Über die Dimensionierung von Energiebereitstellungssystemen in produzierenden Unternehmen

(On the dimensioning of energy conversion systems for manufacturing companies)

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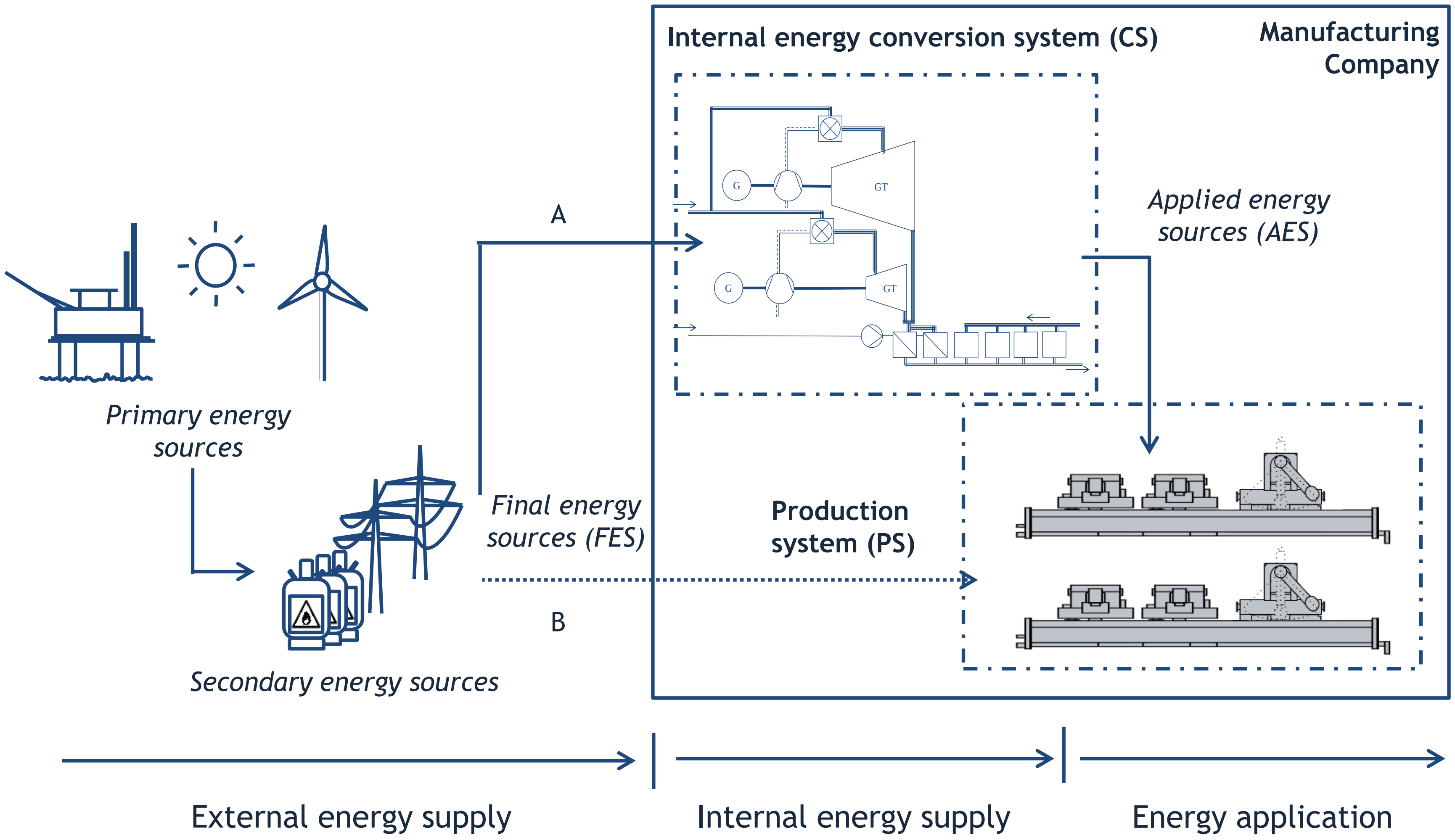
1. Motivation



(Gahm et al. 2016)

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2. Decision problem with special aspects

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Focus

- (internal) Conversion system transforming FES to AES

Special aspects

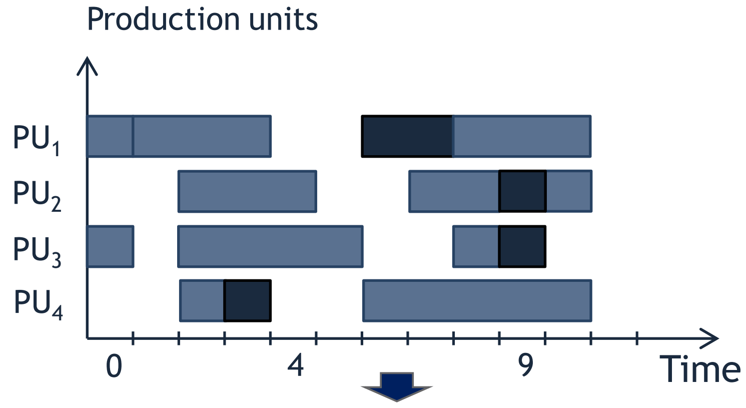
- Interdependencies between the CS and PS
- Technical characteristics of conversion units (CUs), particularly (part load) conversion efficiencies

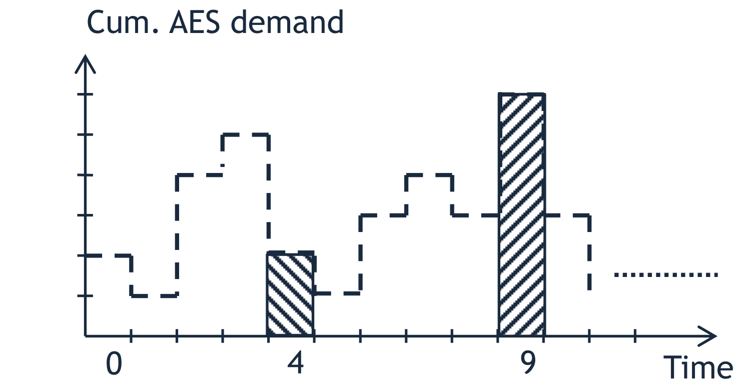
Decision problem:

The simultaneous dimensioning and configuration of energy conversion units for manufacturing companies to improve long-term energy efficiency.

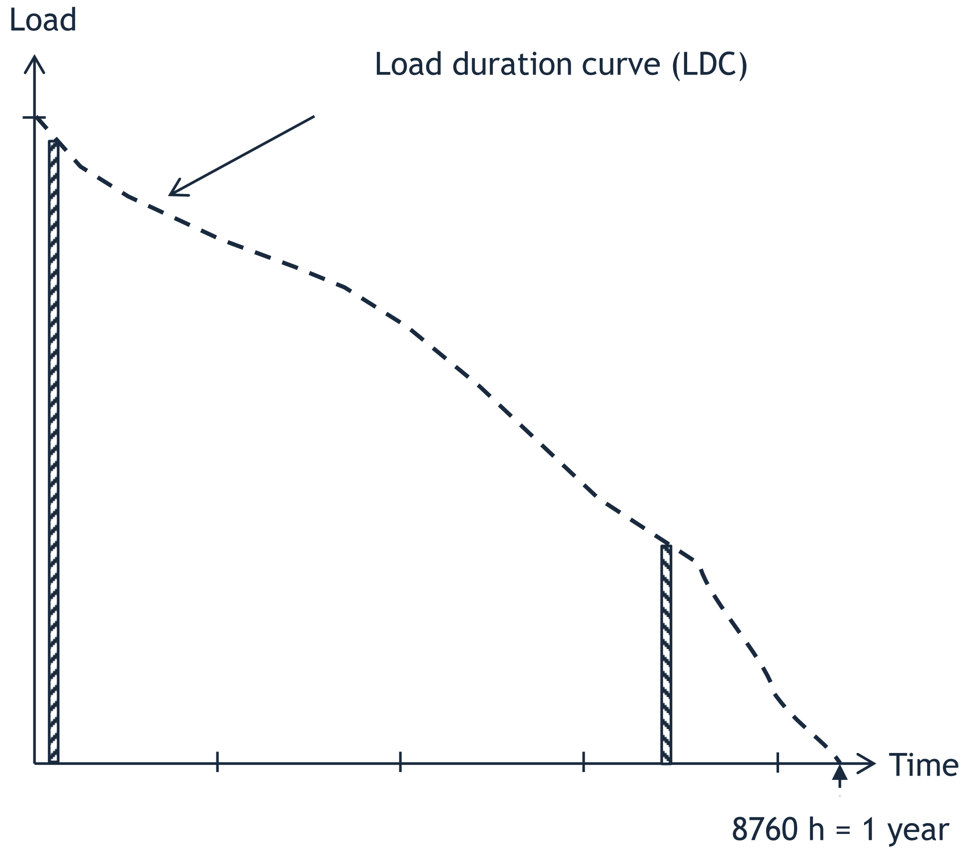
2.1 Load duration curves (LDC)

- PS: Operational scheduling





→ Load duration curves (LDC) represent the (historical) AES demand



2.2 Part load behavior of CUs

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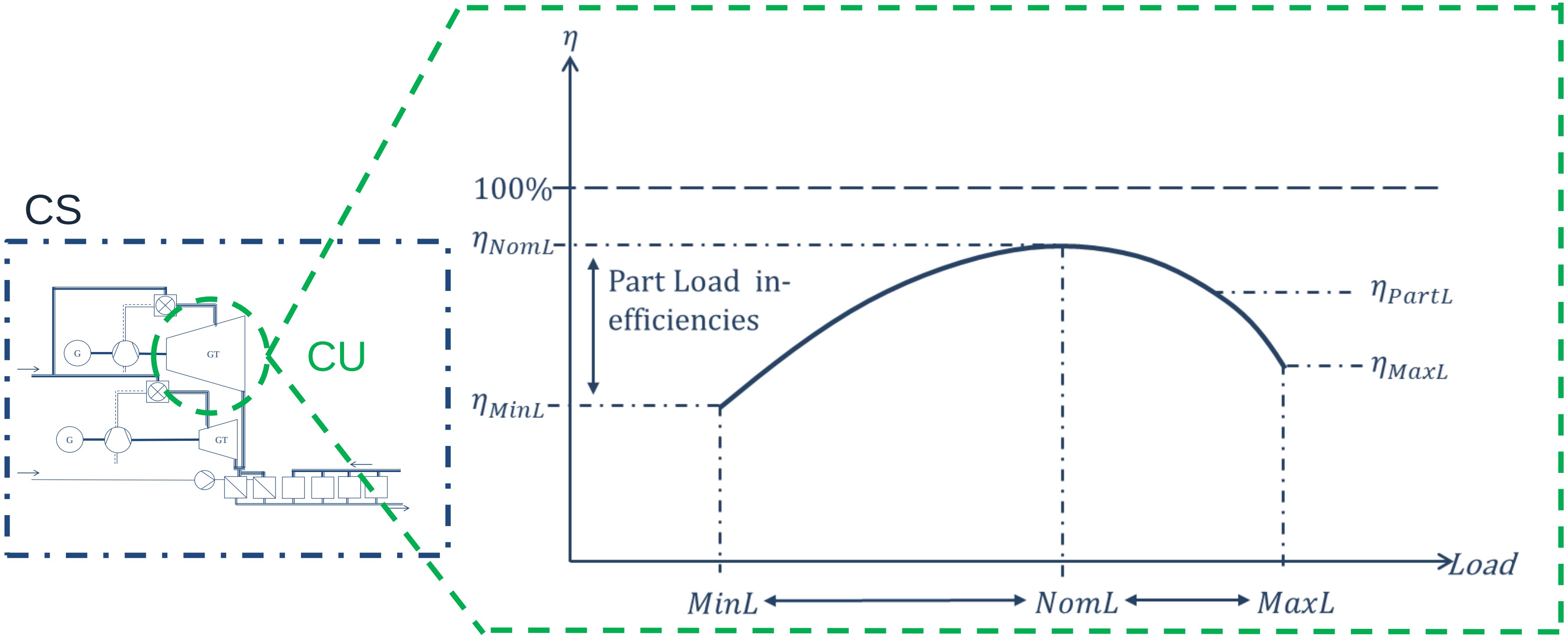
A CS consists of one or more conversion units (CU) with individual characteristics:

- Minimal, nominal and maximal load ($MinL$, $NomL$, $MaxL$)
- Load efficiencies (η_{MinL}, η_{NomL}, η_{MaxL})



2.3 Basic types of CUs

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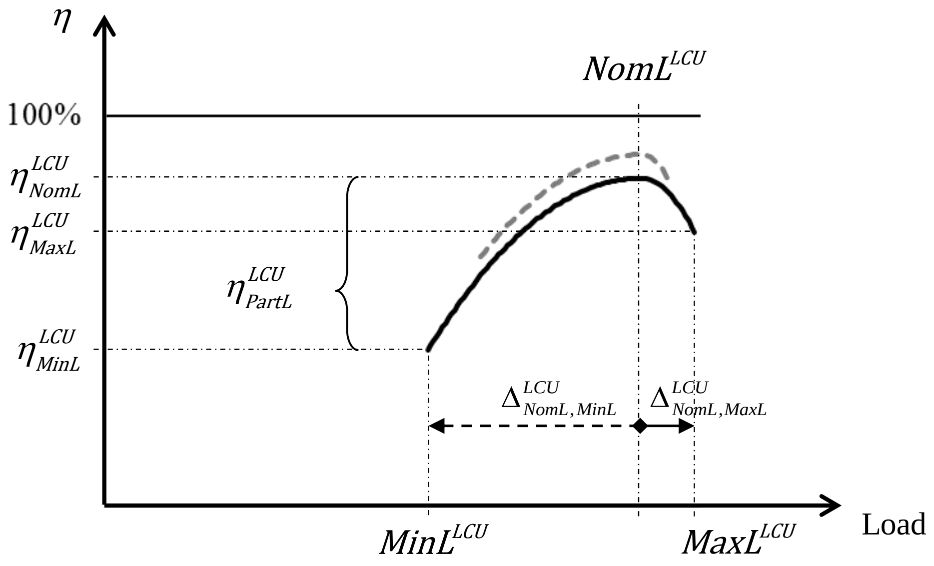

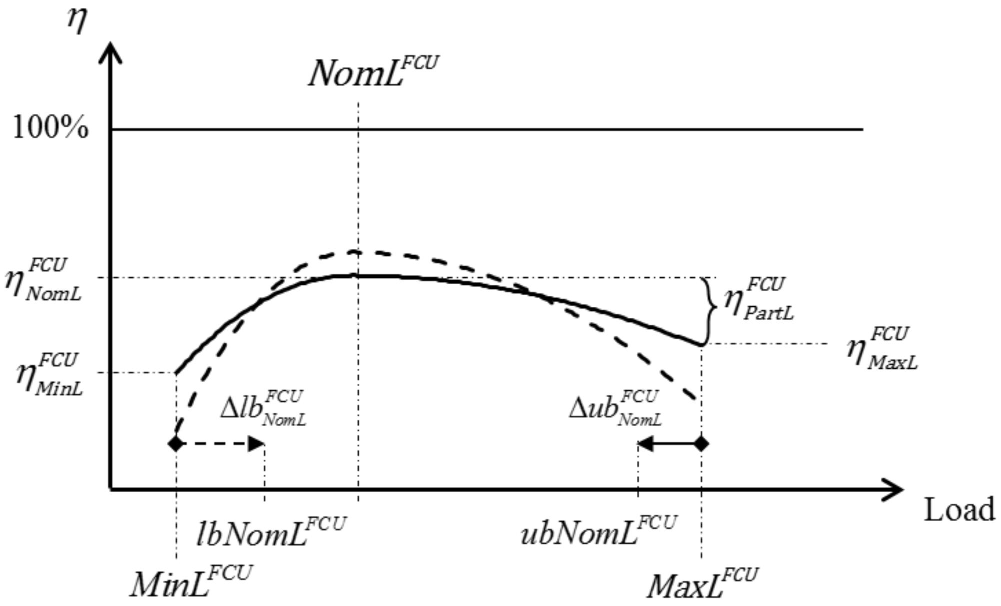

Large conversion unit (LCU)

- Fulfills basic AESD with max. efficiency → high $NomL$ efficiency, small control range
- Based on $NomL$ $MaxL$ and $MinL$ are derived and thus, the dimensions the CU

Flexible conversion unit (FCU)

- Handles AESD peaks → smaller $NomL$ efficiency than LCU but a wider control range
- The $NomL$ of FCUs is configured within a given range based on its $MaxL$ and $MinL$

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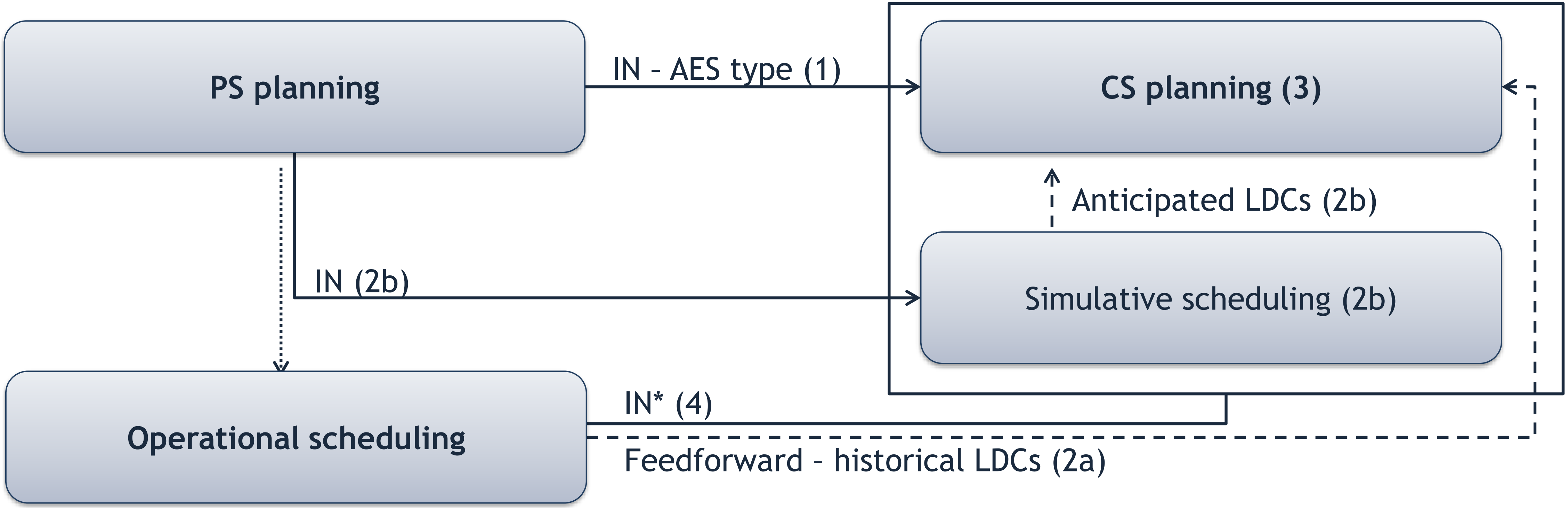
3. Planning approach and implementation

3.1 Decision environment

3.2 Simulative scheduling (2b) - LDC generation

3.3 CS planning (3) - solution methods

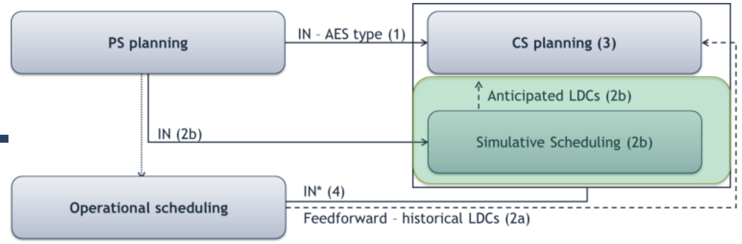
3.1 Decision environment



(based on „ Distributed decision making—a unified approach” by Schneeweiss 2003)

➔ Simulative Scheduling is used to anticipate LDCs if no historical data is available or new scheduling objectives are in mind

3.2 Simulative scheduling (2b) - LDC generation



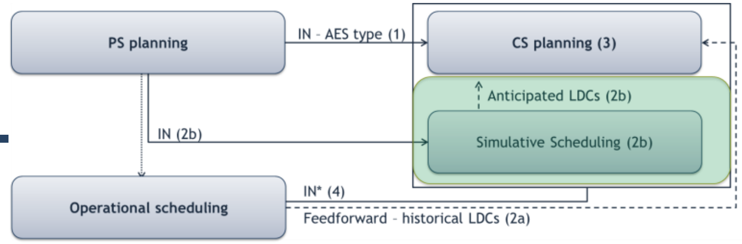
- Simulative Scheduling (2b) to anticipate LDCs
  - 240 schedules per year with ~480 minutes/day (For feasibility the planning horizon T is $T = \max\{480, Makespan^{LPT}\}$)
  - Different production environments
  - Different energy demand characteristics
  - Scheduling with three different objectives

- Company size m (S/M)
- Product complexity p (MS / FC)
- Number of jobs n

Size	p		m	n
S	MS	30	3	[44, 48]
			4	[58, 64]
	FC	80	3	[14, 18]
			4	[18, 24]
M	MS	30	10	[145, 160]
			12	[174, 192]
	FC	80	10	[45, 60]
			12	[54, 72]

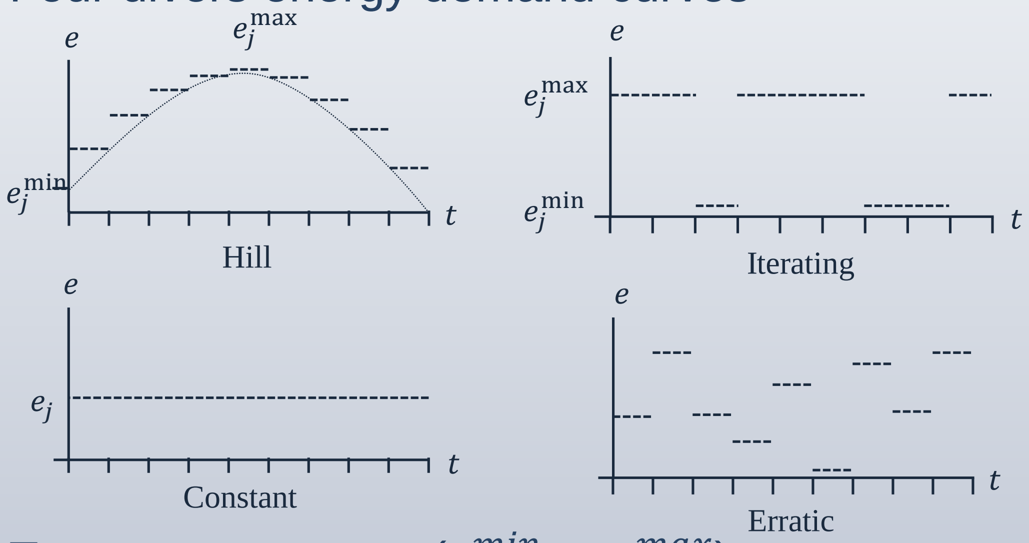
➔ 4 production environments

3.2 Simulative scheduling (2b) - LDC generation



- Simulative Scheduling (2b) to anticipate LDCs
  - 240 schedules per year with ~480 minutes/day (For feasibility the planning horizon T is $T = \max\{480, Makespan^{LPT}\}$)
  - Different production environments
  - Different energy demand characteristics
  - Scheduling with three different objectives

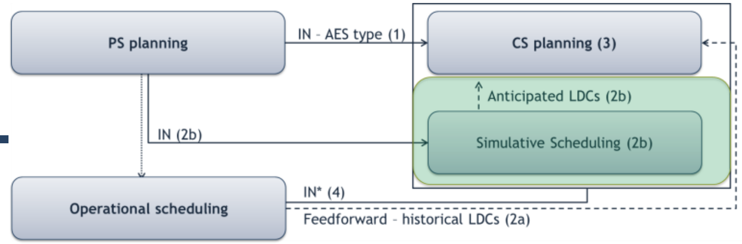
- Four divers energy demand curves



- Two energy ranges (e_j^{min} to e_j^{max})
  - Small range (SR)
  - Long range (LR)

➔ 8 energy settings

3.2 Simulative scheduling (2b) - LDC generation

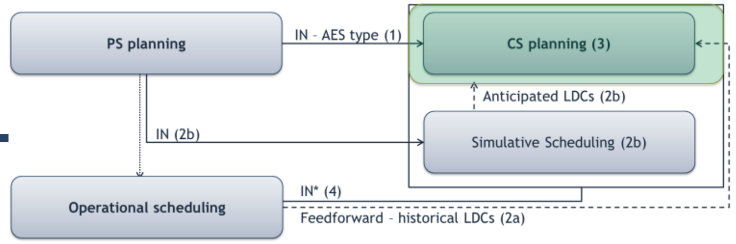


- Simulative Scheduling (2b) to anticipate LDCs
  - 240 schedules per year with ~480 minutes/day (For feasibility the planning horizon T is $T = \max\{480, Makespan^{LPT}\}$)
  - Different production environments
  - Different energy demand characteristics
  - Scheduling with three different objectives
    - Makespan (C_{max})
    - Total flow time (TFT)
    - AESD leveling ($SQmean = Min \sum (e_t - \overline{e})^2$)

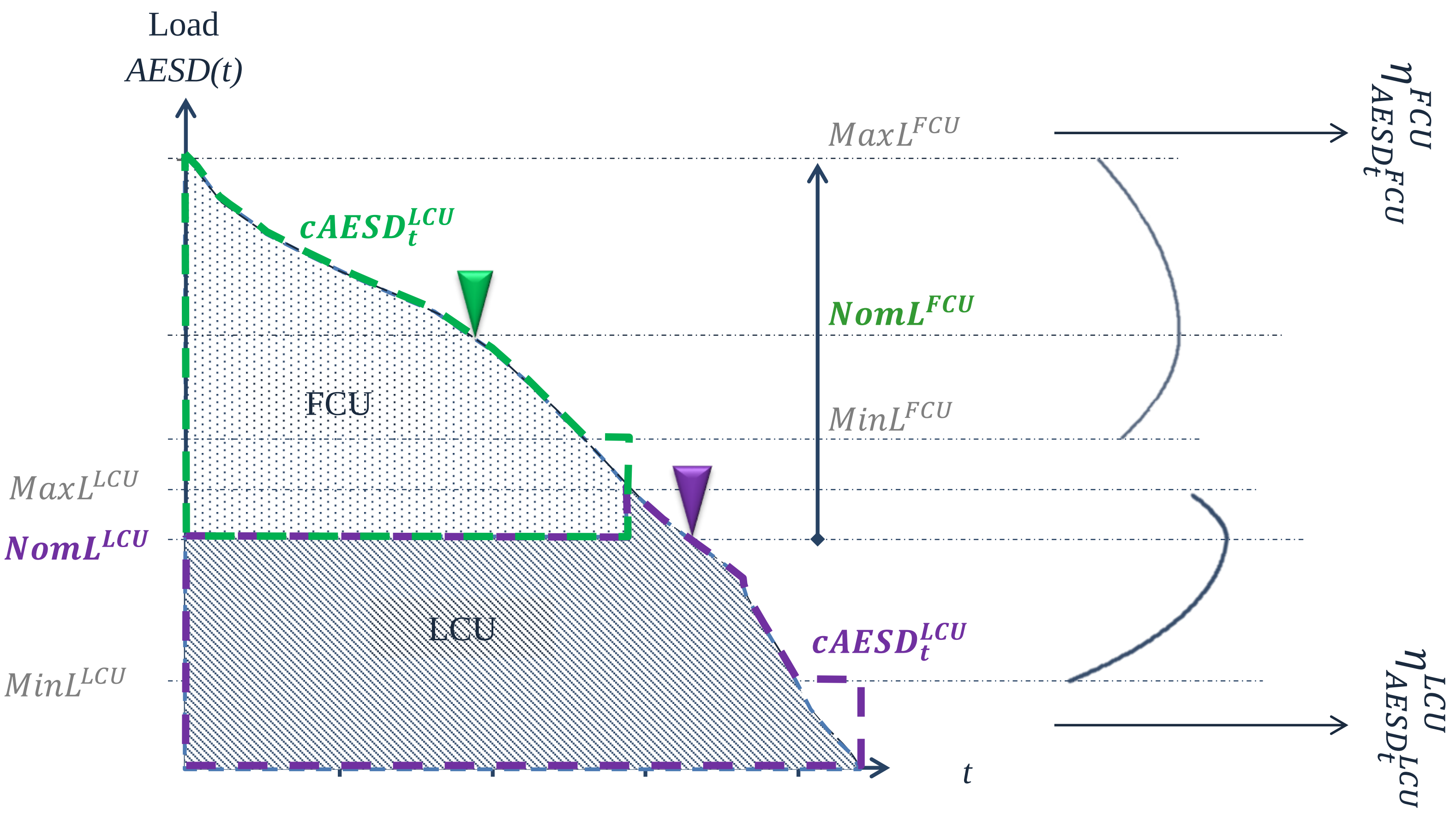
➔ 4 production environments combined with 8 energy settings map 32 company types

➔ The 3 objectives lead to 96 anticipated LDC (3 per company type)

3.3 CS planning (3) - solution methods

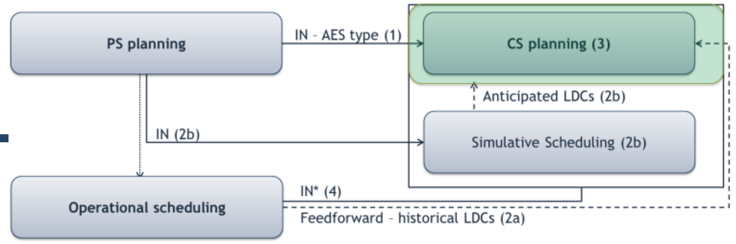


- Assuming an CS with two CUs (one LCU and one FCU):



$$Min \sum_{t=1}^{T} \frac{cAESD_t^{LCU}}{\eta^{LCU}_{AESD_t^{LCU}}} + \frac{cAESD_t^{FCU}}{\eta^{FCU}_{AESD_t^{FCU}}}$$

3.3 CS planning (3) - solution methods



- TEH – two-step truncated enumeration heuristic
  - First step: enumerate $NomL^{LCU}$ by relatively fixed $NomL^{FCU}$
  - Second Step: Enumerate $NomL^{FCU}$ with fixed $NomL^{LCU}$

- MINLP – mixed integer nonlinear program
  - Objective function: Minimize total FESD

$$Min \sum_{L=l}^{L} \left(\frac{cAESD_l^{LCU}}{\mu_l^{LCU}} + X_l * \frac{cAESD_l^{FCU}}{\mu_l^{FCU}} \right) * nop_l$$

with

nop_l Number of periods with AESD level l

X_l = 1 if FCU is needed and = 0 if FCU is not needed to cover the $AESD_l$

  - Determination of the part load efficiencies is not linear

$$\mu_l^{LCU} \leq Y_l^{LCU} * \left(\frac{\mu_{MaxL}^{LCU} - \mu_{NomL}^{LCU}}{\left(MaxL^{LCU} - NomL^{LCU}\right)^2} \right) * \left(cAESD_l^{LCU} - NomL^{LCU}\right)^2 + \mu_{NomL}^{LCU})$$

$$+\left(1 - Y_l^{LCU}\right) * \left(\frac{\mu_{MinL}^{LCU} - \mu_{NomL}^{LCU}}{\left(MinL^{LCU} - NomL^{LCU}\right)^2} \right) * \left(cAESD_l^{LCU} - NomL^{LCU}\right)^2 + \mu_{NomL}^{LCU})$$

Content

4. Results

4.1 LCU and FCU parameter-setting analysis

4.2 Overall results

4.1 LCU and FCU parameter-setting analysis

	LCU-0	LCU-1	LCU-2	LCU-3	LCU-4	LCU-5
η^{LCU}_{MaxL}	87%	87%	85%	85%	80%	91%
η^{LCU}_{NomL}	95%	95%	95%	93%	97%	93%
η^{LCU}_{MinL}	82%	82%	80%	80%	75%	86%
$\Delta^{LCU}_{NomL,MaxL}$	0.05	0.10	0.10	0.10	0.05	0.05
$\Delta^{LCU}_{NomL,,MinL}$	0.30	0.40	0.40	0.40	0.30	0.30

	FCU-0	FCU-1	FCU-2	FCU-3	FCU-4
η^{FCU}_{MaxL}	65%	65%	65%	60%	70%
η^{FCU}_{NomL}	84%	84%	82%	86%	82%
η^{FCU}_{MinL}	60%	60%	60%	55%	65%
$\Delta^{FCU}_{MaxL,\ NomL}$	0,15	0,05	0,05	0,15	0,15
$\Delta^{FCU}_{MaxL,MinL}$	0,30	0,10	0,10	0,30	0,30

Large conversion unit (LCU)

- one LCU as basis of comparison (LCU-0)
- increased operational range (LCU-1)
- increased operational range & modified efficiencies (LCU-2, LCU-3)
- modified efficiencies (LCU-4, LCU-5)
- ➔ 6 divers LCUs

Flexible conversion unit (FCU)

- one FCU as basis of comparison (FCU-0)
- looser bounds of $NomL$ (FCU-1)
- looser bounds of $NomL$ & adjusted $NomL$ efficiency (FCU-2)
- modified efficiencies (FCU-3, FCU-4)
- ➔ 5 divers FCUs

4.1 LCU and FCU parameter-setting analysis

- FCU parameters analysis
  - FCU-3 is most preferable for almost all company types (28 of 32)

    (FCU-3: increased NomL efficiency, but suffers in part-load efficiency)
  - FCU-1 (3 of 32) and FCU-4 (1 of 32) are more suitable for specific company types

    (FCU-1: looser bounds for the NomL)

    (FCU-4: increased part-load efficiency, but suffers in NomL efficiency)

	FCU-0	FCU-1	FCU-2	FCU-3	FCU-4
η^{FCU}_{MaxL}	65%	65%	65%	60%	70%
η^{FCU}_{NomL}	84%	84%	82%	86%	82%
η^{FCU}_{MinL}	60%	60%	60%	55%	65%
$\Delta^{FCU}_{MaxL,\,NomL}$	0,15	0,05	0,05	0,15	0,15
$\Delta^{FCU}_{MaxL,MinL}$	0,30	0,10	0,10	0,30	0,30

- LCU parameters analysis
  - LCU-5 is not preferable due to its lower nominal load efficiency (0 of 32)

    (LCU-5: increased part-load efficiency, but suffers in NomL efficiency)
  - although LCU-4 has the highest nominal load efficiency (11 of 32) , LCU-1 with its larger operational range is preferable for most company types (21 of 32)

	LCU-0	LCU-1	LCU-2	LCU-3	LCU-4	LCU-5
η^{LCU}_{MaxL}	87%	87%	85%	85%	80%	91%
η^{LCU}_{NomL}	95%	95%	95%	93%	97%	93%
η^{LCU}_{MinL}	82%	82%	80%	80%	75%	86%
$\Delta^{LCU}_{NomL,MaxL}$	0.05	0.10	0.10	0.10	0.05	0.05
$\Delta^{LCU}_{NomL,,MinL}$	0.30	0.40	0.40	0.40	0.30	0.30

➔nominal load efficiency of a CU is not the only decisive parameter

➔A CUs operational range is important

4.2 Overall results

- List of Most preferable parameters by company type
  - ➔ depending on a manufacturing company's characteristics, individual combinations of a scheduling objective and CU parameters are most suitable to maximize its energy efficiency
- LCU parameters have a greater influence than FCU parameters
- ANTIGONE (MINLP) & TEH solve with reasonably good solution quality
- SQM has the best mean and the most stable positive influence on energy efficiency
  - ➔ Testing of more energy-related scheduling objectives advisable

Content

5. Further research

5.1 CU state and load transitions

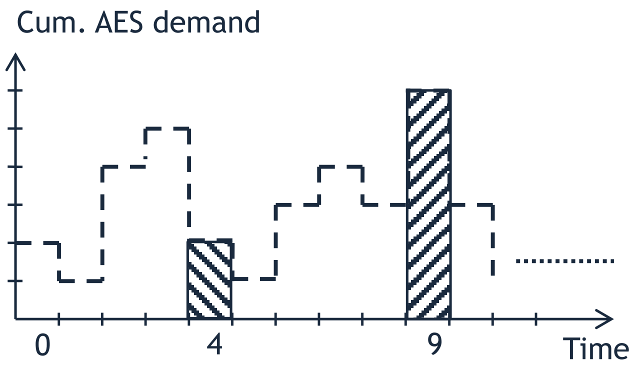
5.2 Modeling of additional energy requirements

5.1 CU state and load transitions

- CU can be in states
  - “operating”, “off-cold”, “cold-startup”, “off-warm”, “warm-startup”, “on”
  - Predefined sequences of CU states
  - Sate- and/or time-dependent transitions
  - Minimum CU state durations

- While CU is in the “operating” state it delivers various AESDs (part loads)
  - Arbitrarily large load transitions within short time are not possible (Restricted ramp-ups/ ramp-downs)
  - Minimum CU part-load durations

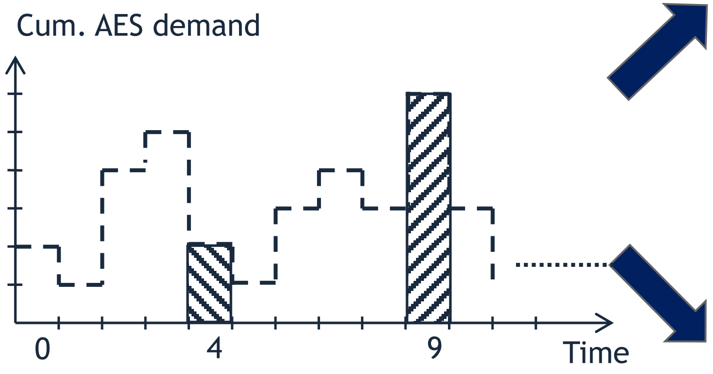
➔both cause additional energy requirements

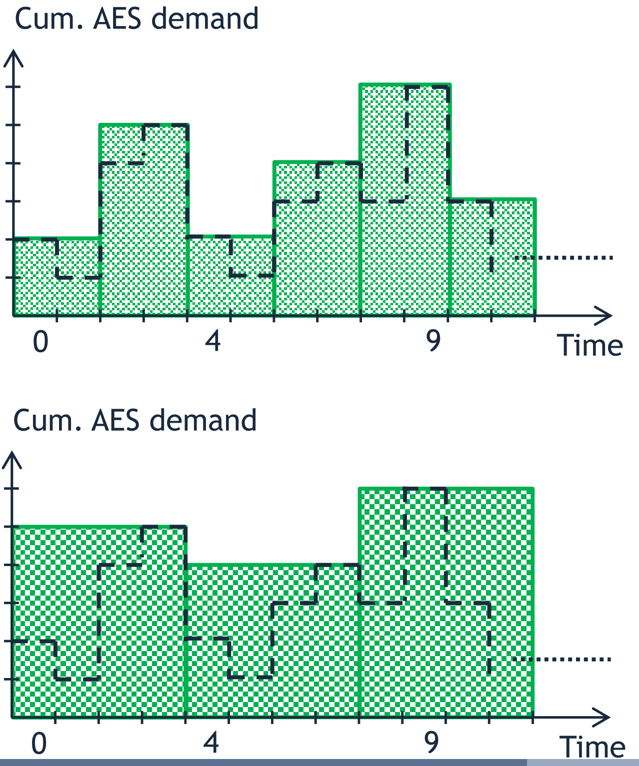


5.2 Modeling of additional energy requirements

How to model additional energy requirements?

- direct consideration within the optimization model
  - level aggregation no longer possible
  - number of variables increases dramatically
- Indirect consideration by adapting the AESD to enforce a corresponding FESD
  - Minimum durations of CU states and part-loads can be considered by aggregation
  - ➔ how many time periods have to be aggregated to a constant AESD-level?
  - ➔ How should the level be chosen? Max. vs Mean

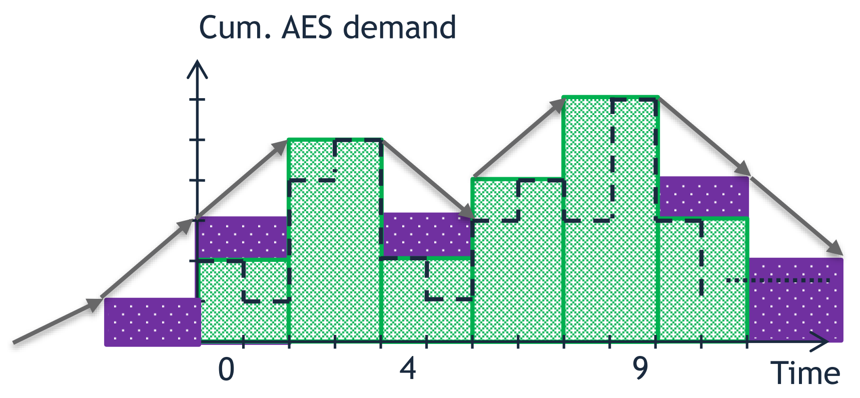




5.2 Modeling of additional energy requirements

How to model additional energy requirements?

- Indirect consideration by adapting the AESD to enforce a corresponding FESD
  - Additional FESDs (e.g., for ramp-ups) have to be approximated
  - Possible height difference of load transition depends on available time for the transition
  - ➔What difference of AESD is manageable between aggregated time intervals?



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