Energy and CO_2 efficient scheduling of smart home appliances in the Stockholm Royal Seaport

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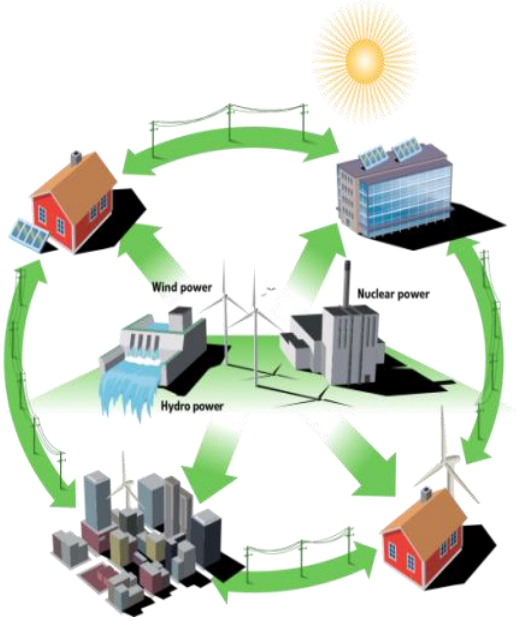
Outline



- Stockholm Royal Seaport
- CO_2 vs. electricity tariff in Sweden
- Scheduling smart home appliances
- Virtual Smart Grid Lab

Stockholm Royal Seaport - Now

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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 - Future

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2010

- Oil depot
- Container terminal
- Ports
- Gas plant

2030

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- 600,000 m2 commercial space
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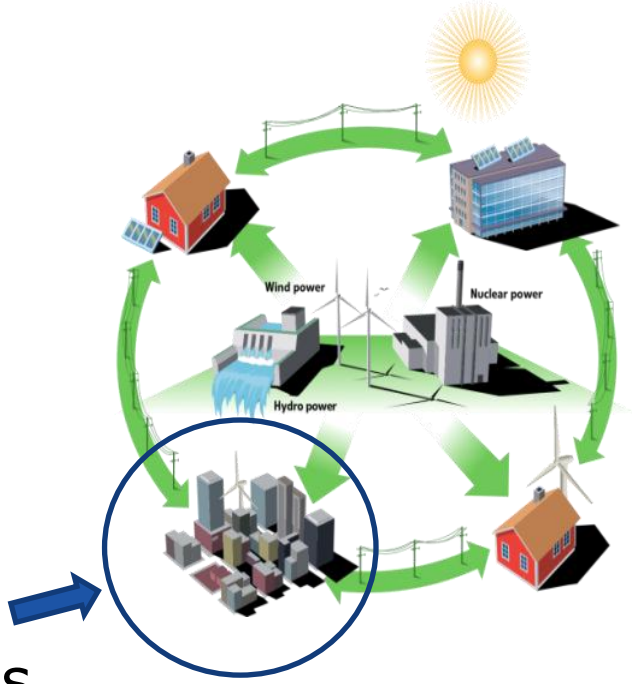
From a brown field area to a sustainable city district

Stockholm Royal Seaport in Brief



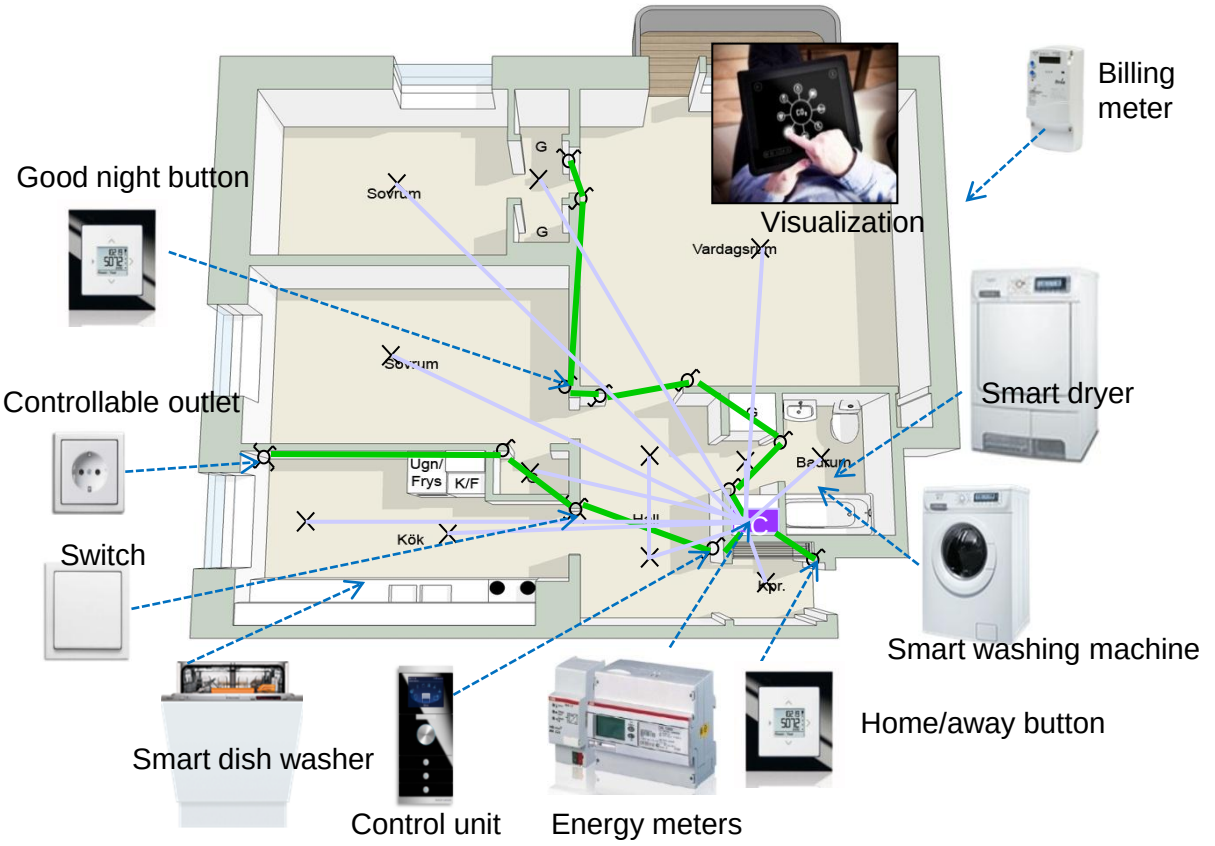
- Part of the Clinton Climate Initiative
- Cities responsible for 2/3 of CO_2 emissions
- Demands local energy generation, energy efficiency, robust power supply, market models, regulations,…
- **Goal:** CO_2 emissions below **1.5** tons per person by 2020 (today **4.5**); fossil fuel-free by 2030

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

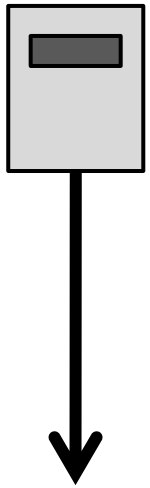


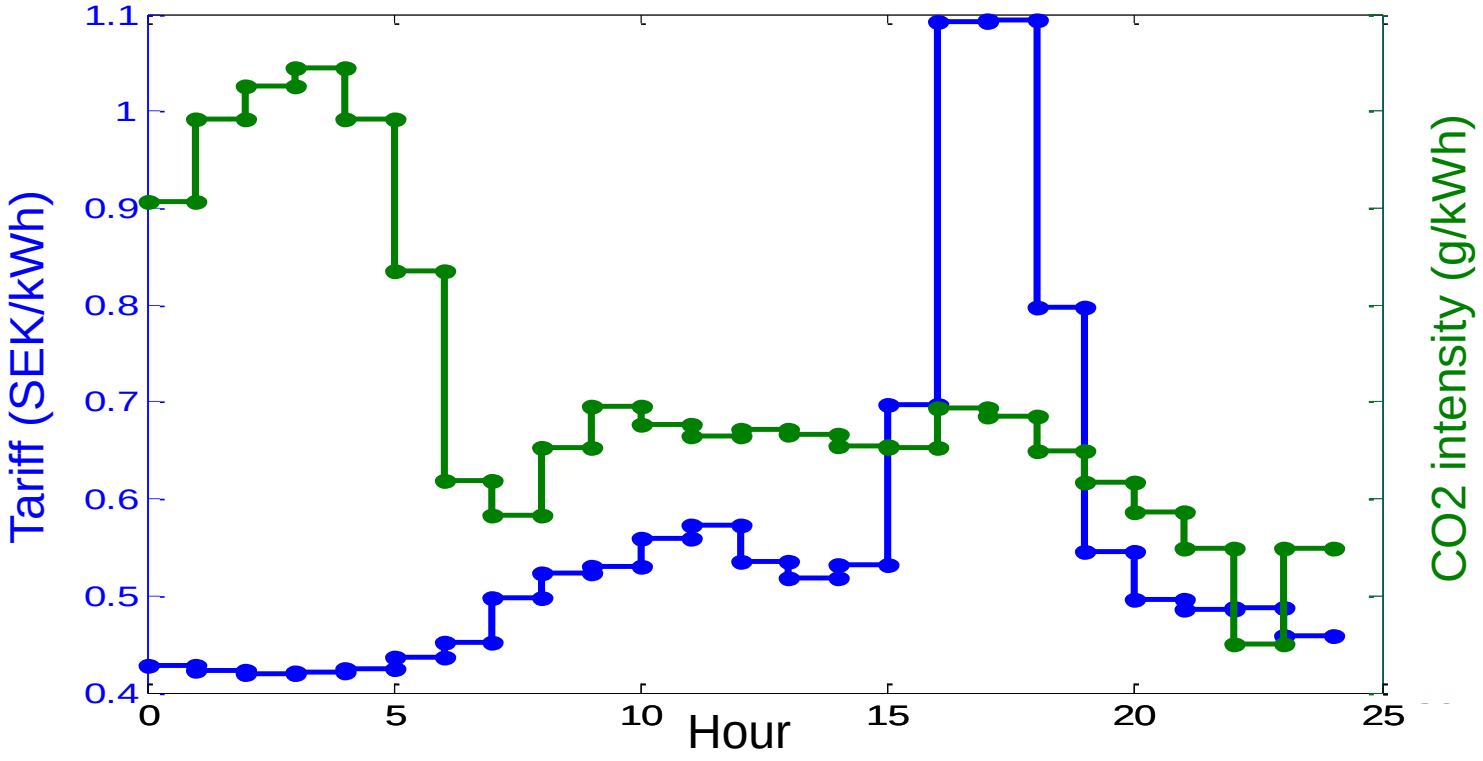
- ***ICT system should***

give energy management support to reach the high set climate goals!

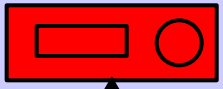
Smart Home Appliances Scheduling

basic home gateway





smart home gateway

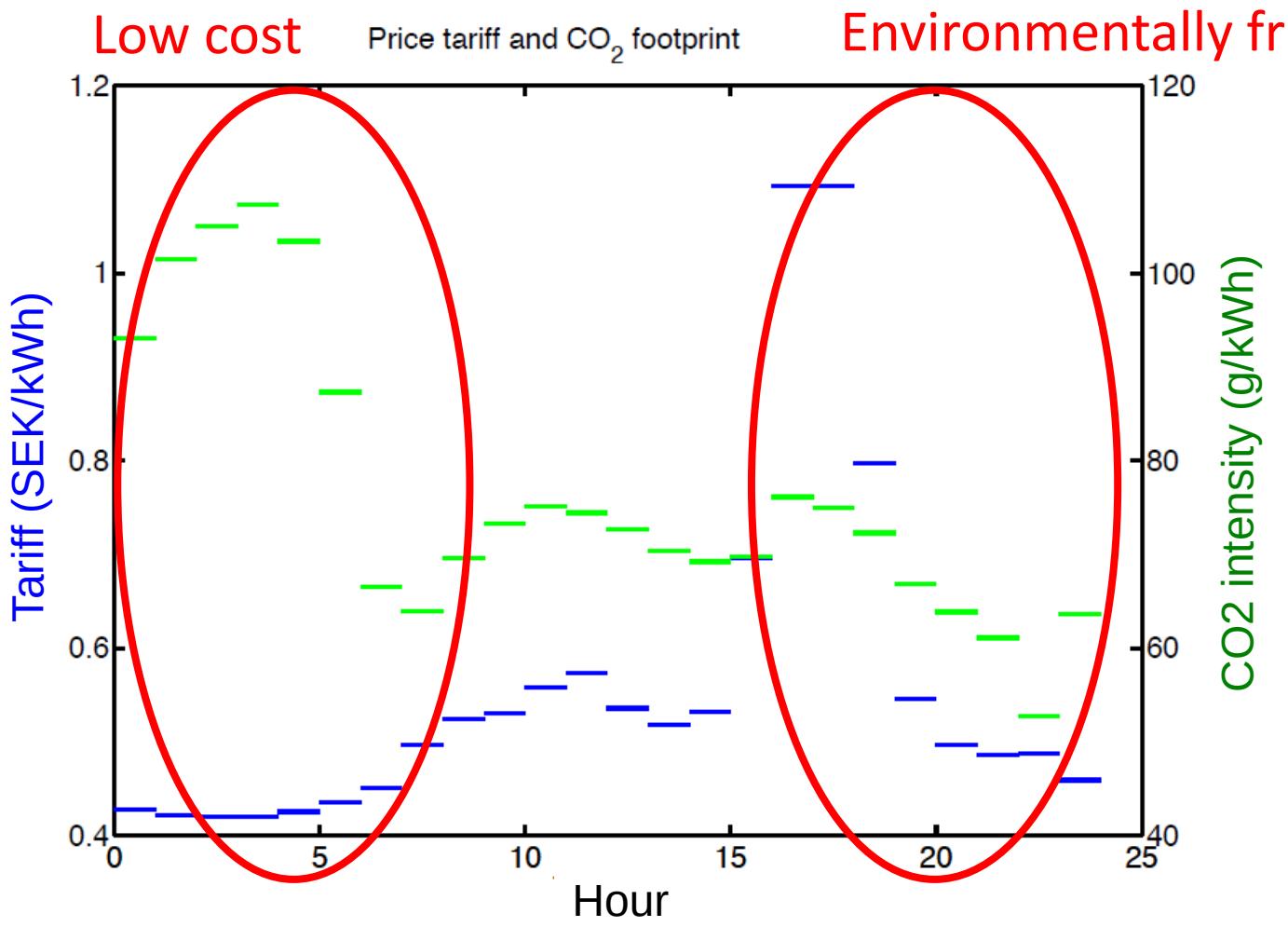


smart appliance

Optimal power profile scheduling for smart appliances

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

Budget and CO_2 Tradeoff on a Cold Day



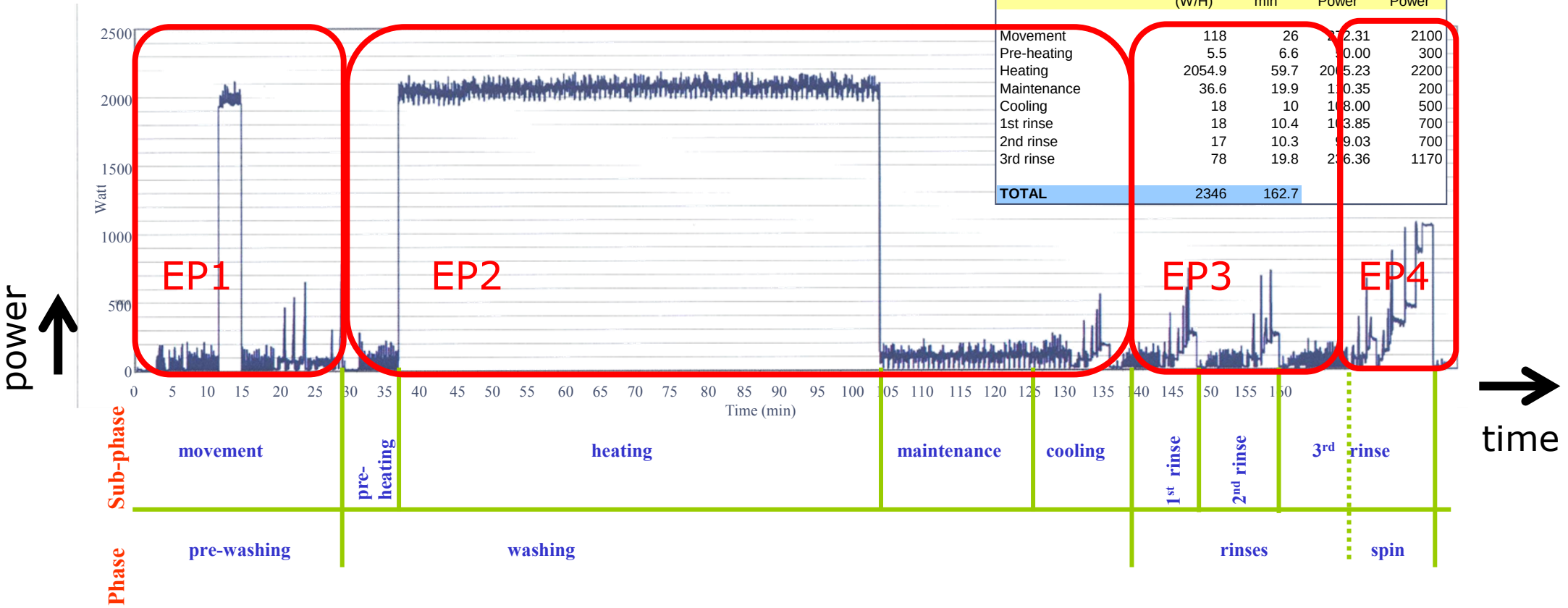
Automatic power profile scheduling, based on users' concern

(Data courtesy of Anna Kristinsdóttir, KTH Industrial Ecology)

Smart Appliance Power Profile

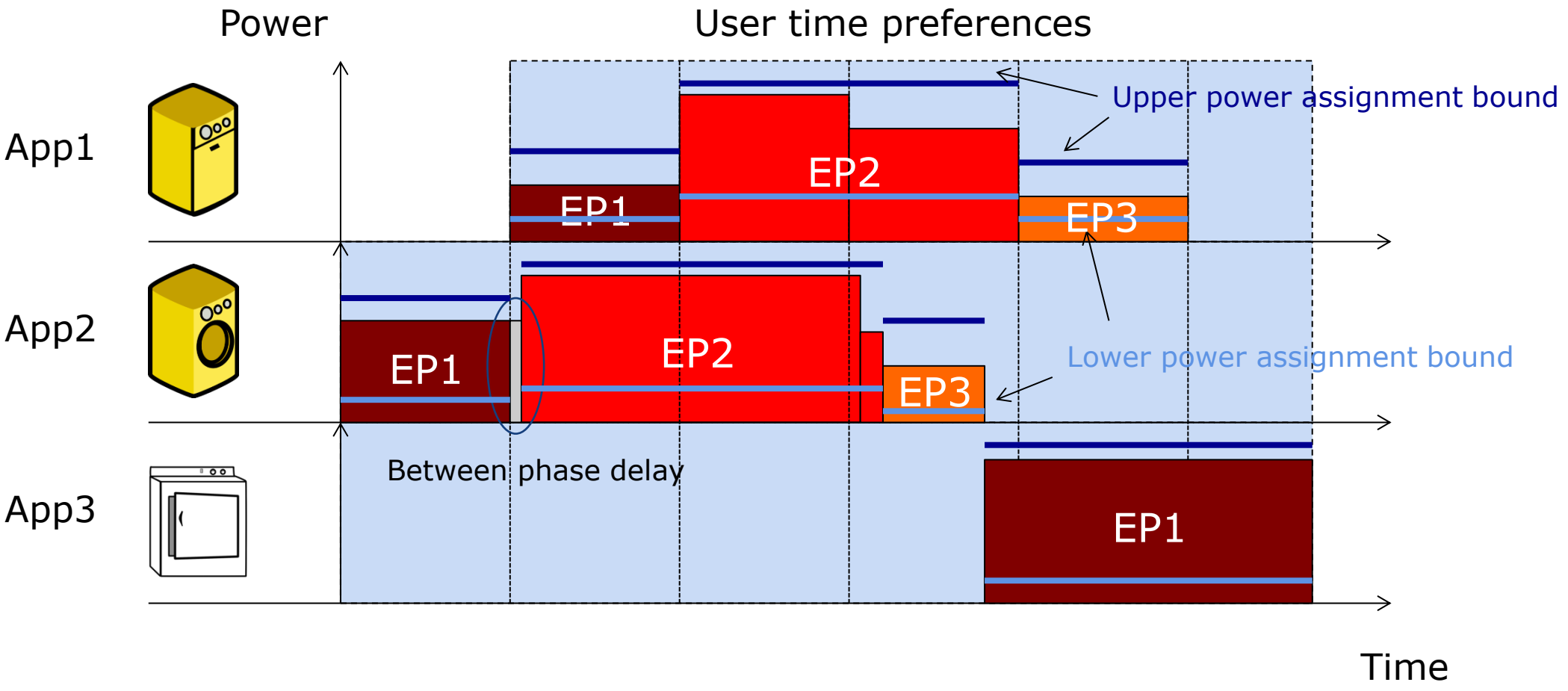
Power assignment over time

Cotton 90 PW	7 kg			
Sub Phase	Energy (W/H)	Time min	Mean Power	Peak Power
Movement	118	26	272.31	2100
Pre-heating	5.5	6.6	50.00	300
Heating	2054.9	59.7	2065.23	2200
Maintenance	36.6	19.9	170.35	200
Cooling	18	10	108.00	500
1st rinse	18	10.4	103.85	700
2nd rinse	17	10.3	99.03	700
3rd rinse	78	19.8	236.36	1170
TOTAL	2346	162.7		



(Data courtesy of Electrolux)

Scheduling Problem



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Profile Scheduling Problem

Determine optimal power profile to

minimize electricity bill and/or CO_2 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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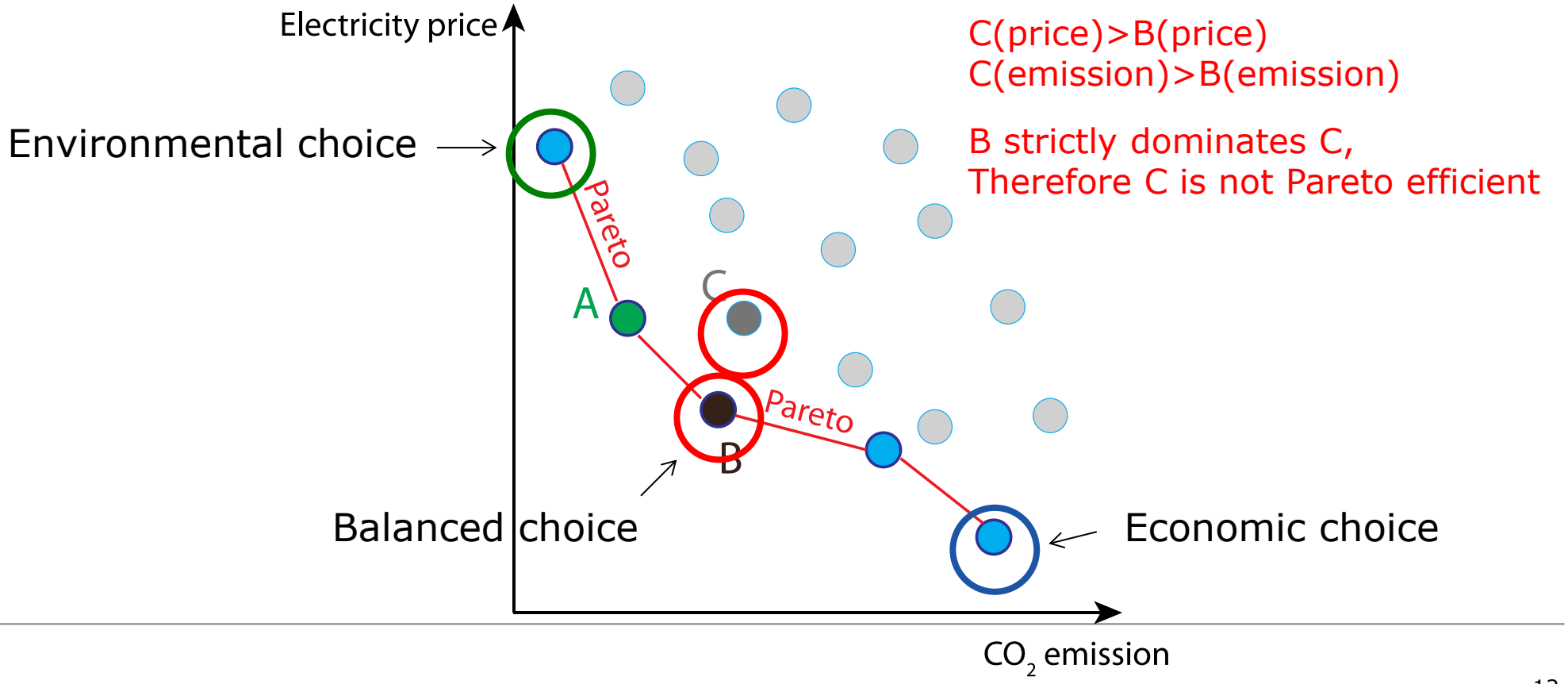
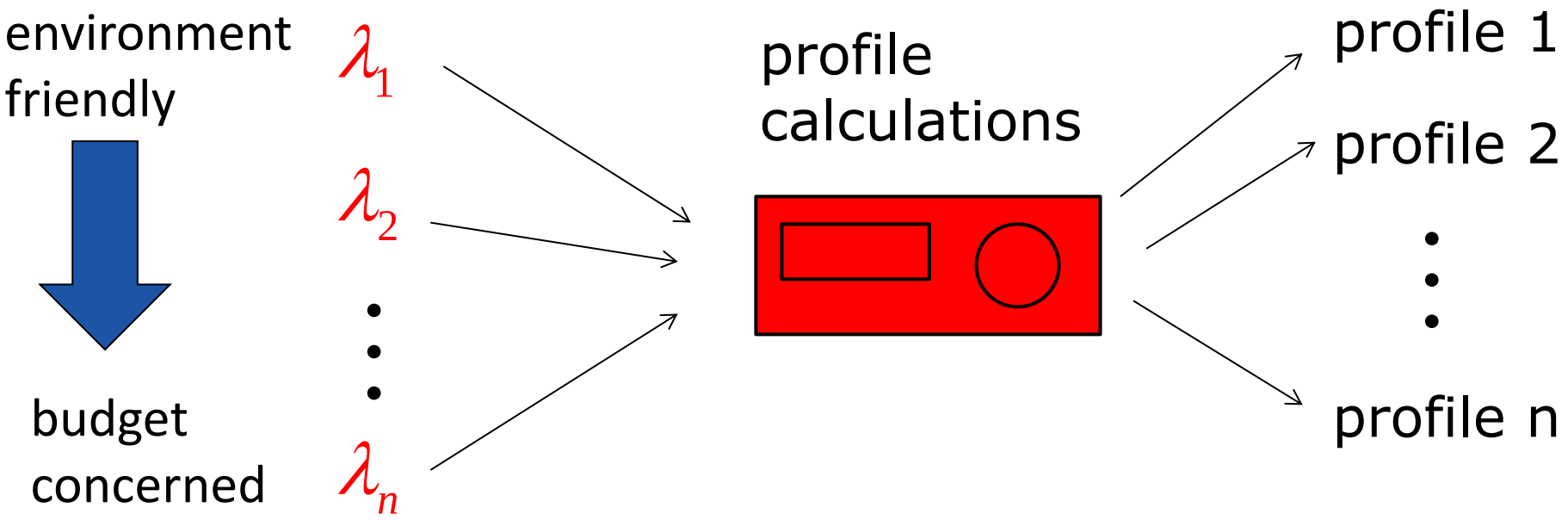
Trade-off Analysis between the Electricity Price and the CO2 Emission

- 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

Minimize

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

Subject to

Energy constraints

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

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

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

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

Timing constraints

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

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

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

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

$$x_{i1}^k\le s_{i\tilde{n}_i}^k,\quad\forall\,k$$

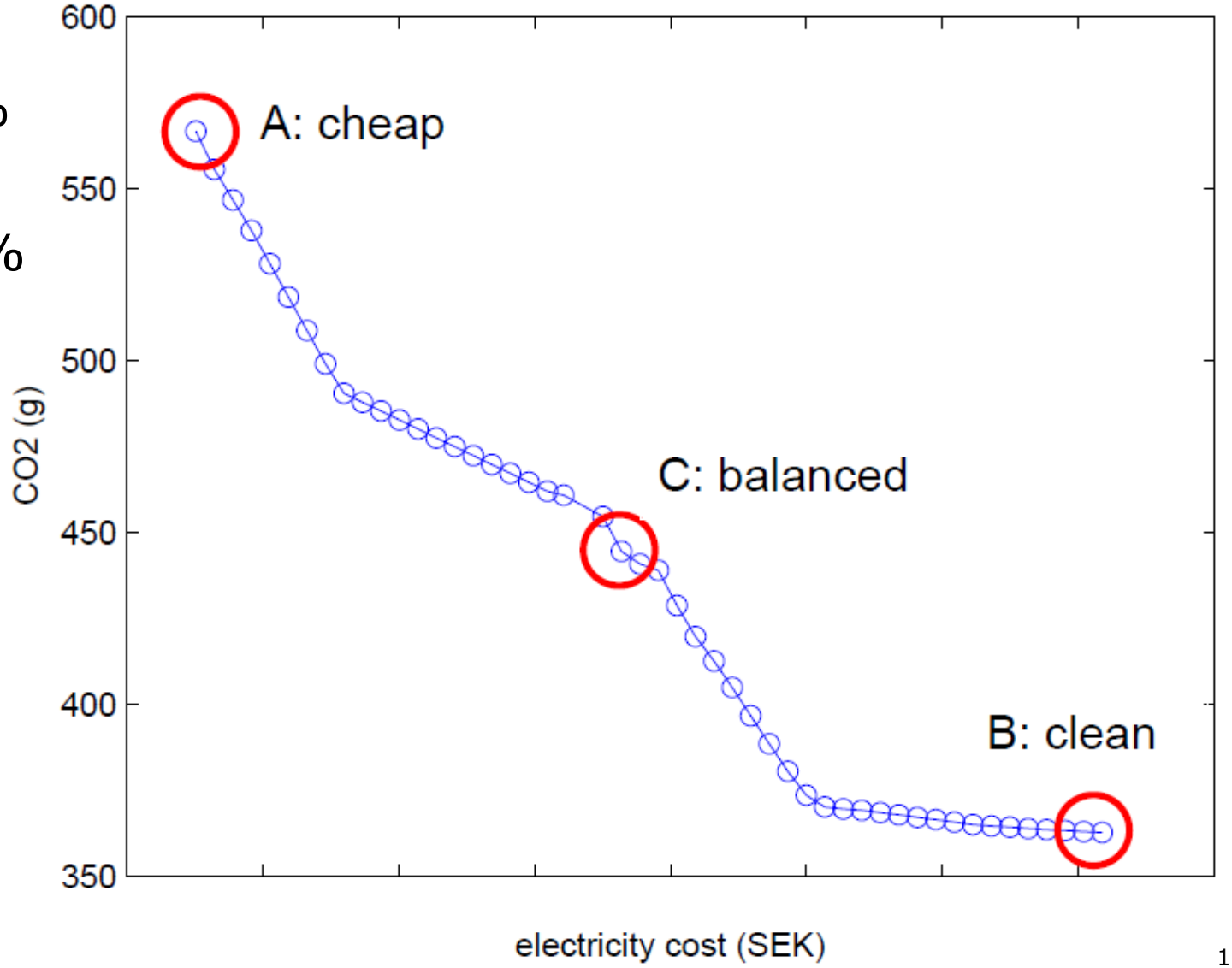
$$\underline{D}_{ij}\le\sum_{k=1}^{m}t_{ij}^k\le\overline{D}_{ij},\quad\forall\,j=2,3,\ldots,n_i$$

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

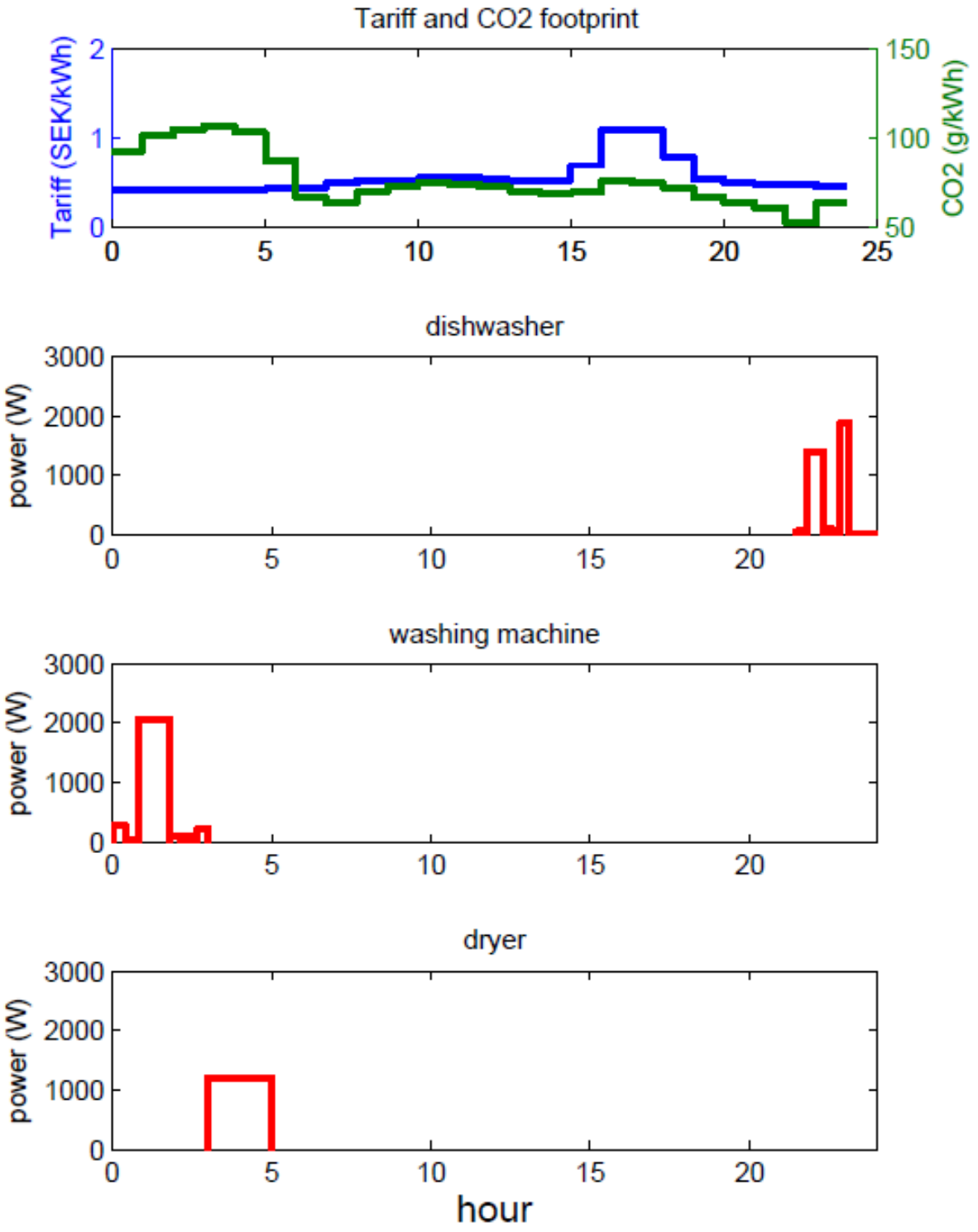
$$x_{ij}^k\le\mathrm{TP}_i^k,\quad\forall\,i,j,k$$

Pareto Frontier, Sweden 2010-01-05

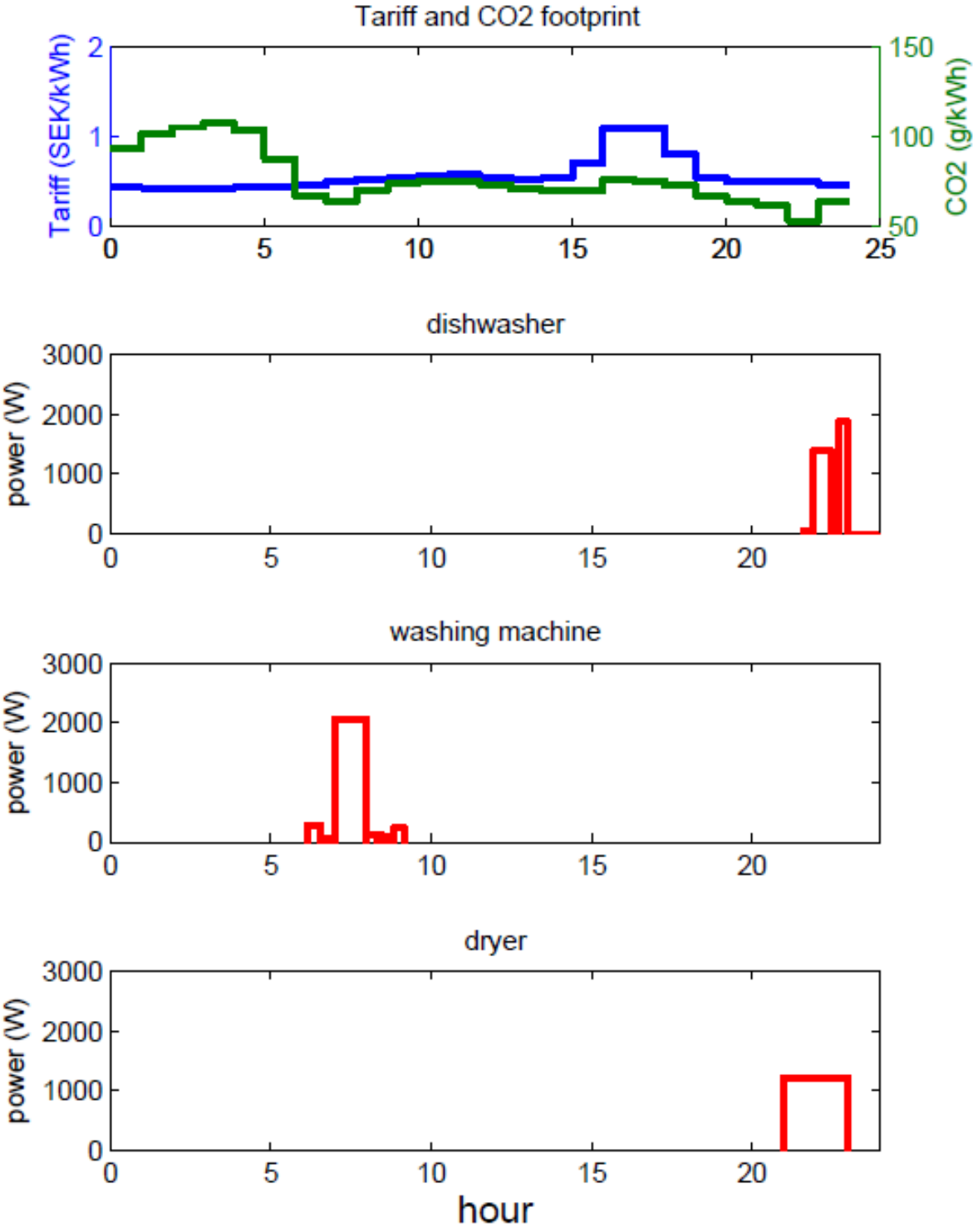
- CO_2 variation: ~57%
- Cost variation: ~12%
- A cold day with unusually large tariff variation
- 10,000 households; what about scalability?



(A): Cheap


Tariff and CO2 footprint
Tariff (SEK/kWh)
CO2 (g/kWh)
dishwasher
washing machine
dryer
power (W)
hour

(B): Clean


Tariff and CO2 footprint
Tariff (SEK/kWh)
CO2 (g/kWh)
dishwasher
washing machine
dryer
power (W)
hour

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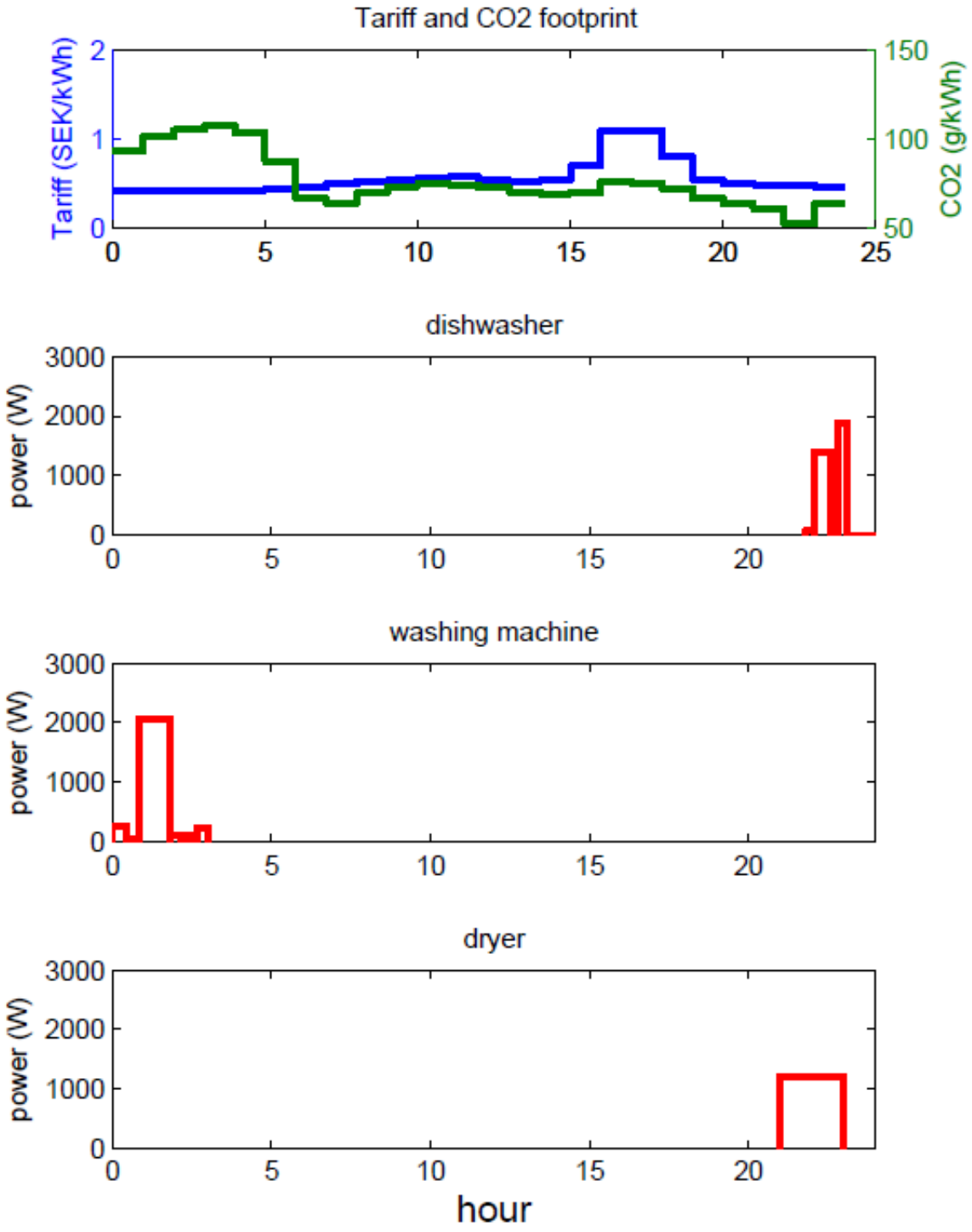
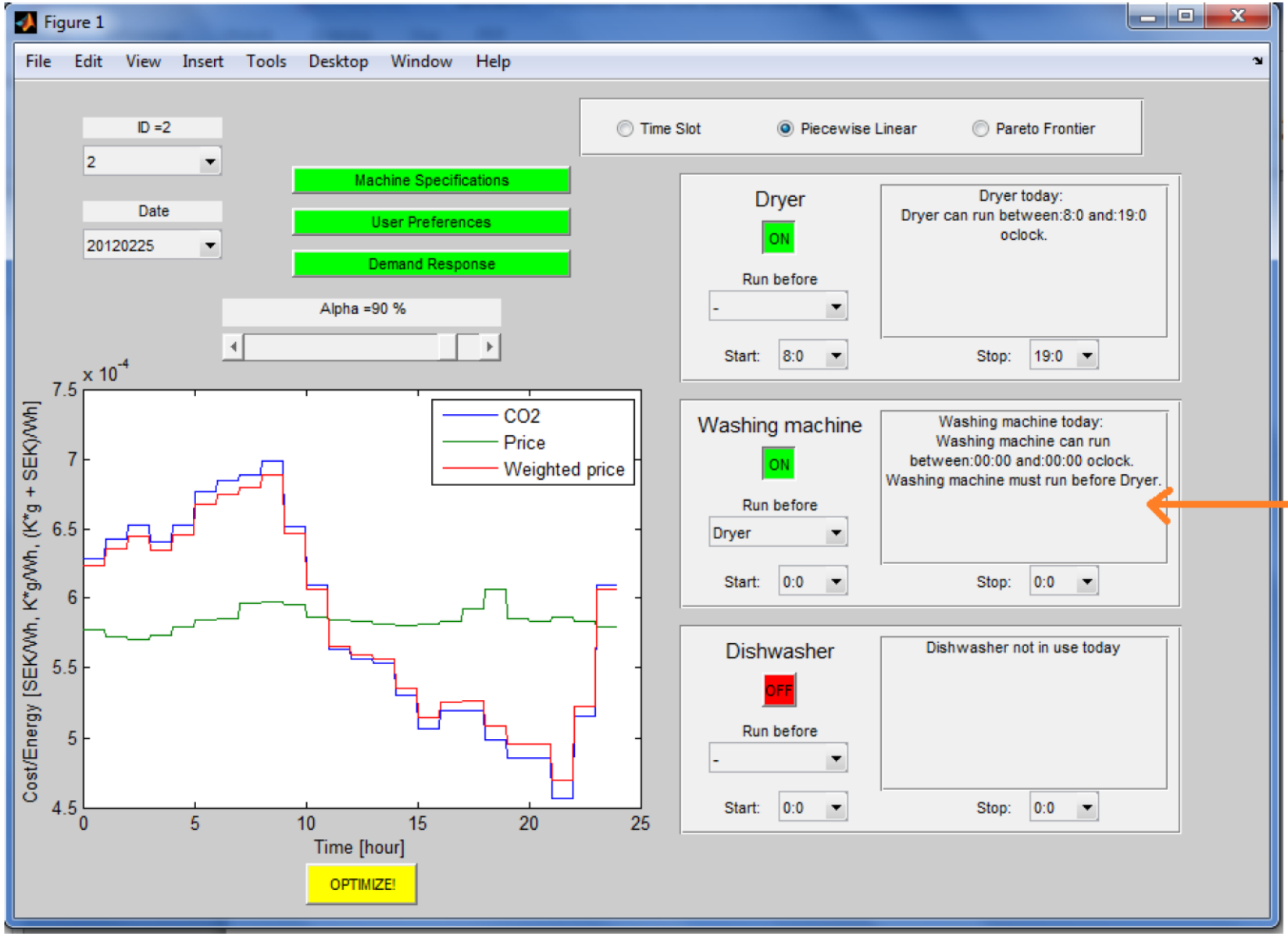
(C): Balanced

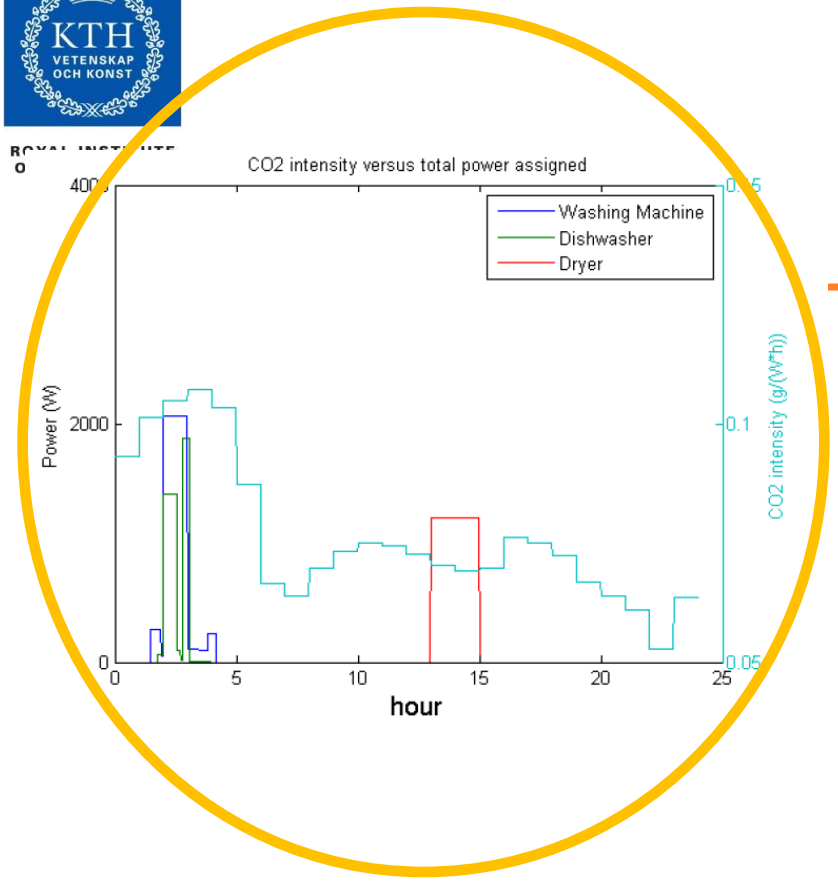


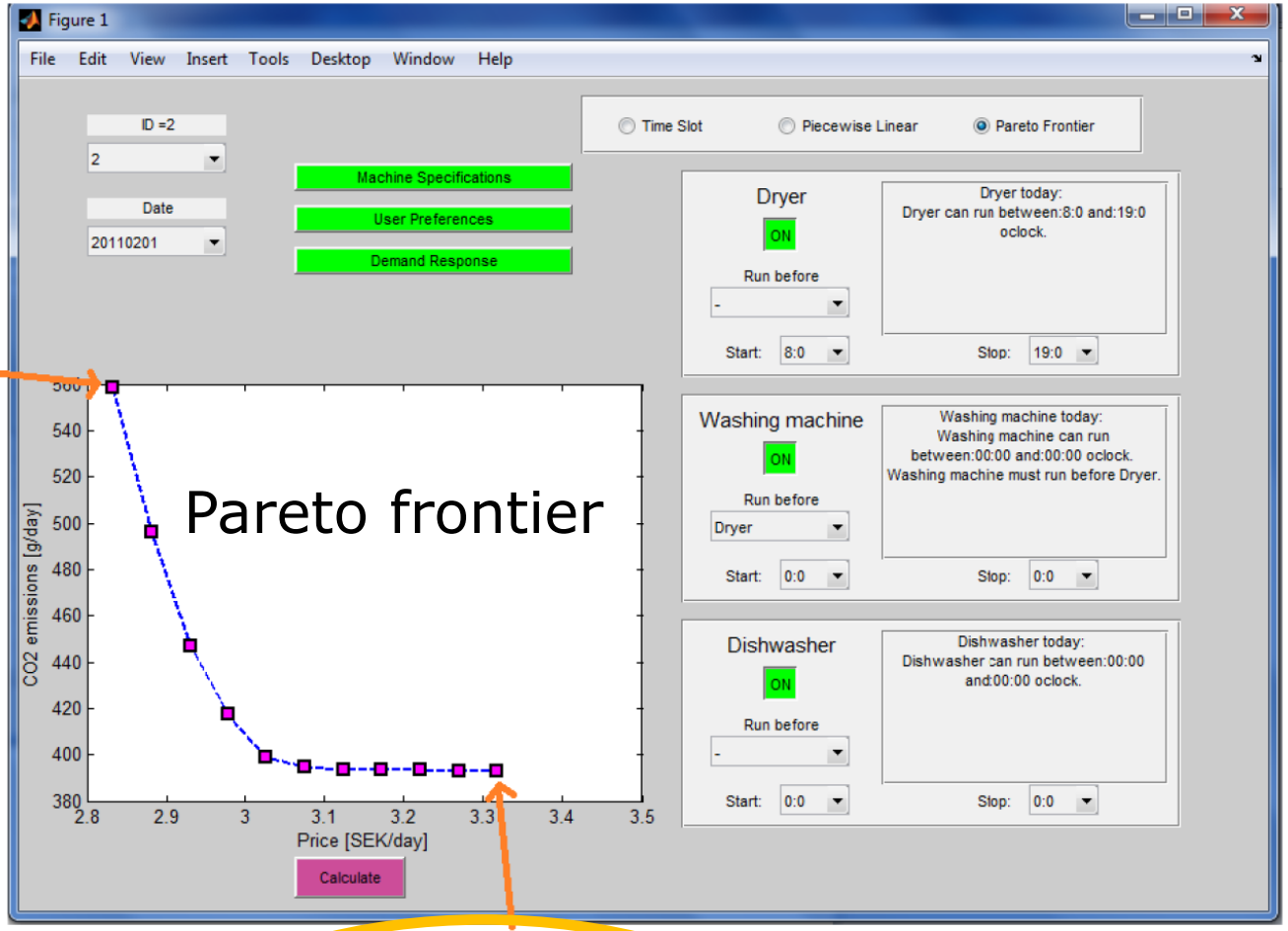
Virtual Smart Grid Lab

- 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 CO_2 scheduling tool has been implemented

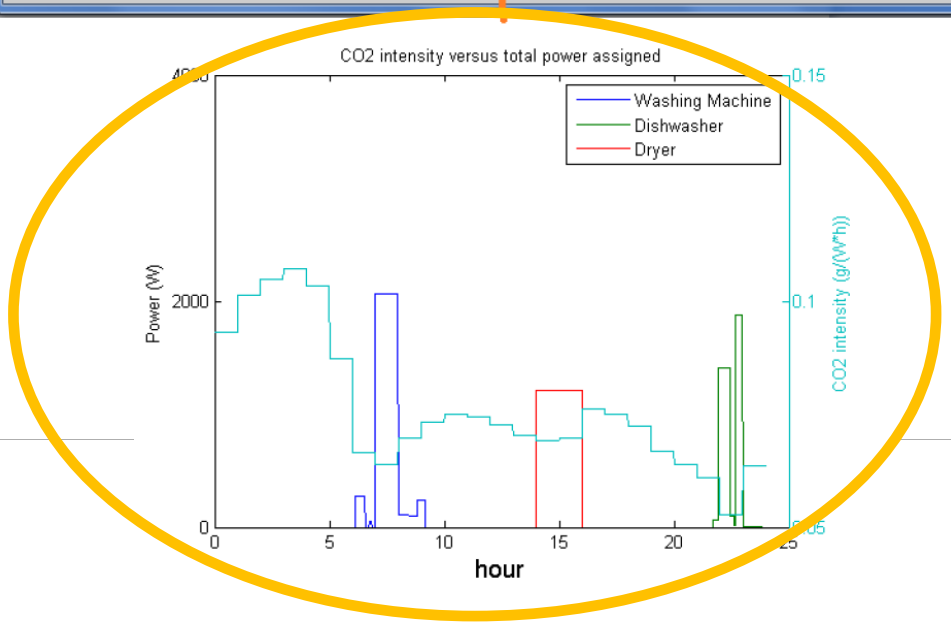
User Interface for Scheduling







Pareto frontier



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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 CO_2 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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