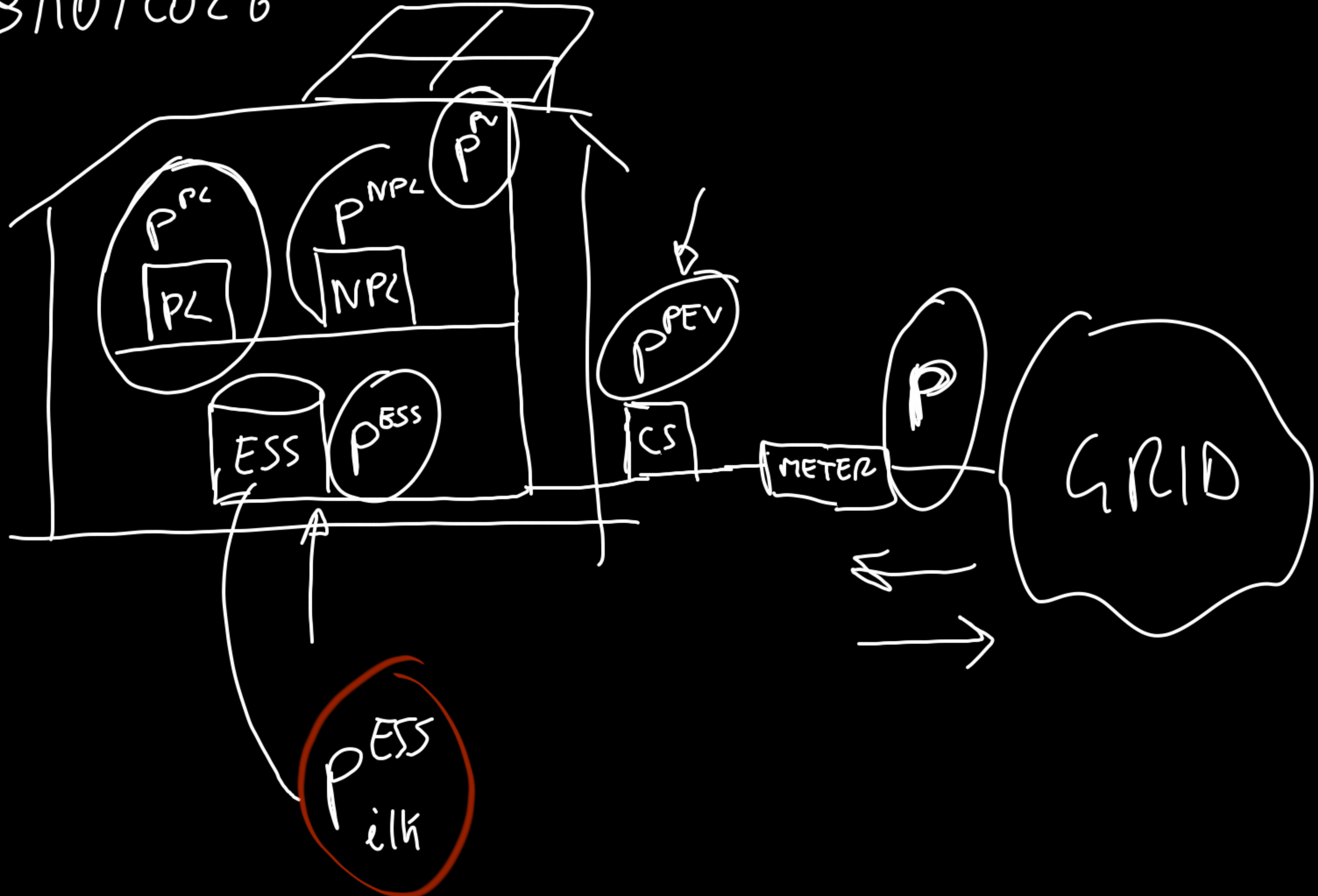
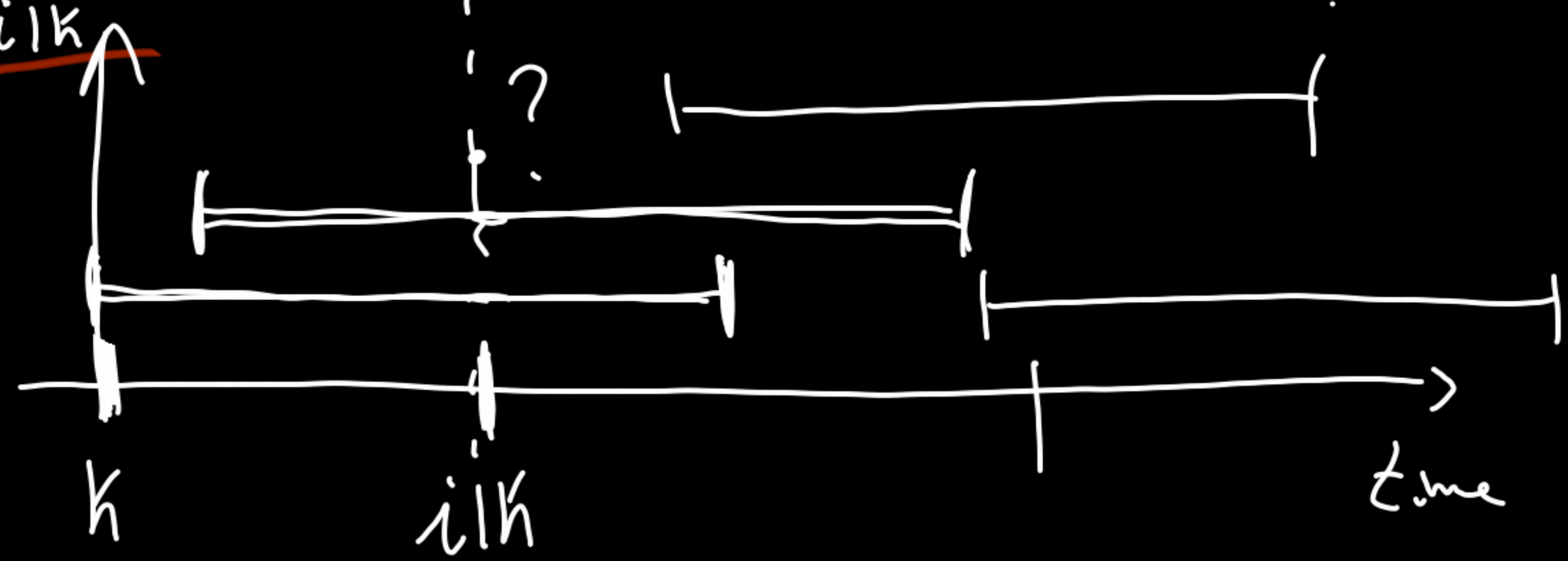


19/10/2026



P_{ilk}^{PL} POWER OF PLANNABLE LOADS ACTIVE AT i/k .



L SET OF ALL PLANNABLE LOADS.

$$\underline{P_{ilk}^{PL}} = \sum_{\substack{e \in L_{ilk}}} \textcircled{P_{ilk,e}^{PL}}, i=0,1,\dots,N-1$$

S_e FIRST POSSIBLE START TIME e
 F_e DEADLINE
 N_e DURATION
 USER PREFERENCES P_e

$P_{ilk,e}^{PL}$

POWER CONSUMED BY PLANNABLE LOAD e AT TIME ilk .

e :

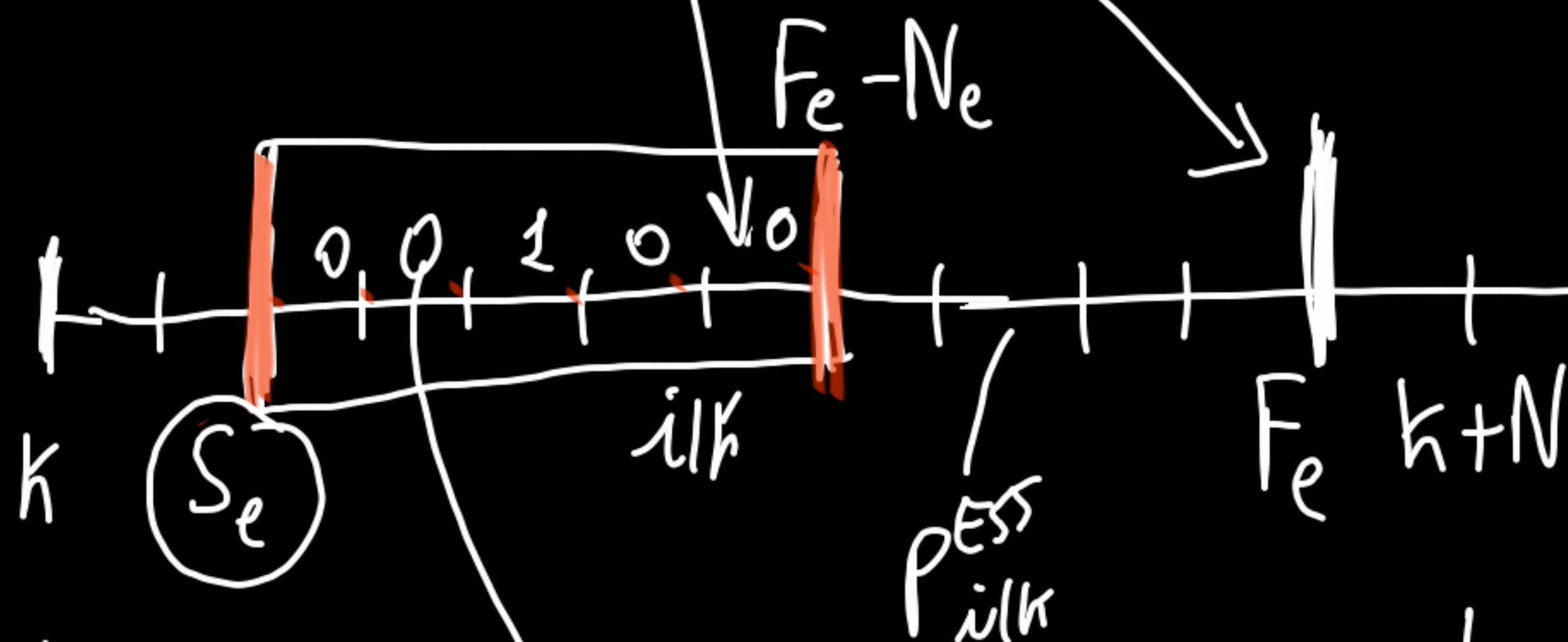
P_e



S_e, F_e

START VARIABLE

$S_{ilk,e} = 1$ means
LOAD e IS STARTED
AT BEGINNING OF
INTERVAL ilk



NOTE: ilk RELATIVE TIME

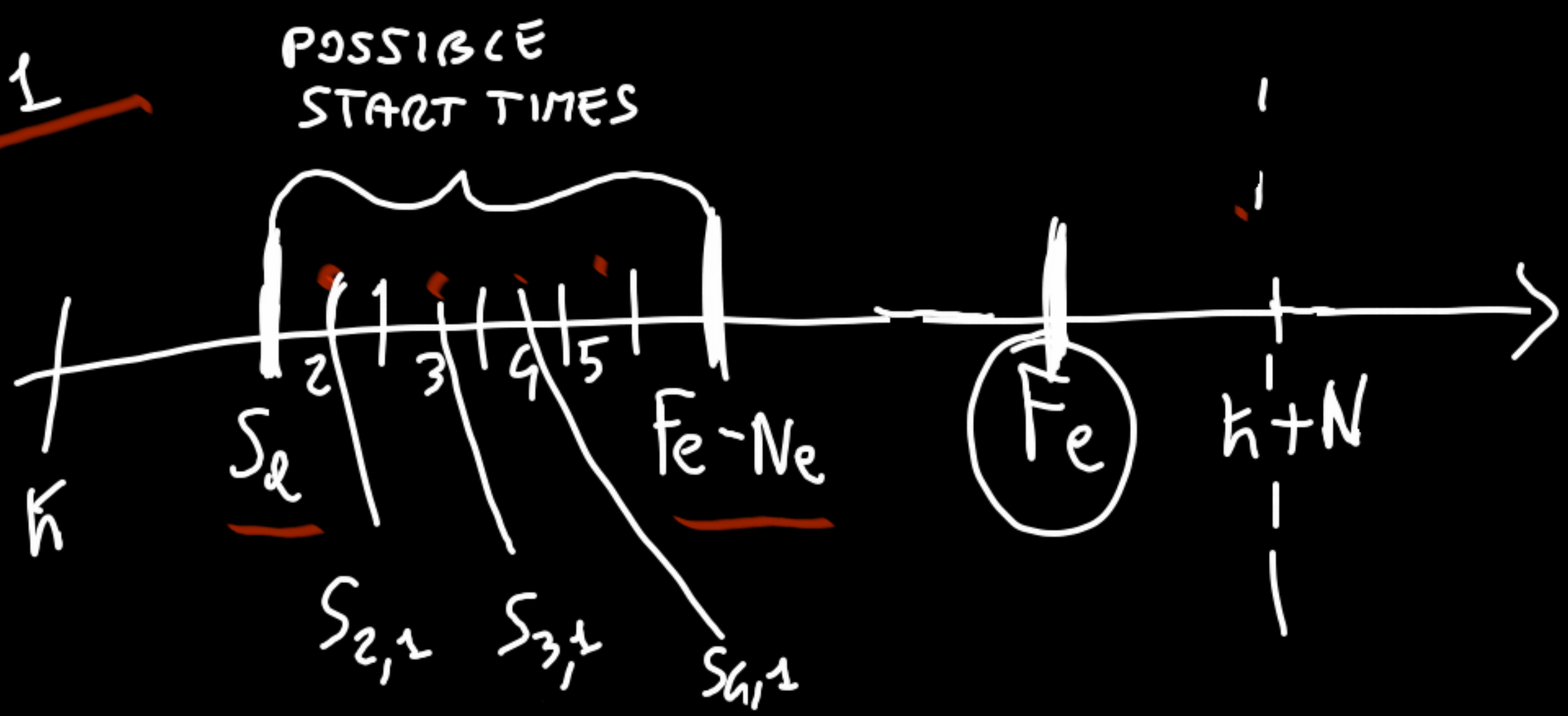
F_e, S_e : ABSOLUTE TIME

$S_{ilk,e} \in \{0, 1\}$

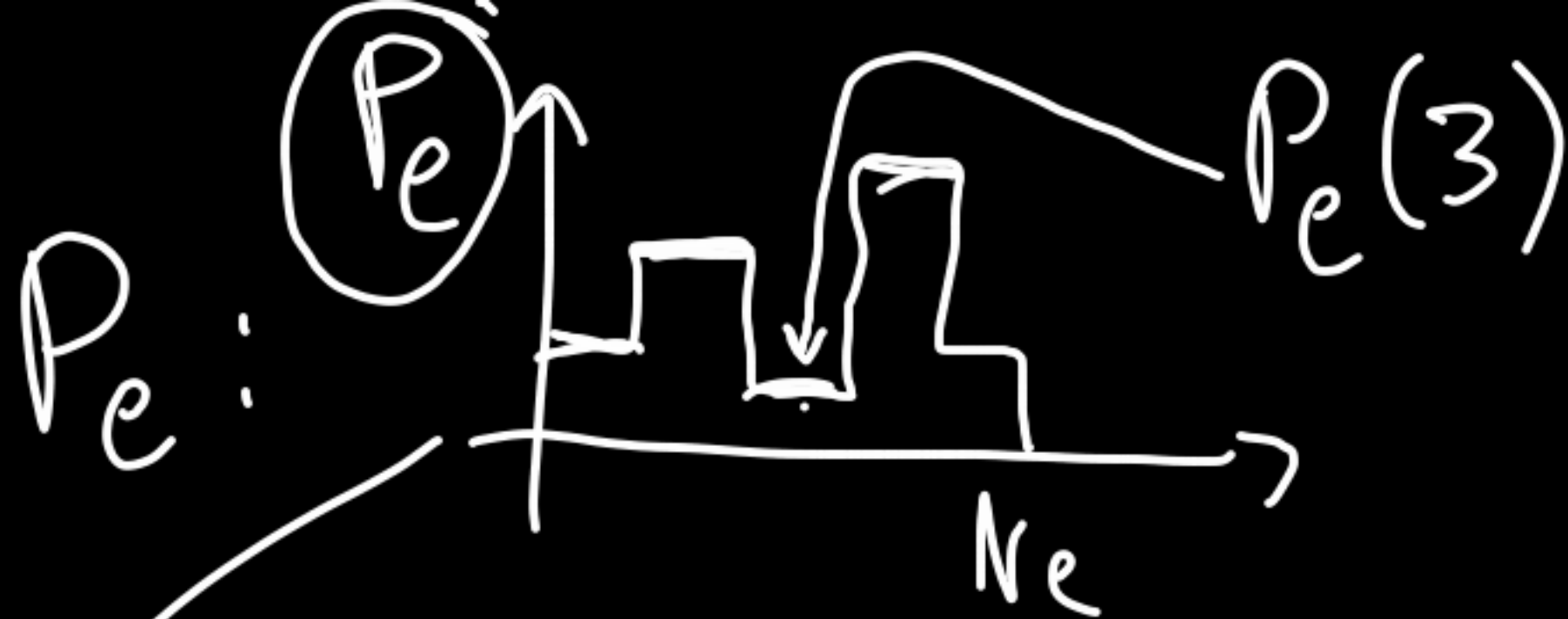
LOGICAL CONSTRAINT: THE CONTROLLER MUST START EACH PLANNABLE APPLIANCE ONLY ONCE:

$$\sum_{i=\textcircled{S_e}}^{Fe-Ne} S_{ik,l} = 1 ; \quad \forall l \in \mathcal{L}_{ik}$$

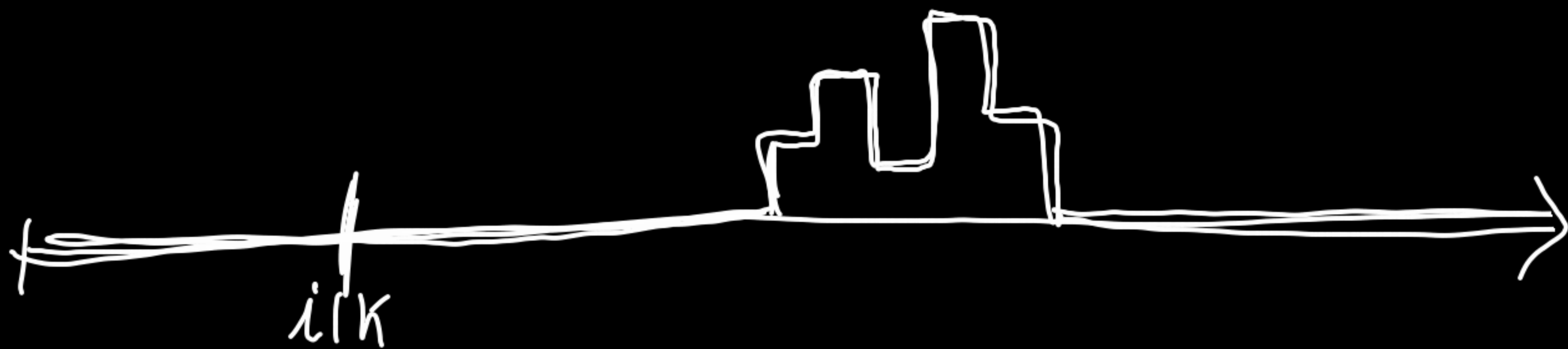
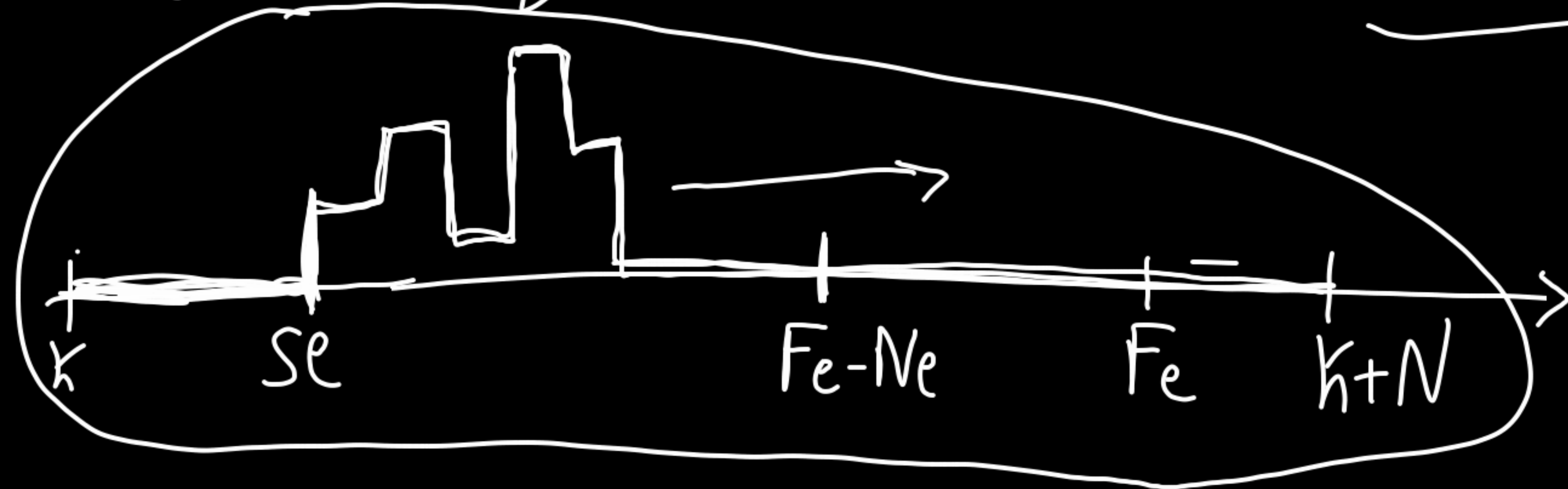
$l=1$



$P_{ik,e}^{PL}$



$$P_{ik,e}^{PL} = \sum_{l=0}^{\infty} S_l \cdot P_e(l)$$

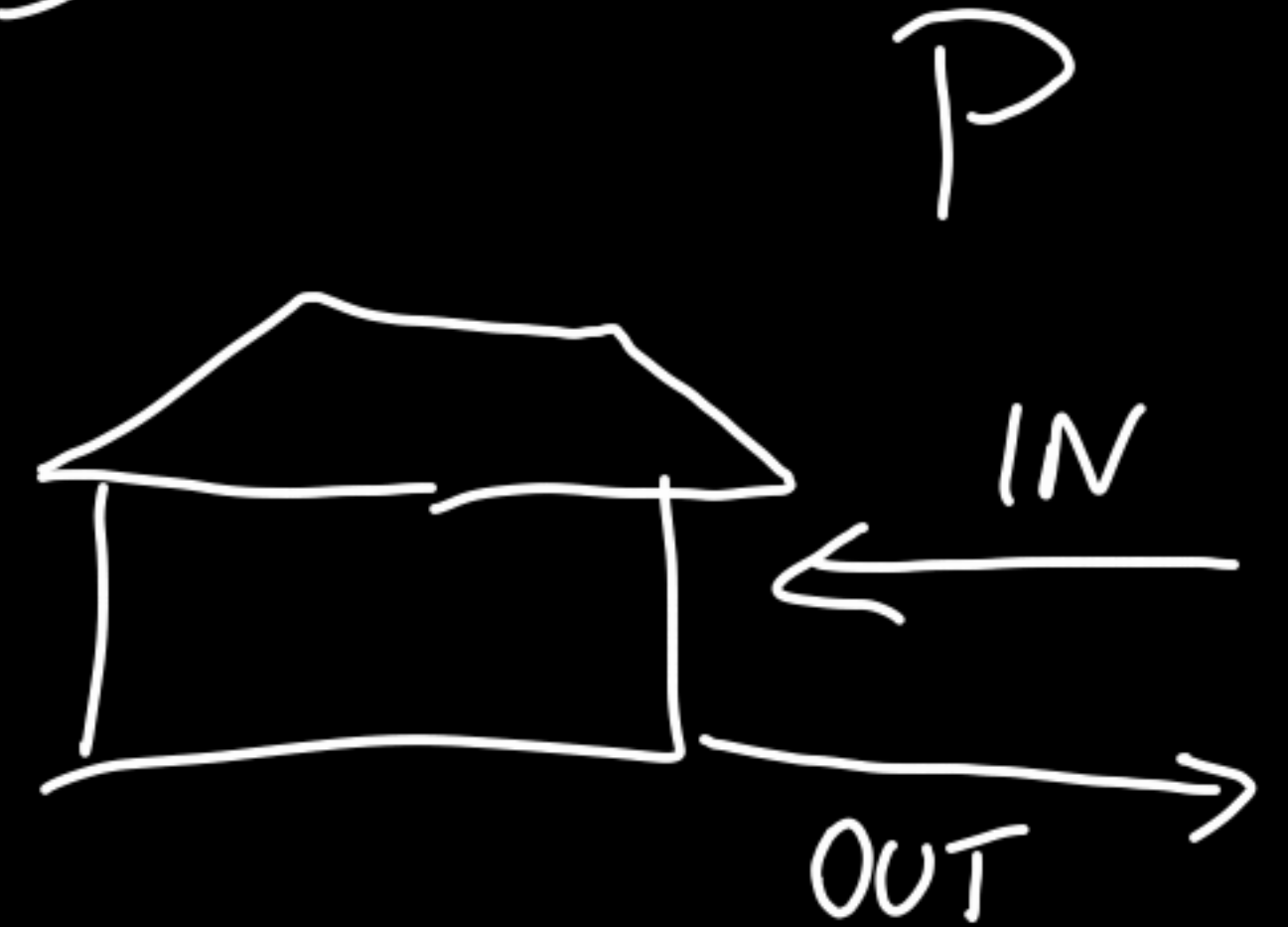
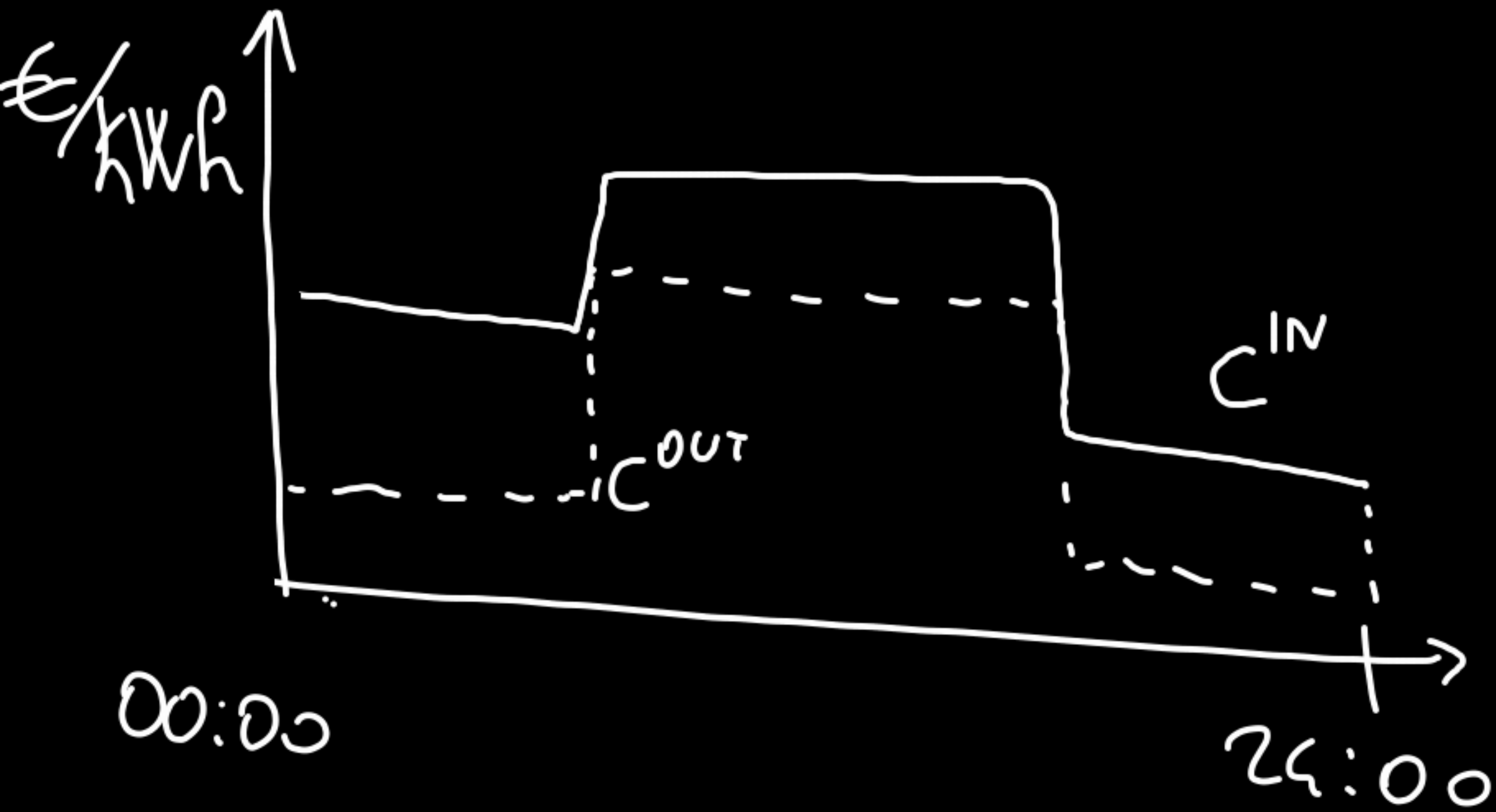


$$\underline{P_{ik}^{PL}} = \sum_{\ell \in \mathcal{L}_{ik}} P_{ik,\ell}^{PL}, \quad i=0,1,\dots,N-1$$

$$P_{ik,\ell}^{PL} = \underbrace{\sum_{-} \cdot P_{\ell}(-)}_{?}, \quad \forall \ell \in \mathcal{L}_{ik}, i=0,\dots,N-1$$

$$S_{ik,\ell} \in \{0,1\}, \quad \forall \ell \in \mathcal{L}_{ik}, \quad i = S_{\ell}, S_{\ell+1}, \dots, F_{\ell} - N_{\ell}$$

MODELING OF COSTS AND PROFITS

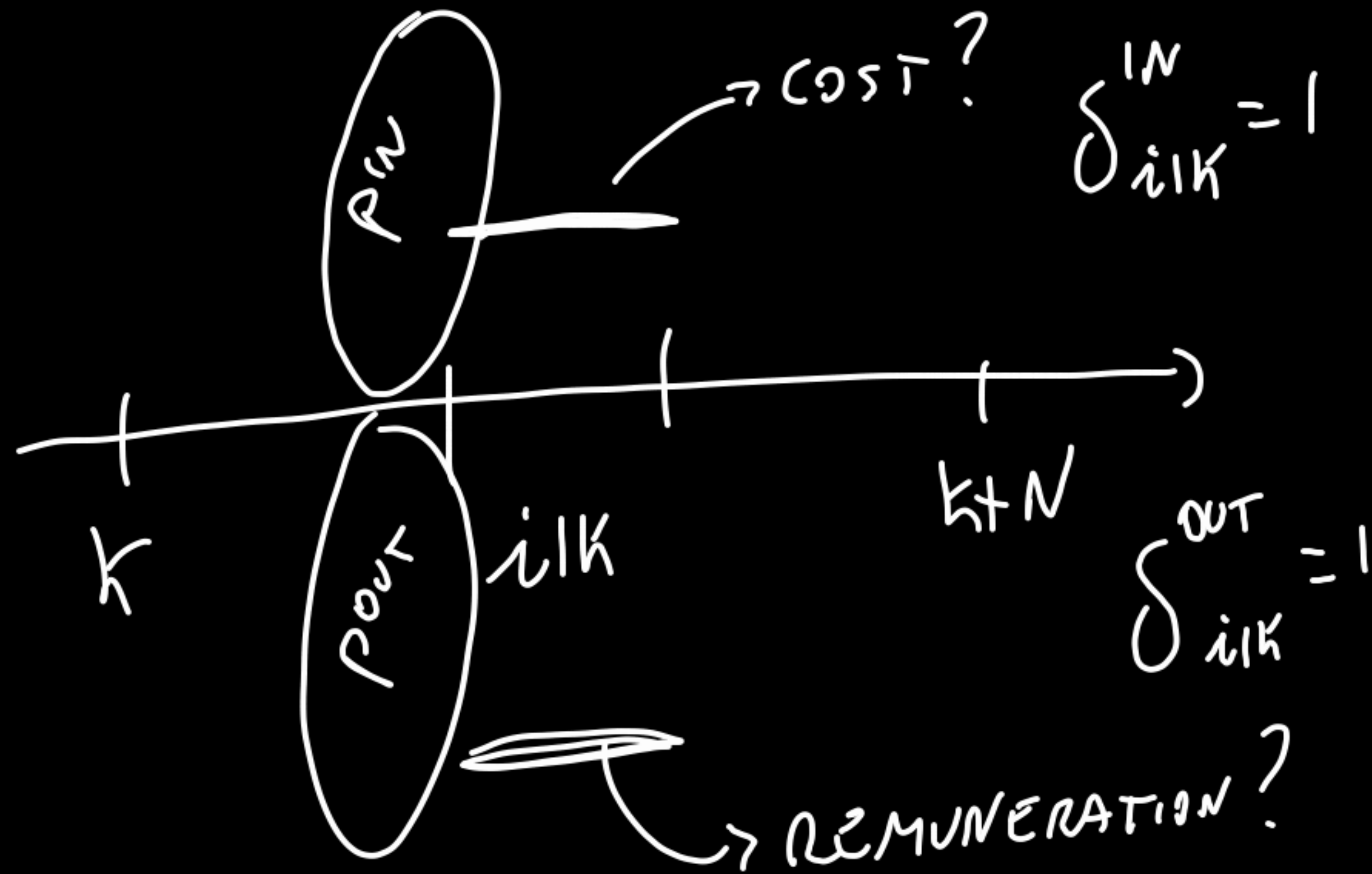


C^{IN} [€/kWh] COST OF ELECTRICITY CONSUMPTION

C^{OUT} [€/kWh] REMUNERATION FOR ENERGY INJECTION INTO GRID

PROBLEM:

GIVEN $\underline{P_{ik}}$, HOW TO COMPUTE THE ASSOCIATED COST OR REMUNERATION, KNOWING THE TARIFFS C^{IN}, C^{OUT} ?



SPLIT P_{ik} :

$$P_{ik}^{IN} \geq 0, i=0, \dots, N-1$$

$$P_{ik}^{OUT} \geq 0, i=0, \dots, N-1$$

$$P_{ik} = P_{ik}^{IN} - P_{ik}^{OUT}, i=0, \dots, N-1$$

$$\underline{\delta_{ik}^{IN}}, \underline{\delta_{ik}^{OUT}} \in \{0, 1\} \quad i = 0, \dots, N-1$$

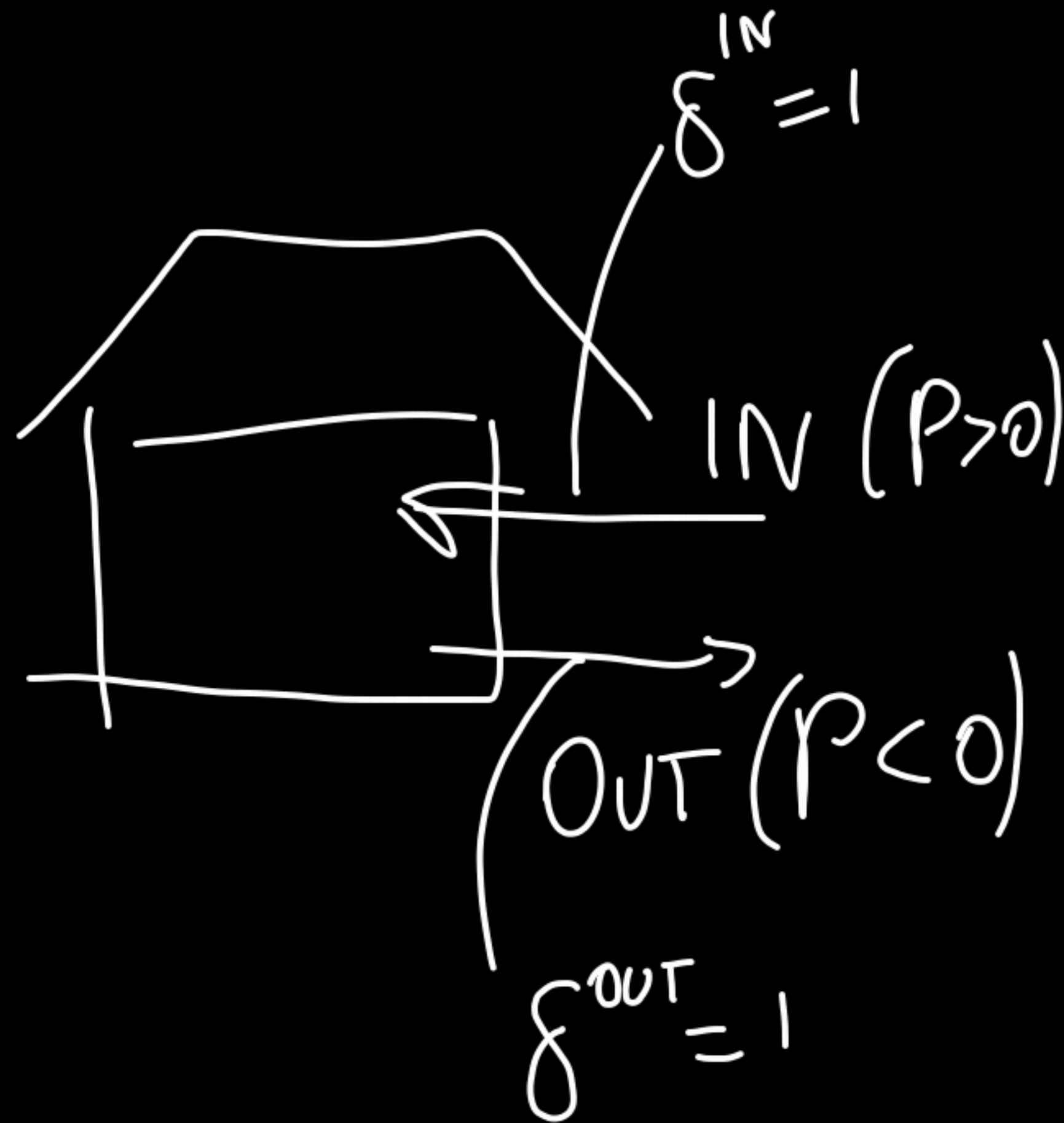
INDICATOR CONSTRAINTS:

$$P_{ik}^{IN} \leq P^{MAX} \cdot \delta_{ik}^{IN}, \quad i = 0, 1, \dots, N-1$$

$$P_{ik}^{OUT} \leq |P^{MIN}| \cdot \delta_{ik}^{OUT}, \quad i = 0, 1, \dots, N-1$$

MUTUAL EXCLUSION CONSTRAINT

$$\delta_{ik}^{IN} + \delta_{ik}^{OUT} \leq 1, \quad i = 0, 1, \dots, N-1$$

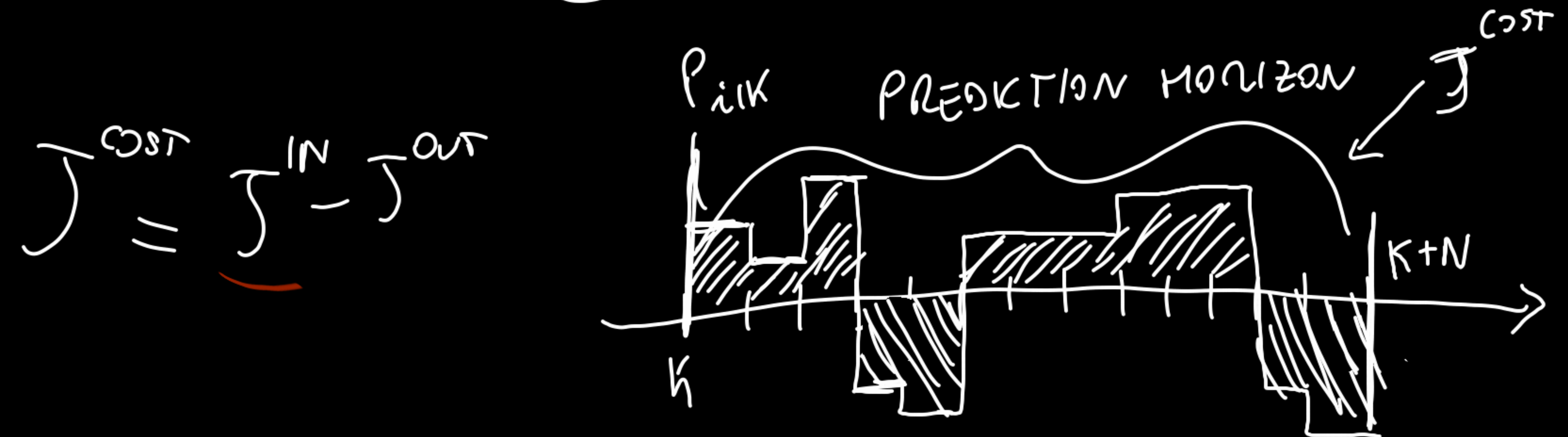


OBJECTIVE FUNCTION:

CONTROL GOAL: OPTIMIZE ELECTRICITY BILL (MINIMIZE COST OF ELECTRICITY CONSUMPTION).



$\underbrace{P_{ik}}$, P_{ik}^{IN} , P_{ik}^{OUT} , T , $\underbrace{C_{ik}^{IN}}$, $\underbrace{C_{ik}^{OUT}}$, $\dots$



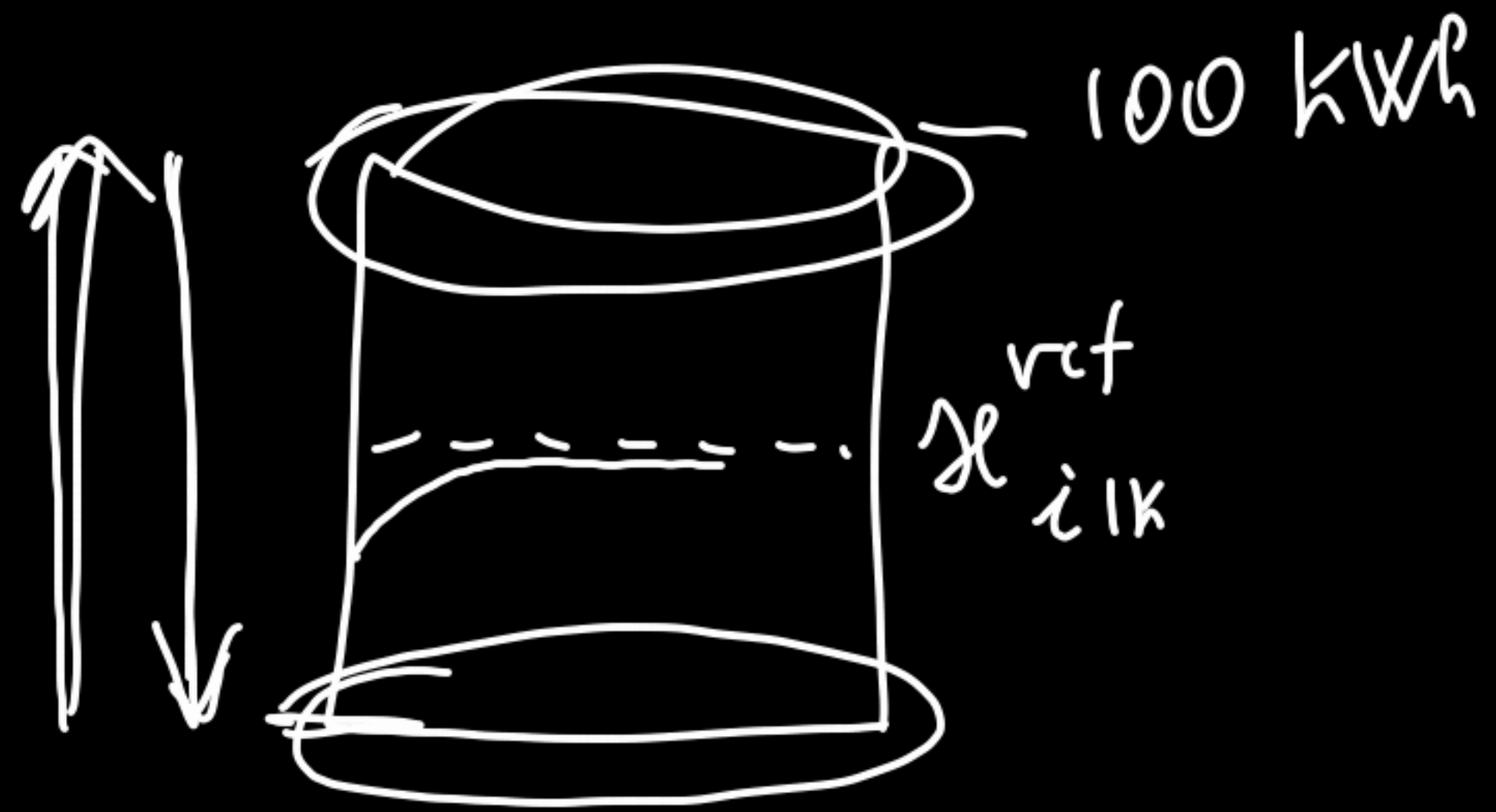
$$J^{IN} = \sum_{i=0}^{N-1} \underbrace{(P_{ik}^{IN} \cdot T)}_{\substack{\text{ENERGY [K.W.H]} \\ \text{CONSUMED AT} \\ ik}} \cdot C_{ik}^{IN}$$

$$J^{OUT} = \sum_{i=0}^{N-1} (P_{ik}^{OUT} \cdot T) \cdot C_{ik}^{OUT} \quad \left(\max J^{OUT} \equiv \min (-J^{OUT}) \right)$$

$$J^{COST} = \sum_{i=0}^{N-1} T \left(P_{ik}^{IN} \cdot C_{ik}^{IN} - P_{ik}^{OUT} \cdot C_{ik}^{IN} \right)$$

$$J^{\text{reg}} = \sum_{i=0}^{N-1} (x_{i|h}^{\text{ESS}} - x_{i|h}^{\text{ref}})^2$$

J^{cost}



J^{depr}

ESS

10000
CYCLES

FULL CHARGING CYCLES OF EXPECTED

= 1 MWh

LIFE

$x_{\text{ESS,MAX}} [kWh]$

$$E^{\text{LIFE}} = \textcircled{2} \cdot x_{\text{ESS,MAX}} \cdot \text{CYCLES}$$

[kWh]

AMOUNT OF ENERGY
WE ARE EXPECTED TO
BE ABLE TO CHARGE/
DISCHARGE WITH ESS.

$$\underline{E^{LIFE}} = 2 \cdot \mathcal{H}^{max} \cdot CYCLES$$

$$\underline{COST^{ESS}} \quad (20k€)$$

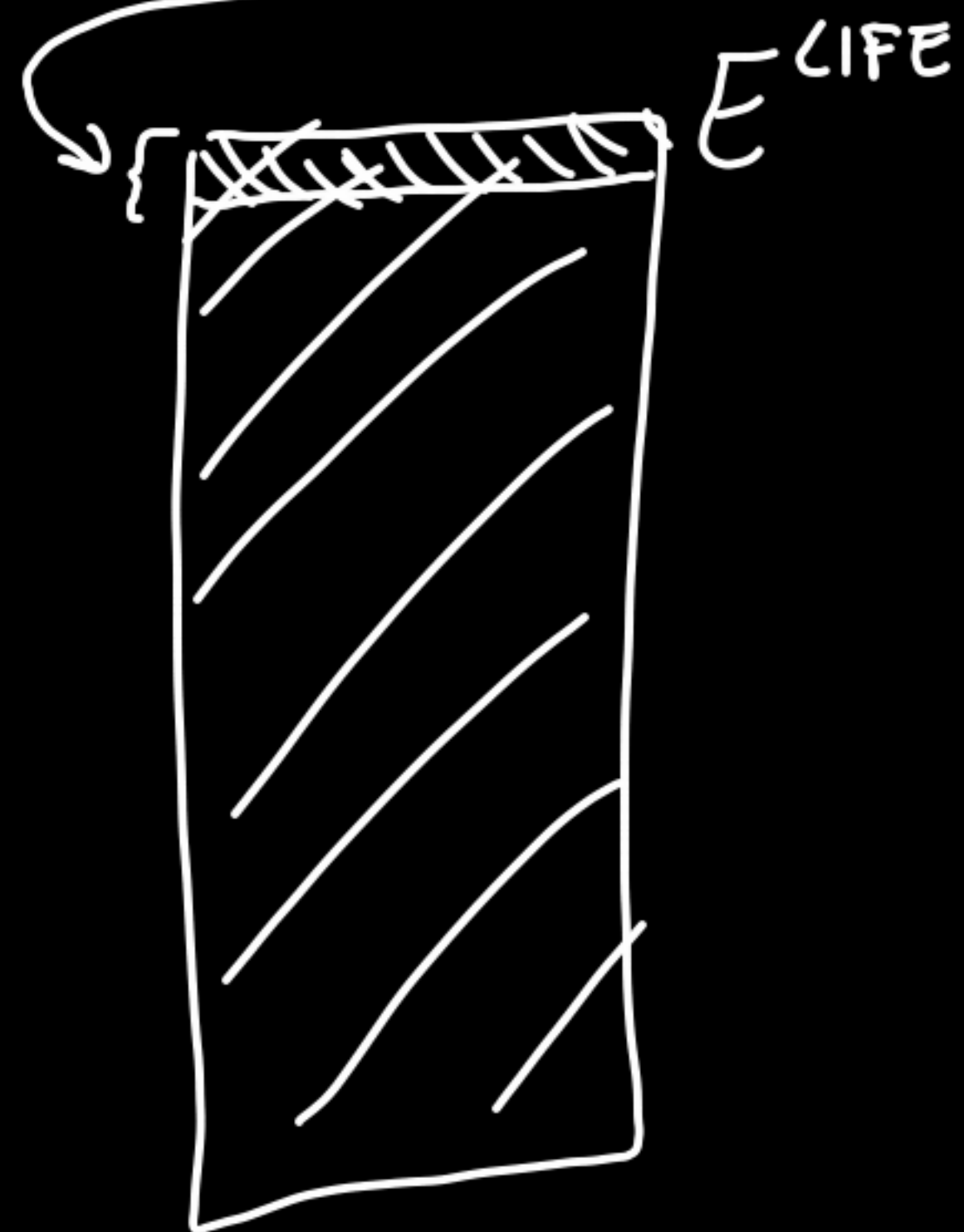
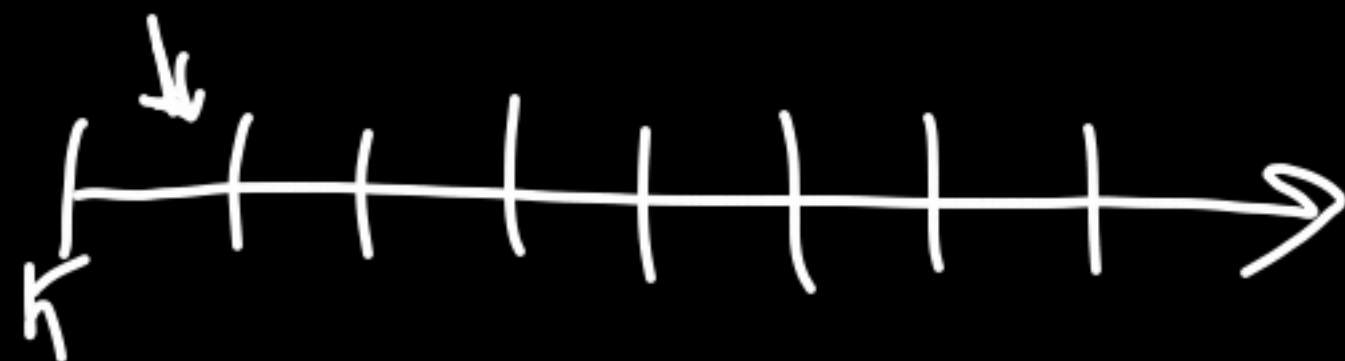
Q: WHAT IS THE "HIDDEN"
COST OF USING ESS (P_{ilk}^{ESS})
IN TERMS OF COST OF
LOSS OF RESIDUAL LIFE.

$$P_{ilk}^{ch, ESS}$$

$$P_{ilk}^{dis, ESS}$$

$$\underline{P_{ilk}^{ESS}} = P_{ilk}^{ch, ESS} - P_{ilk}^{dis, ESS}$$

$$J^{depr.} = ?$$



$$J^{\text{dep.}} = \sum_{i=0}^{N-1} \left(\begin{array}{c} \text{COST FOR USING} \\ \text{ESS AT INTERVAL} \\ i/k \end{array} \right) = \sum_{i=0}^{N-1} C^{\text{dep}} \underbrace{|P_{i/k}^{\text{ESS}}|}_{P_{i/k}^{\text{ESS}}} \cdot T^{\text{[R]}} =$$

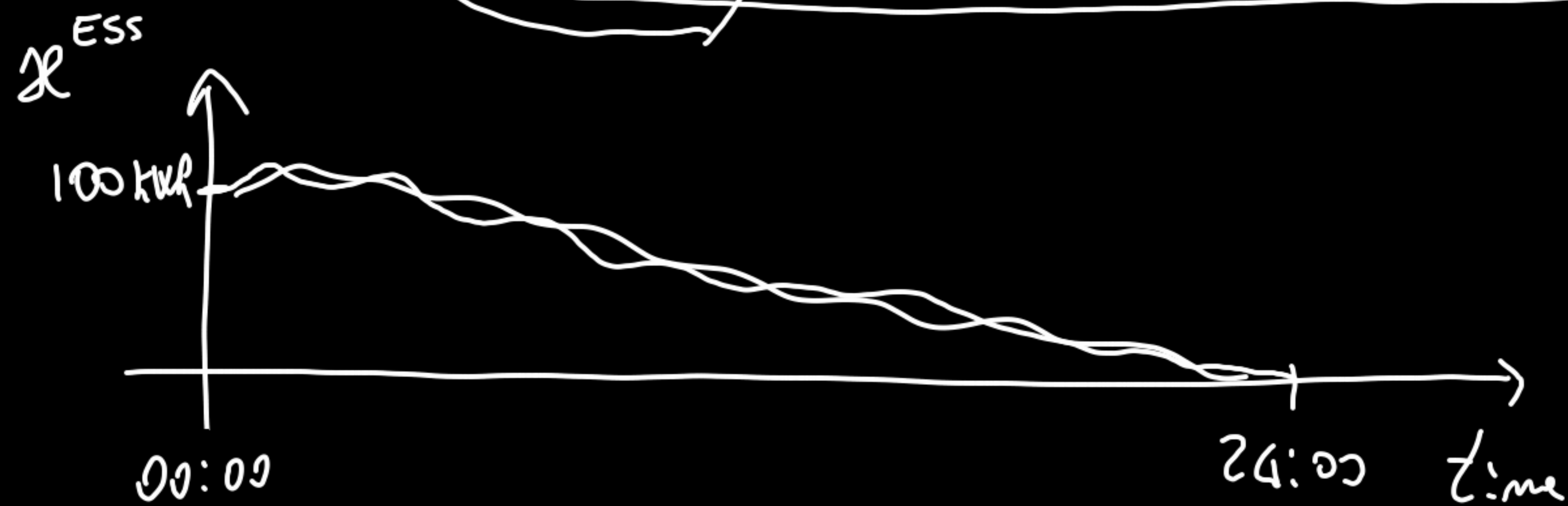
$$C^{\text{dep.}} = \frac{\text{COST}^{\text{ESS}}}{E^{\text{CIFE}}} \left[\text{€}/\text{kWh} \right]$$

(< 1)

COST, IN TERMS OF LOSS OF
LIFE, OF CHARG./DISCH. 1
kWh WITH ESS.

$$J^{\text{COST}} = \sum_{i=0}^{N-1} C^{\text{dep}} \underbrace{\left(P_{i/k}^{\text{ch, ESS}} + P_{i/k}^{\text{dis, ESS}} \right)}_{|P_{i/k}^{\text{ESS}}|} \cdot T$$

$$\min J = \underbrace{\alpha_1 \cdot J^{\text{cost}}}_{\text{ESS}} + \alpha_2 J^{\text{reg}} + \alpha_3 J^{\text{depr.}}$$



STRANGE BEHAVIOR: ESS TENDS TO FULLY DISCHARGE.

