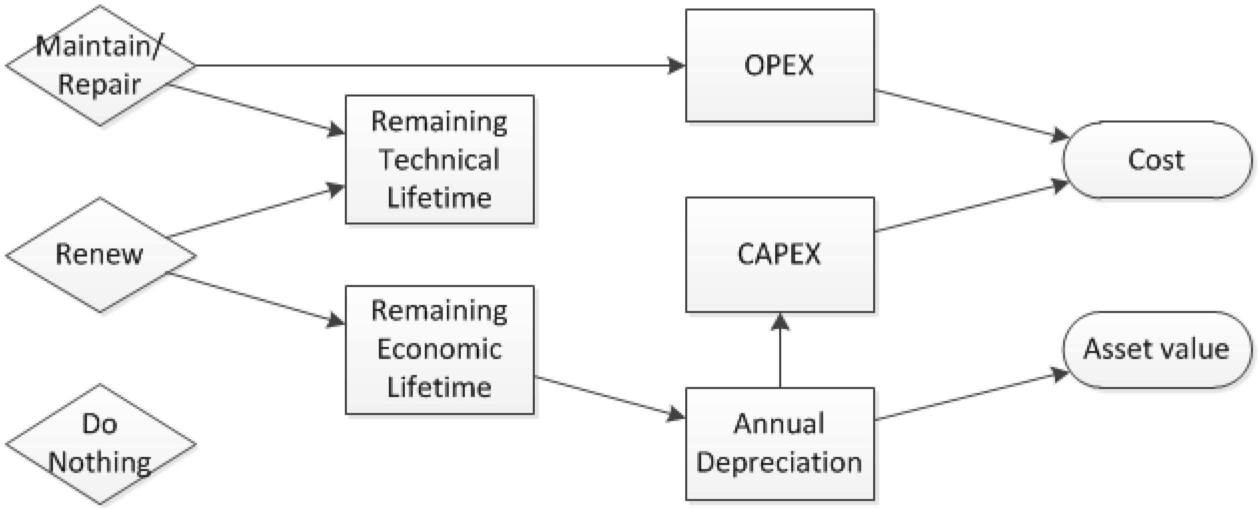
→ Incentives for overinvestment

Incident-based vs. Condition-based maintenance

# ECONOMIC MODELS

## Distribution System Operators

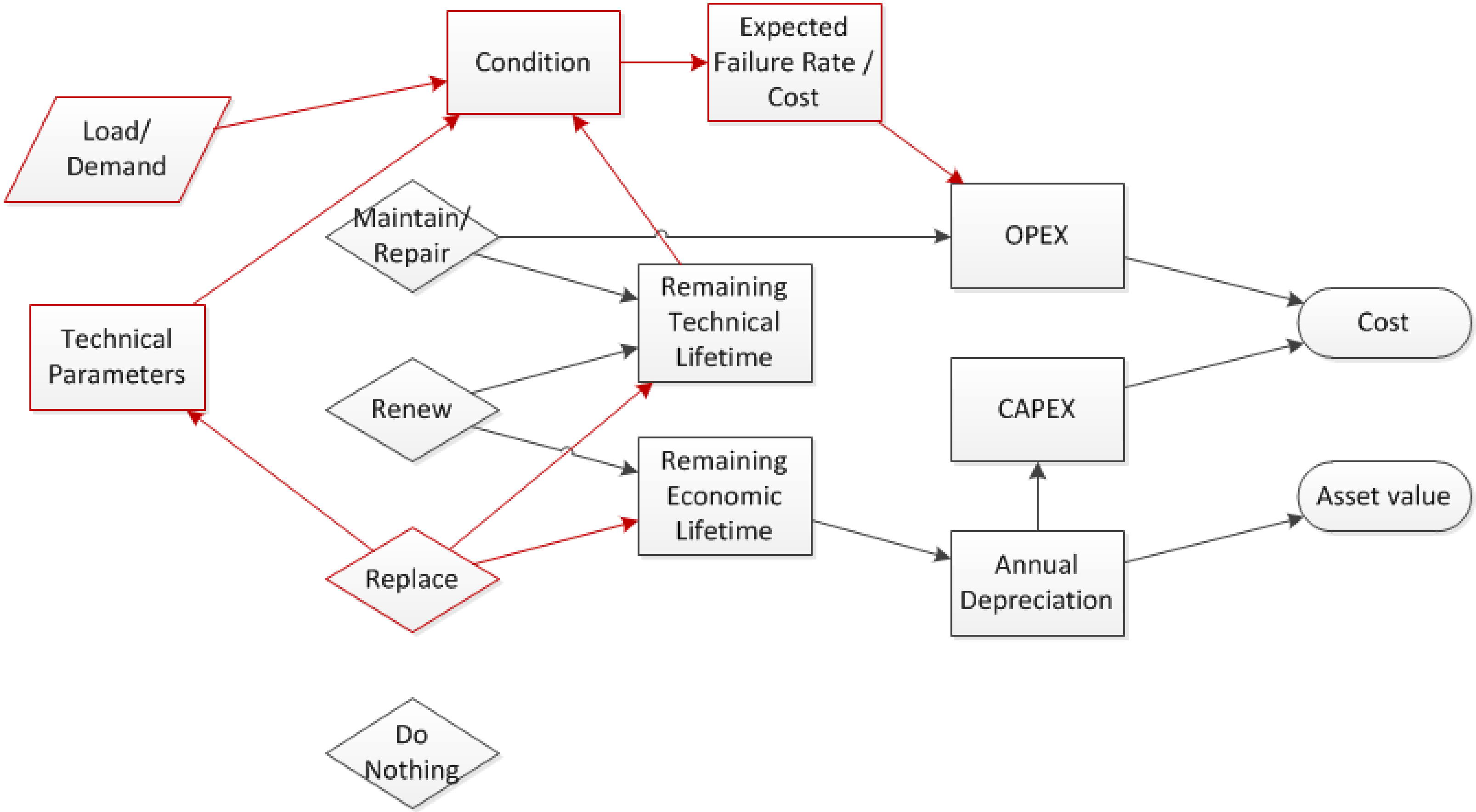
- First implementation: Basic mixed-integer re-investment planning model
- Logical structure: Options per asset (e.g. transformer) per year:



# ECONOMIC MODELS

## Distribution System Operators

- Extension (currently in development)



# CONCLUSION & OUTLOOK

## Conclusion

A formal framework has been developed describing the economic interactions in hybrid energy retail markets that enables:

- Simultaneous consideration of different energy domains
- Individual evaluation of benefits for different market participants
- Flexible consideration of different technology portfolios and business model designs

## Outlook

- Scaling the formal framework to specific use cases in the OrPHEuS demonstration sites (currently in progress)
- Extending the Distribution System Operator model (currently in progress)
- Quantitative evaluation of different Business Model designs and Control Strategies

# CONTACTS AND DISCLAIMER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