



ROYAL INSTITUTE
OF TECHNOLOGY

Energy and CO₂ efficient scheduling of smart home appliances in the Stockholm Royal Seaport

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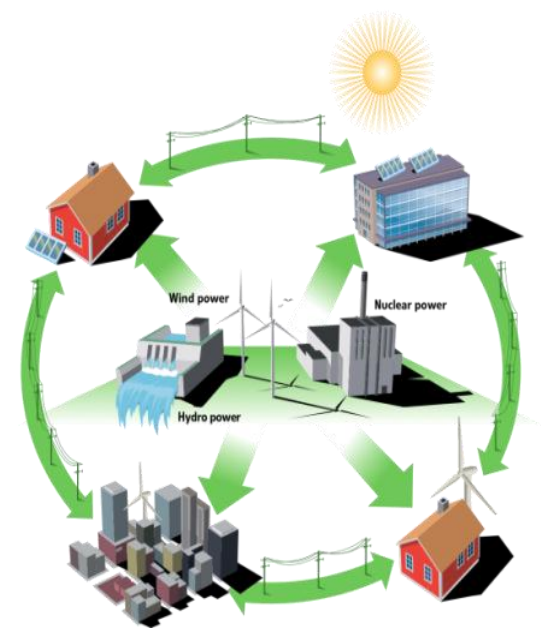
Automatic Control Lab, ACCESS Linnaeus Centre, KTH

HYCON2 Workshop on Energy, September 3rd, 2012



Outline

- Stockholm Royal Seaport
- CO₂ vs. electricity tariff in Sweden
- Scheduling smart home appliances
- Virtual Smart Grid Lab



Stockholm Royal Seaport - Now

2010

- Oil depot
- Container terminal
- Ports
- Gas plant

2030

- 10,000 new homes
- 30,000 new work spaces
- 600,000 m² commercial space
- Modern port and cruise terminal
- 236 hectares sustainable urban district
- Walking distance to city centre

From a brown field area to a sustainable city district



Stockholm Royal Seaport

Stockholm Royal Seaport - Future

2010

- Oil depot
- Container terminal
- Ports
- Gas plant

2030

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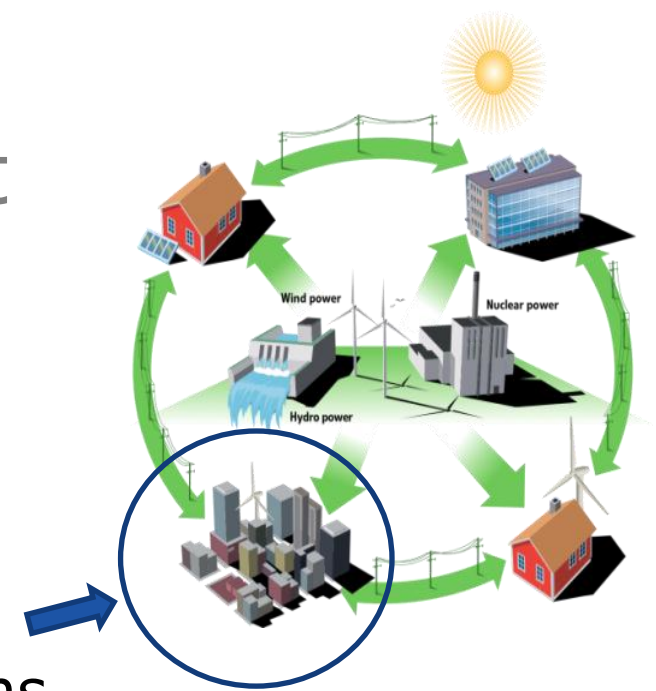
From a brown field area to a sustainable city district



Stockholm Royal Seaport

Stockholm Royal Seaport in Brief

- Part of the Clinton Climate Initiative
- Cities responsible for 2/3 of CO₂ emissions
- Demands local energy generation, energy efficiency, robust power supply, market models, regulations,...
- **Goal:** CO₂ emissions below **1.5** tons per person by 2020 (today **4.5**); fossil fuel-free by 2030



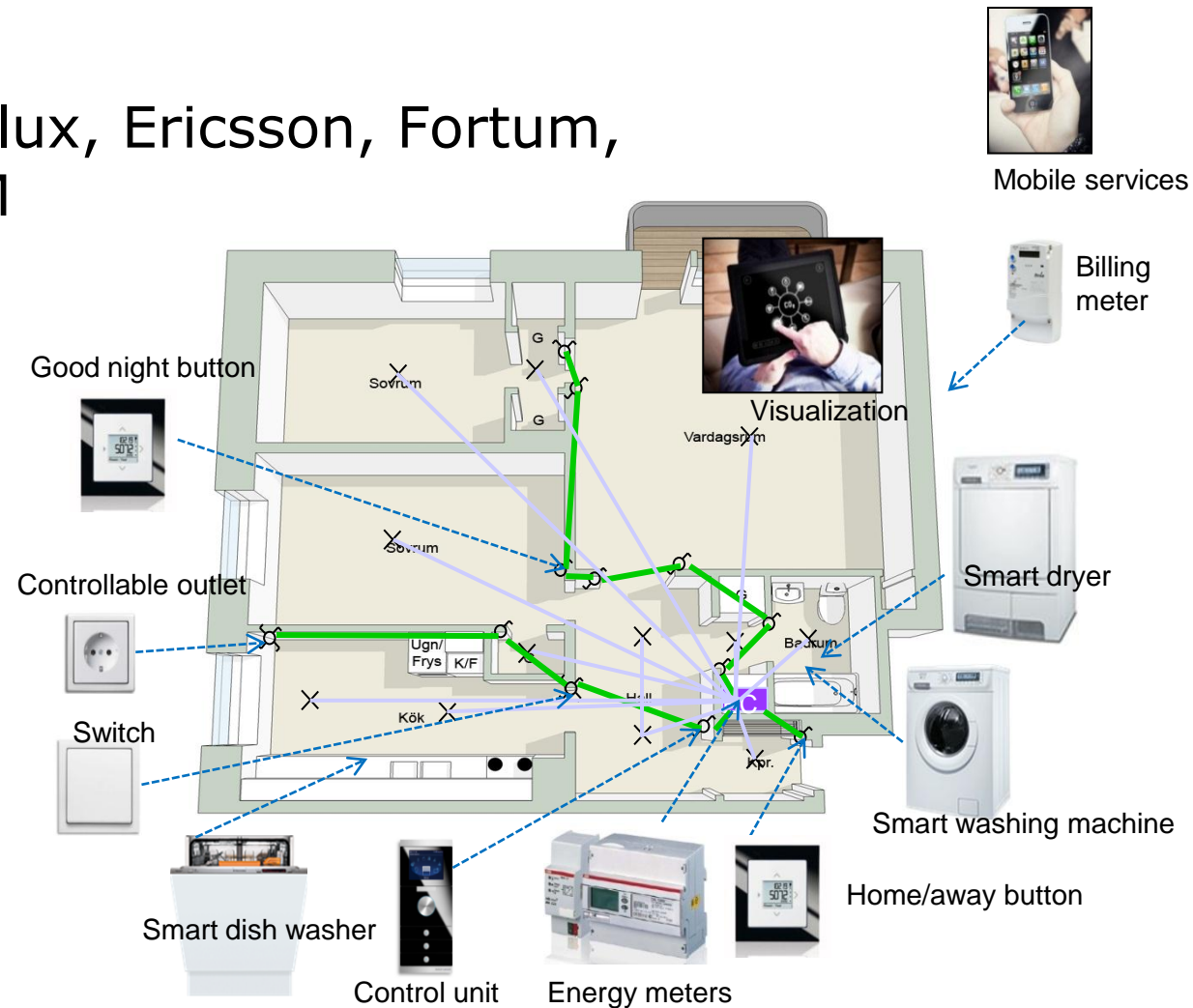
The Active House in the Royal Seaport

- Partners: KTH, ABB, Electrolux, Ericsson, Fortum, Interactive Institute, and JM

- Smart home appliances and controllable loads

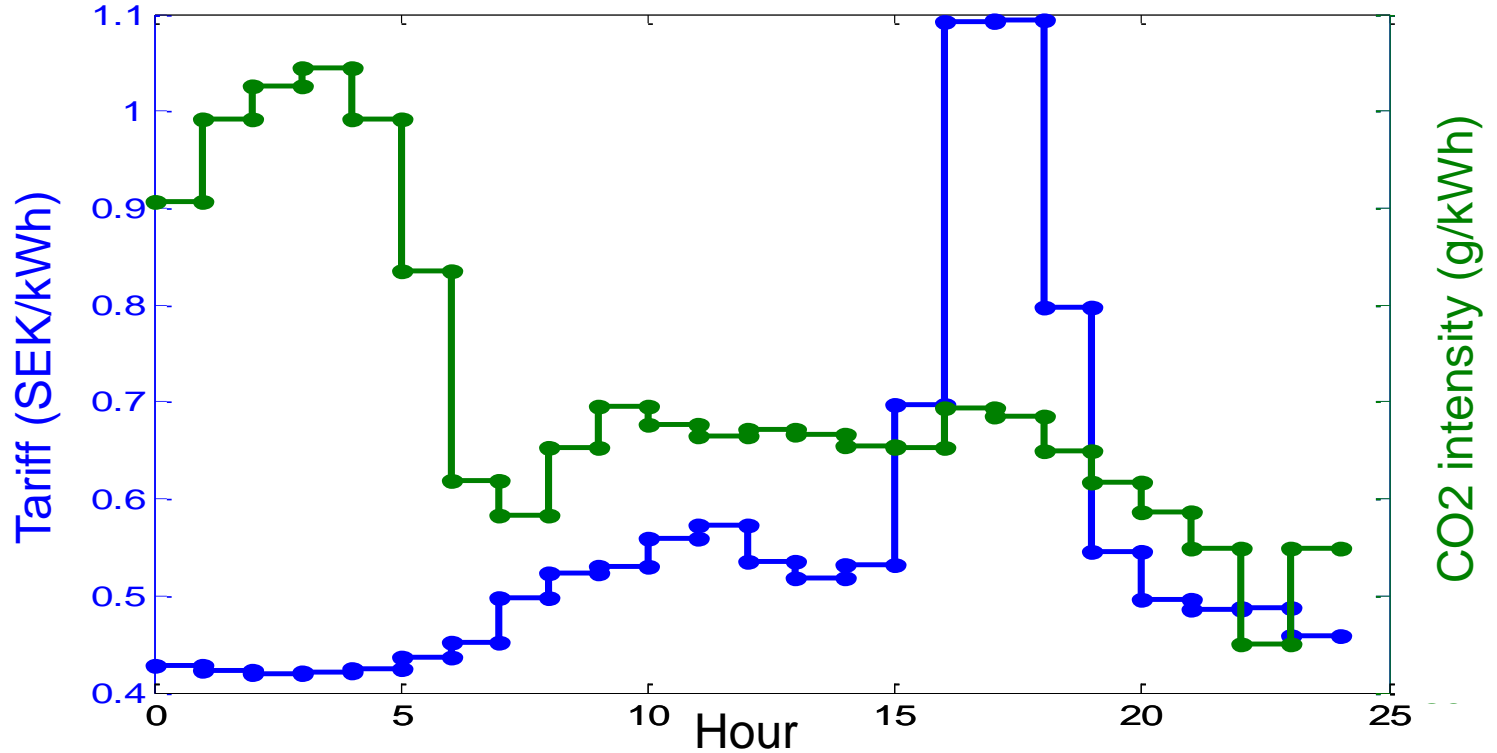
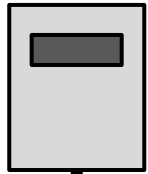
- ICT system connects the active house to power distribution company and energy market

- ***ICT system should give energy management support to reach the high set climate goals!***

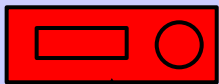


Smart Home Appliances Scheduling

basic home gateway



smart home gateway

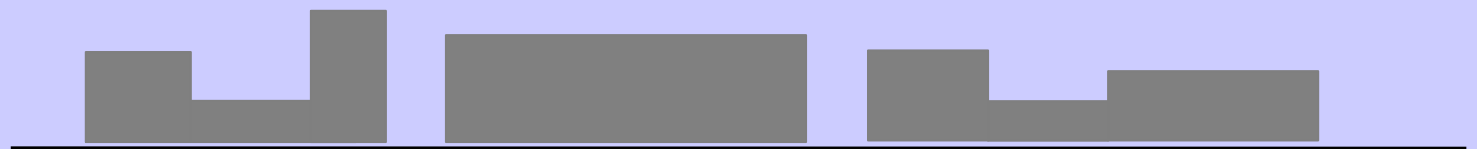


smart appliance

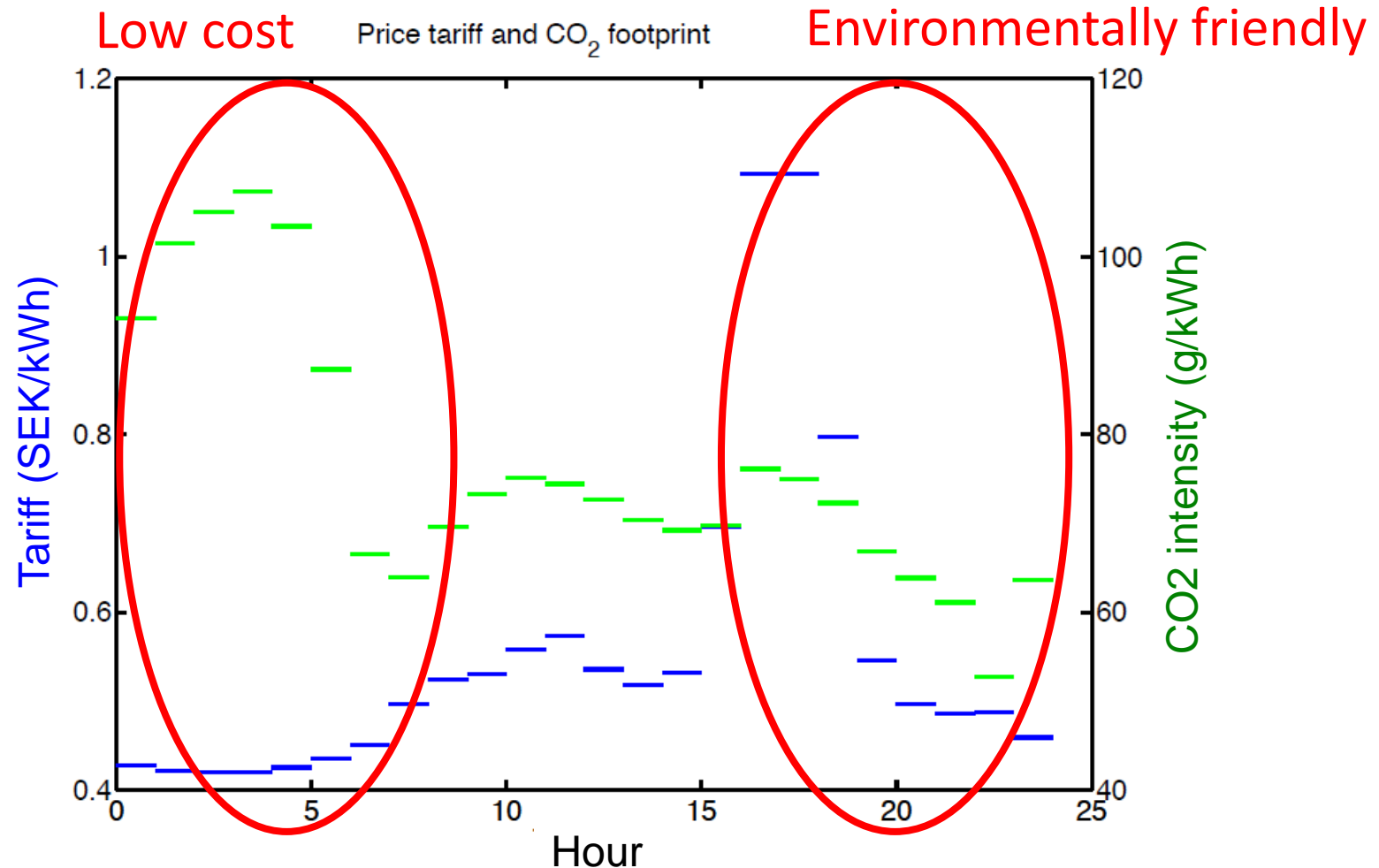


Optimal power profile scheduling for smart appliances

Decision: **when** to run? **How much power** to assign?



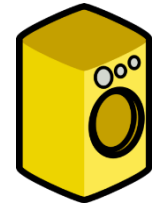
Budget and CO₂ Tradeoff on a Cold Day



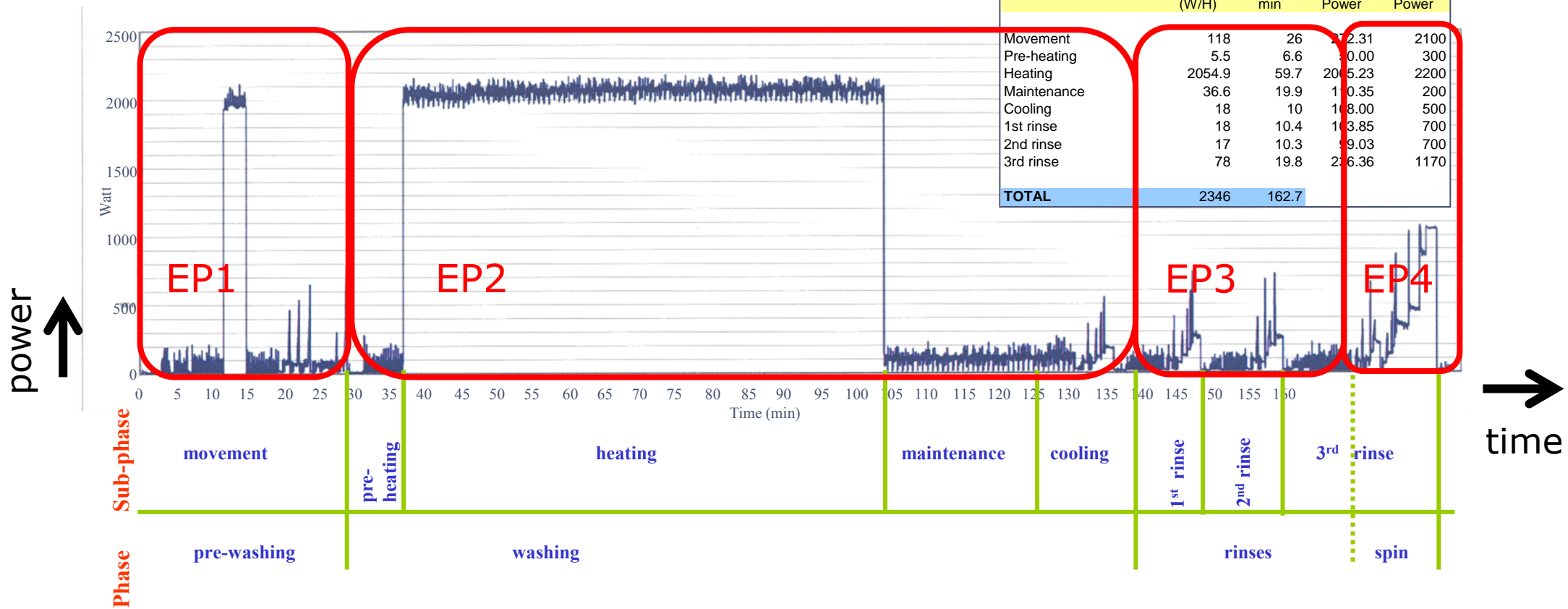
Automatic power profile scheduling, based on users' concern

(Data courtesy of Anna Kristinsdóttir, KTH Industrial Ecology)

Smart Appliance Power Profile

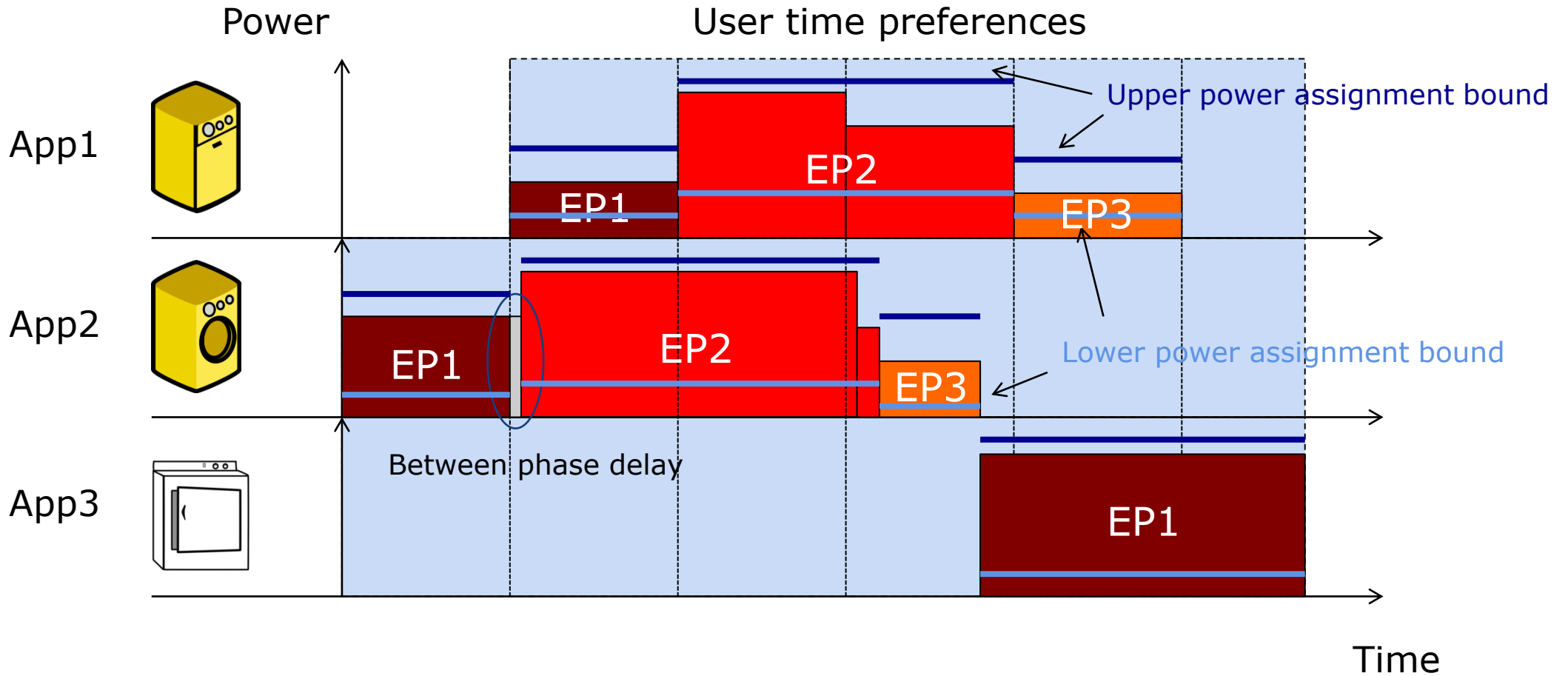


Power assignment over time



(Data courtesy of Electrolux)

Scheduling Problem



Profile Scheduling Problem

Determine optimal power profile to

minimize electricity bill and/or **CO₂ emission**

subject to **constraints** such as

dryer cannot be started before washing machine is done

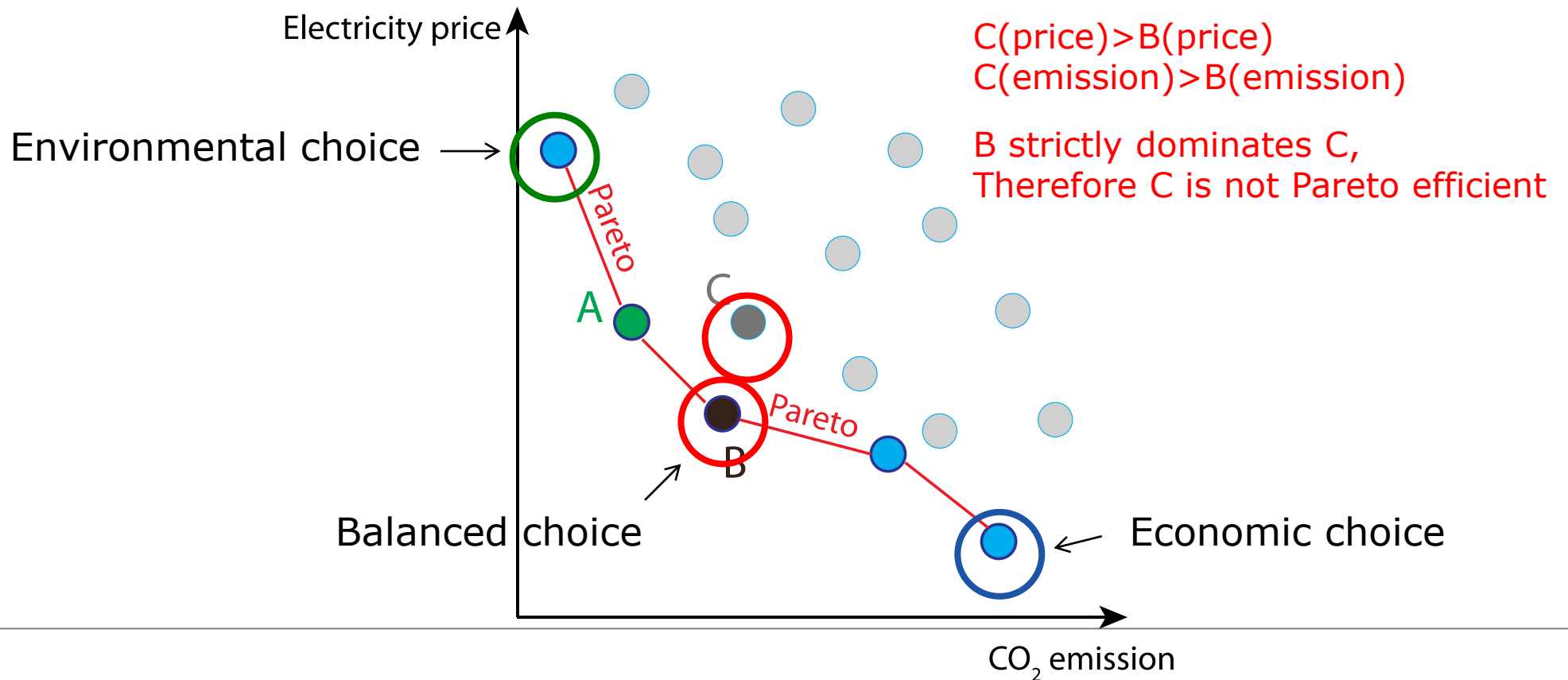
laundry should be ready by 17:00

power utility requests load shedding to reduce energy peaks

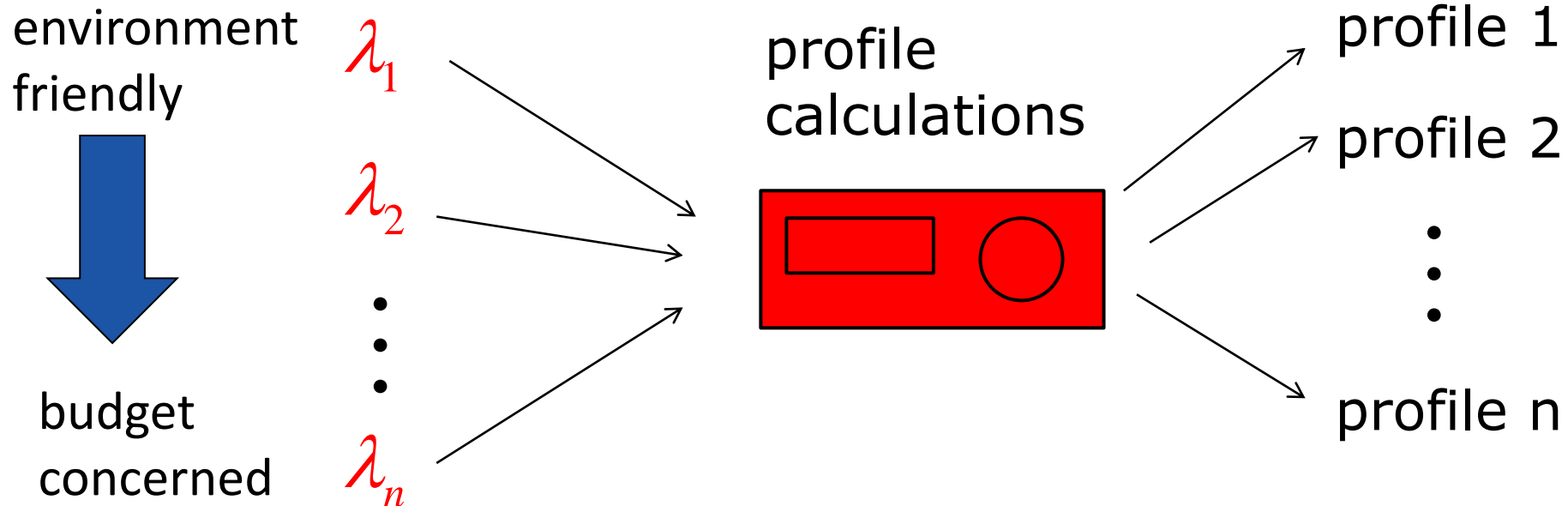
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Trade-off Analysis between the Electricity Price and the CO₂ Emission

- The trade-off is studied through a Pareto frontier exploration



Automatic Decision Support



Compute **many** profiles, let user choose **one**

Time Slot Based Formulation

- The number of decision variables depends on the time slot length

Timing constraints

Minimize

$$\sum_{k=1}^m (c^k + \alpha d^k) \sum_{i=1}^N \sum_{j=1}^{n_i} p_{ij}^k$$

Subject to

$$\sum_{k=1}^m p_{ij}^k = E_{ij}, \quad \forall i, j$$

$$\underline{P}_{ij}^k x_{ij}^k \leq p_{ij}^k \leq \overline{P}_{ij}^k x_{ij}^k, \quad \forall i, j, k$$

$$\sum_{i=1}^N \sum_{j=1}^{n_i} p_{ij}^k \leq \text{PEAK}^k, \quad \forall k$$

$$\underline{T}_{ij} \leq \sum_{k=1}^m x_{ij}^k \leq \overline{T}_{ij}, \quad \forall i, j$$

$$x_{ij}^k \leq 1 - s_{ij}^k \quad \forall i, j, k$$

$$x_{ij}^{k-1} - x_{ij}^k \leq s_{ij}^k \quad \forall i, j, \forall k = 2, 3, \dots, m$$

$$s_{ij}^{k-1} \leq s_{ij}^k \quad \forall i, j, \forall k = 2, 3, \dots, m$$

$$x_{ij}^k \leq s_{i(j-1)}^k, \quad \forall i, k, \forall j = 2, 3, \dots, n_i$$

$$x_{i1}^k \leq s_{in_i}^k, \quad \forall k$$

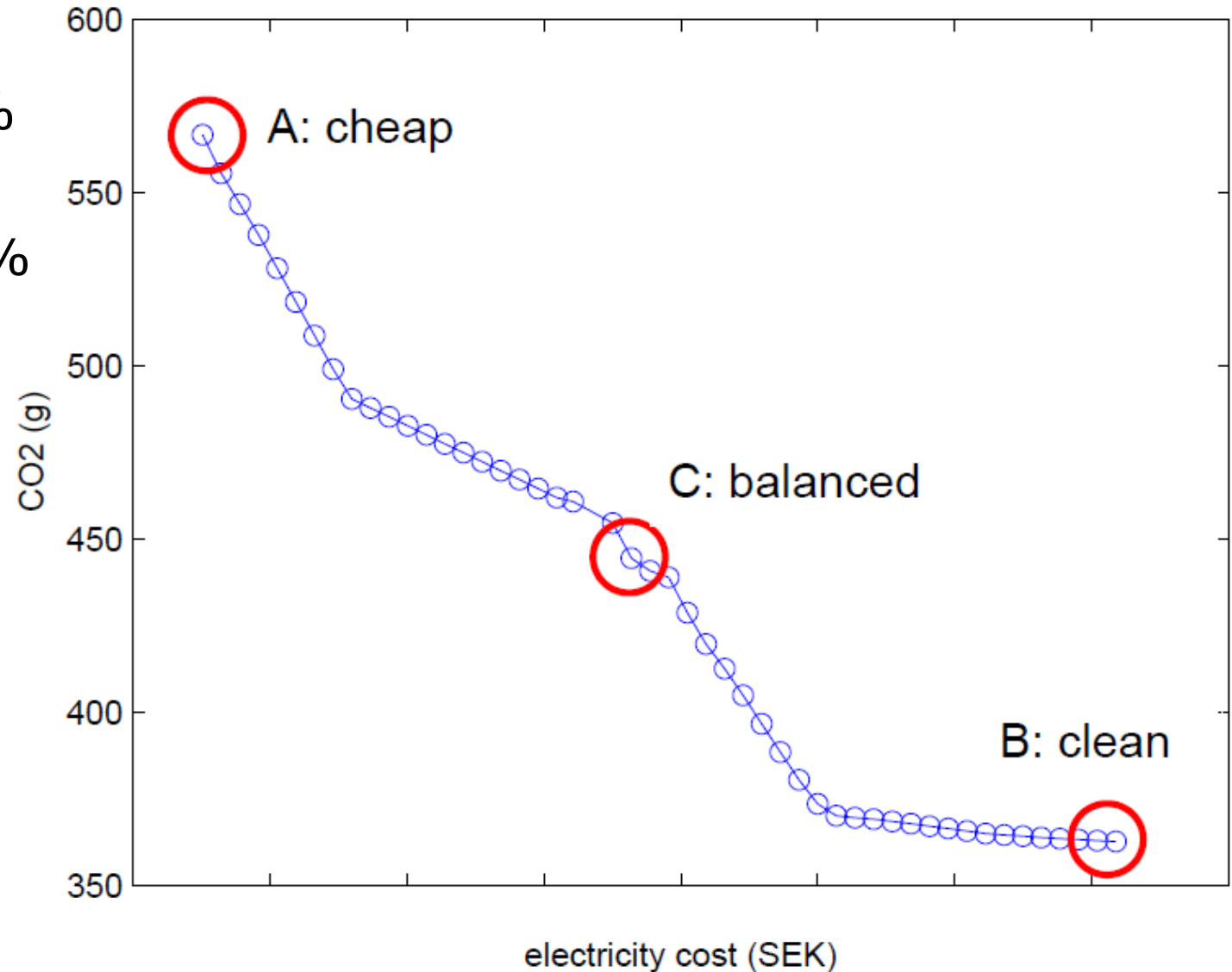
$$\underline{D}_{ij} \leq \sum_{k=1}^m t_{ij}^k \leq \overline{D}_{ij}, \quad \forall j = 2, 3, \dots, n_i$$

$$t_{ij}^k = s_{i(j-1)}^k - (x_{ij}^k + s_{ij}^k), \quad \forall j = 2, 3, \dots, n_i$$

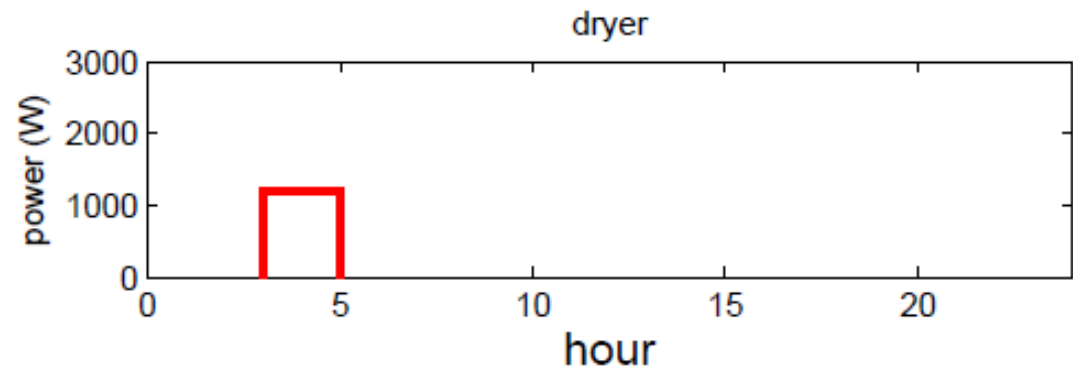
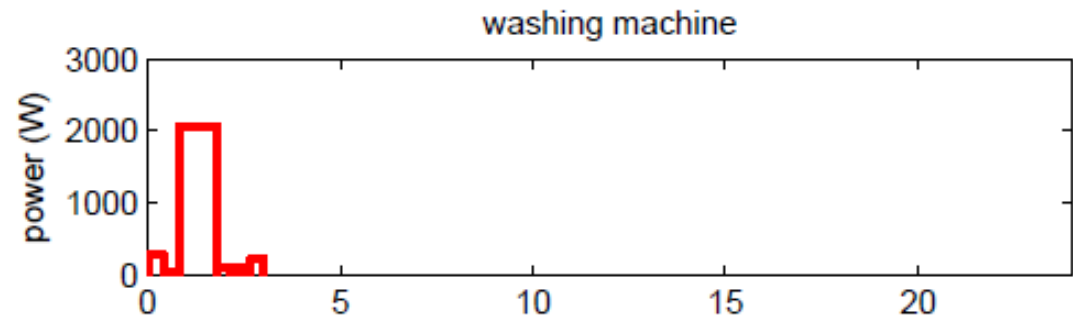
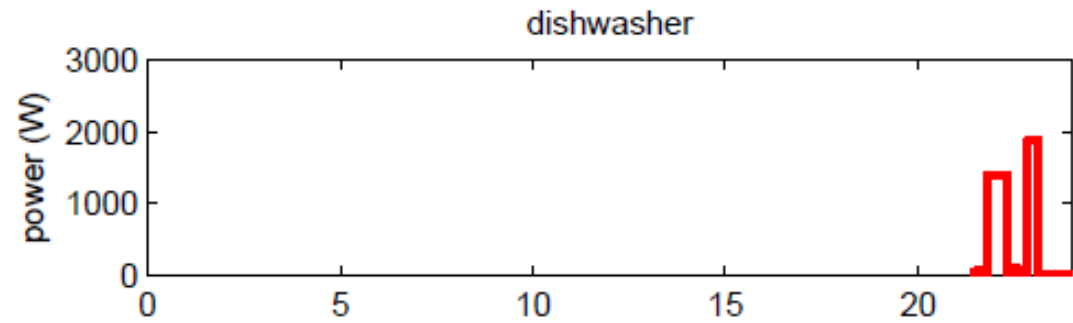
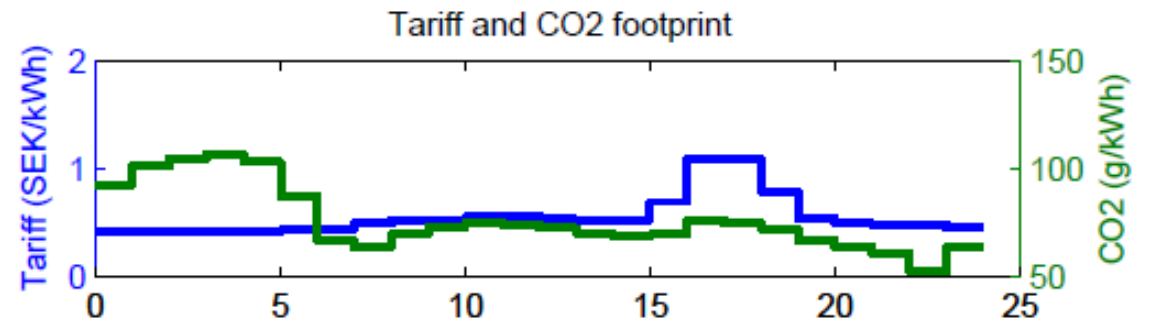
$$x_{ij}^k \leq \text{TP}_i^k, \quad \forall i, j, k$$

Pareto Frontier, Sweden 2010-01-05

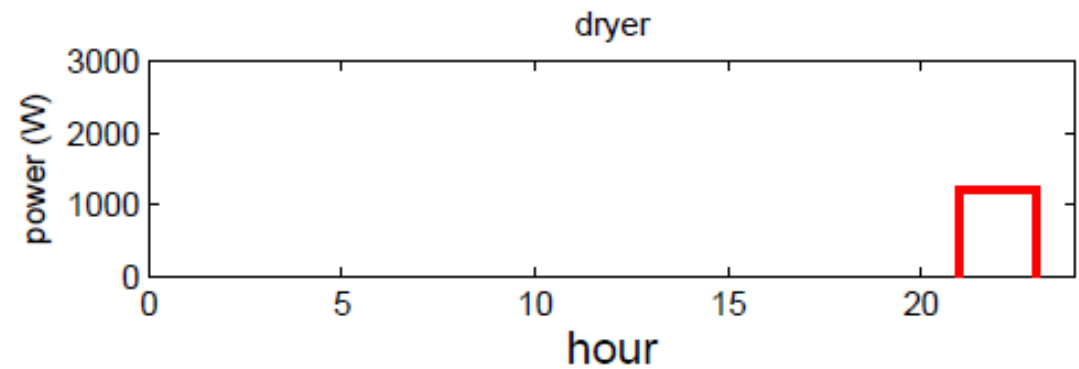
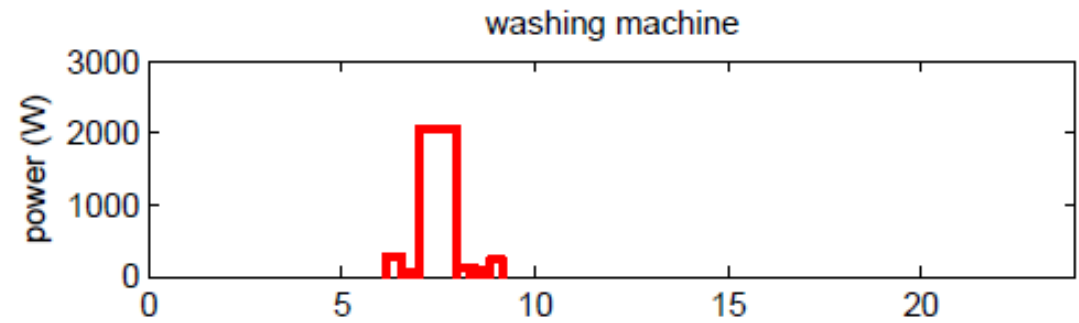
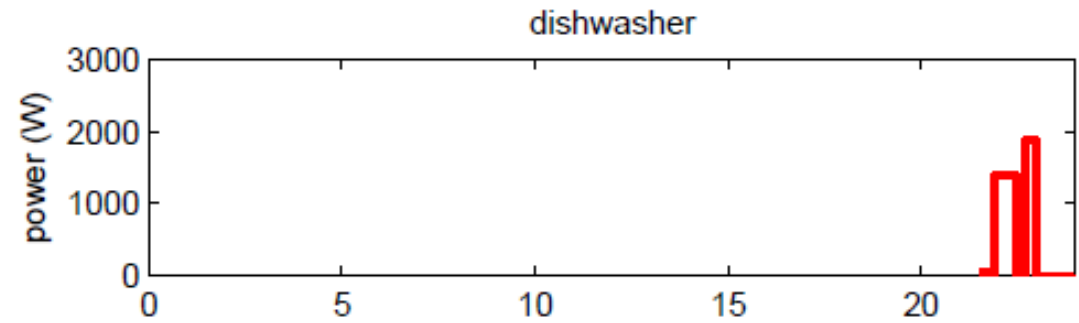
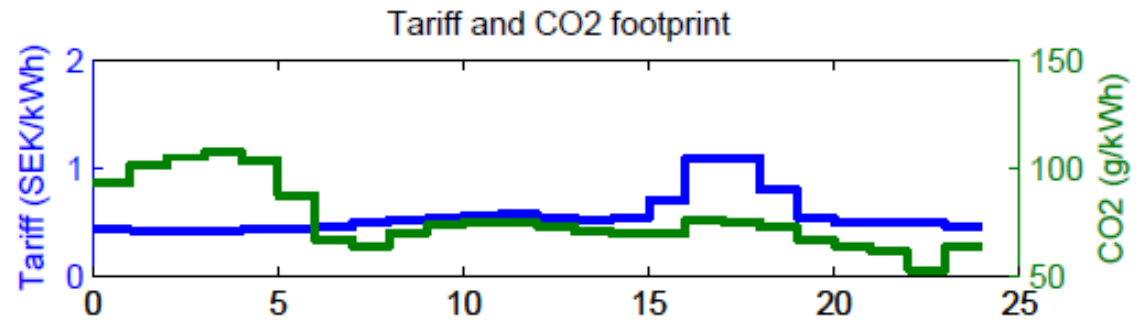
- CO₂ variation: ~57%
- Cost variation: ~12%
- A cold day with unusually large tariff variation
- 10,000 households; what about scalability?



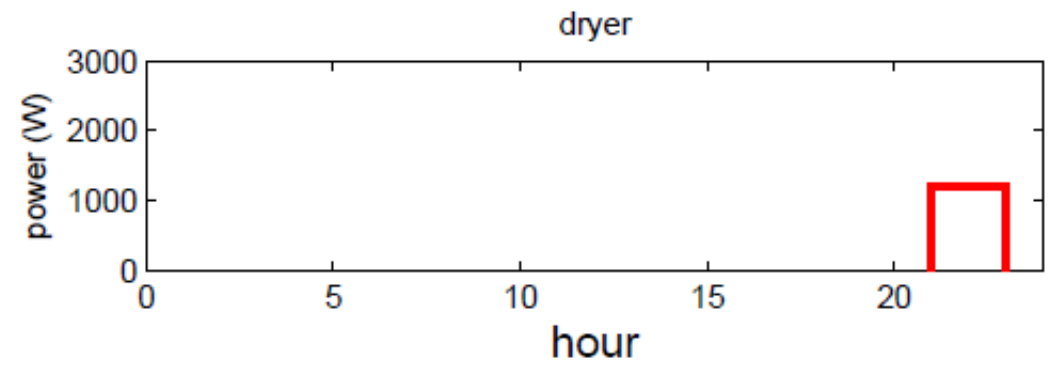
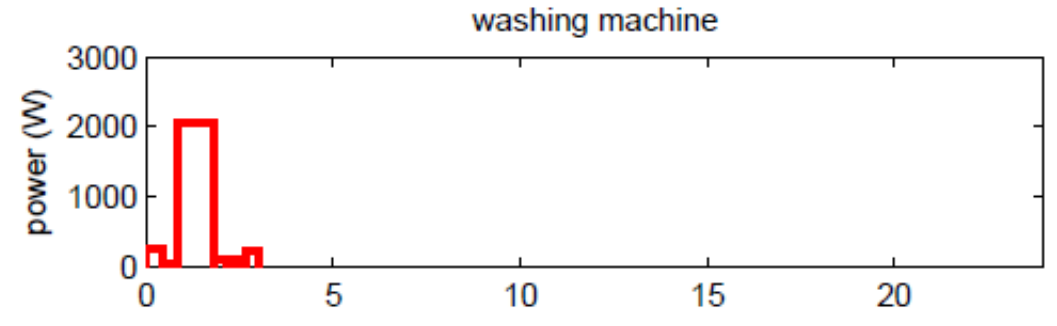
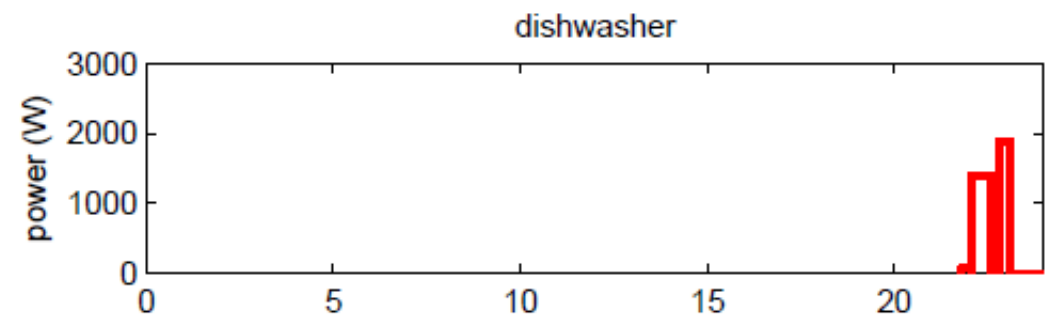
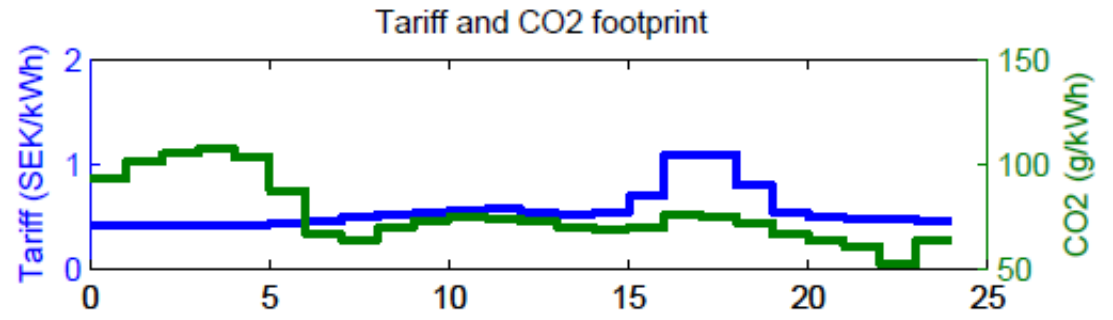
(A): Cheap



(B): Clean



(C): Balanced

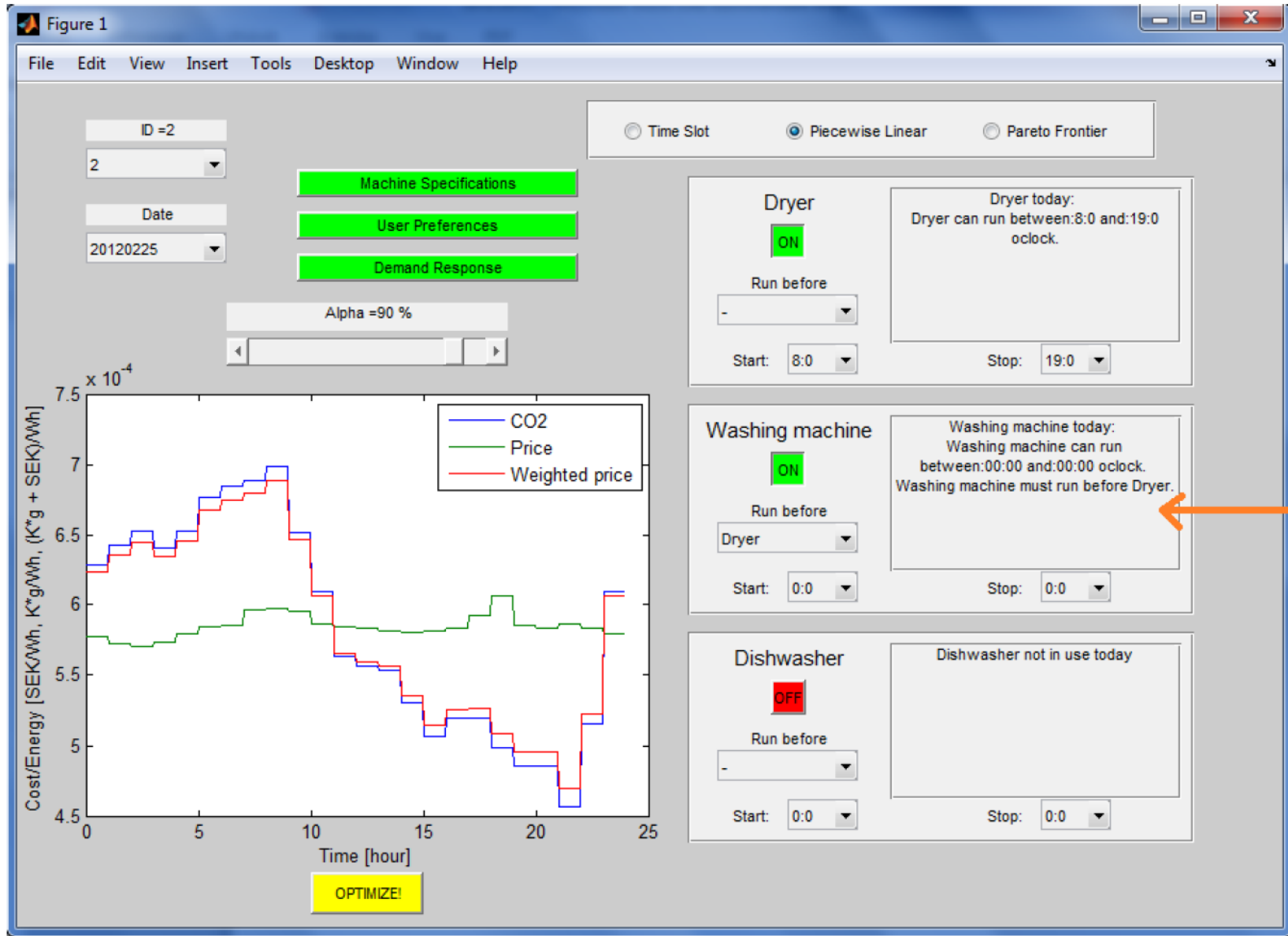


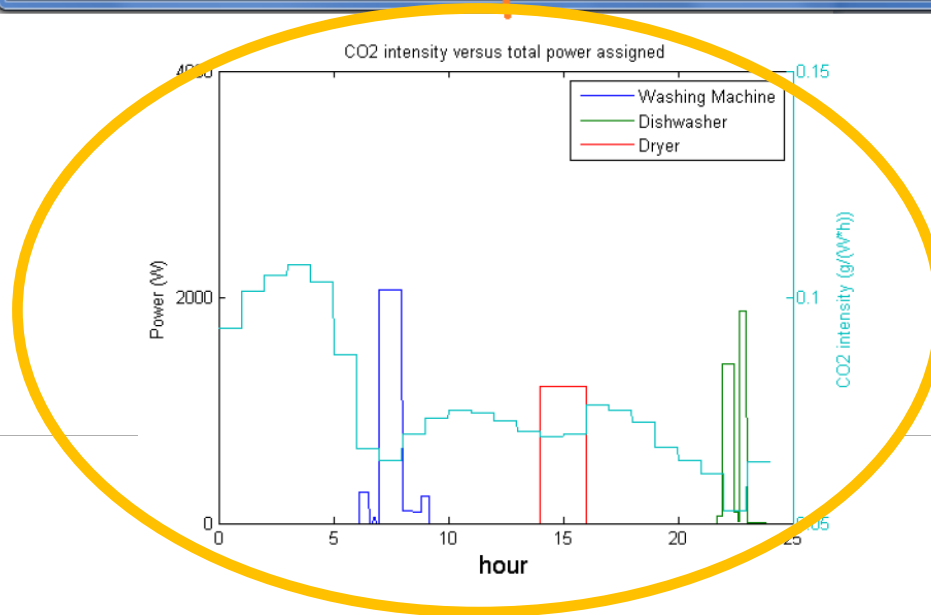
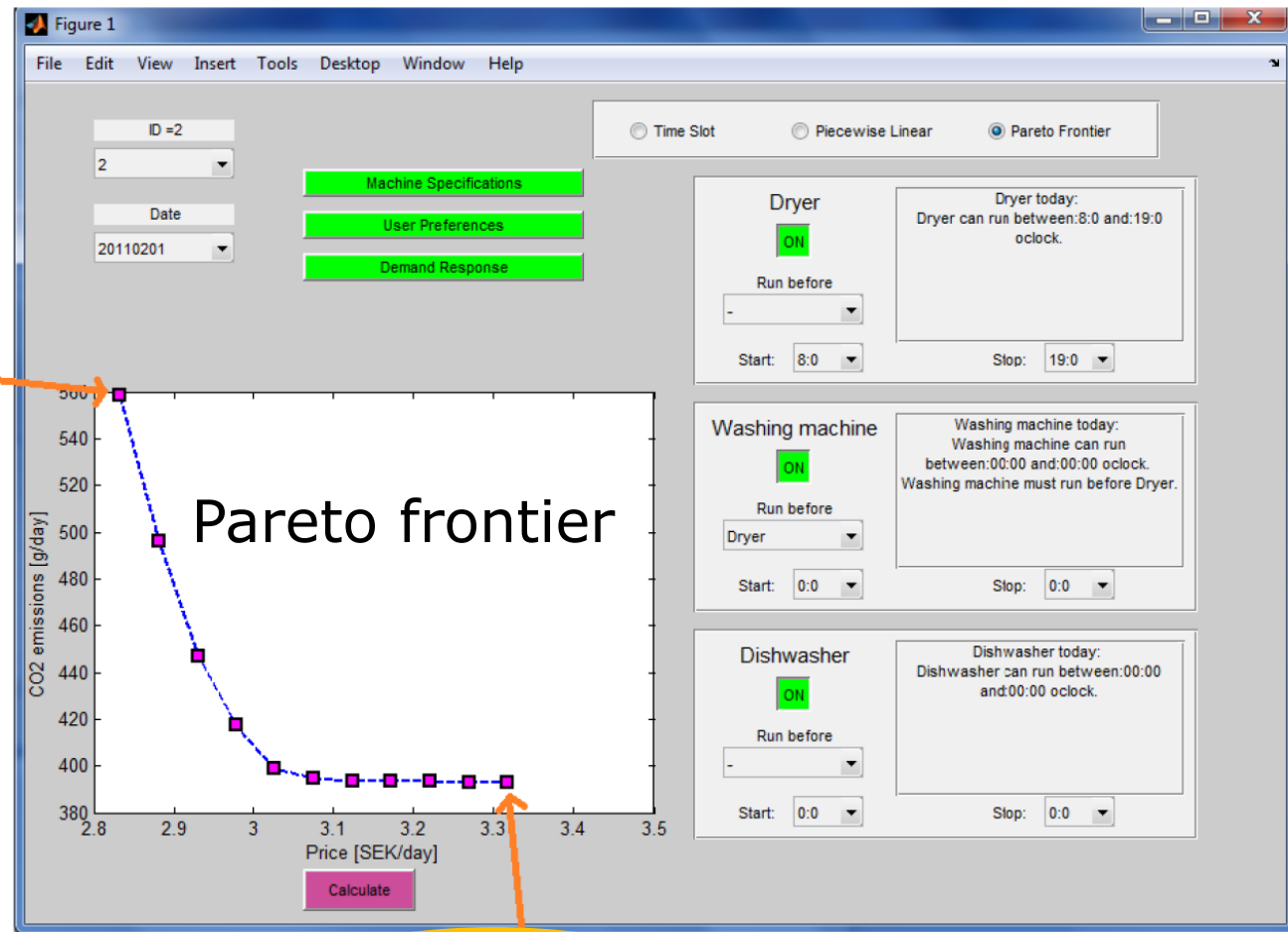
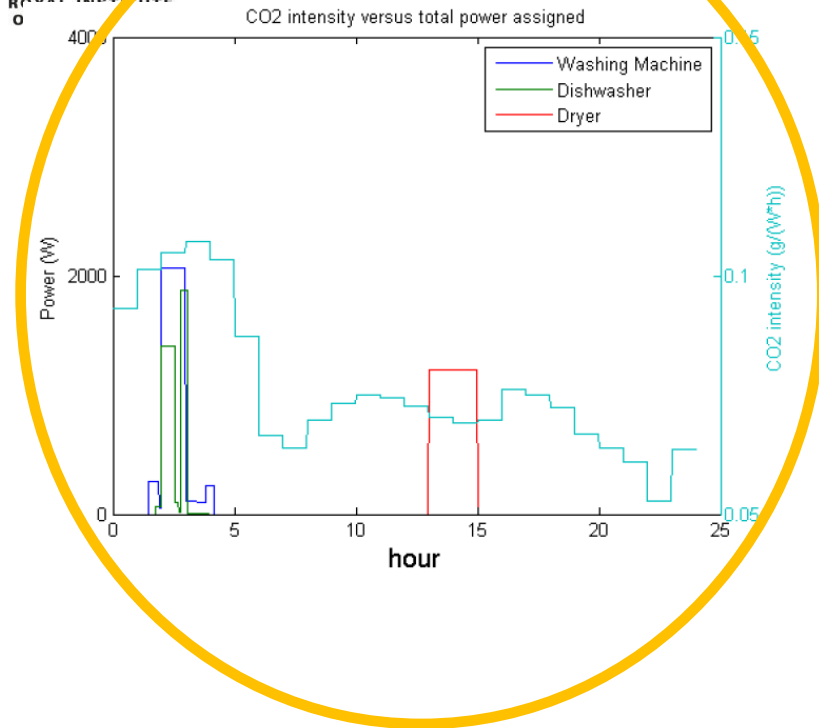
Virtual Smart Grid Lab



- A Virtual Laboratory for Micro-Grid Information and Communication Infrastructures is established by EIT ICT Lab/Smart Energy Systems
- Publication October 2012: 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe) Article Title: A Virtual Laboratory for Micro-Grid Information and Communication Infrastructures
- A Java-based energy and CO₂ scheduling tool has been implemented

User Interface for Scheduling





Conclusion

- ICT, control, and optimization all necessary to achieve the high set climate goals in the Stockholm Royal Seaport and in smart cities in general
- Need for automatic decision support and user friendly interfaces to operate on the optimal trade-off (Pareto) curve between CO₂ emission and energy cost
- Virtual Smart Grid Lab with EIT ICT Lab/Smart Energy Systems and Ericsson

Thank you for your attention!

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