IBM Research – Zurich
Carl Binding, Olle Sundström
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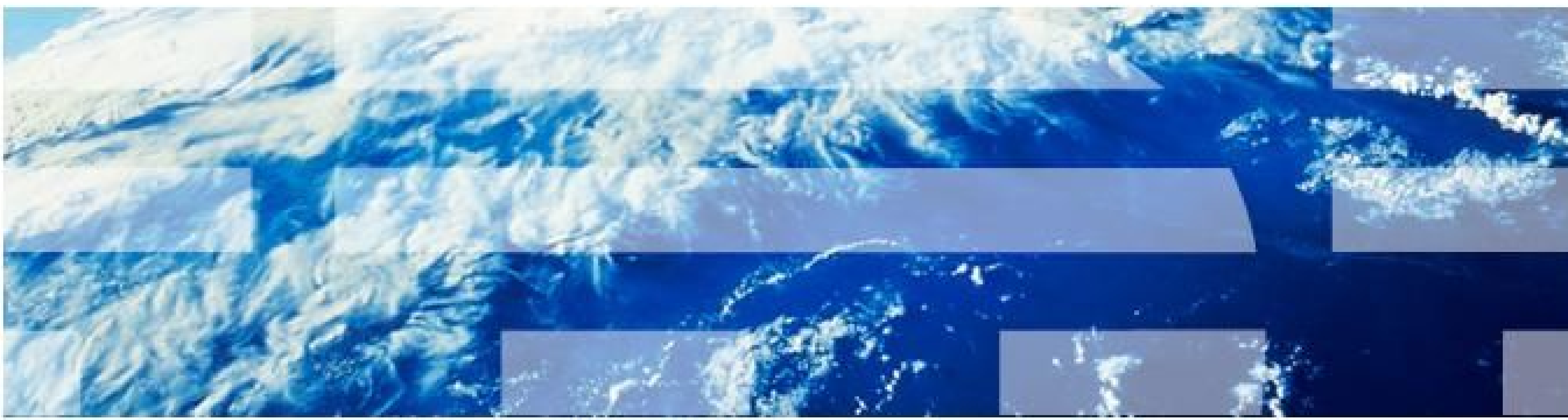
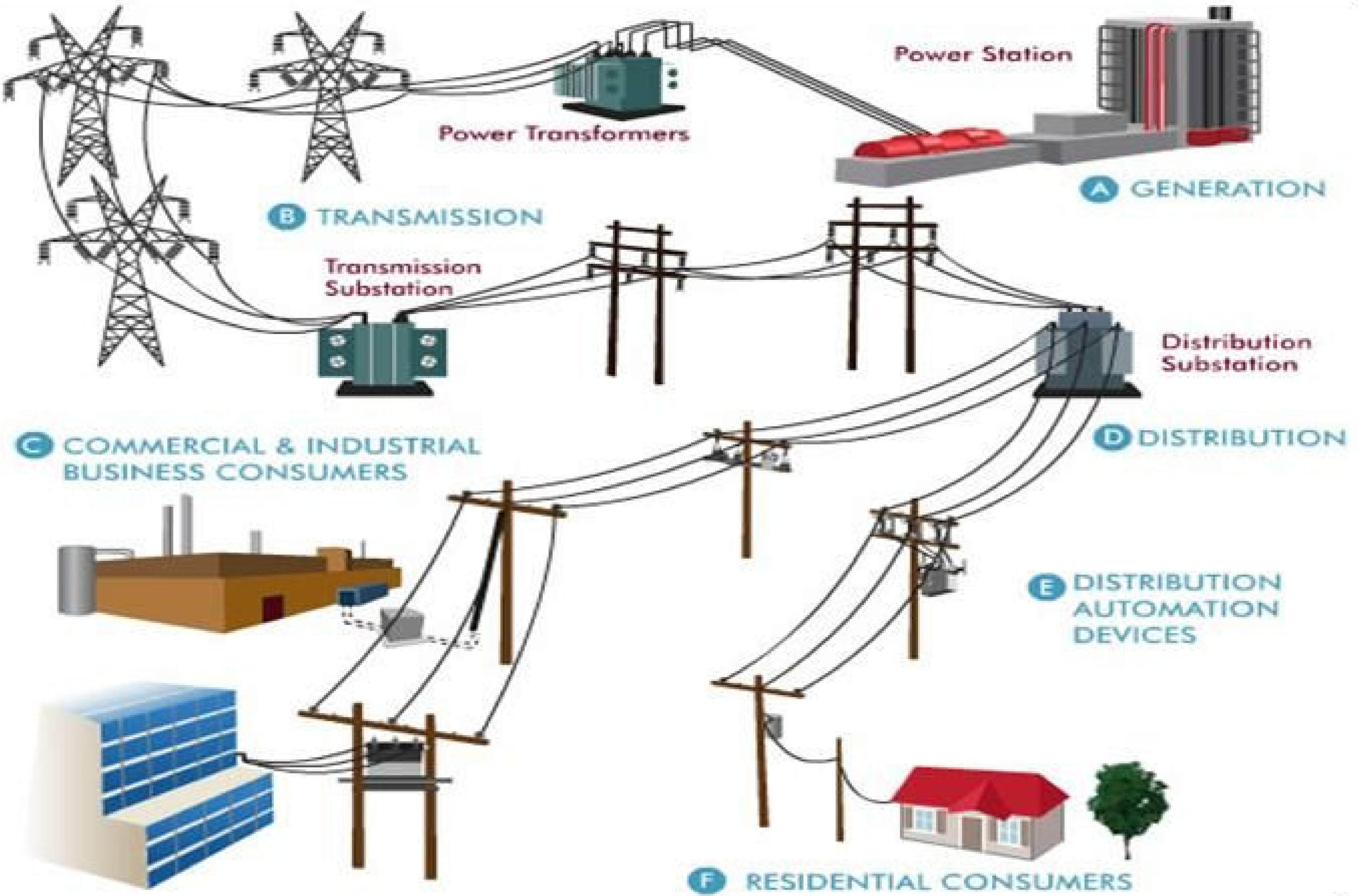
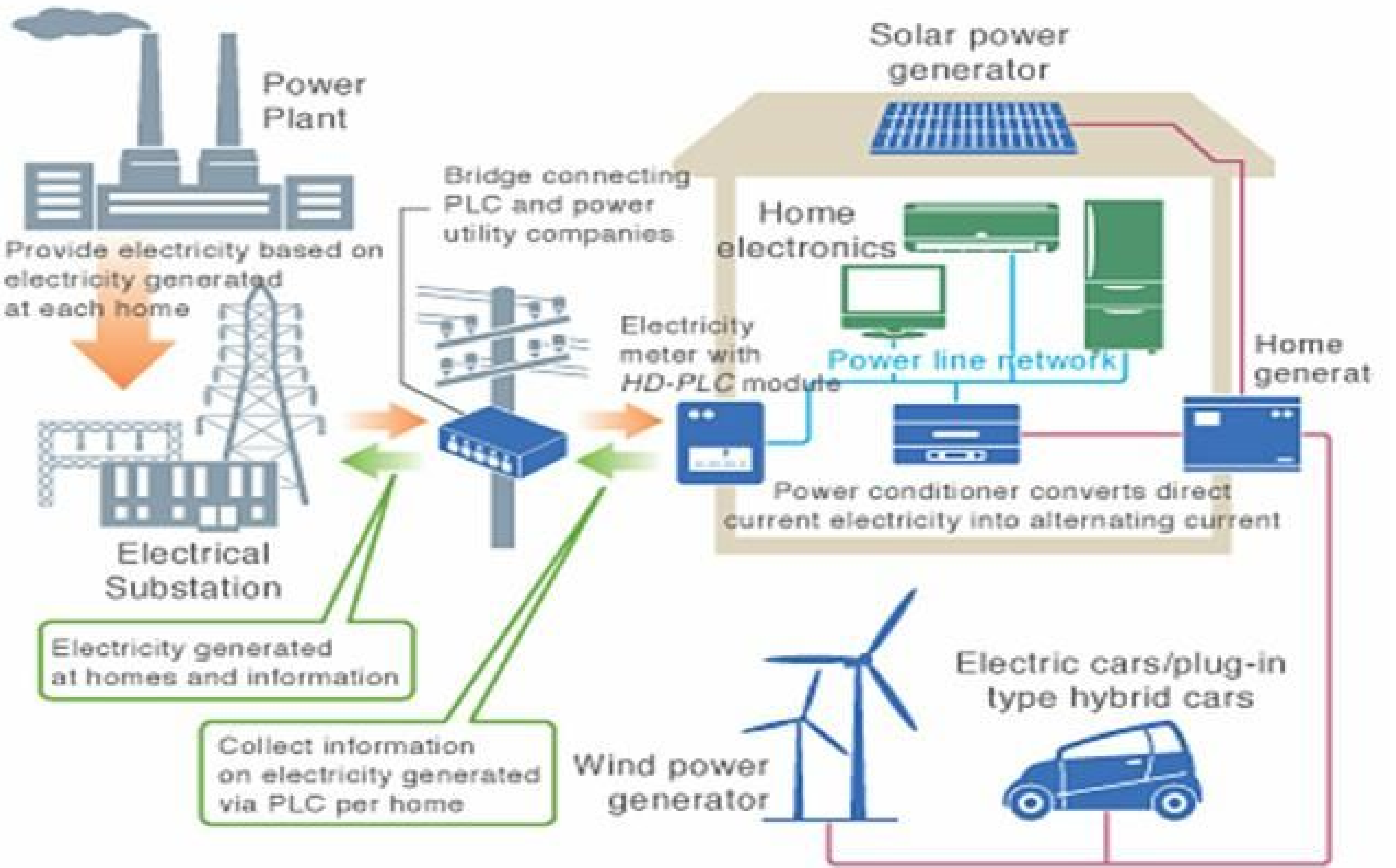
Requirements for flexibility description

iPower WP 4 Aarhus November 21-23 2011



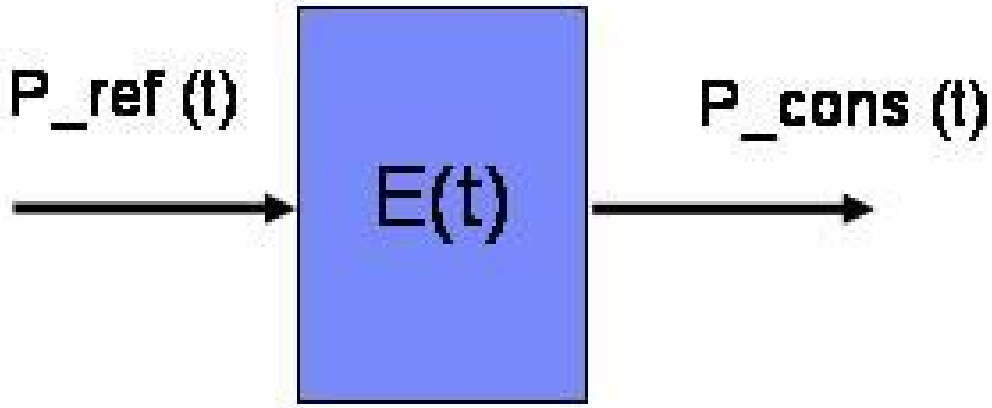

Power Station
Power Transformers
A GENERATION
B TRANSMISSION
Transmission Substation
Distribution Substation
C COMMERCIAL & INDUSTRIAL BUSINESS CONSUMERS
D DISTRIBUTION
E DISTRIBUTION AUTOMATION DEVICES
F RESIDENTIAL CONSUMERS

Smart grid home

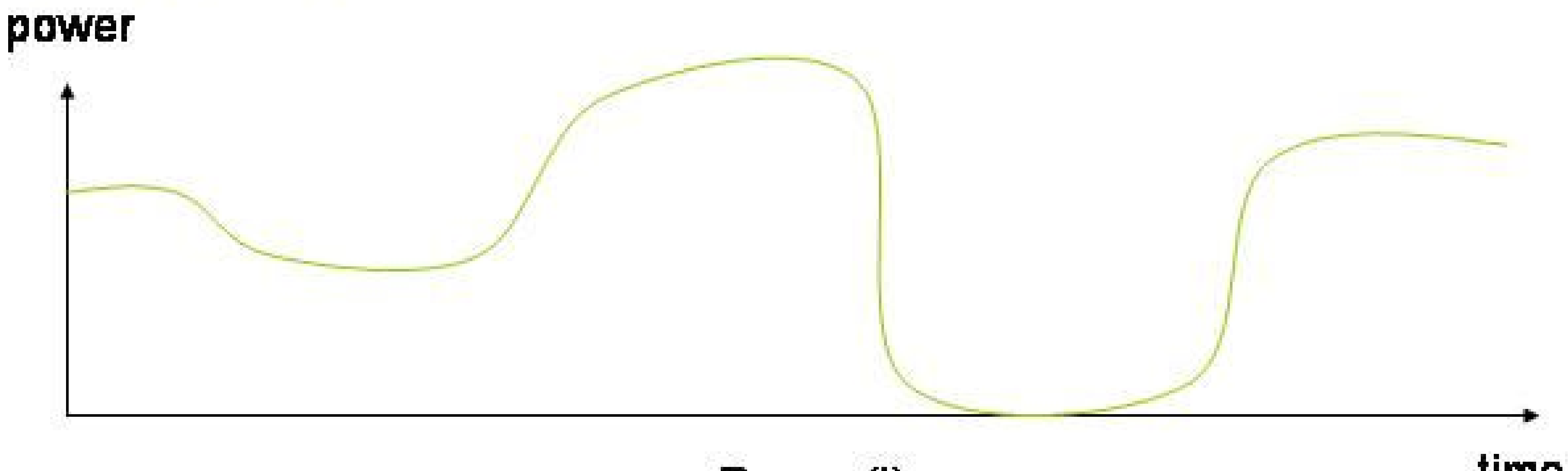


Device model

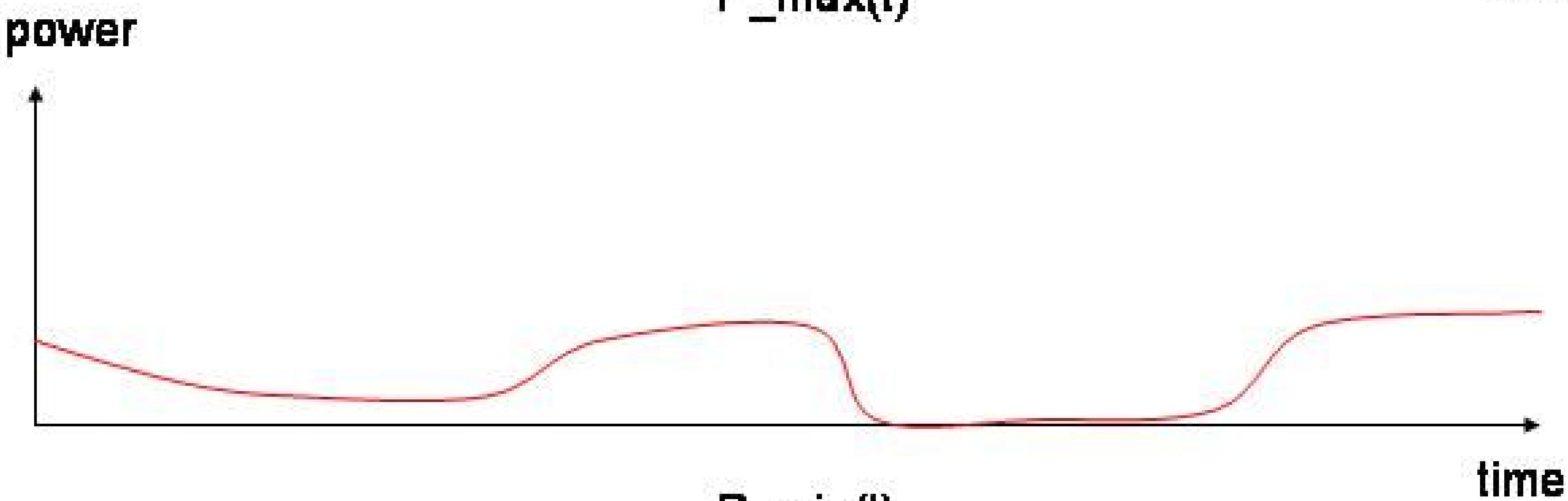
- E(t) = inflow – outflow + initial energy
- $E(t) = \int P_{ref}(t)\,dt - \int P_{cons}(t)\,dt + e_i$
- P_{ref}: supplied, reference, power
- P_{cons}: power consumed
  - User level power: "real" demand
  - Leakages
- Min. & max. input power
- Min. & max. energy stored



P_min(t), P_max(t)

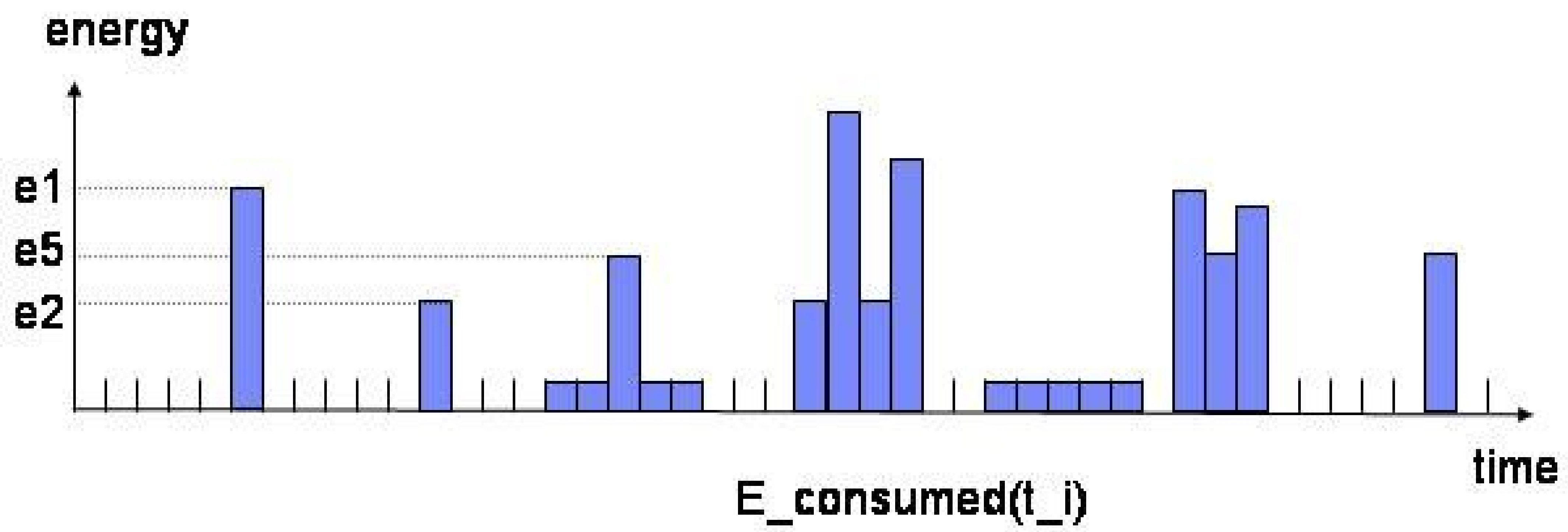


P_max(t)



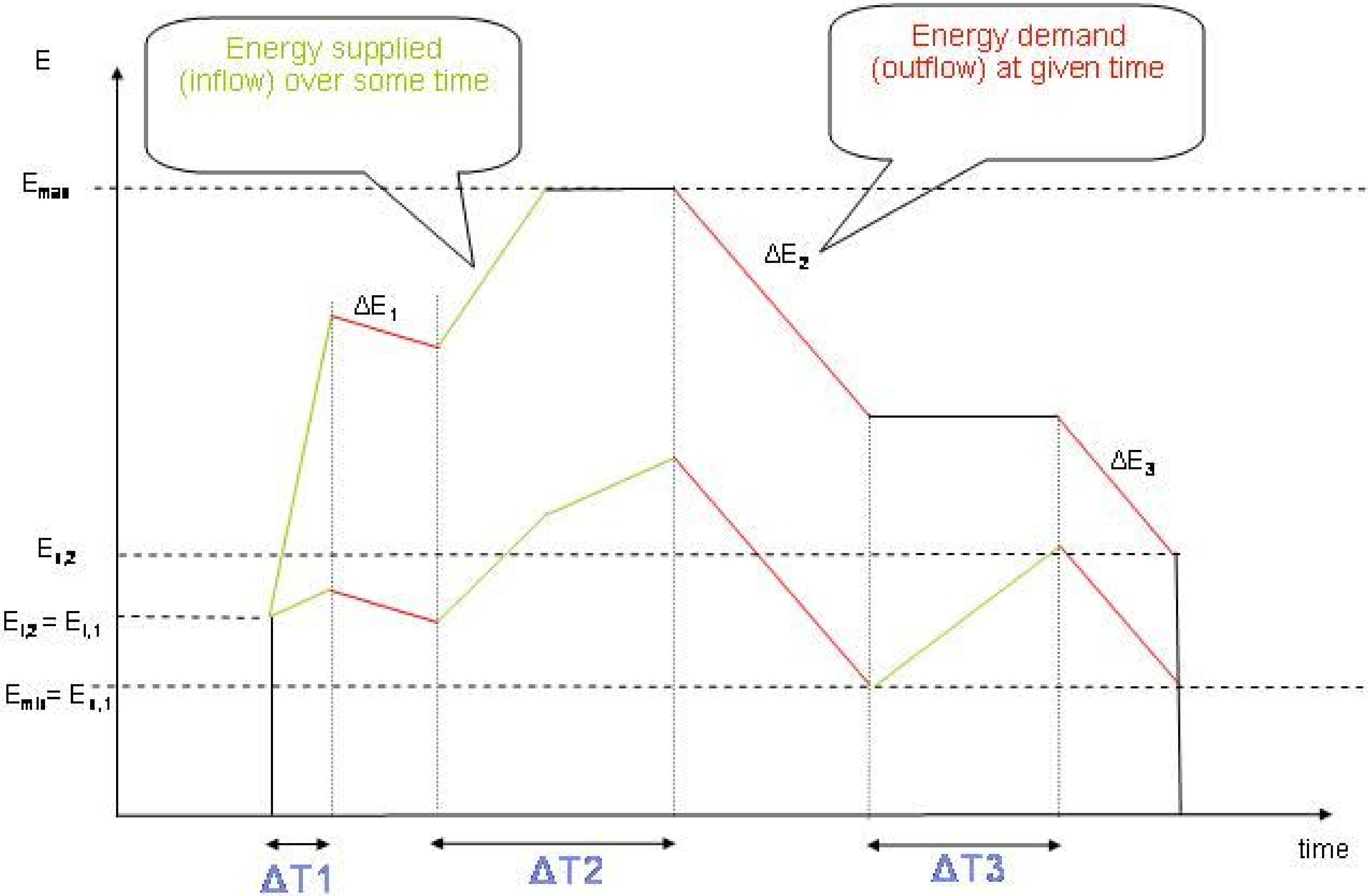
P_min(t)

E_consumed(t)



- Discretize energy consumed in a given time-slot
- Reflects demand of energy over time (outflow)
  - Leakages
  - "Real" demand
- For every demand to be satisfied, enough energy must be in buffer
  - Enough power inflow until time-of-use
    - Ex: take a hot bath, drive an EV, drink a cool beer!
- **We have flexibility to supply energy until time-of-consumption**

Energy balances



$$\underline{E} \leq E_i + \int_{\Delta T_1} P(t)dt - \Delta E_1 \leq \overline{E}$$

$$\underline{E} \leq E_i + \int_{\Delta T_1} P(t)dt - \Delta E_1 + \int_{\Delta T_2} P(t)dt - \Delta E_2 \leq \overline{E}$$

$$\underline{E} \leq E_i + \sum_{j=1}^{M_{in}} \int_{\Delta T_j} P(t)dt - \sum_{j=1}^{M_{out}} \Delta E_j \leq \overline{E}$$

$$\underline{E} \leq E_i + \sum_{j=1}^{M_{in}} \sum_{l=1}^{L_j} P_{j,l}\Delta t - \sum_{j=1}^{M_{out}} \Delta E_j \leq \overline{E}$$

Having K devices:

$$\underline{E_k} \leq E_{i,k} + \sum_{j=1}^{M_{in,k}} \sum_{l=1}^{L_{j,k}} P_{j,l,k}\Delta t - \sum_{j=1}^{M_{out,k}} \Delta E_{j,k} \leq \overline{E_k}$$

$$\underline{P_{j,k}} \leq P_{j,l,k} \leq \overline{P_{j,k}}$$

$$\sum_{j=1}^{M_{in,k}} \sum_{l=1}^{L_{j,k}} \sum_{k=1}^{K} P_{j,l,k} \leq P_{gen,j}$$

Requirements

- Define *total energy supplied*: integral of energy supplied E_sup(t)
- Need to capture the power envelope and the total energy envelope
  - P_min(t), P_max(t), E_sup_min(t), E_sup_max(t)
- Total energy demand (consumption) E_cons(t) must lie between E_sup_min(t) and E_sup_max(t) to be satisfied
- Easy encoding as a set of time-series for P_min(t), P_max(t), E_cons(t), E_sup_min(t), E_sup_max(t)
  - Discretized time-slots of arbitrary duration and number
- **Challenges**:
  - **Predict** the energy demand (consumption) into the future (i.e. planning horizon) for flexible loads
  - **Predict** generation for variable supply sources (wind, solar…)
  - **Find a trajectory** of E_sup(t) that matches power generation and satisfies the constraints E_sup_min(t) and E_sup_max(t) assuming that the supplied energy can be controlled
  - **Robustness**: uncertainty in generation and consumption…
  - **Scalability**: millions of consumers and generators, administrative boundaries.
    - We propose a bottom-up approach
  - **Non-local** optimization: greedy local optimization does not yield non-local optima