Why energy efficiency is not sufficient

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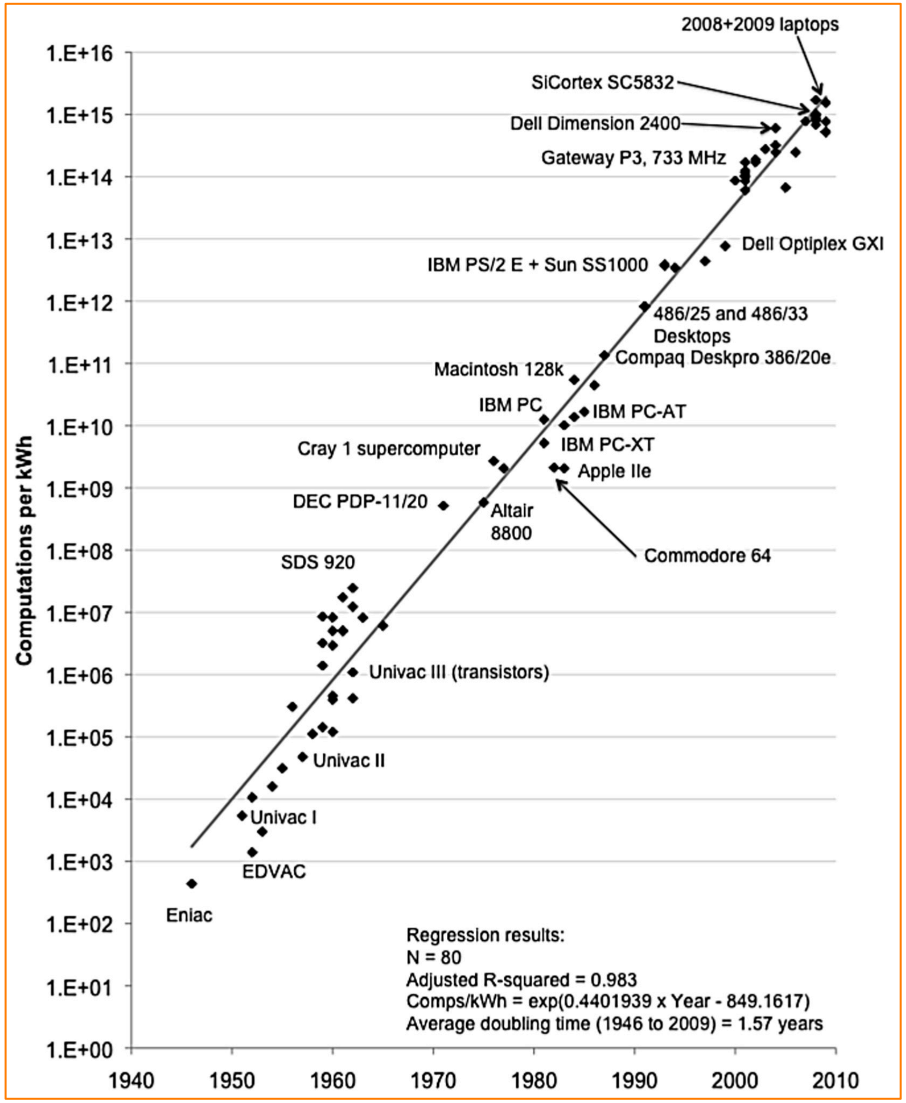
Overview

1. The energy efficiency of computation
2. The energy efficiency of data transfer
3. ICT as an enabler of energy efficiency
   Example: Smart vending machines
4. ICT as an enabler of renewable energy integration
   Example: Smart heating and cooling
5. Conclusion

1. The energy efficiency of computation

Koomey's Law

Computations per kWh over time. Efficiency doubled every 1.57 years from 1946 to 2009.



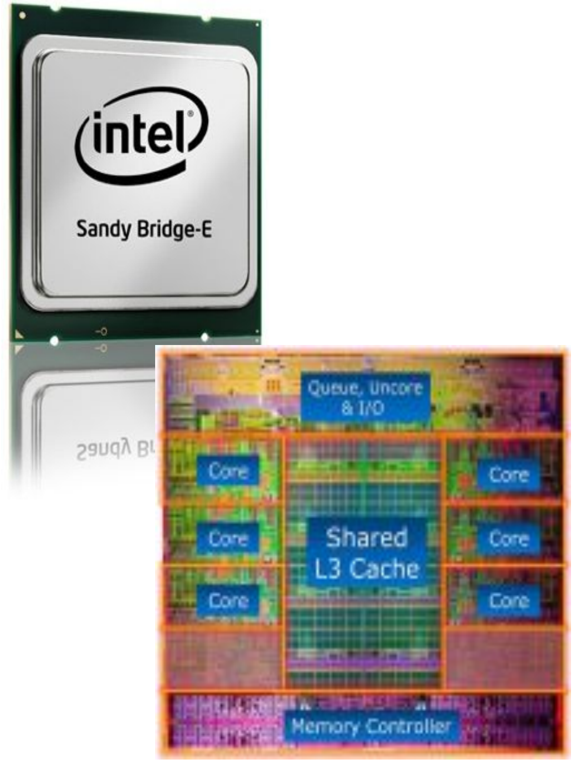
Source: Koomey, J., Berard, S., Sanchez, M., and Wong, H. (2011): "Implications of Historical Trends in the Electrical Efficiency of Computing" Annals of the History of Computing, IEEE, March 2011, Volume: 33 (3), pp. 46 - 54

Cray 1A Supercomputer (1976)
5.5 tons
160 MIPS / 115 kW

MIPS = Million Instructions Per Second

$ 7 900 000 Picture source: Wikipedia

Intel Core i7 3960X Microproc. (2012)
45 g
178 000 MIPS / 130 W



$ 990 Picture source: Wikipedia

Energy efficiency and prize

Power consumption per transistor 1971-2011:
decrease by factor **5000**

Price per transistor 1971-2011:
decrease by factor **50 000**

Energy efficiency of computation is increasing very fast,

but

the price of computation is decreasing even 10 times faster.

Source: Heikell, J.: A brief history of computing technology and related science. 2011.

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2. The energy efficiency of data transfer

The transfer of **1 Gigabyte** of data over the Internet causes an average consumption of electric energy of:

A:	**136 kWh**	57 h
B:	**7 kWh**	3 h
C:	**1.8 kWh**	45 min
D:	**0.2 kWh**	5 min

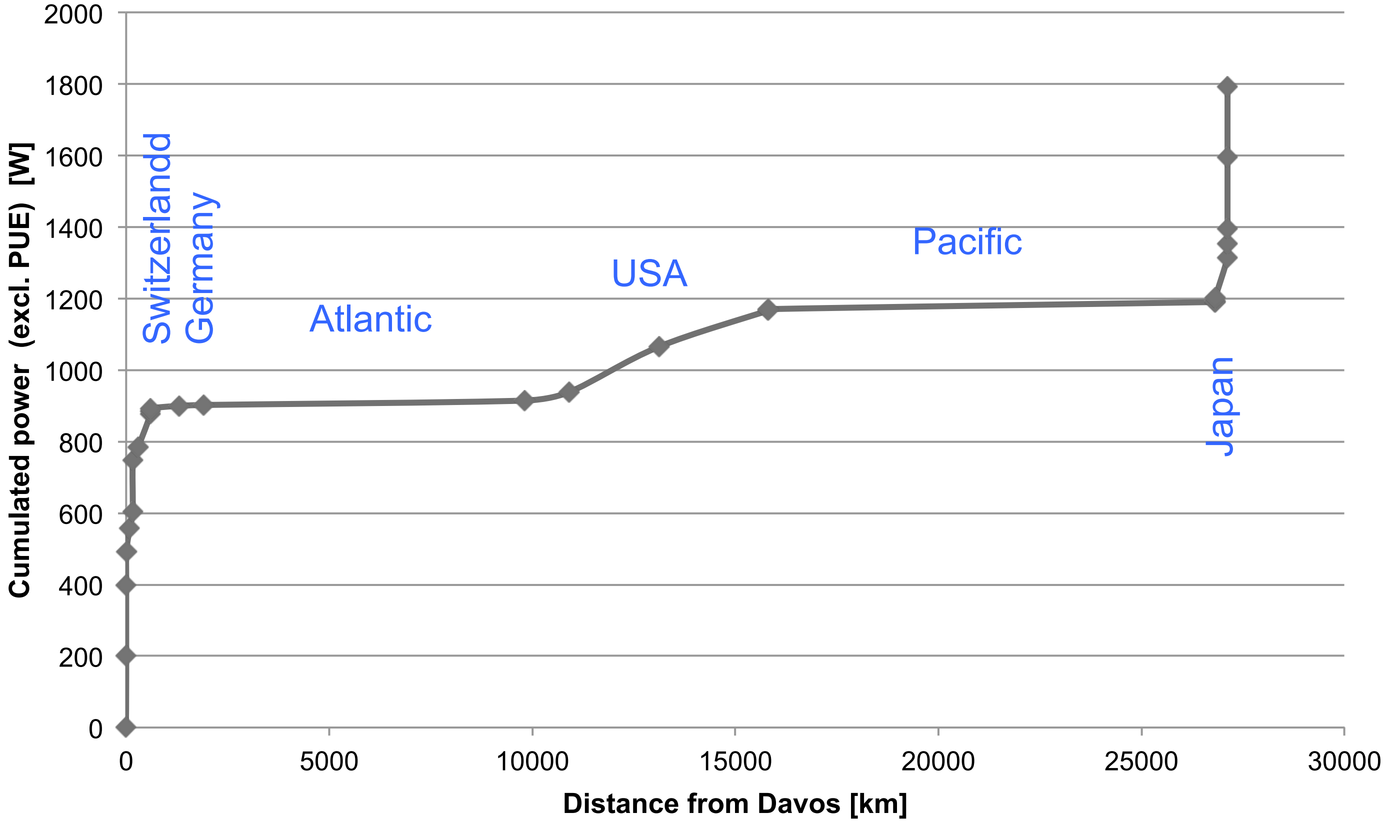
Different results in literature:

material submitted for publication

Assuming the relatively low value of 0.2 kWh/GB, one can estimate that 4 billion downloads of youtube videos per day result in a continuous power demand of 260-3000 MW.
(All Swiss households together consume approx. 2000 MW electricity.)

Energy and distance in the Internet

Case study in full HD videoconferencing at 40 Mbit/s
Davos (Switzerland) – Nagoya (Japan)



Source: own study, submitted for publication

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3. ICT as an enabler of energy efficiency
Example: The history of smart vending machines

Problem:

Studies in the 1990s reported that vending machines were using a relevant amount of electricity (e.g., 3.7% of electricity in Japan). Roughly half of this consumption could be attributed to refrigerated drink vending machines with poor energy management.

Solution:

Governments created incentives for industry to produce smarter, more energy-efficient vending machines.
Japan: Included vending machines in “Toprunner” program in 2002
US: Introduced “Energy Star” label for vending machines in 2004

ENERGY STAR

Effect:

Average **energy consumption per machine dropped by 54%** between 2000 and 2009, arriving at less then 4kWh/day.
→ How is this possible, and what does it mean at the macro level?

Success stories…

Quick Facts

State University of New York at Buffalo
132 vending machines

Annual Savings: $20,948
Annual Energy Savings: 261,849 kWh

The vending machines in Holyoke Center won't pour your soda for you, but they know you're there.

Features:

- Intelligent energy management
- Monitoring and fore-casting the ambient temperature
- Motion detectors to sense the presence of potential customers
- Remote monitoring for optimized servicing

The other side of the coin

The American anthropologist Joseph A. Tainter reports about a man who proposed a business model for vending machines:

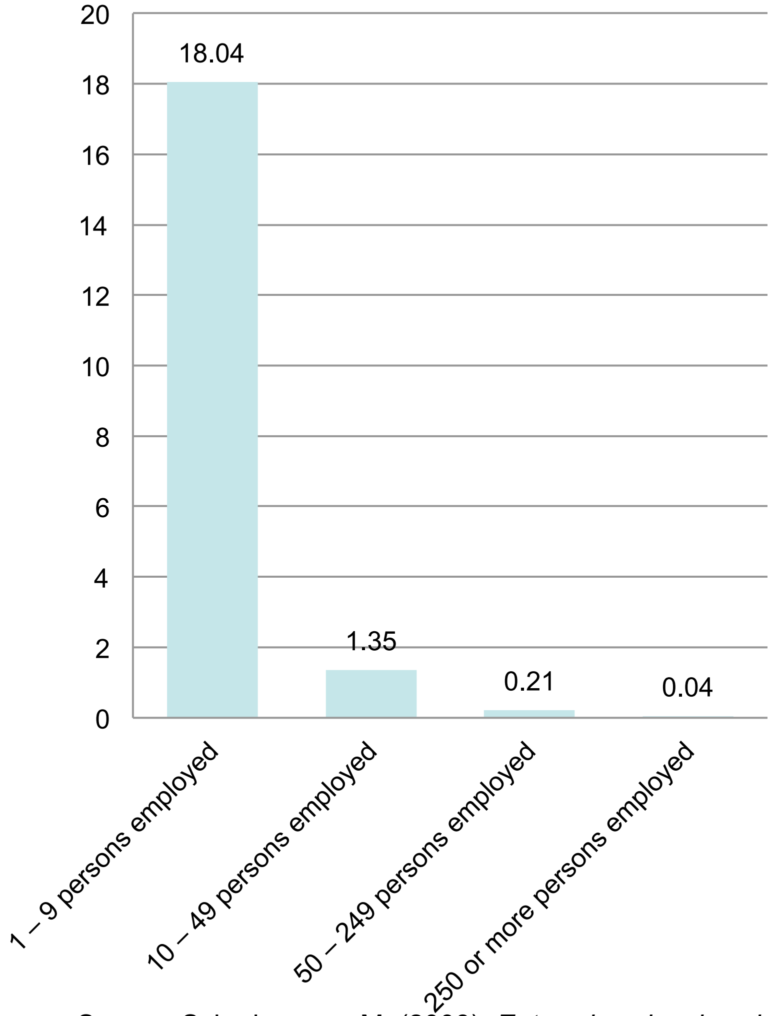
"His specialty was to place the machines in **small offices** where only a few people work. How, one might wonder, could one profit from placing these machines in small offices?

...

With reduced energy consumption, the machines can now be operated at a profit even in places where only a handful of people per day might purchase a soft drink."

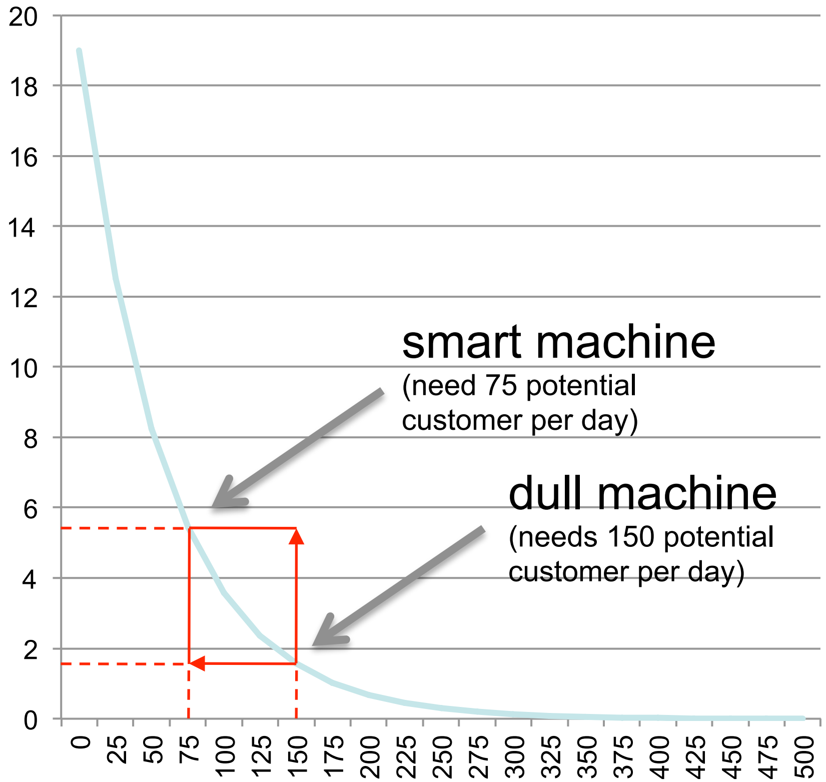
Source: J. M. Polimeny et al., The Myth of Resource Efficiency. Earthscan, London 2009

Number of enterprises in millions by size class (EU-27, 2005)



Source: Schmiemann, M. (2008). *Enterprises by size class - overview of SMEs in the EU.* eurostat. Statistics in focus, 31/2008, pp. 1. (non-financial business economy)

Number of profitable locations in millions by number of potential customers per day (idealized, EU data)



Under the assumption of a negative exponential distribution of the number of locations by the number of the potential customers of a vending machine, any factor of decreasing operating costs (factor 2 in the example) will lead to an overproportional growth in the number of profitable locations for the given type of machine.

Dynamics of the U.S. vending business

Vending machine manufacturers report annual growth rates of the vending business of about 10%, which means that the U.S. vending market **doubles almost every seven years.**

The annual growth rate of the **production of vending machines** in the U.S. is about 5%, i.e., every year more machines are produced than in the preceding year, which all are supposed to be installed and guzzle power for some years.

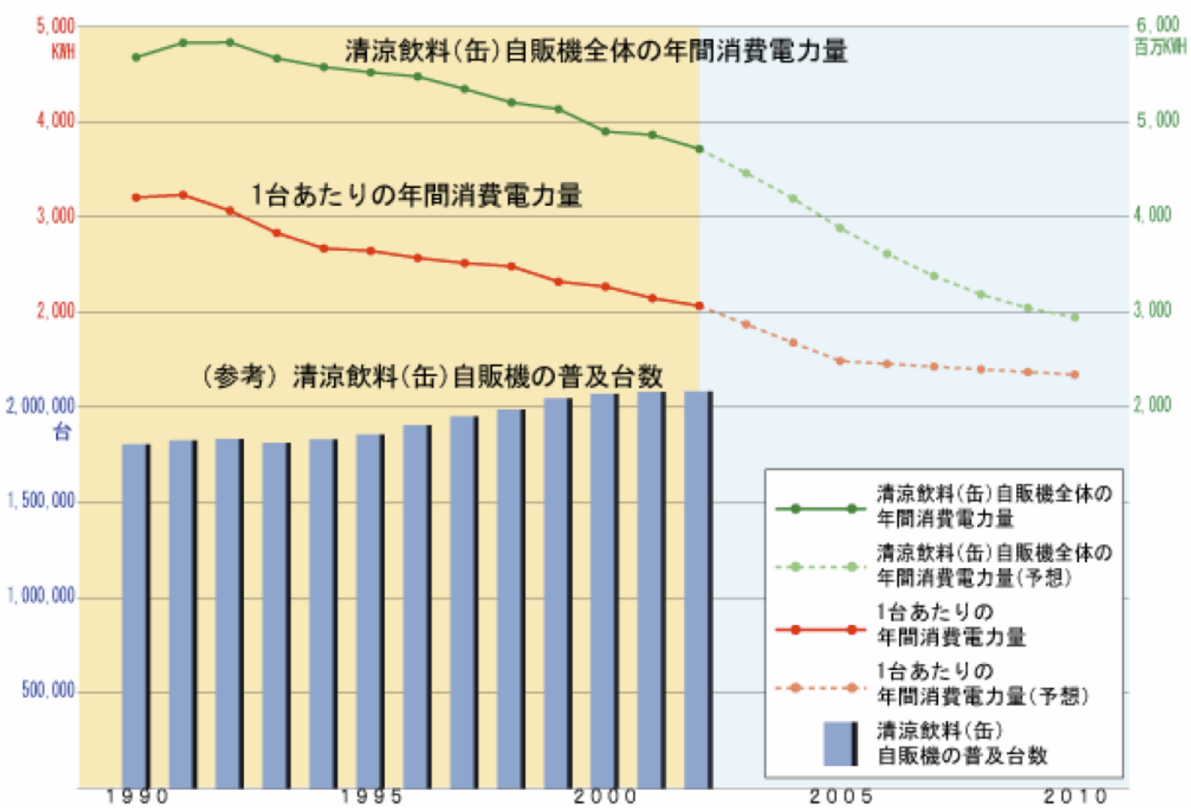
Sources:

US-Machine.com (2010): Vending Machines. http://us-machine.com/vending-machines.php (last accessed 14 July 2012)

Bool, H. (2006): Vending Machines, Ezine Articles, http://EzineArticles.com/204905 (last accessed 7 July, 2012)

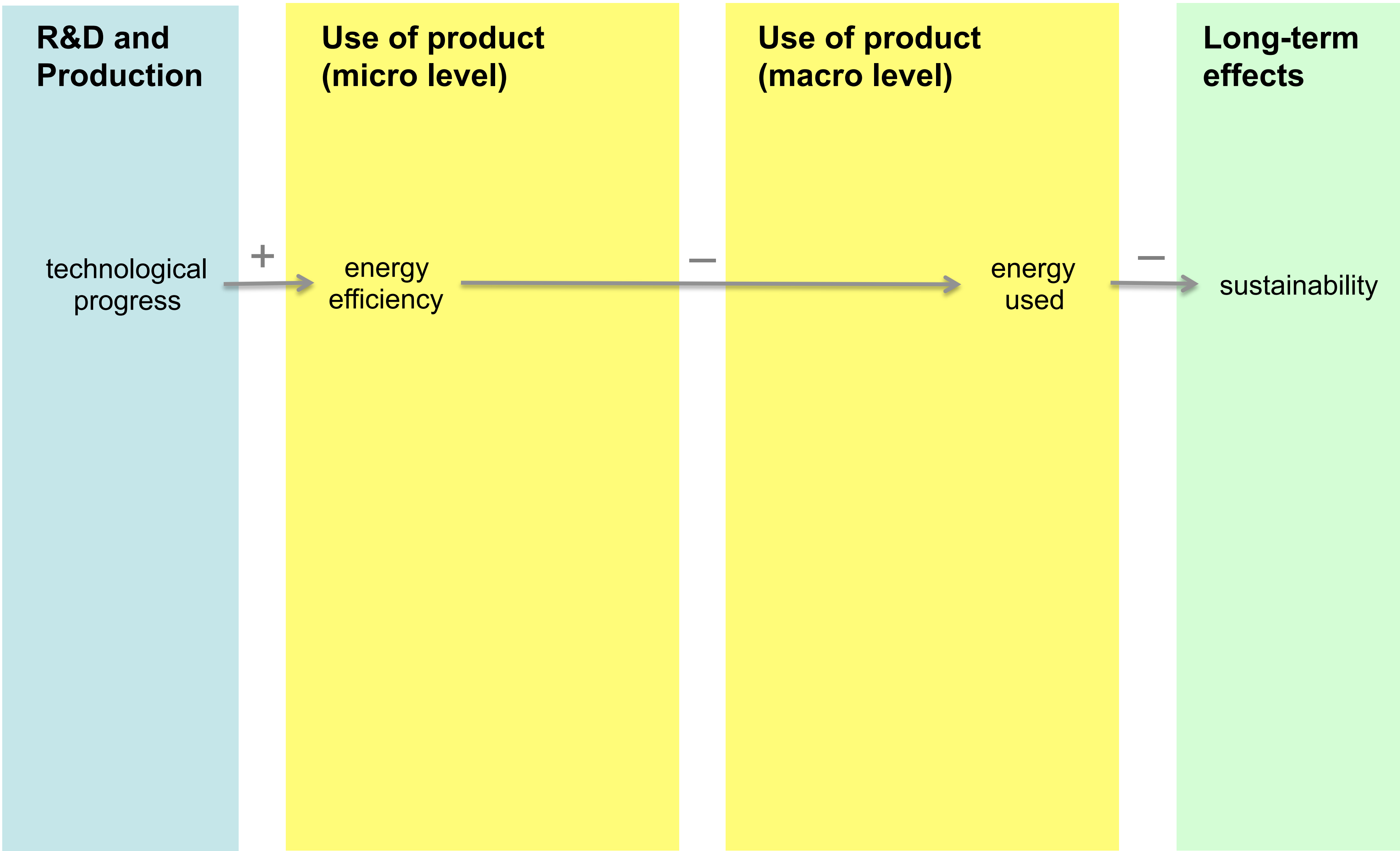
Development of Electricity Consumption of Soft Drink Vending Machines from 1990 to 2010 in Japan

Blue bars: Number of installed machines in 1000
Red line: Electricity use per machine in kWH/a
Green line: Total electricity consumption of the installed machines in GWh/a

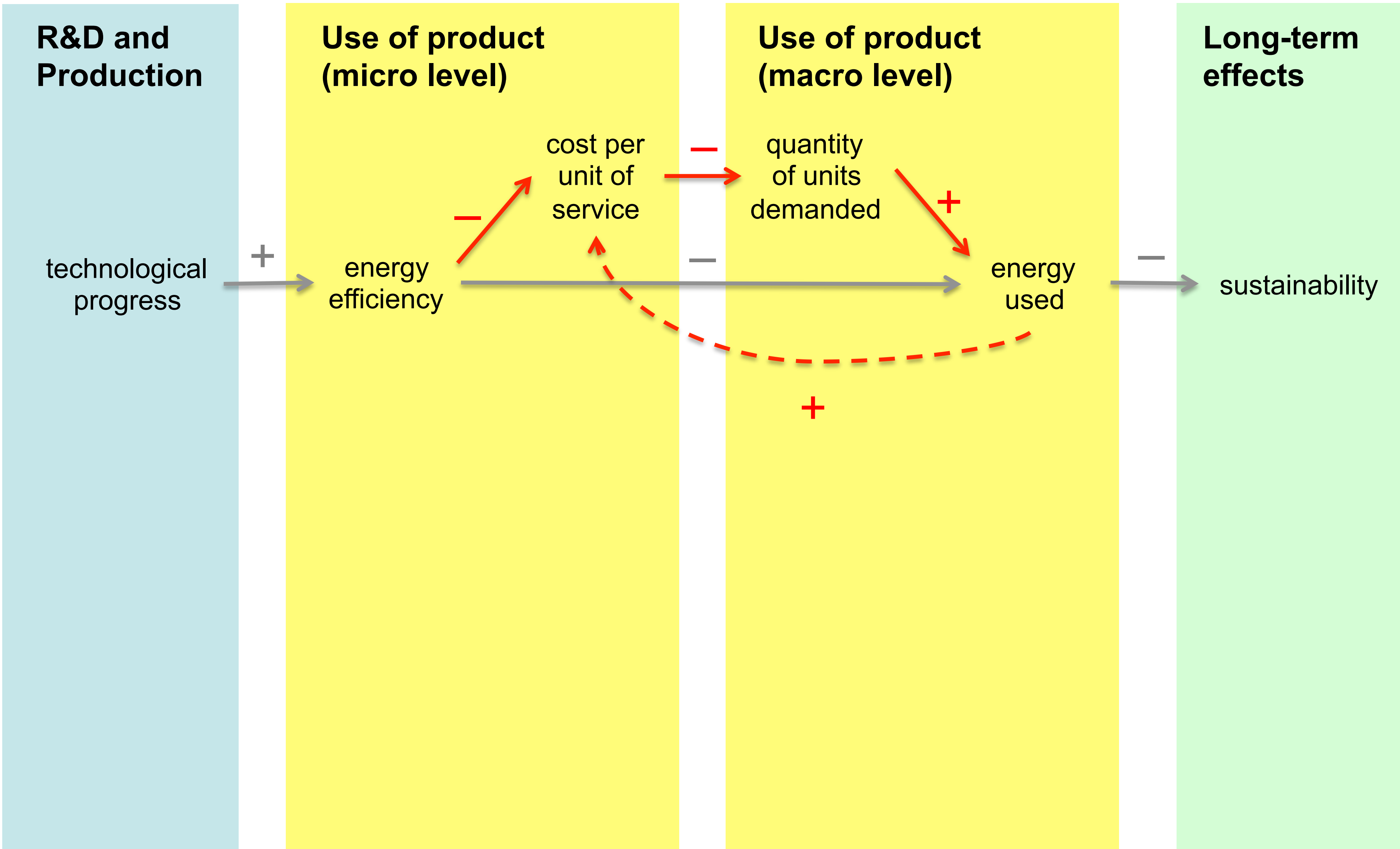


Source: Japanese Soft Drink Association

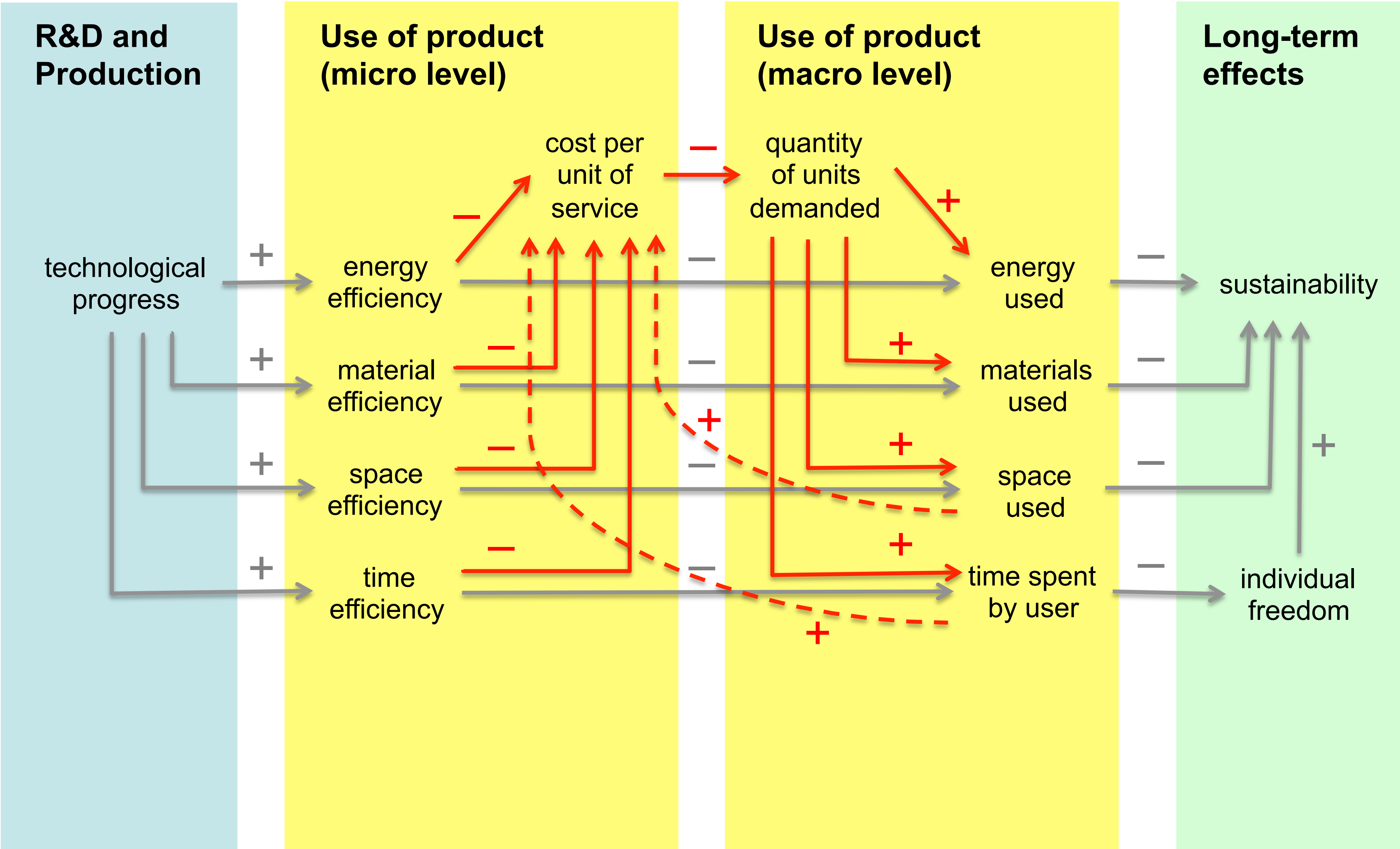
The mono-causal theory of energy efficiency (causal loop diagram):



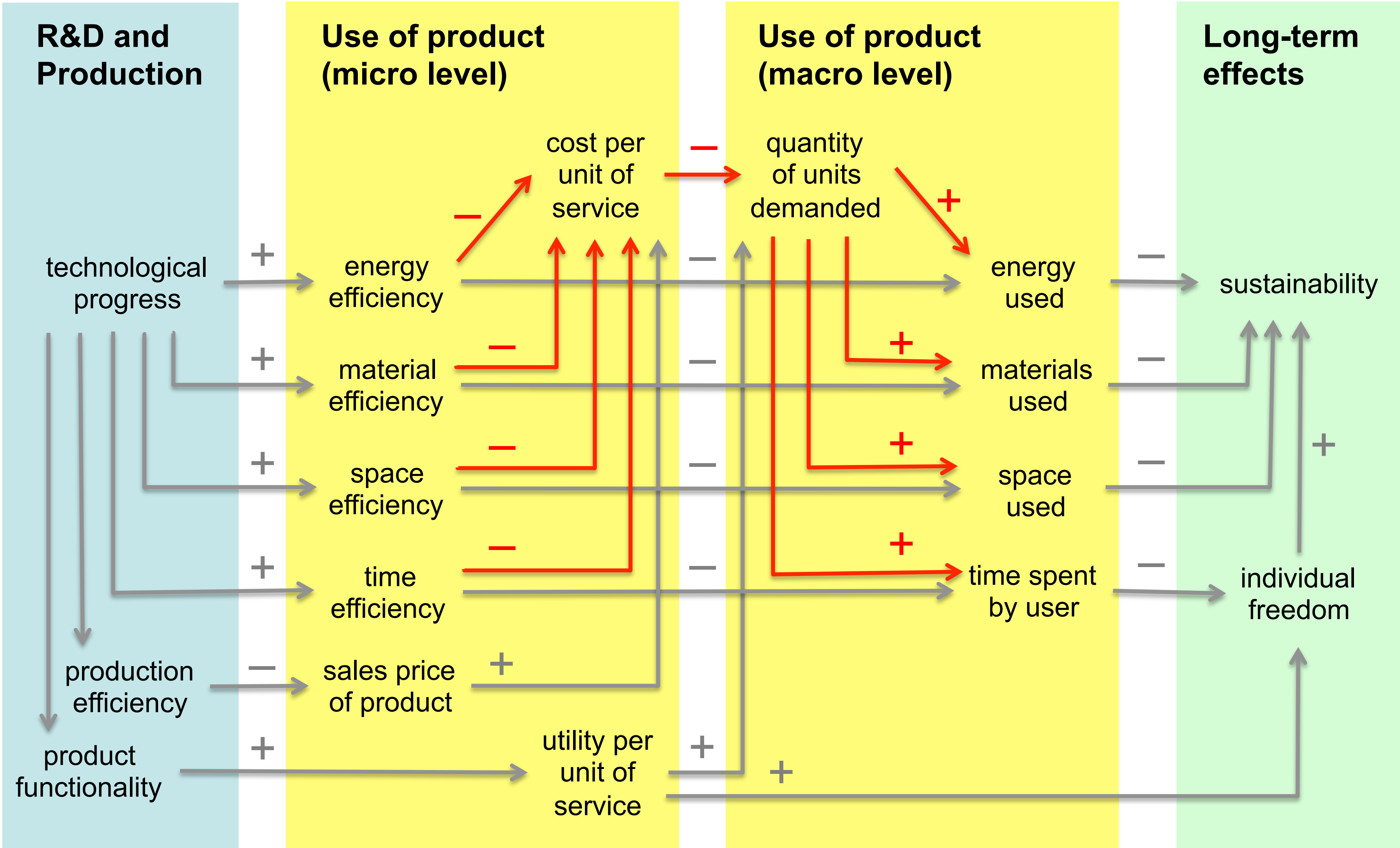
The rebound-effect theory of energy efficiency:



The generalized rebound-effect theory of energy efficiency:



The generalized rebound-effect theory of energy efficiency (completed):



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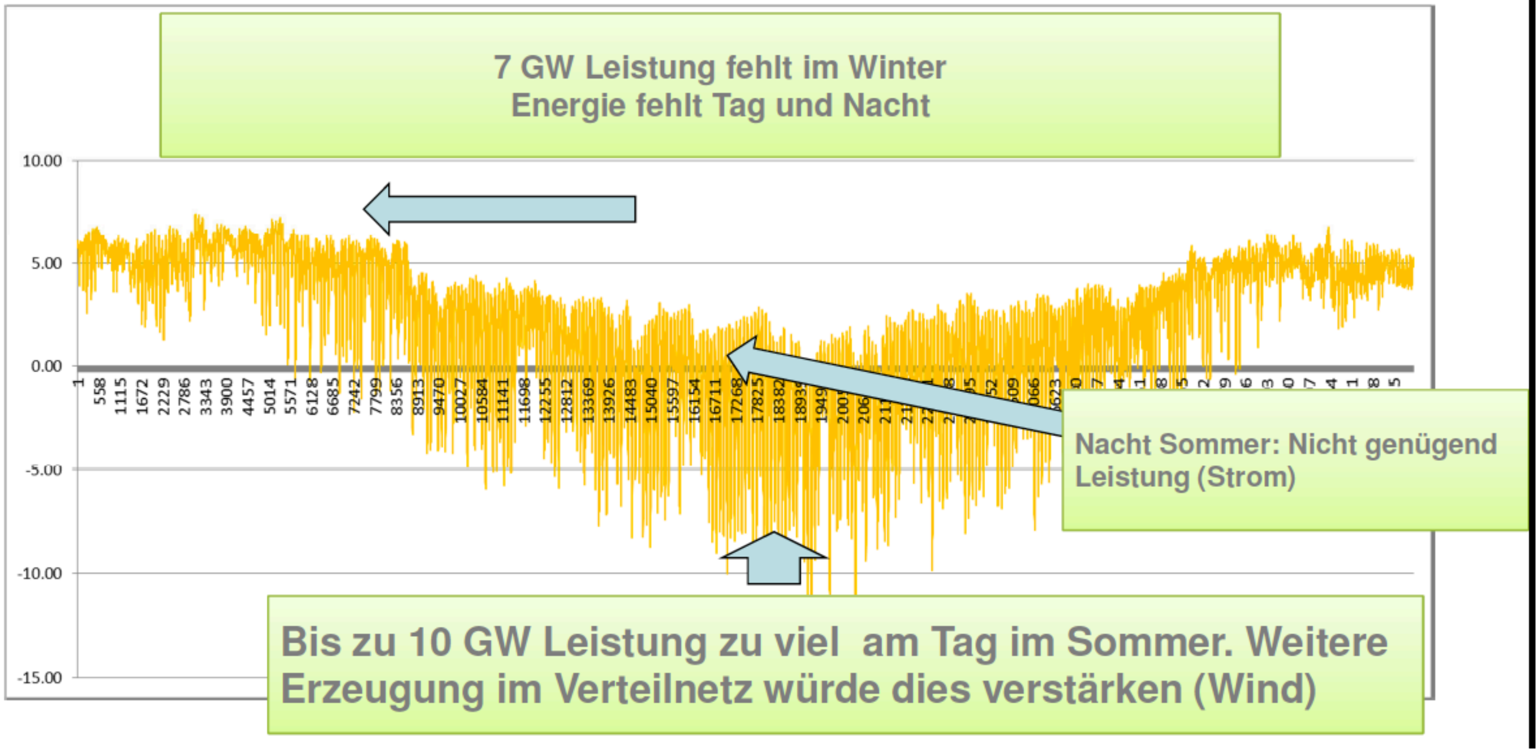
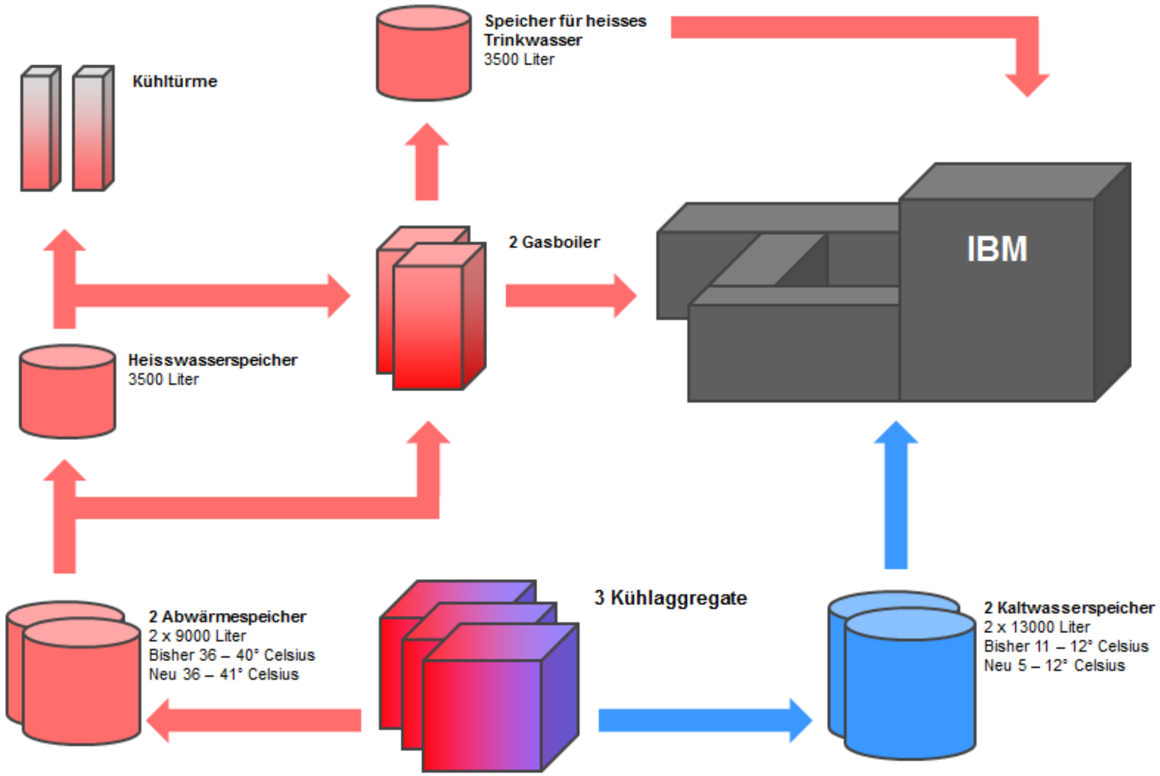
Example: Dynamics of power demand in Switzerland minus potential solar power that could be generated in Switzerland



Source: Rainer Bacher, Bacher Energie AG, 2012

Simulation of smarter heating and cooling in an existing office building



The heat pumps are used to produce cold and hot water at the same time. The ability to store both cold and hot water can be used to intelligently adapt to dynamic electricity prices.

Results

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Cold water storage 2 x 13 000 Liter

	Winter	Summer
Current situation (measured data)	43 398 kWh	92 2167 kWh
Simulation Results		
New Control Strategies	37 054 kWh	76 979 kWh
Dynamic Electricity Pricing	31 770 kWh	76 138 kWh

Not only energy cost, but also energy could be saved due to better *internal* coordination of demand and supply of hot and cold water

Source: Rasathurai, S. Improving on the Electricity Costs of Office Buildings by Optimal Smart Grid Integration, University of Zurich 2012

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- Energy efficiency may be a necessary, but is not a sufficient condition to reduce energy consumption at the macro level.
- The effects of increased technical efficiency should be analyzed with regard to all resources relevant to the user: energy, material, space and time.
- Not all energy is equal. Energy has qualities such as storability, transportability, convertibility, and temporal patterns of supply. More important than technical energy efficiency may be the efficiency of the **coordination mechanisms** for energy supply and demand, which can be supported by ICT.

Thank you for your attention !

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ETH Zurich, Switzerland

February 14 – 16, 2013

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Further Reading

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