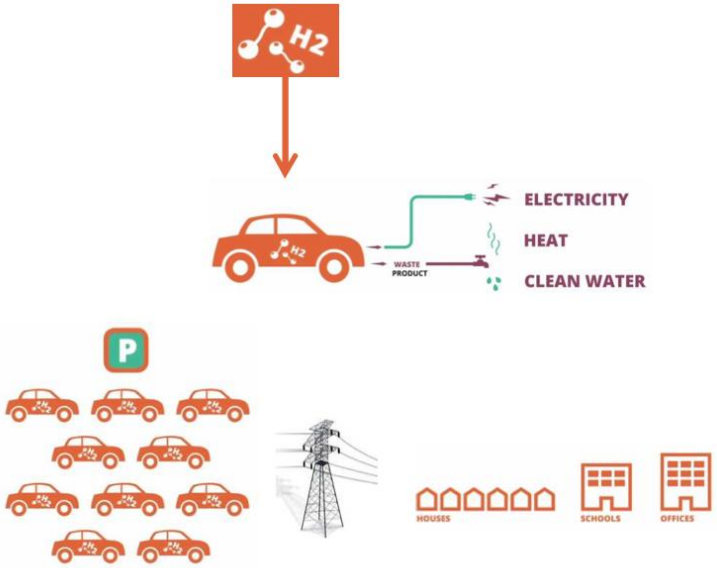
Electric mobility in future energy systems. Car as power plant?



Dr. ir. Zofia Lukszo

Section Energy and Industry
Technology, Policy and Management
@: Z.Lukszo@tudelft.nl

Delft University of Technology

Content

- Variability in future energy systems
- Electric mobility and responsive demand
- Are the goals of many actors involved the same?
- Why EVs can be compared to cold storage warehouses?
- What can we learn from looking at different price scenario's?
- Car as Power Plant

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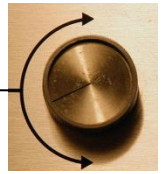
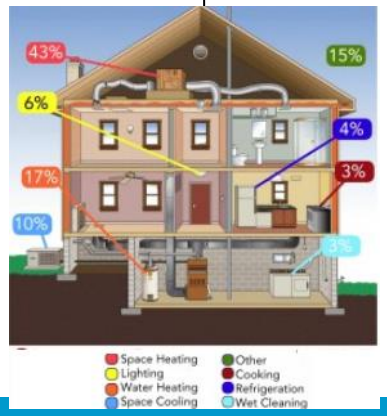
Future energy systems

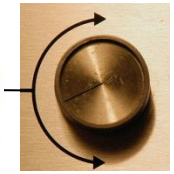
Old
schedule generation
to meet demand





New
schedule demand
to meet generation

e.g.
electric
mobility



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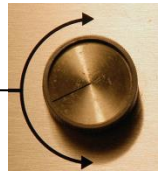
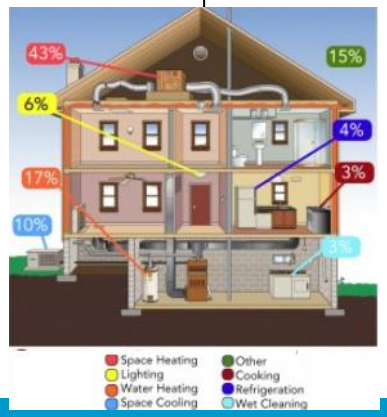
Future energy systems

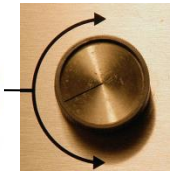
Old
schedule generation
to meet demand





New
schedule demand
to meet generation

DSM - e.g.
electric
mobility



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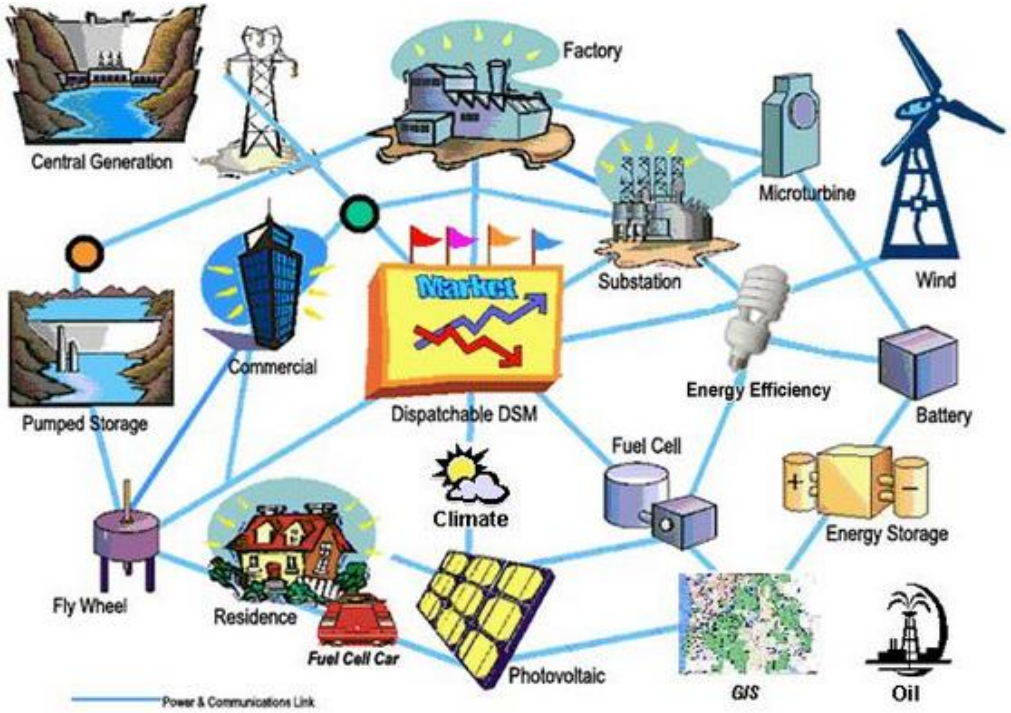
Future energy systems

- From "scheduling the generation to meet demand" to "everything interacts with everything"
- Increased real-time balancing
- Introduction of aggregators



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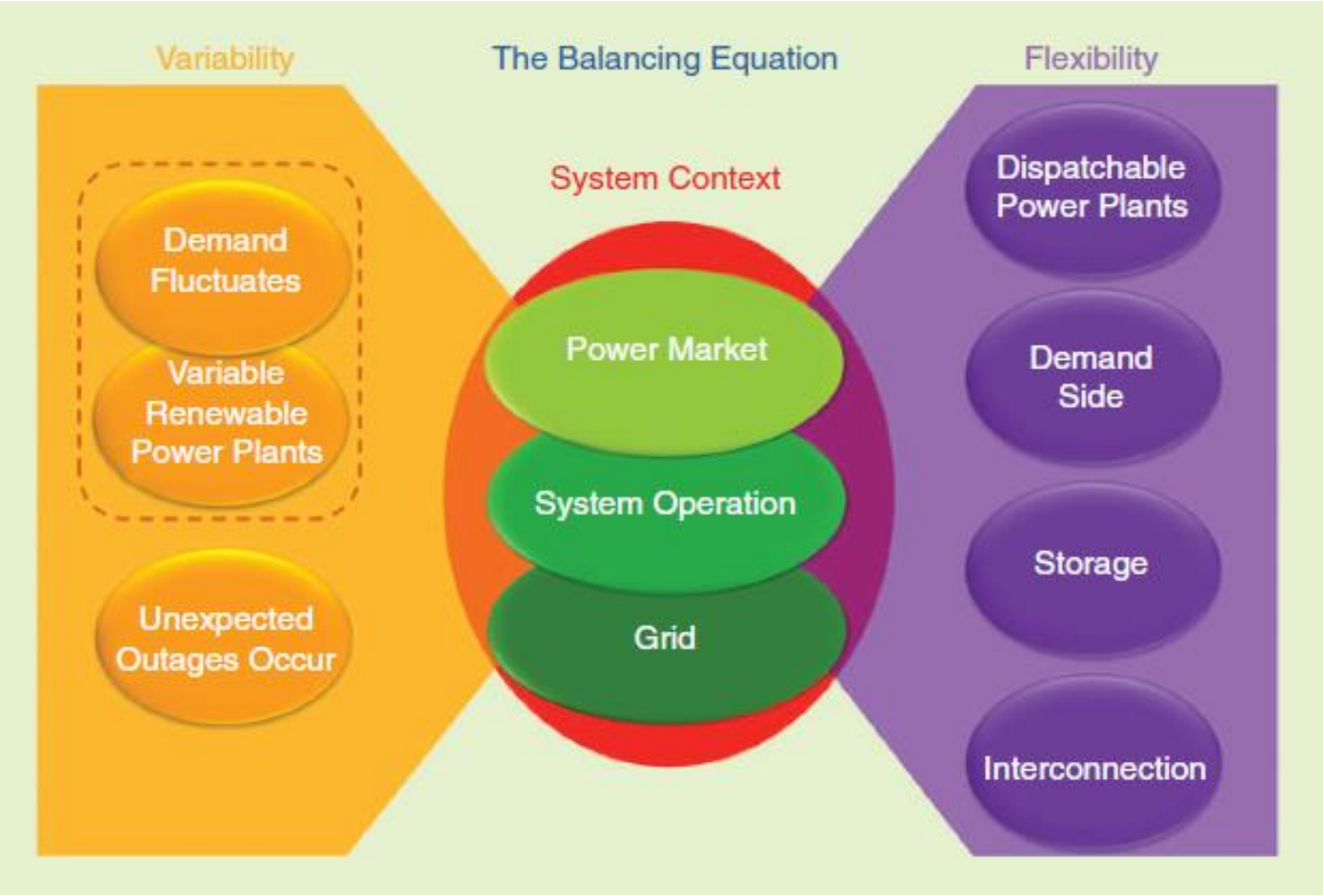
Variability vs. Flexibility



From: Holttinen, H., et.al.,*The Flexibility Workout: Managing Variable Resources and Assessing the Need for Power System Modification,* IEEE Power and Energy Magazine, 11(6), 2013

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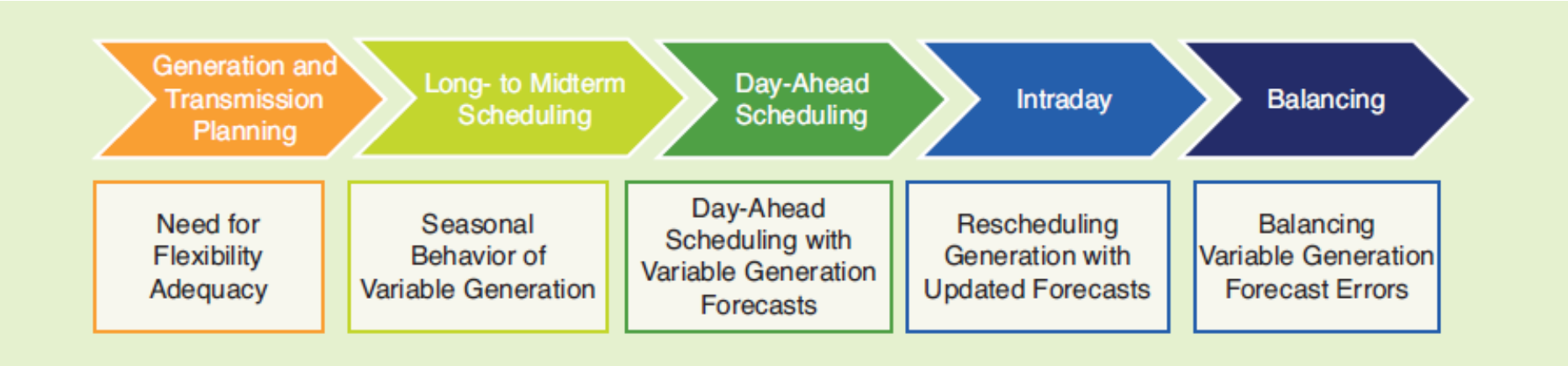
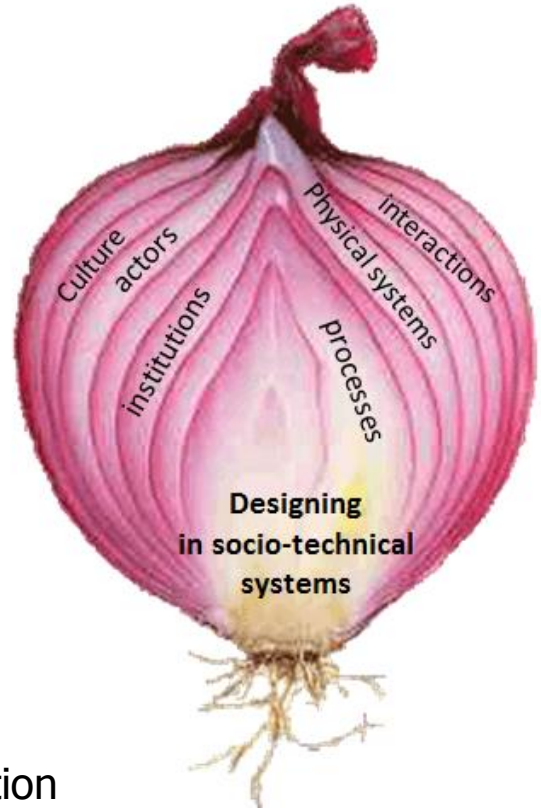
The impact of variable generation



From: Holttinen, H., et.al., *The Flexibility Workout: Managing Variable Resources and Assessing the Need for Power System Modification,* IEEE Power and Energy Magazine, 11(6), 2013

Our approach

- The world in "layers":
  - institutions: laws and regulations
  - actors (social networks)
  - physical networks
- Strong Complex Adaptive Systems perspective
  - Socio-technical complexity
  - Evolution / coevolution / dynamics
  - Multi level / Multi actors / Multi criteria / Multi time scale
- Multidisciplinary teams
  - combinations of different methods/theories
    - Mathematical modeling, optimization and control
    - Socio-technical ABM of systems evolution *and* operation
    - Gaming
    - Network theory / topology …
  - out of the box thinking, e.g. are theoretically expected situations achieved?: If not, then what?
  - Empiricism: How do the different countries operate?



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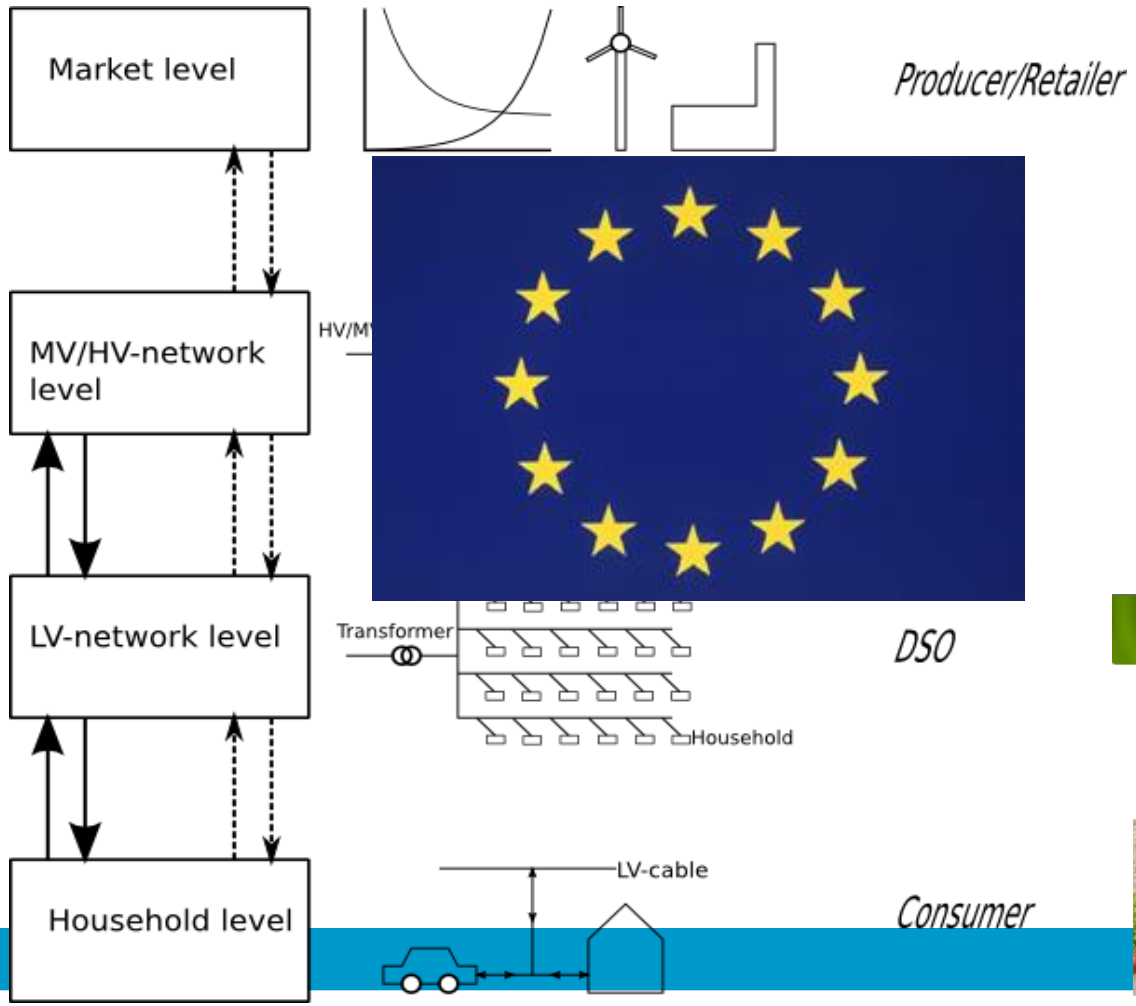
Power sector
complex socio-technical system



Demand side - Electric mobility

How can electric mobility contribute to a more
sustainable transportation & electrical power system
and on the same time align the interests
of its relevant actors?

*See: **Remco Verzijlbergh**, The Power of Electric Vehicles, PhD Thesis TU Delft, 2013, http://repository.tudelft.nl/*

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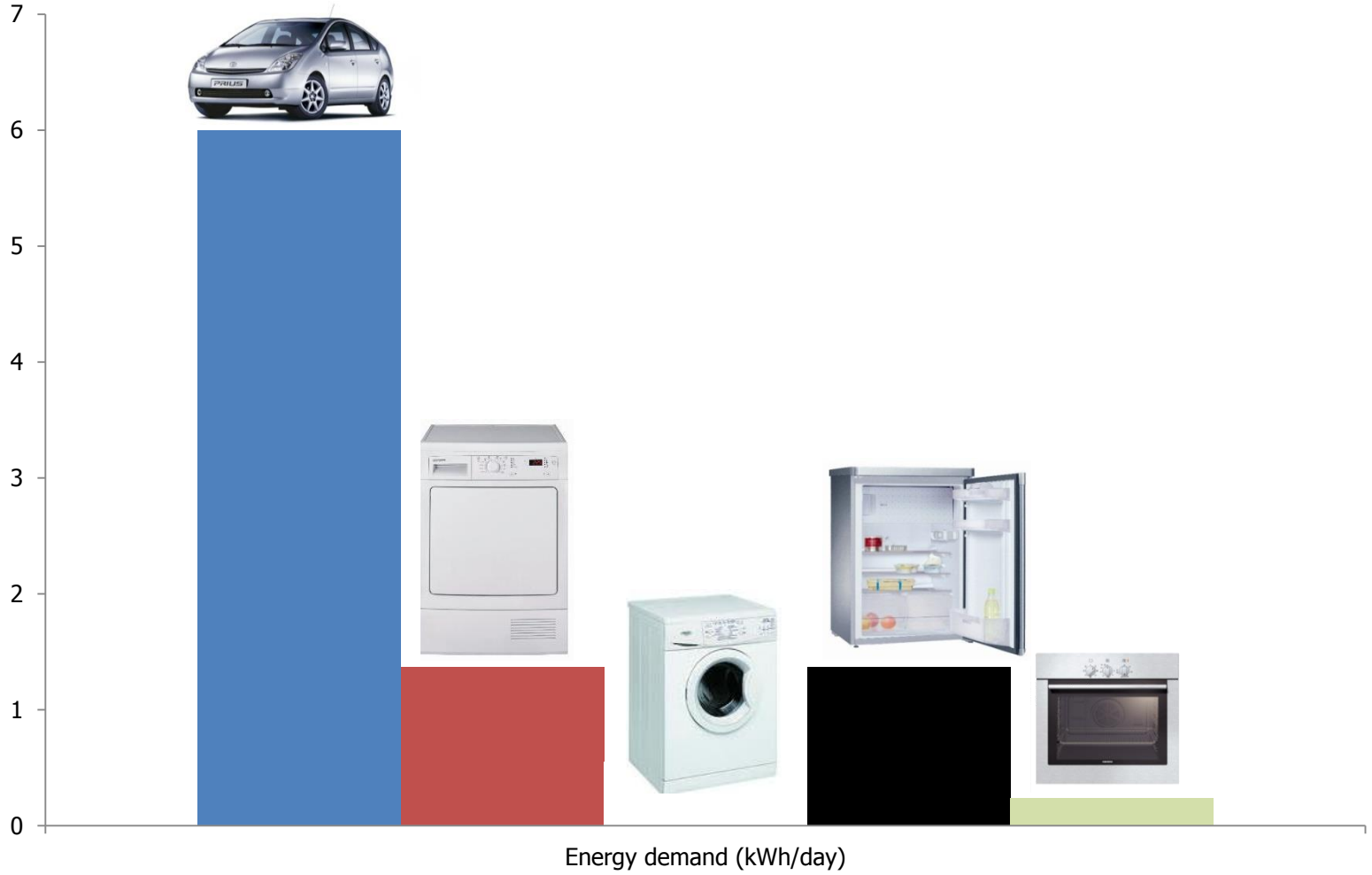
Energy usage households +/- 10 kWh



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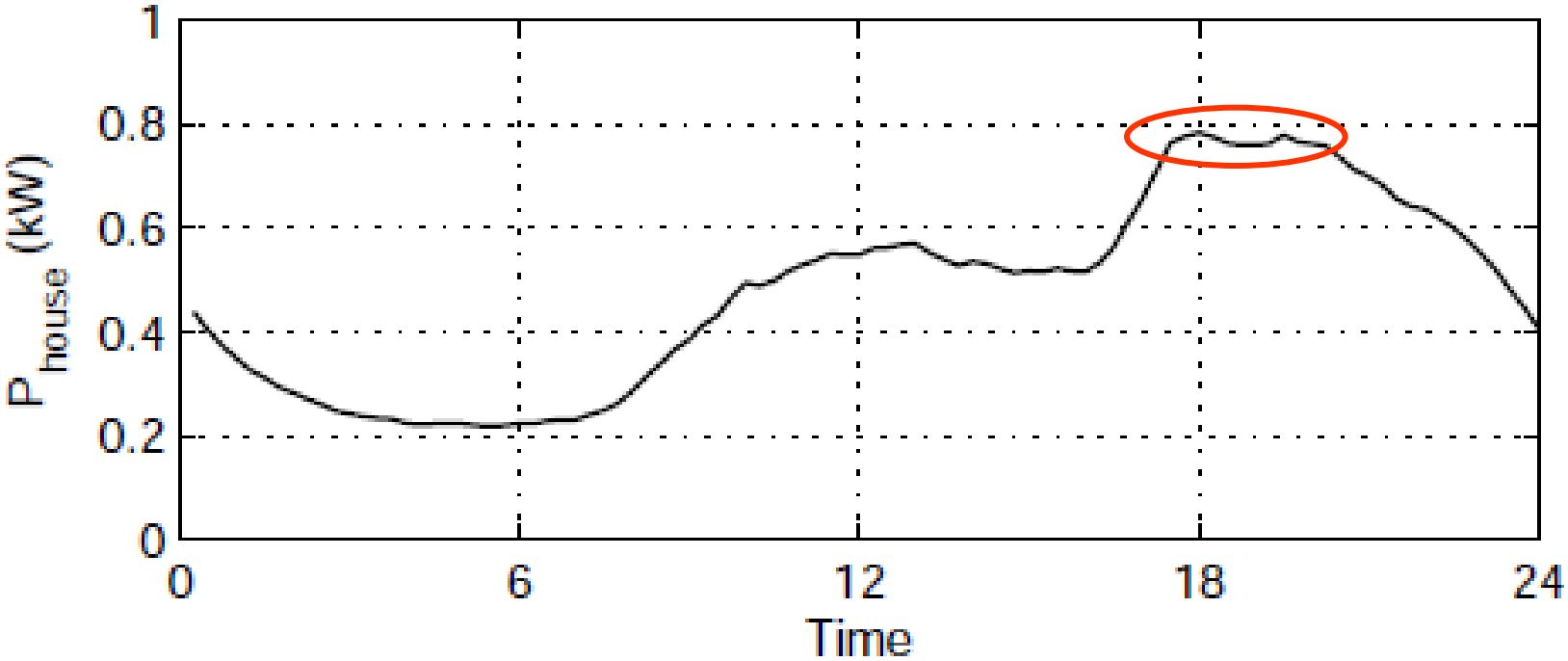
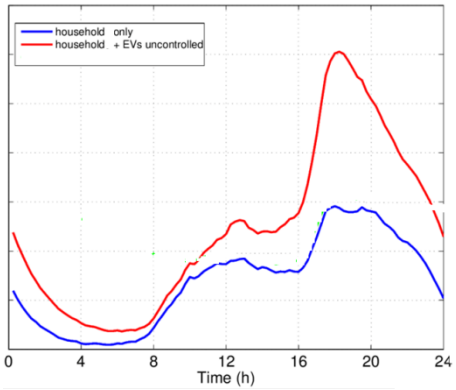
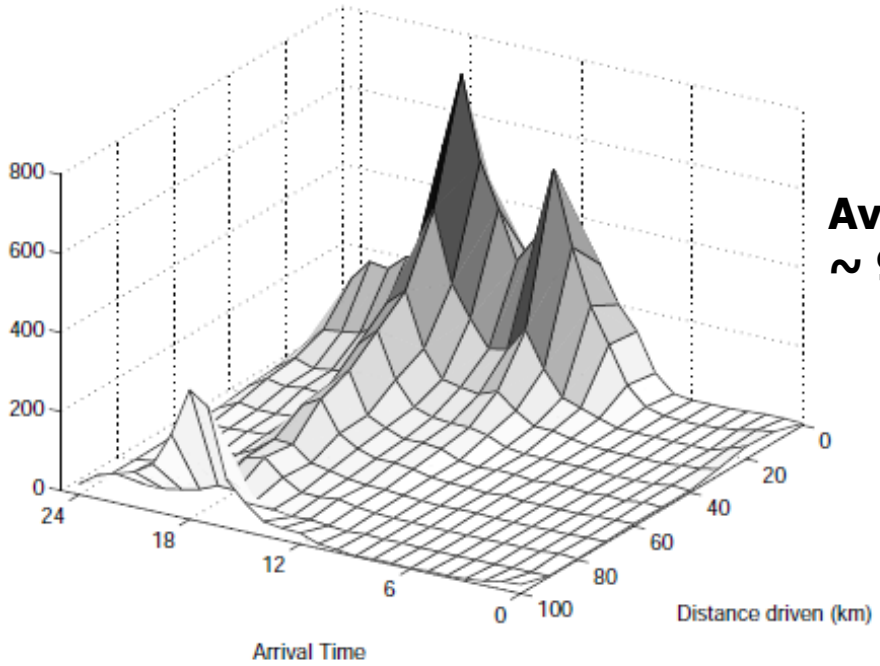
Standard Household Profile



Estimation of the expected energy usage of EVs

Data from Mobility Research Netherlands





Average: ~34 km
~ 90% < 100km

Ministry of Transport, Public Works and Water Management, "Mobiliteitsonderzoek Nederland (in Dutch)"
Available: www.mobiliteitsonderzoeknederland.nl

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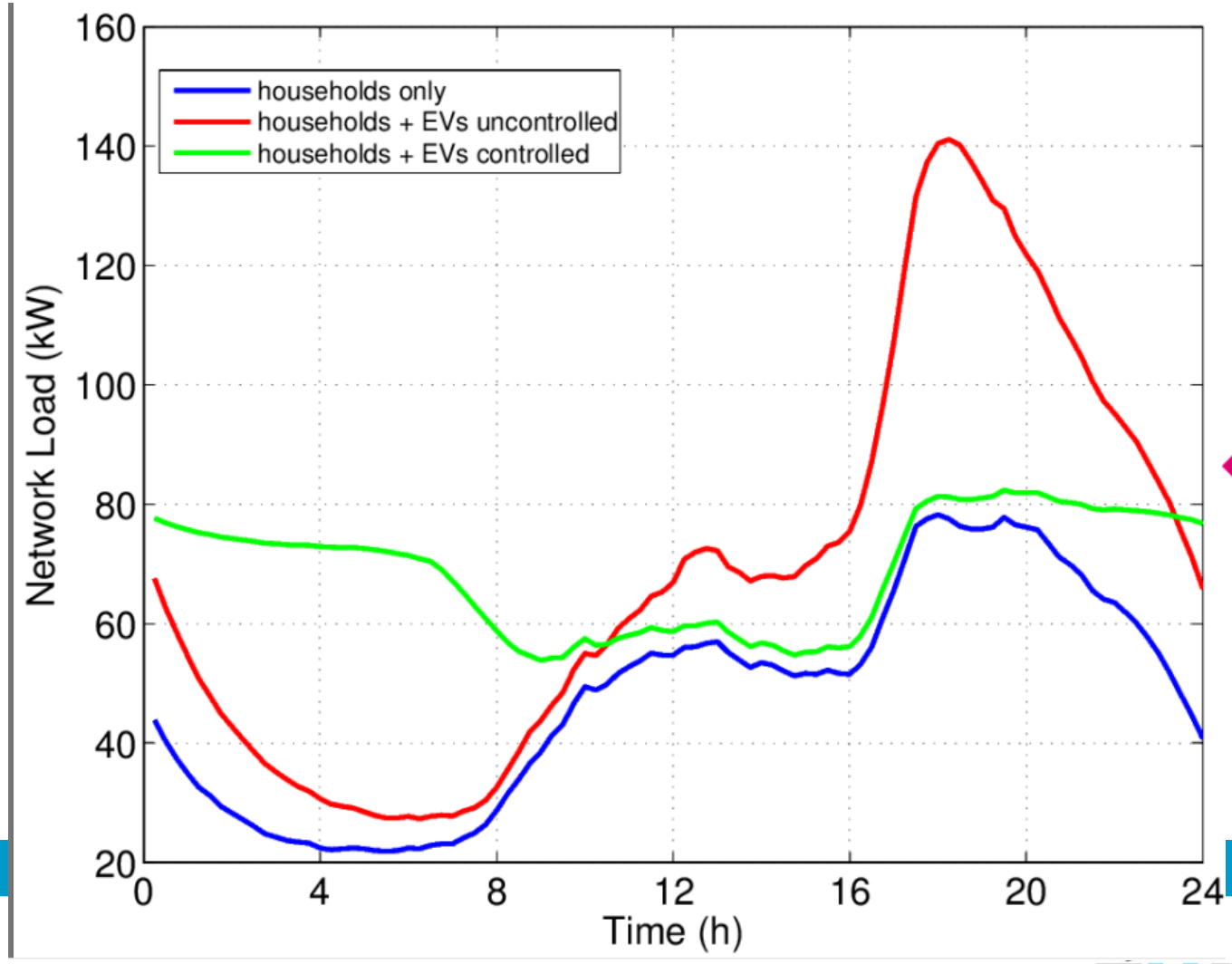
Charging scenario's and network load

Based on real life data



ENEXIS

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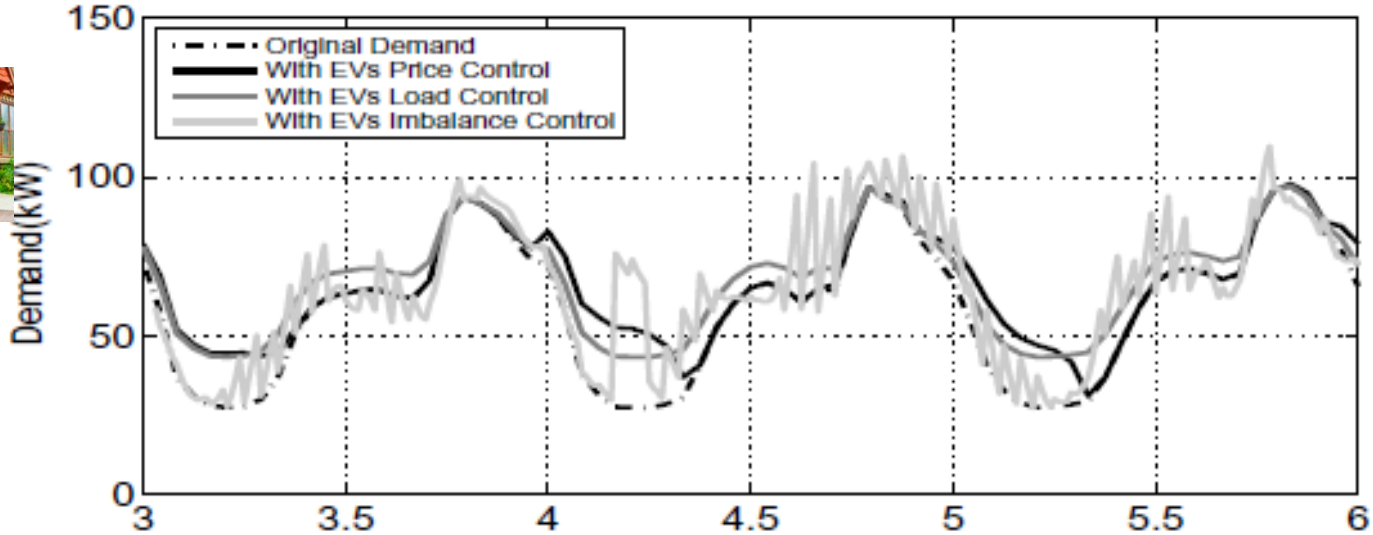
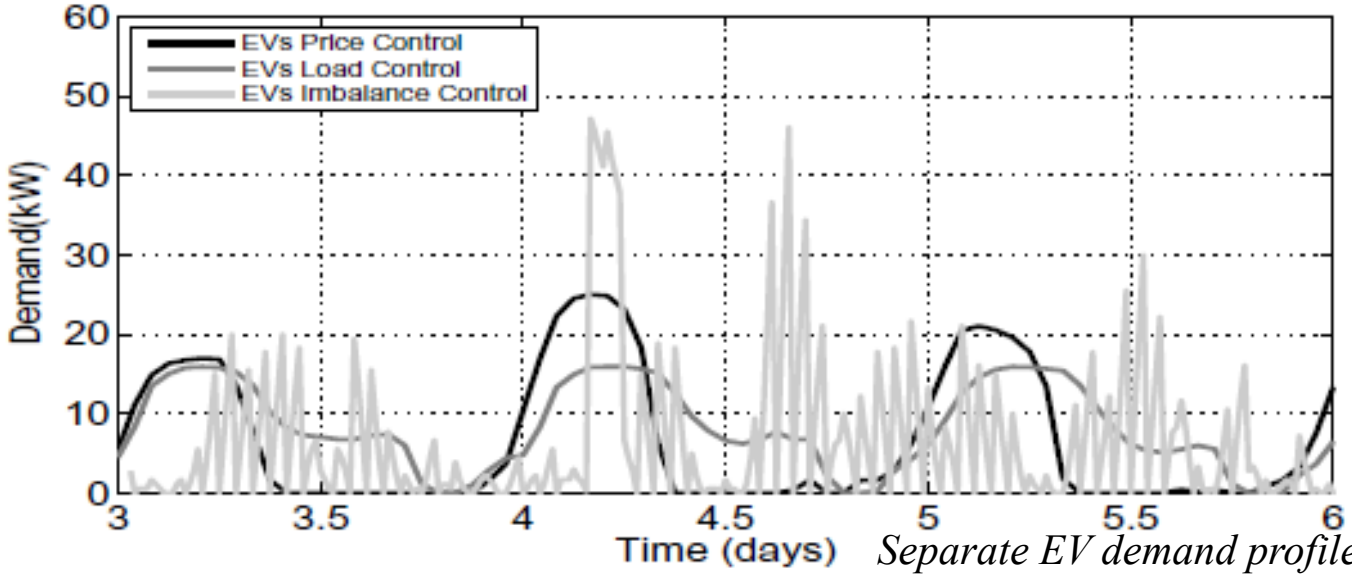
Network load:100 houses and 50 EVs

Price control

Load Control

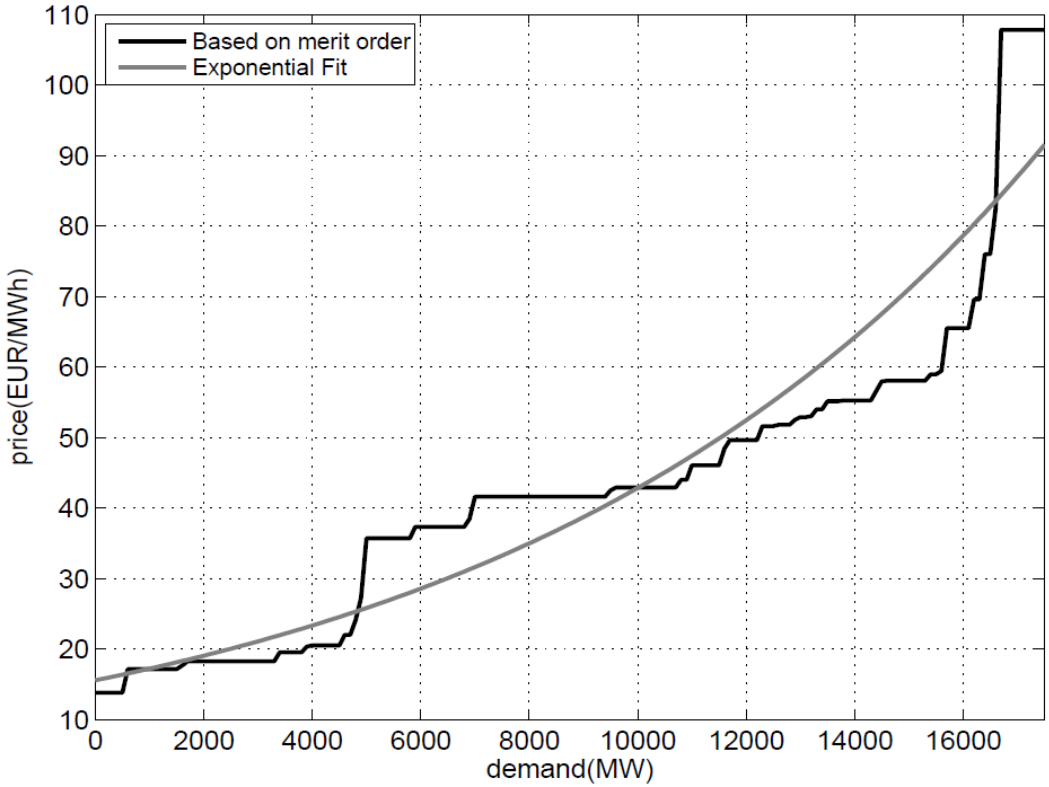
Imbalance Control



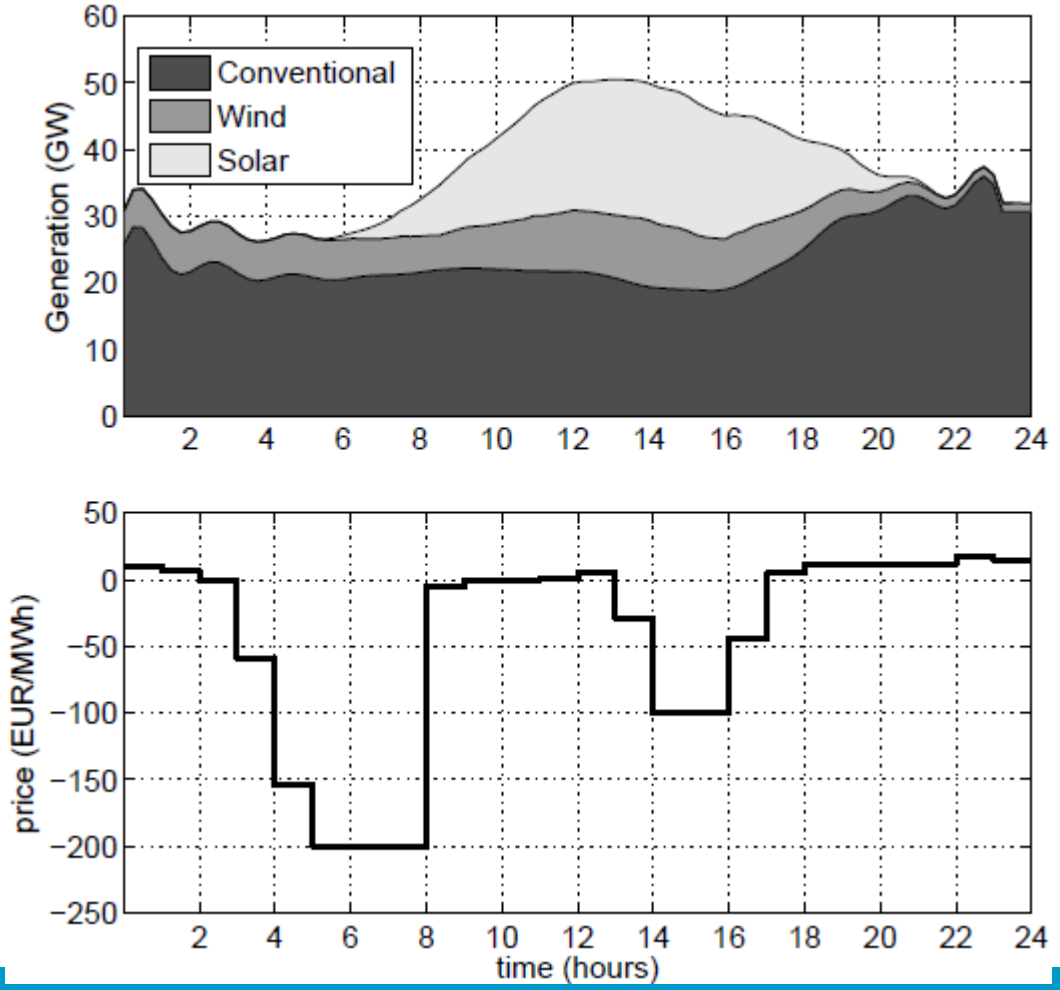


Separate EV demand profiles

Charging strategy based on predicted price



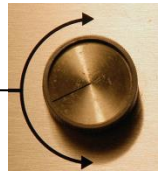
Negative price?



Conventional, wind and solar power and spot prices for the German system on June 16th 2013.

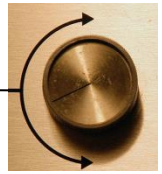
Demand side – cold storage

Old
schedule generation
to meet demand

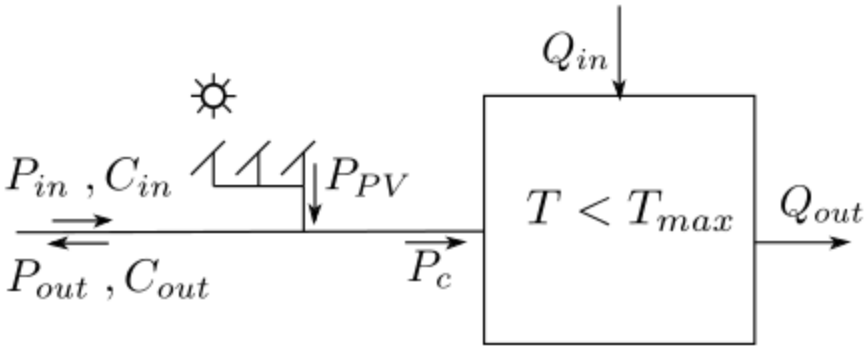


New
schedule demand
to meet generation

e.g. with
a cold
storage
warehouse



Matching renewable energy and demand response through price



System model:

- Cold store has PV generation on site
- PV production known in advance
- Pays price $C_{in}(t)$ for energy, receives $C_{out}(t)$
- Temperature upper bound T_{max}

<u>Goal:</u> Investigate relations between demand response strategy of a cold store and electricity prices & Evaluate different pricing regimes on optimal energy use

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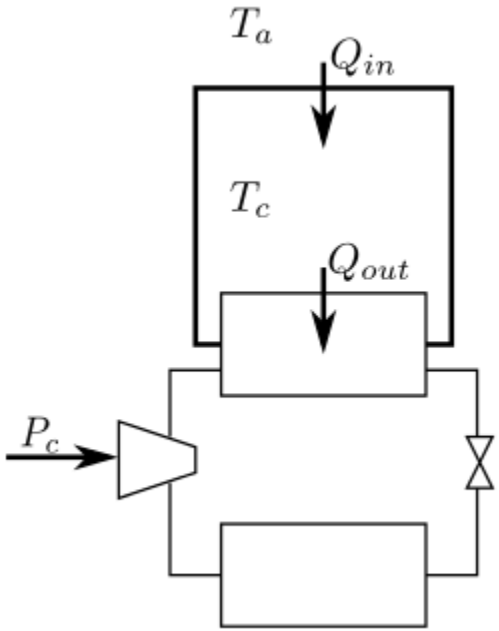
Physical model of cold store

Heat balance

$$C_p \frac{dT_c}{dt} = Q_{in} - Q_{out}$$



Incoming heat

$$Q_{in} = UA(T_a - T_c)$$

Outgoing heat

$$Q_{out} = \eta P_c$$

Resulting equation for T dynamics

$$C_p \frac{dT_c}{dt} = UA(T_a - T_c) - \eta P_c$$

$$a = \frac{UA\Delta t}{C_p}$$

$$b = \frac{\eta \Delta t}{C_p}$$

Discretized in time

$$T_c[k+1] = (1-a)T_c[k] + aT_a[k] - bP_c[k]$$

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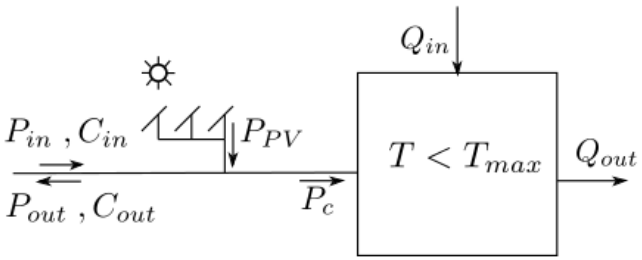
Optimization formulation

Objective function

$$\min_{P_{in}[k],P_{out}[k]} \sum_{k=1}^{N_k} C_{in}[k]P_{in}[k] - C_{out}[k]P_{out}[k]$$



constraints

$$T_c[k+1] = (1-a)T_c[k] + aT_a[k] - bP_c[k]$$

$$P_c[k] = P_{PV}[k] + P_{in}[k] - P_{out}[k]$$

$$P_{c,min}[k] \leq P_{PV}[k] + P_{in}[k] - P_{out}[k]$$
$$P_{c,max}[k] \geq P_{PV}[k] + P_{in}[k] - P_{out}[k]$$

Compare cold store with EV optimization problem

Optimization problem

$$\min_{P_{in}[k],P_{out}[k]} \sum_{k=1}^{N_k} C_{in}[k]P_{in}[k] - C_{out}[k]P_{out}[k]$$

$$\text{s.t.} \quad T_{min}[k] \leq T_c[k] \leq T_{max}[k]$$

$$P_{c,min}[k] \leq P_c[k] \leq P_{c,max}[k]$$

$$\min_{P_{i,t}} \sum_t \sum_i C_t P_{i,t}$$

$$\text{s.t.} \quad x_{min,i} \leq x_{i,t} \leq x_{max,i}$$

$$P_{min,i} \leq P_{i,t} \leq P_{max,i}$$

State dynamics

$$T_c[k+1] = (1-a)T_c[k] + aT_a[k] - bP_c[k]$$

$$P_c[k] = P_{PV}[k] + P_{in}[k] - P_{out}[k]$$

$$x_{i,t+1} = x_{i,t} + \eta_i P_{i,t} \Delta t - d_{i,t}$$

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Price scenarios

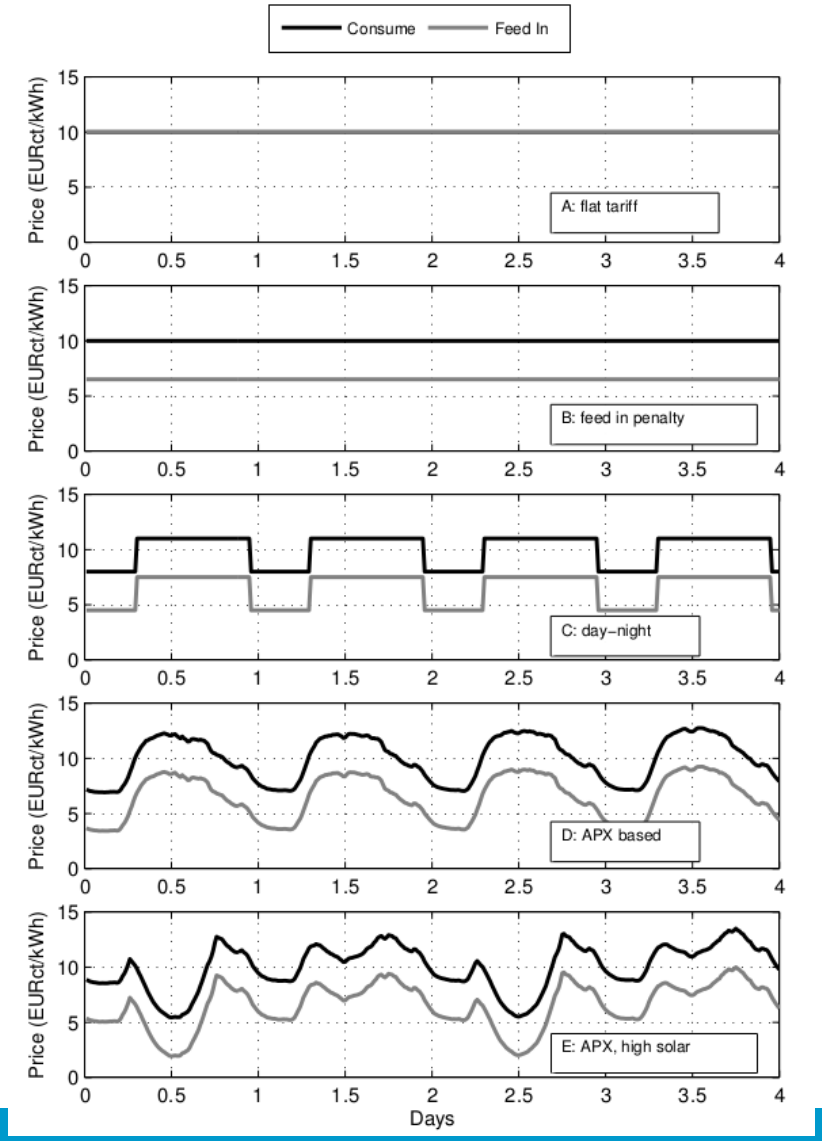
A: flat tariff

B: flat double tariff

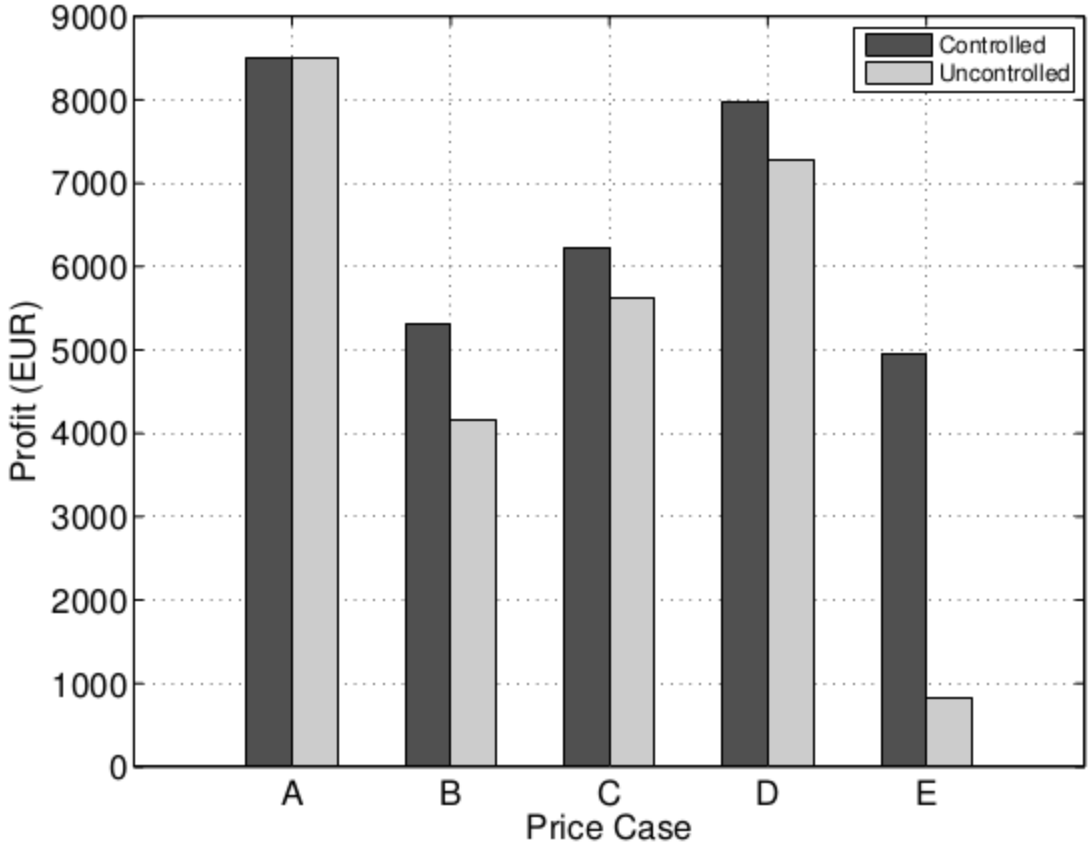
C: day-night tariff

D: APX based real time tariff

E: APX based real time tariff, high solar penetration



Comparison



- Optimal cooling trajectory depends strongly on tariff structure.
- Local use of PV energy depends on tariffs
- Most 'value' of control in case with high solar penetration.
- **The effective use of demand response requires the right tariff structure**

Price case	Profit (EUR)	Cooling Energy Used (MWh)	Total Energy Withdrawn (MWh)	Total Energy Fed In (MWh)	Maximum Power Withdrawn (kW)	Maximum Power Fed In (kW)
A: flat tariff	8500	19.4	9.9	31.2	220	1780
B: flat tariff, feed-in penalty	5310	20.3	0	20.4	0	1780
C: day-night tariff	6220	19.7	5.1	26.2	220	1780
D: APX based real time	7960	20.7	18.9	38.9	2000	2000
E: APX based high solar	4960	22.5	0	18.2	0	1504

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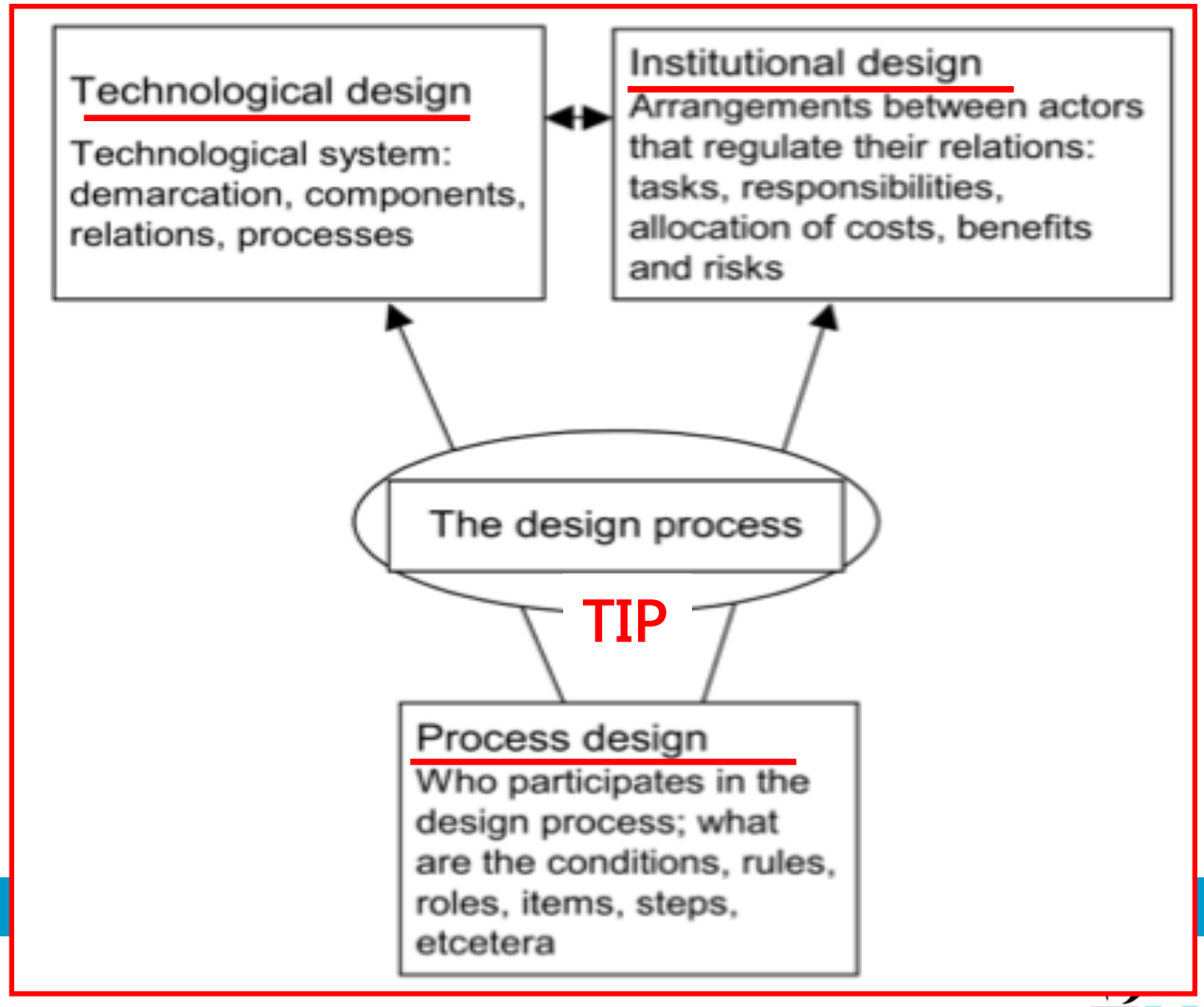
How to define effective use of the demand response?



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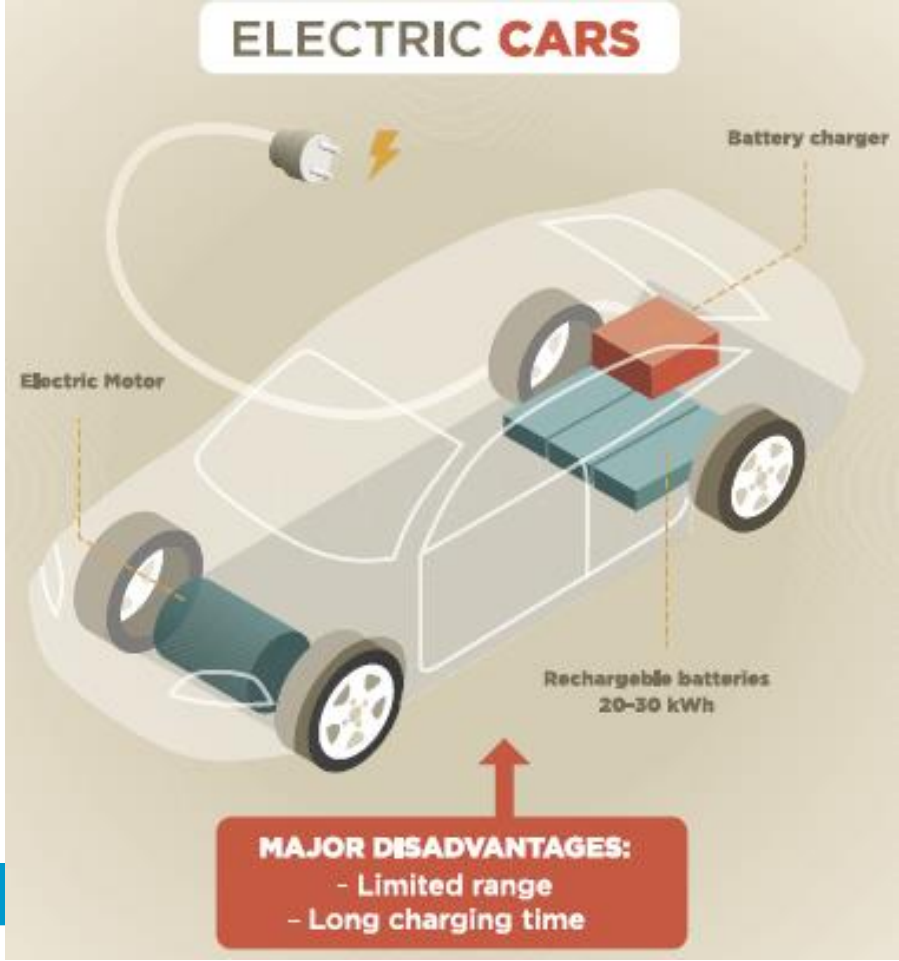
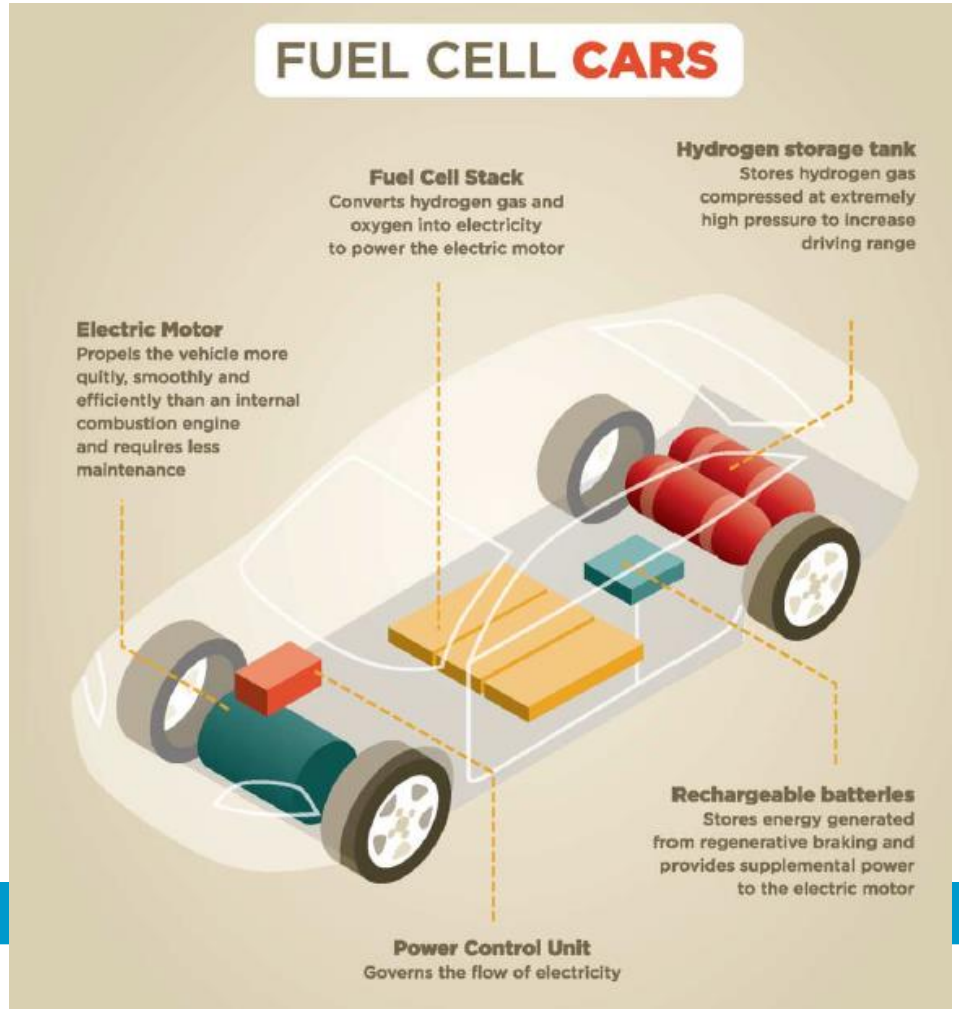
Electric cars – disadvantages



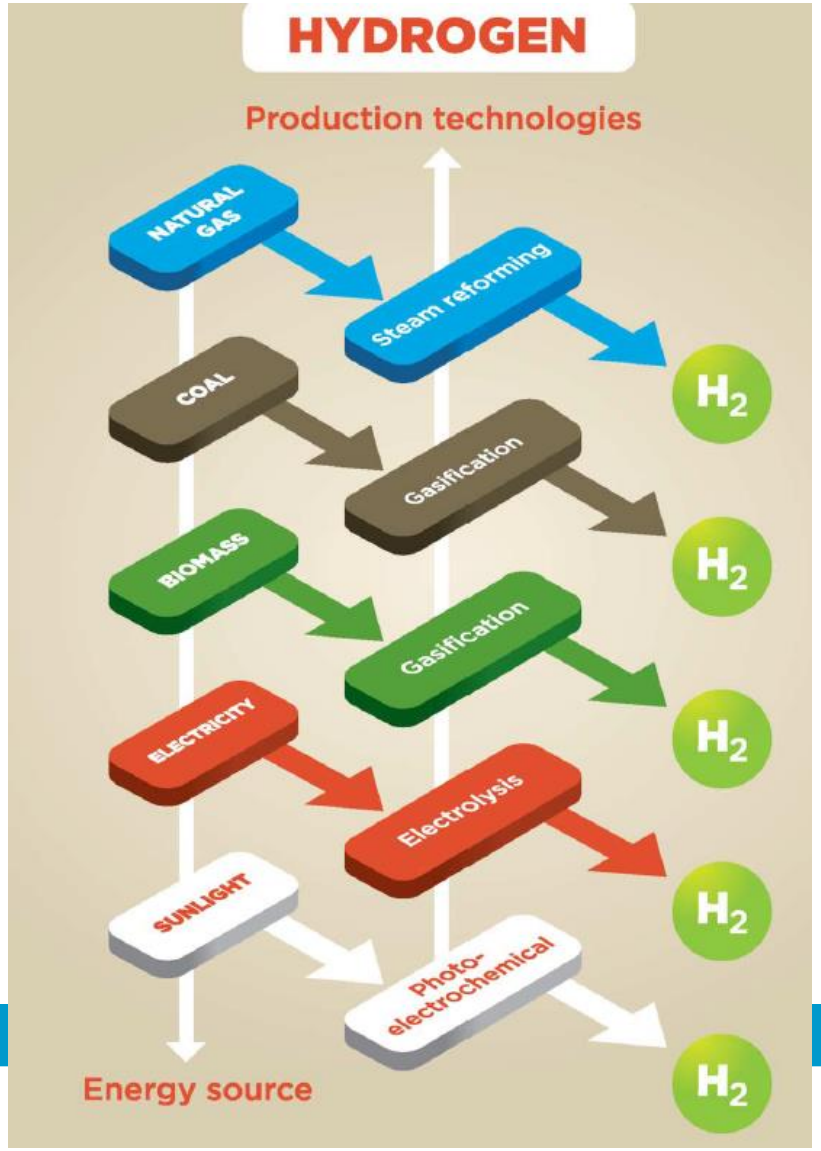
Ad van Wijk & Leendert Verhoef, Our Car as Power Plant, Delft, 2014.

Fuel cell cars

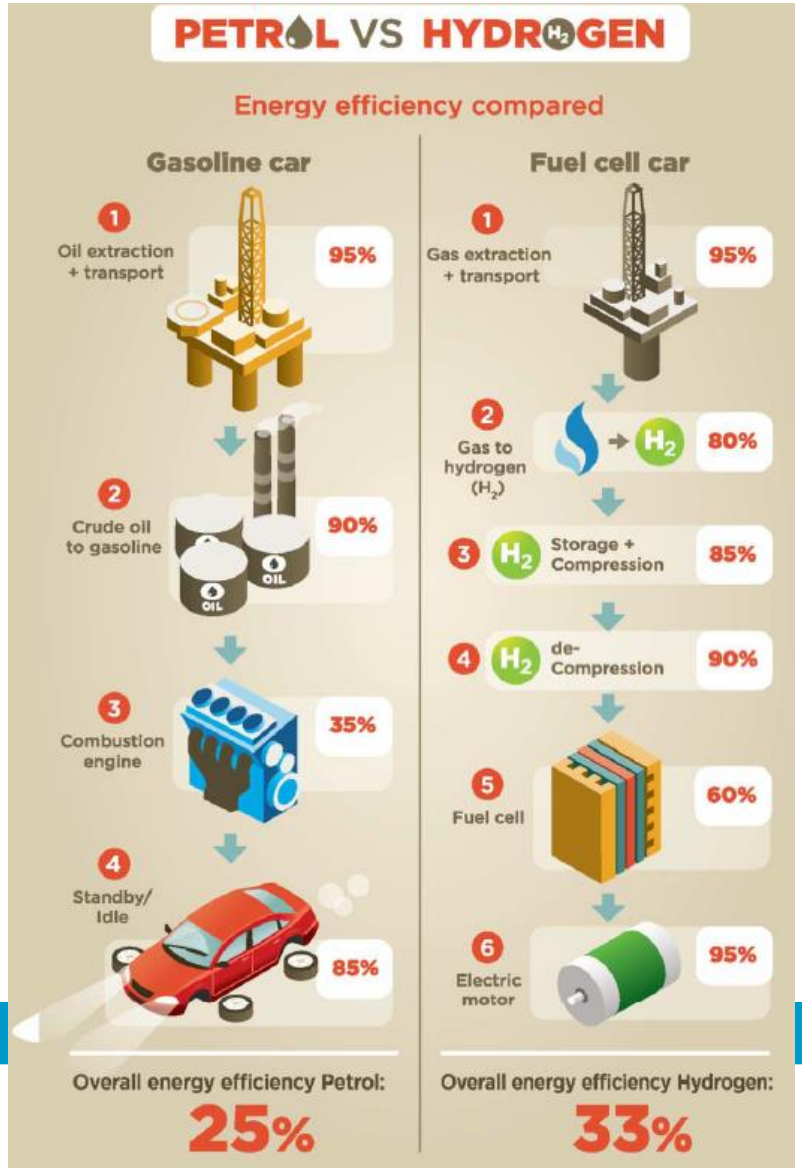
converts the chem. energy of a fuel (hydrogen) directly to electricity



Hydrogen production technology



Efficiency cars



Power plants and car power capacity

Transport and Electricity system – expected changes

SYSTEM	TRANSPORT/ELECTRICITY	SYSTEM CHANGE
Present	Transport- and electricity systems are separated	
Electric cars with batteries	Transport system with electric cars consumes electricity and can store electricity	**More Electricity**
Fuel cell car as power plant to produce electricity	Transport system with fuel cell cars produces electricity and will replace power plants	**More Gas**
Fuel cell car as power plant to balance electricity demand and -supply	Electricity will be produced by renewable energy sources; hydro, geothermal, biomass, wind, solar Transport system with fuel cell cars consumes electricity and biogas converted in hydrogen, produces electricity when necessary to balance electricity demand and supply	**Fully Renewable**

Reasons to believe

EFFICIENCY	• Fuel cell in the car has an efficiency of 60% to convert hydrogen into electricity • Hydrogen production from gas or electricity has an efficiency of about 70-80%
BETTER	• Car engines at present have an efficiency of 25-40% • Power system efficiency is below 40%
TIME	• Cars are in use for transportation less than 5% of the time • Over 90% of time, cars are parked at home, at work, in a car park, on the street
AVAILABLE	• Power plants are used between 5% and 90% of the time
CAPACITY	• Worldwide 1 billion cars on the road; with an average engine capacity of 50 kW this represents a power capacity of 50.000 GW
ABUNDANT	• 80 million cars were sold in 2011; with an average engine capacity of 100 kW this represents a power capacity of 8.000 GW • Worldwide the electricity production capacity of all power plants is about 5.000 GW

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How to organize such a system?

- A wide variety of new products, services and systems to come, but who will deliver this?

- The cars need to be integrated in the larger energy and transport system. These challenges are on all system levels: from individual cars, to car parks, houses, offices, neighbourhoods, cities and regions.

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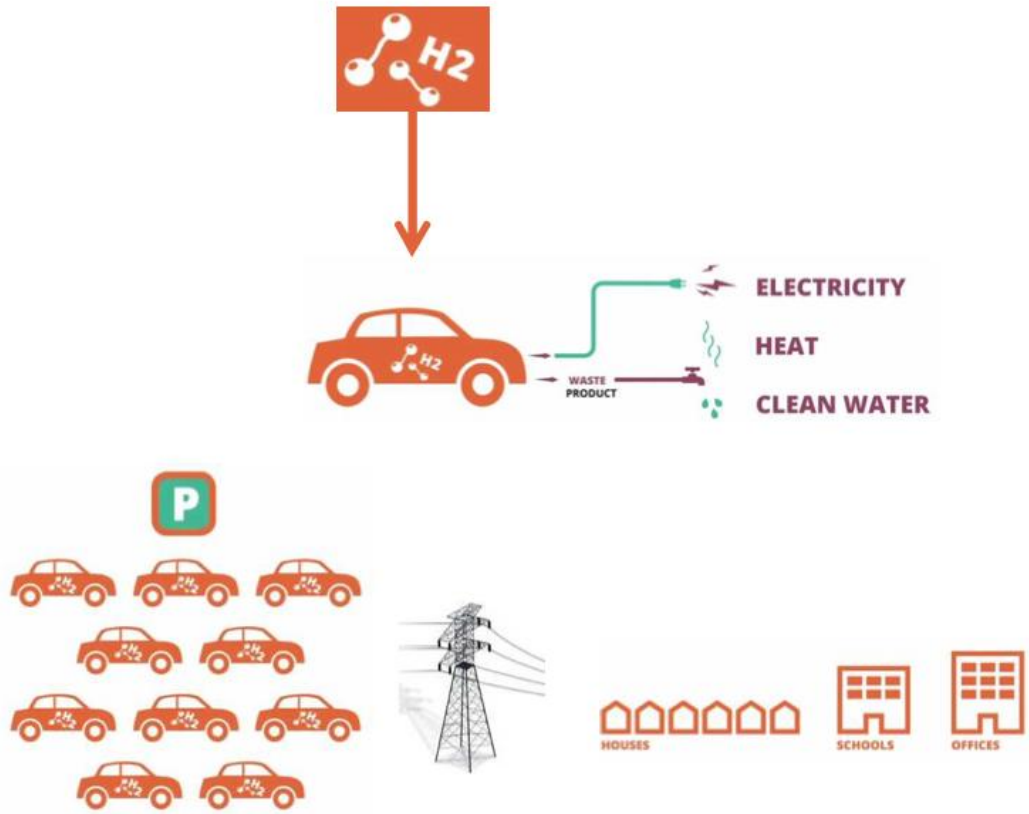
Exploring the emergence of the Car as Power Plant with a socio-technical TIP design perspective



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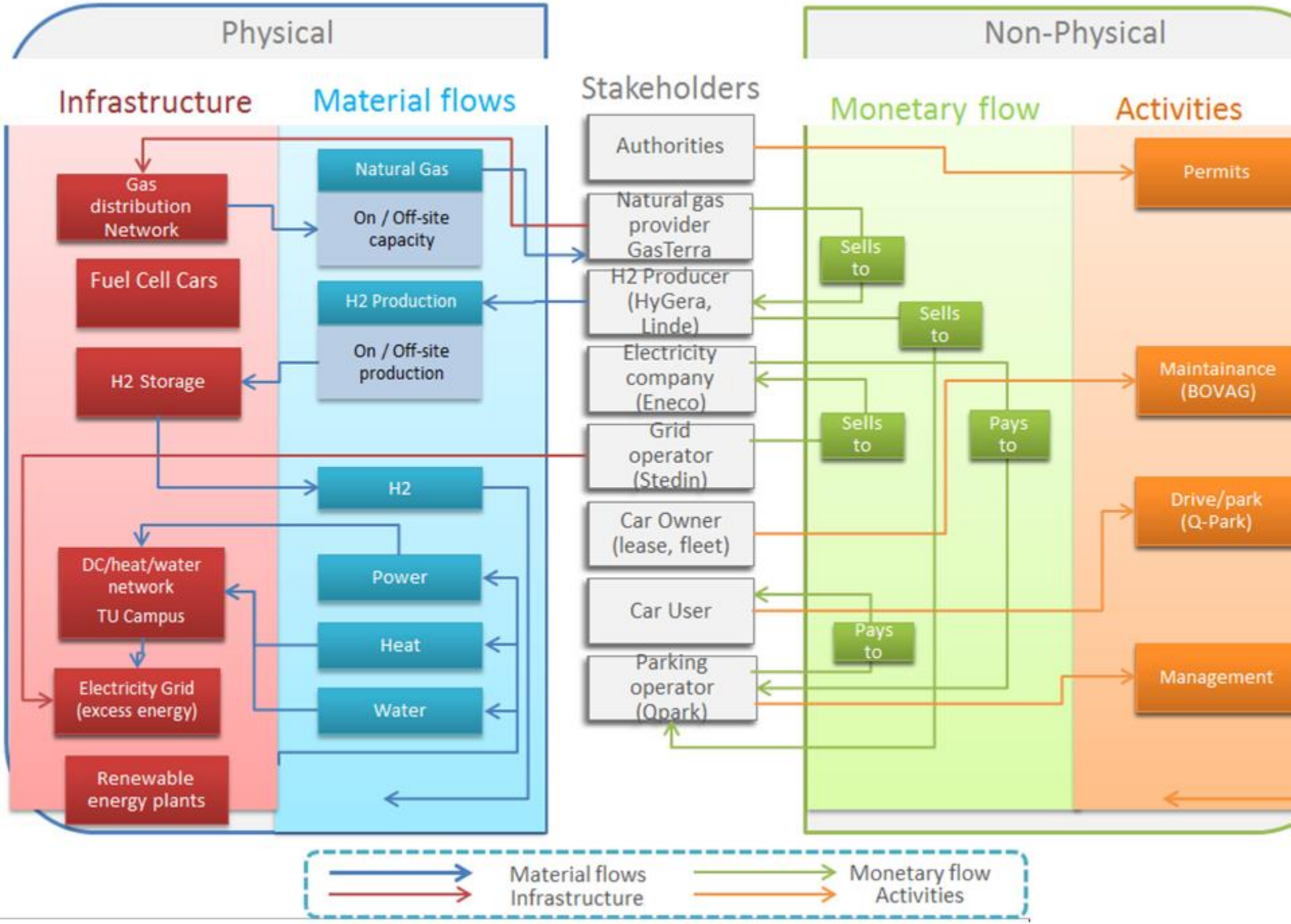
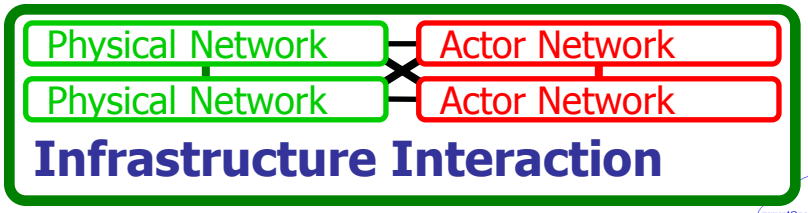
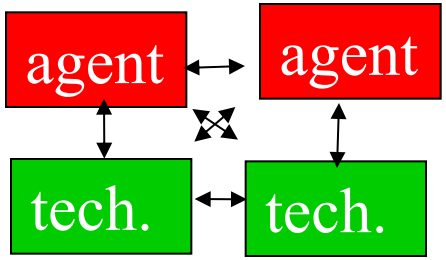
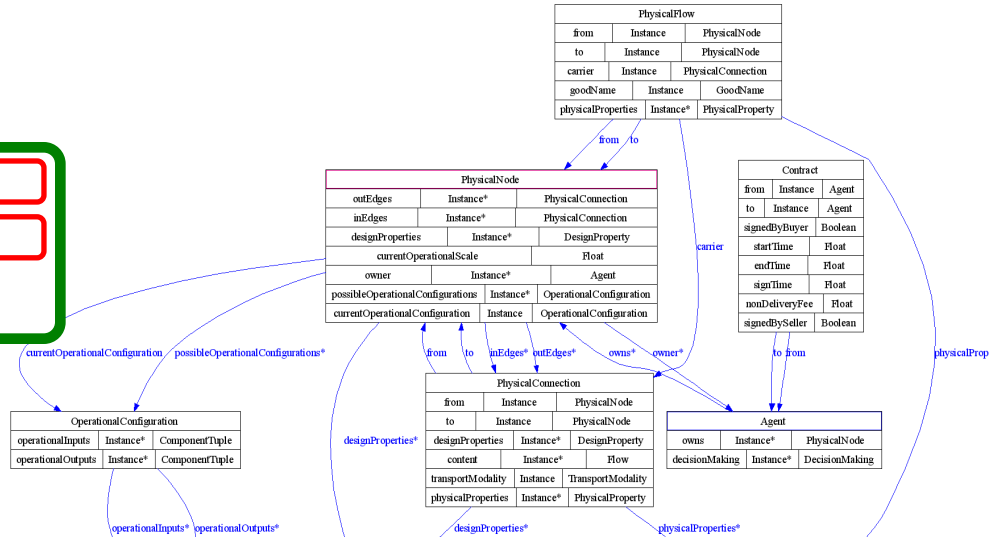
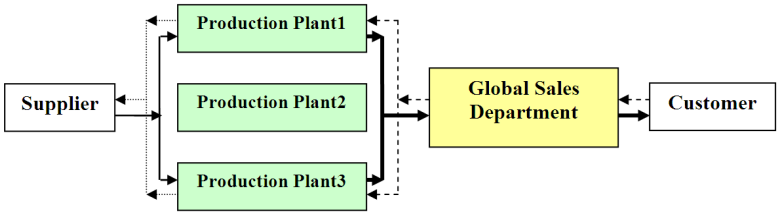

Physical
Non-Physical
Infrastructure
Material flows
Stakeholders
Monetary flow
Activities
Gas distribution Network
Fuel Cell Cars
H2 Storage
DC/heat/water network TU Campus
Electricity Grid (excess energy)
Renewable energy plants
Natural Gas
On / Off-site capacity
H2 Production
On / Off-site production
H2
Power
Heat
Water
Authorities
Natural gas provider GasTerra
H2 Producer (HyGera, Linde)
Electricity company (Eneco)
Grid operator (Stedin)
Car Owner (lease, fleet)
Car User
Parking operator (Qpark)
Sells to
Sells to
Sells to
Pays to
Pays to
Permits
Maintainance (BOVAG)
Drive/park (Q-Park)
Management
Material flows
Infrastructure
Monetary flow
Activities

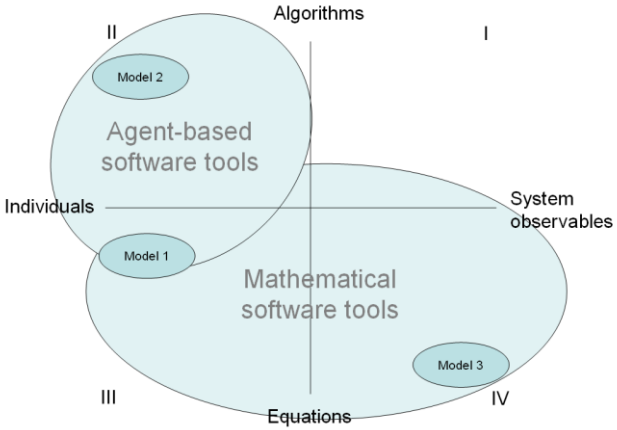
Agent-Based Model (ABM) for TIP design











Koen H. van Dam, Igor Nikolic and Zofia Lukszo (Eds.), *Agent-based modelling of socio-technical systems*, 275 p., Springer, 2013

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ABM components

- Agents
- States
- Decision rules
- Actions
- Environment
- Time

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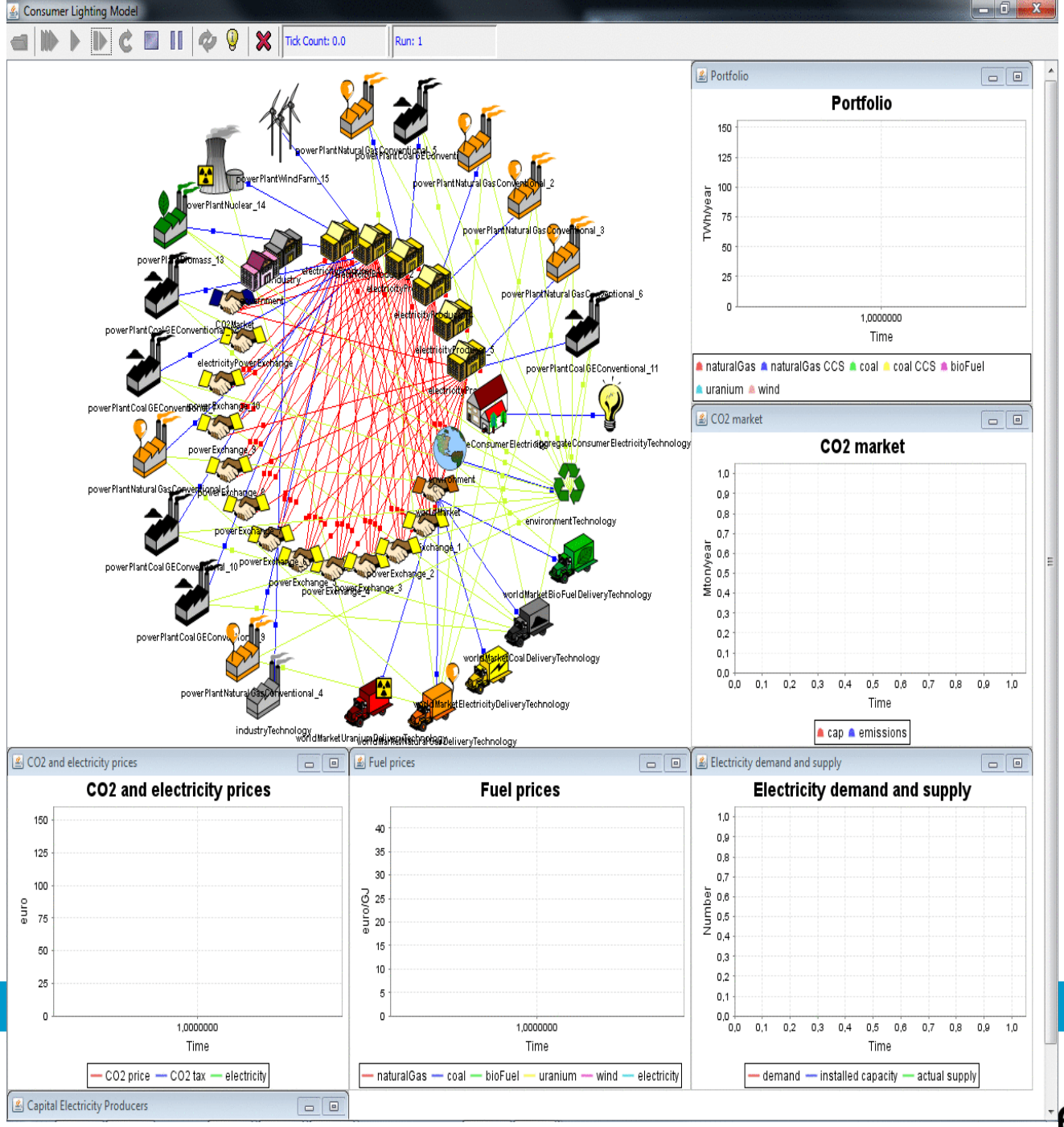

Simulating Energy Transitions. Emile Chappin, 2011, Delft University of Technology, the Netherlands. Thesis, 2011. ISBN: 9789079787302

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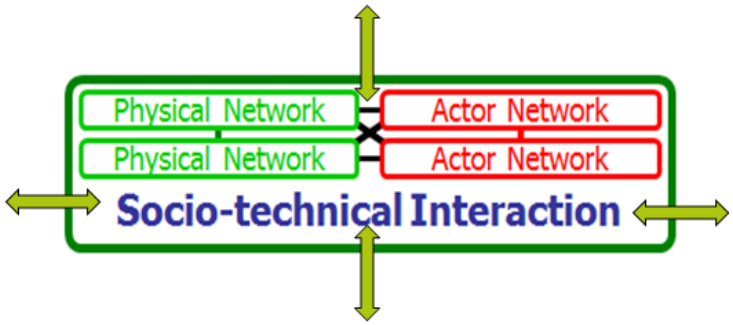
Modeling of energy infrastructures: ABM and TIP

- help to reduce uncertainty for actors in the energy chain by developing tools that are needed for smart energy systems

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