CLEEN
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Smart Grids and Energy Markets

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Energy Efficiency

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Institute of LUT Energy
Energy Technology | Electrical Engineering | Environment Technology

Contents

- Efficient use of energy – definition, drivers and impacts
- Possibilities to increase the efficiency of the energy usage in different sectors
  - Heating & cooling
  - Home & office appliances
  - Lighting
  - Industrial and service sector applications
  - Transportation & work machines

Energy efficiency

- Increasing energy efficiency : Same level of the energy service is achieved with less amount of the (primary) energy
- Typical problem in the energy consumption is Jevon's Paradox:
  - When improvements in technology make it possible to use fuel more efficiently, the consumption of fuel tends to go up, not down.

Energy efficiency – environmental impacts in energy chain

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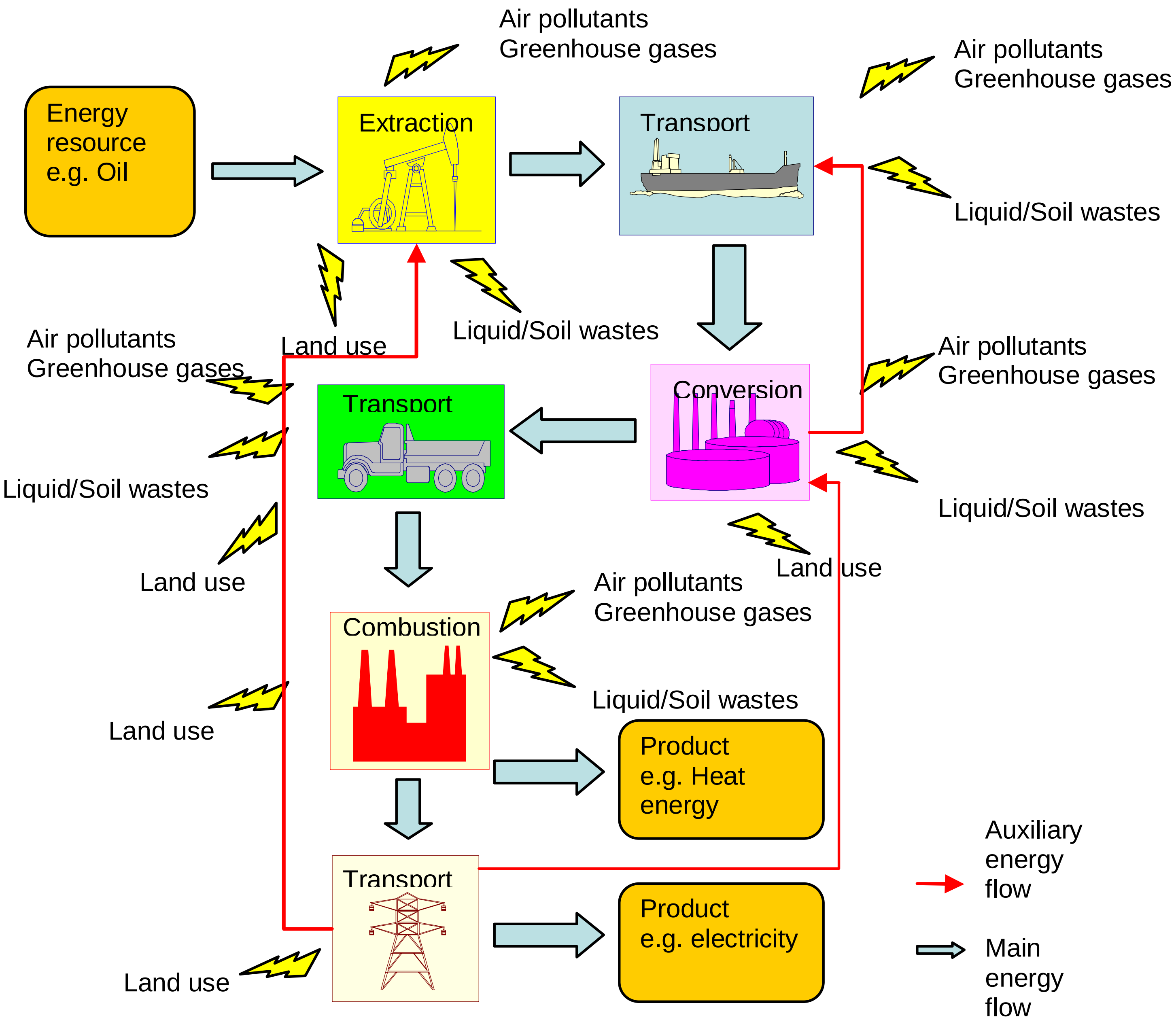

Öko-Institut 2007

Efficiency in energy chain

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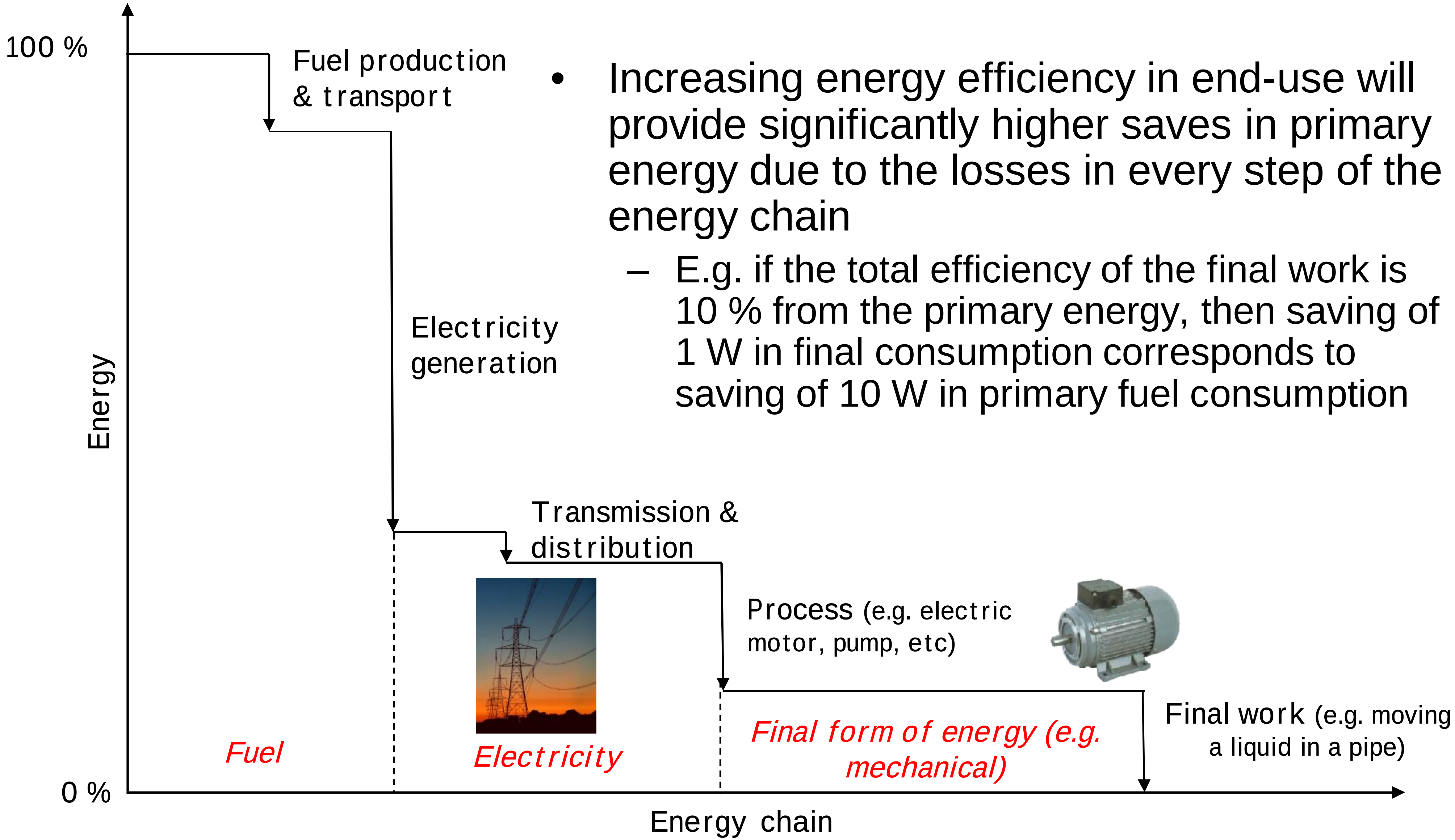
- Increasing energy efficiency in end-use will provide significantly higher saves in primary energy due to the losses in every step of the energy chain
  - E.g. if the total efficiency of the final work is 10 % from the primary energy, then saving of 1 W in final consumption corresponds to saving of 10 W in primary fuel consumption



Drivers for energy efficiency

- Sustainability of living standards
- Fossil fuel depletion
- Energy security
- Competitiveness of EU industry
- EU legislation (e.g. lighting directive)
- Taxation of energy usage
- Life cycle cost thinking
- Attitudes of people against wasting resources of nature
- Environmental disasters due to the extraction of fuels
- Decreasing the amount of energy related emissions

Energy efficiency in end use and production

Emissions = Number of people X GDP/person X Energy/GDP X Emissions/energy

Drivers for energy efficiency

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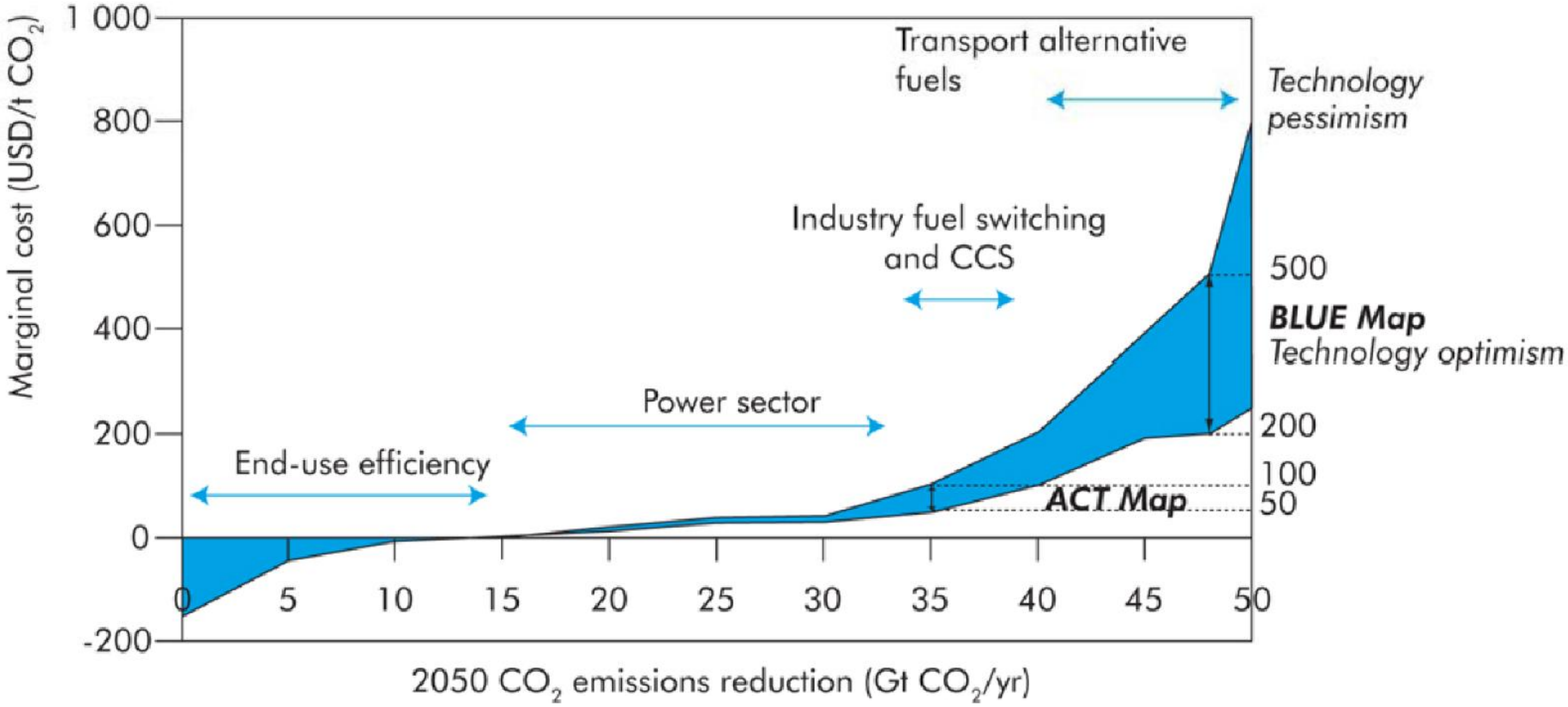
- Possibilities to reduce CO_2 emissions with negative costs



Energy Technology Perspectives 2008, International Energy Agency 2008

Energy efficiency

- Gross Domestic Product (GDP) is in relation with energy usage
  - The slope can be changed by increasing energy efficiency

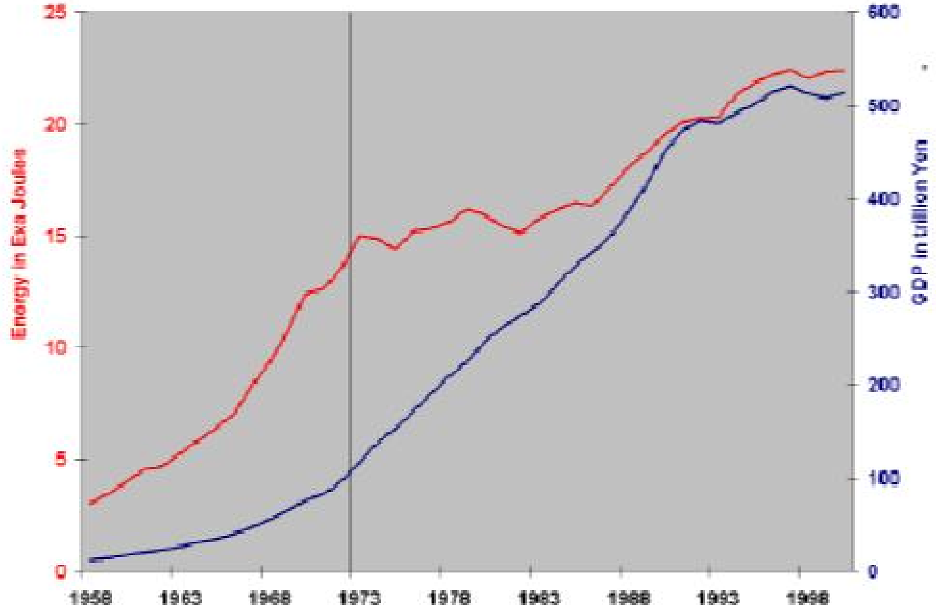


Figure 1. Japanese GDP and energy consumption 1958-2000. [1]

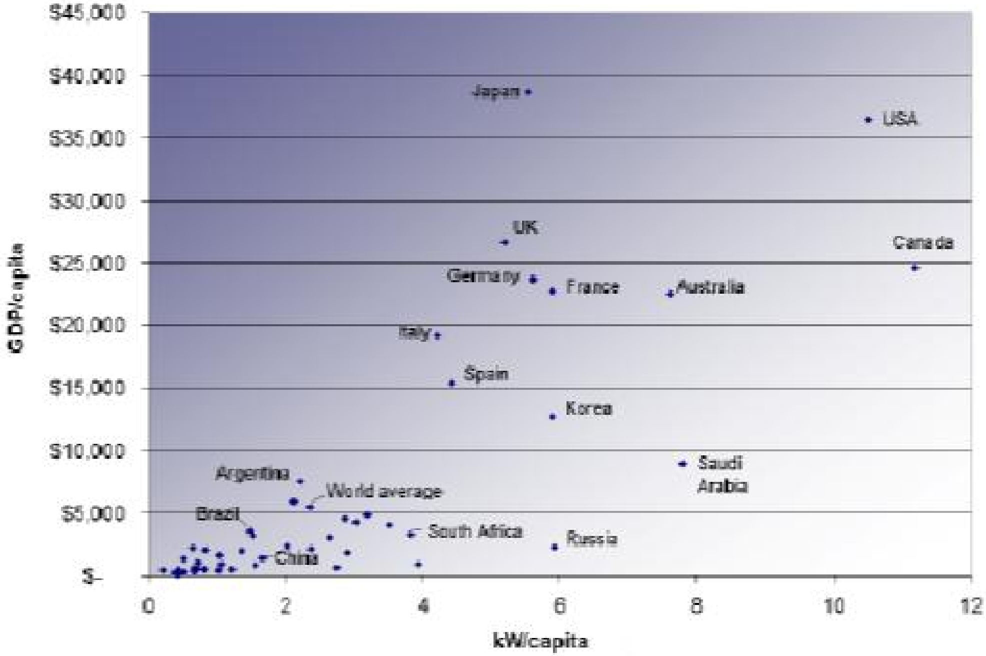


Figure 2. GDP and (P/capita) [1]

[1] Wikipedia: World energy consumption

Energy and electricity intensity in Finland

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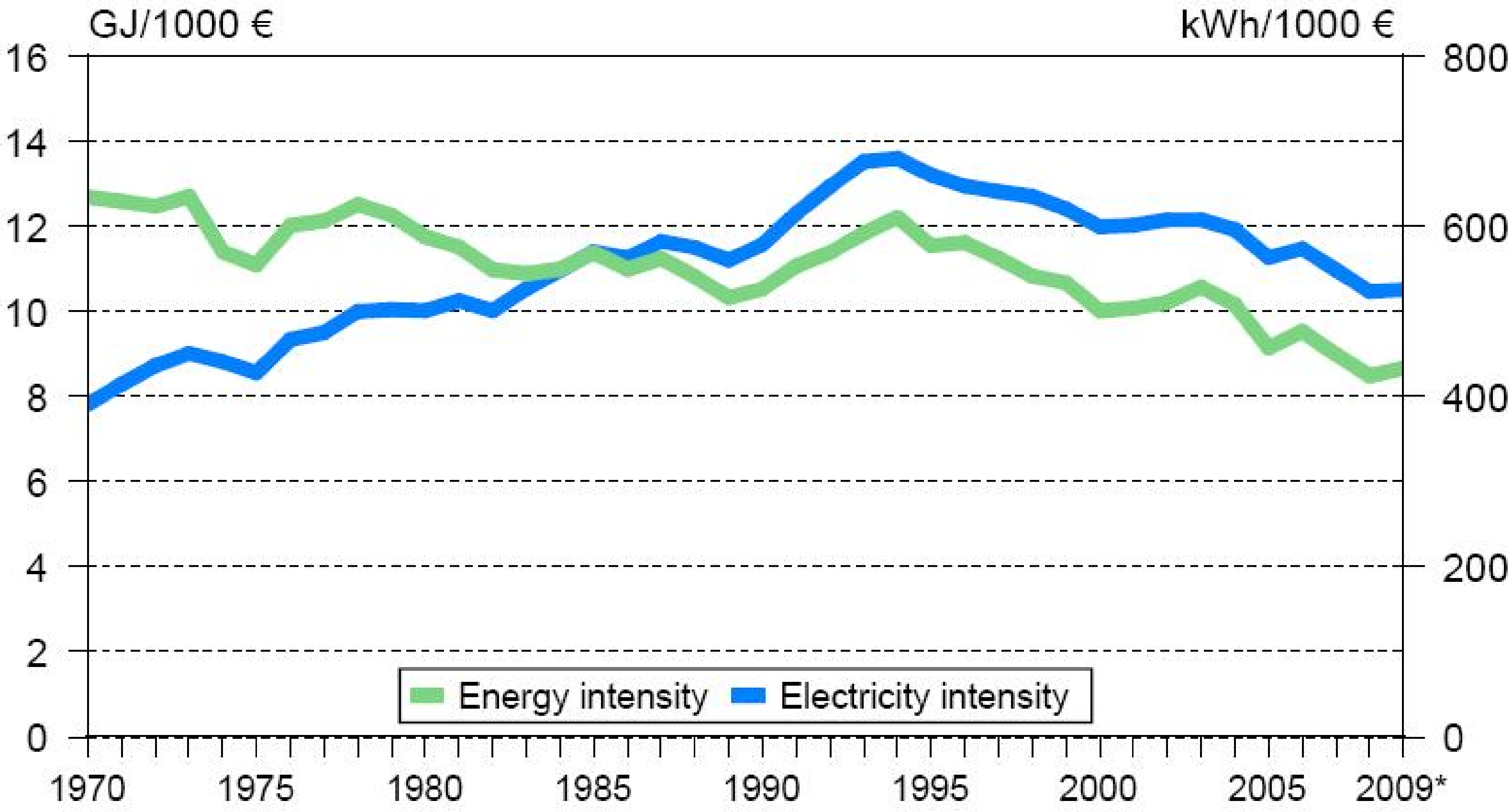

Statistics Finland

Energy efficiency

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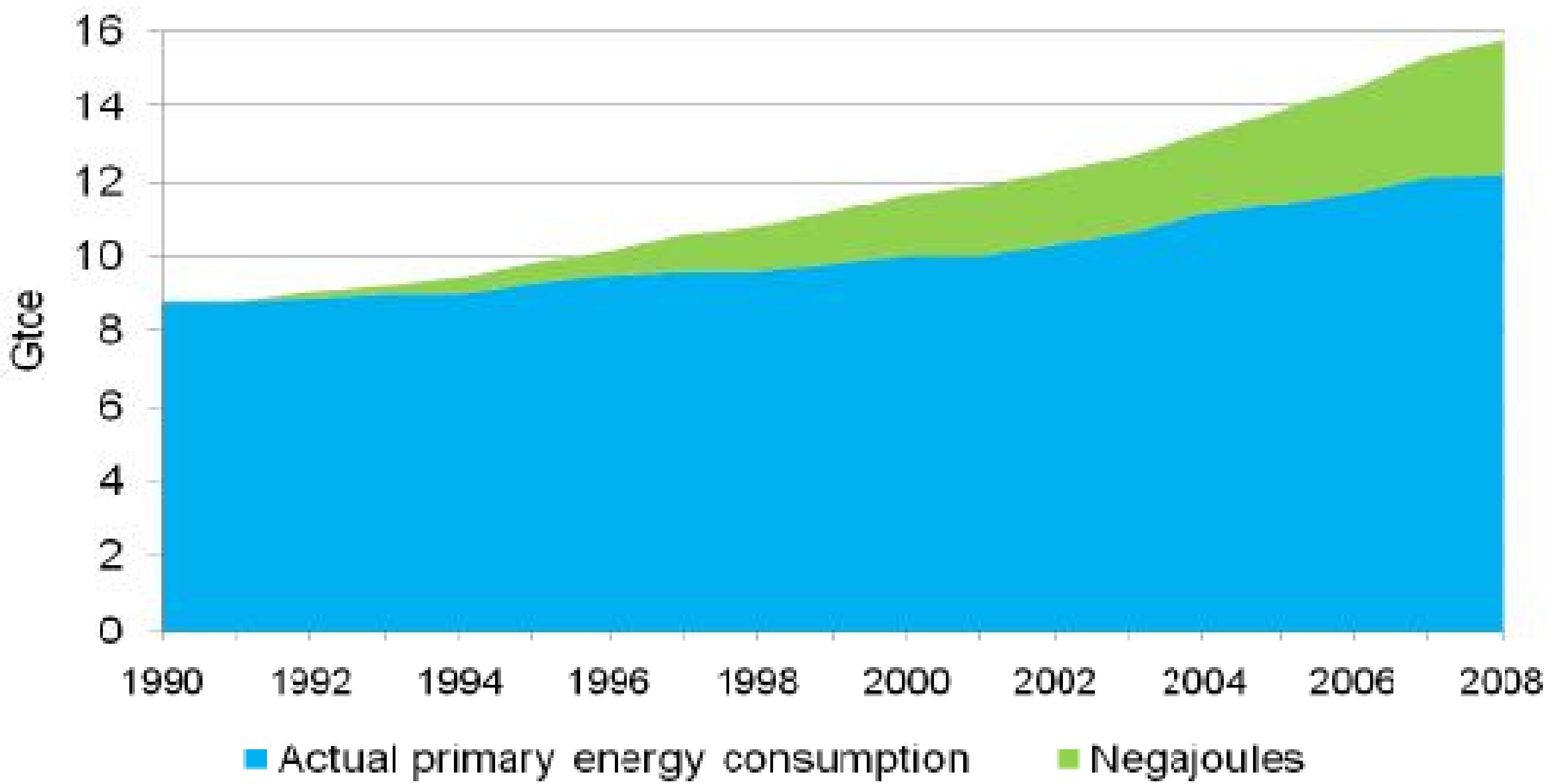
Energy savings from energy intensity decrease worldwide



WEC 2010

Energy intensity trends worldwide

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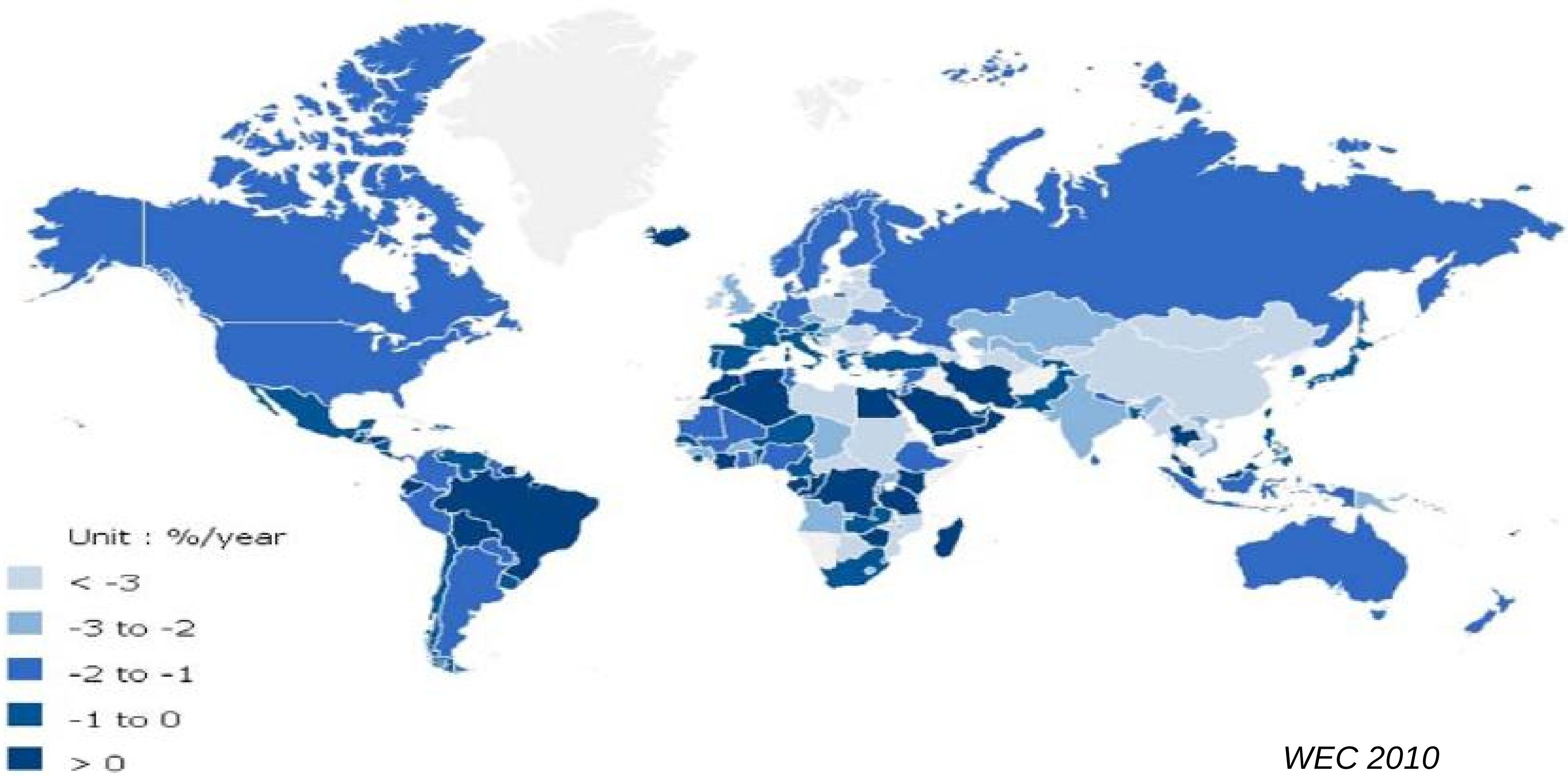
Primary energy intensity trends by country 1990-2008



WEC 2010

Energy efficiency worldwide - Average efficiency of thermal power plants by country (%) in 2008

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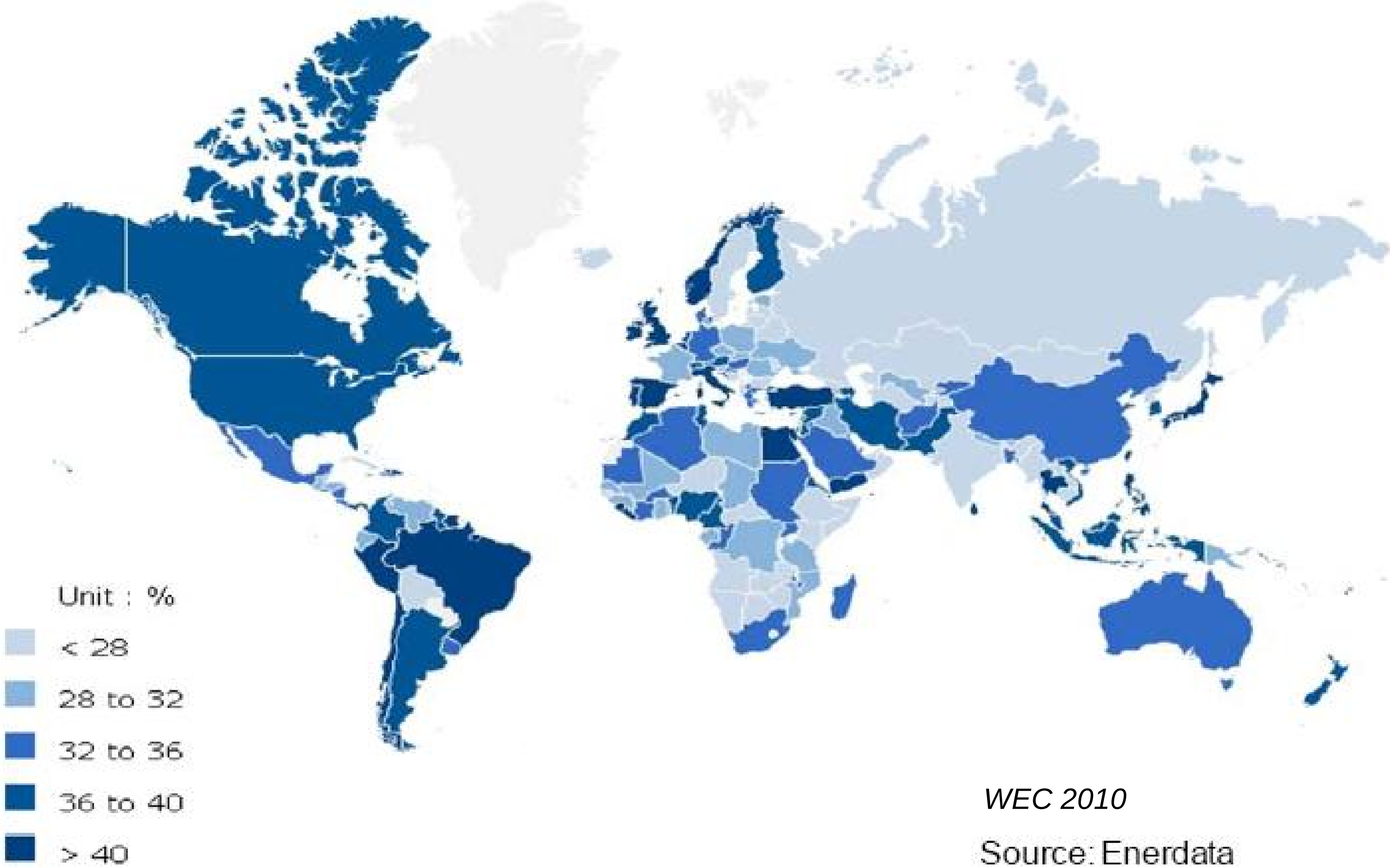
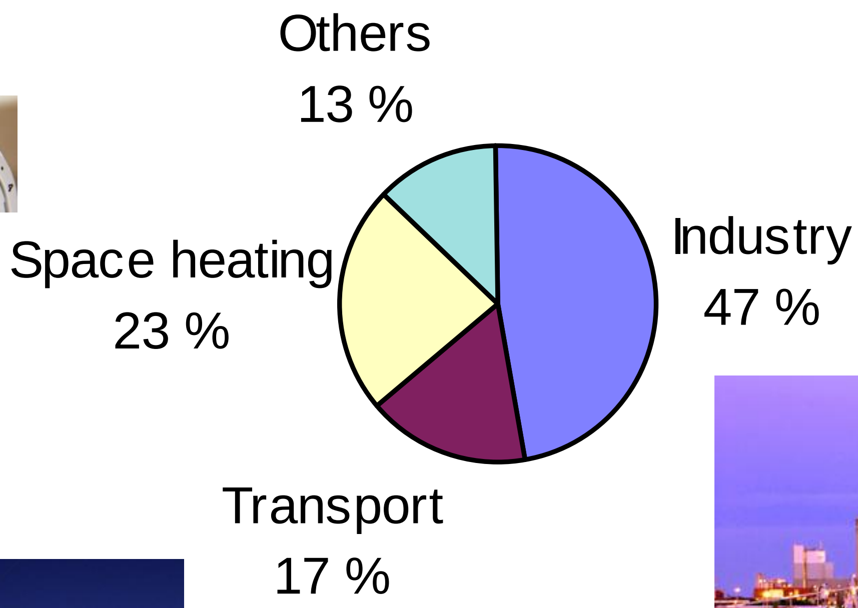


WEC 2010

Source: Enerdata

Final energy consumption in Finland in 2009



Statistics Finland

Energy efficiency potential in heating

- Decrease the heat demand of the buildings
  - Better insulation; low energy and passive houses
  - Use of passive heat sources (e.g. solar)
  - Tightening of the building standards
  - Heat recovery in ventilation
  - Typically needs rebuilding or renovation => slow changes

- More efficient heating methods
  - Decrease the losses in the heating process
    - Boilers, pipes, etc.
  - Improve the dimensioning and control
    - Thermostat type and settings
  - Heat pumps and other renewable energy sources
  - Possibilities for quite quick changes (e.g. heat pumps)

Energy efficiency and demand in heating

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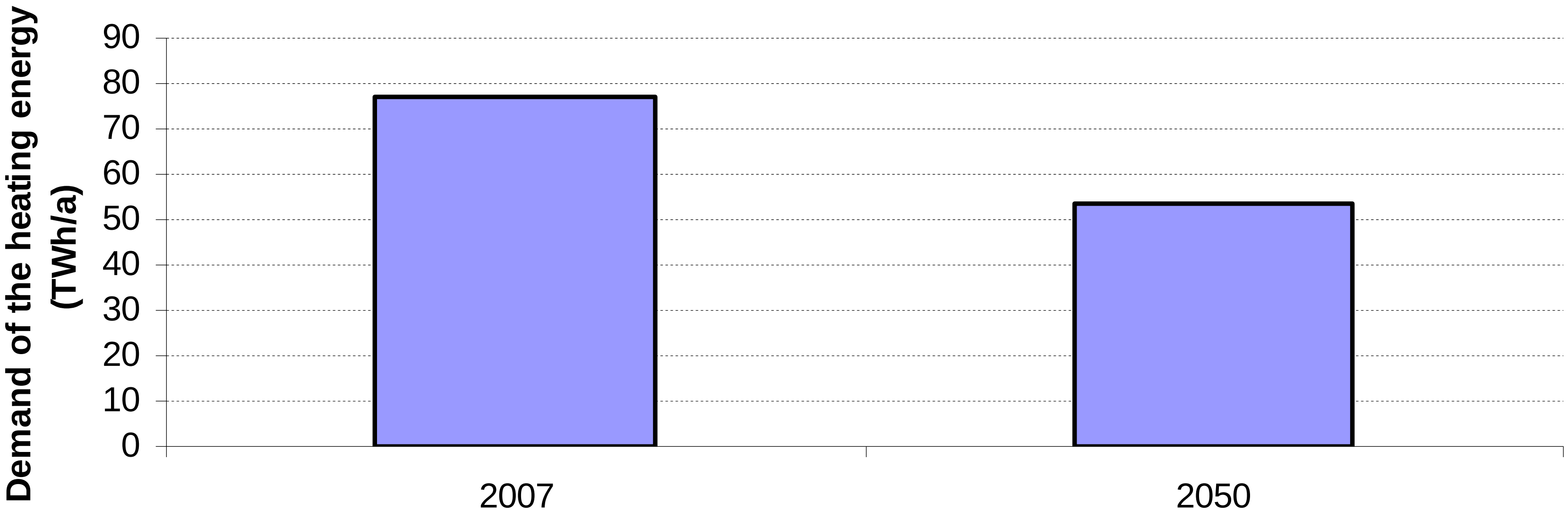
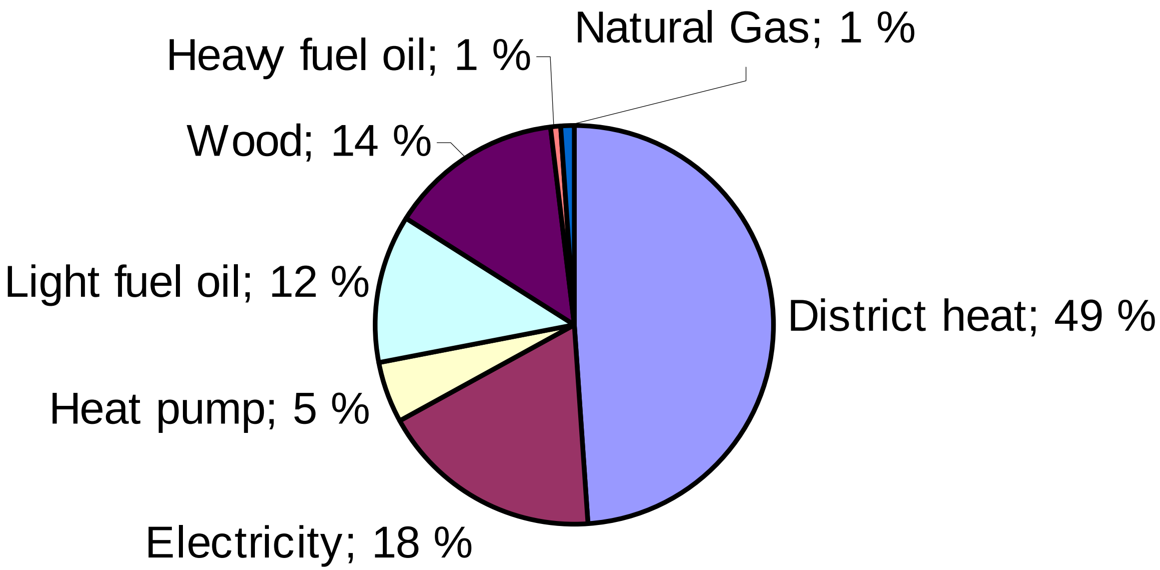
Total heating energy demand of the Finnish building stock is estimated to decrease by 30 % by the year 2050, although the amount of the heated space is estimated to increase. Reasons:

- Improved insulation of the buildings
- Improved efficiency of the heating technology
- Global warming



Heating energy of residential, commercial, and public buildings in Finland in 2009



Statistics Finland

Energy efficiency of the heating systems - District heating

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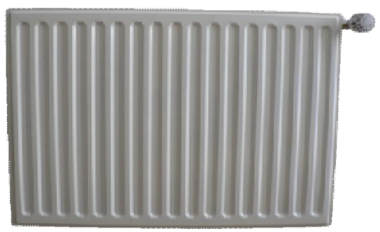
- System level impacts important
  - Demand of the district heat enables CHP production => higher efficiency of the electricity generation
    - Efficiency in CHP over 90 % vs. efficiency in condensate power ~ 40 %
    - ~30 % of the electricity used in Finland is produced by CHP
  - High variety of the potential fuels (natural gas, coal, peat, biofuels, oil, waste, etc.)
    - Emission level depend on the fuel
  - Heat losses (in average 9 % of energy, 270 kWh/m) and investment costs of the distribution network => profitable only in the densely populated areas
- For end user
  - Availability issues
  - High fixed costs (connection cost, heat exchanger, fixed charge), but low energy cost
  - Easy to use
    - No need for fuel tanks, minor maintenance needs



Energy efficiency of the heating systems - District heating

- Future development possibilities – smart grid for district heating and cooling
  - District heating and cooling network as interactive infrastructure, which connects different heat and cold sources into the demand
    - Small- and large scale heat and cold production, waste heat and heat recovery from different sources, solar heat, ground heat, heat and cold storages etc.

DHC+

District heating – fuel consumption savings due to CHP

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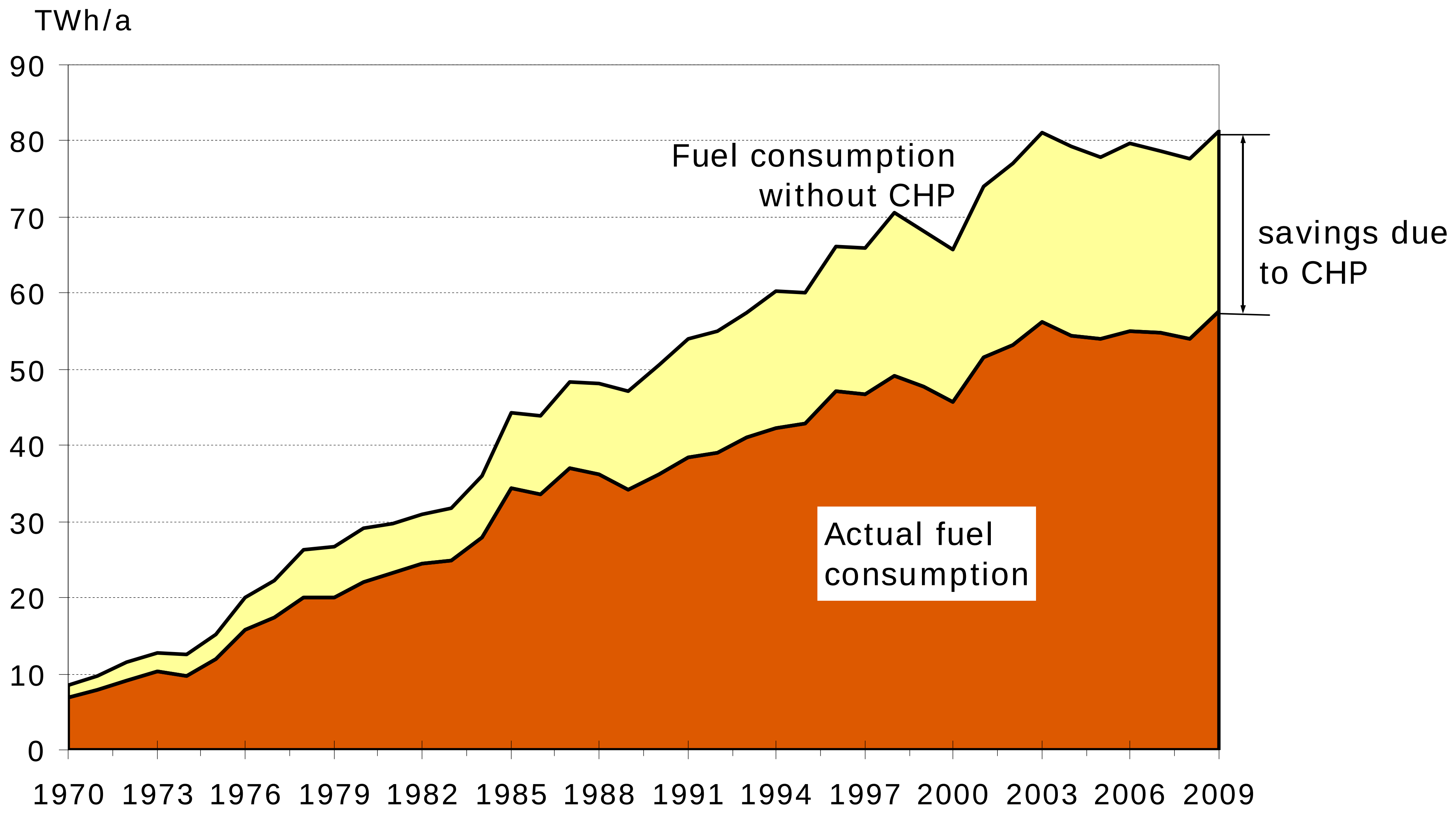

Finnish energy industries

Energy efficiency of the heating systems - Oil

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- Boiler and water circulation based central heating
  - Radiators, under floor heating, heating of the tap water
  - Some amount of electricity needed for pumps (typically ~600 kWh/a)
- Fossil fuel => CO_2 emissions
- High volatility in fuel price, imported fuel
- Space needs for fuel tank and heat accumulator
- Some need for maintenance
- Efficiency ~85…90 %
- Renovation possibilities
  - Fuel change to wood or other biofuels
  - Installing the heat pump or solar water heater for secondary heat source

Energy efficiency of the heating systems - Wood

- Pellets, woodchips or chopped firewood
- Boiler and water circulation or wood stove
- No CO_2 –emissions (in GHG calculations), some small particle emissions (depending on combustion technology)
- Domestic and renewable fuel
- Space needs (for heat accumulator and store for wood)
- Maintenance needs
- High investment costs, modest fuel costs
- Efficiency ~ 75 % (varies significantly)
- Secondary heating method in many detached houses
- Electricity needed for pumps in case of water circulation

Energy efficiency of the heating systems - Electricity

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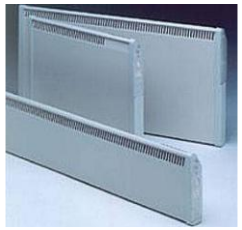
- Direct or accumulating
  - Electric heaters or central heating based on water circulation
- Efficiency and CO_2 emissions depend on the electricity production technology and fuel
- High volatility in fuel price (at present short term price fluctuation only in wholesale markets)
- Low investment costs in direct electrical heating
- System level impacts
  - In direct electric heating, highest demand in many cases during system peak hours
  - Possibilities for demand response in case of accumulating electric heating
- Typical energy saving actions to install heat pump and/or use wood as supportive heating source



Energy efficiency of the heating systems – Air-source heat pumps

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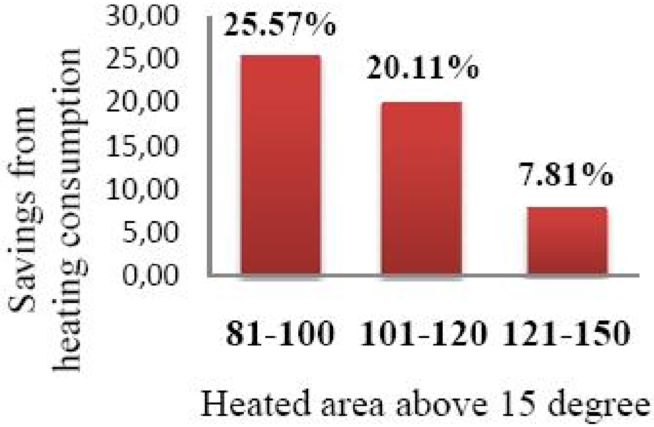
- Air-to-air, air-to-water or exhaust-air heat pumps
- Air-to-air is most common heat pump type in Finland
- Secondary heating method; needs some primary heating source (electricity, oil, wood…)
  - About 80 % of air-source heat pumps in Finland are installed in direct electric heated buildings
- Commonly used also for cooling
- Typical SPF (seasonal performance factor) in Finnish climate
  - Air-to-air heat-pump 1.8…2.2
  - Air-to-water heat pump 1.5…2.0
  - Exhaust-air heat pump 1.5…2.2



Lehtonen, M., Aalto-university

Energy efficiency of the heating systems – Ground source heat pumps

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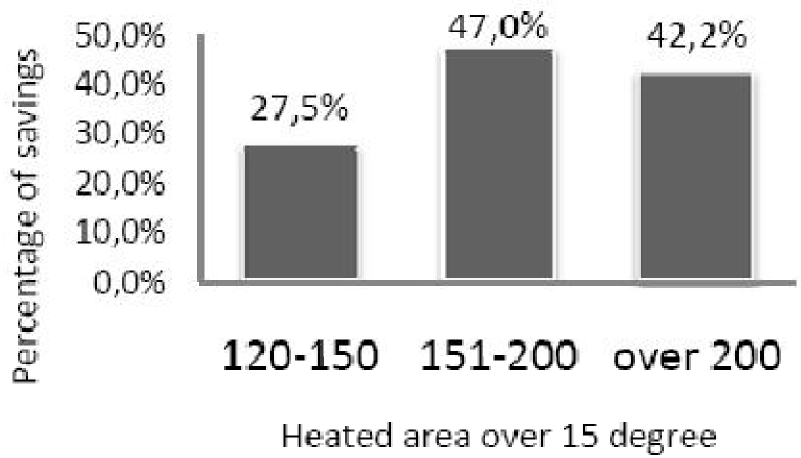
- Ground, rock or water as heat source
- Highest efficiency in under floor heating, due to the low temperature of the circulating water
- Full or partial power dimensioning
- Produces 85..98 % of the annual heat energy demand
- Support of the electrical heating needed only occasionally and for final heating of the tap water
- Typical SPF in Finland 2.6…3.3

$$COP_C = \frac{\Phi_{Hot}}{P} = \frac{\Phi_{Hot}}{\Phi_{Hot} - \Phi_{Cold}} = \frac{T_{Hot}}{T_{Hot} - T_{Cold}}$$



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Air-source heat pumps in Finland

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Year	Amount	Heating capacity [MW]	Generated heat [GWh]	Consumed electricity [GWh]	Utilized primary energy [GWh]
1995	252	0,66	5,11	2,63	2,48
1996	506	1,34	11,19	5,75	5,44
1997	958	2,54	20,23	10,40	9,83
1998	1 662	4,41	35,20	18,11	17,09
1999	2 214	5,87	45,23	23,26	21,96
2000	3 014	7,99	53,90	27,73	26,17
2001	3 968	10,52	82,29	42,31	39,98
2002	5 872	15,57	123,57	63,53	60,05
2003	10 876	28,83	230,13	118,25	111,89
2004	18 876	50,03	403,08	207,06	196,02
2005	35 880	95,10	730,28	375,05	355,23
2006	65 880	174,60	1 356,28	696,84	659,44
2007	102 880	247,00	1 865,00	958,00	906,00

http://www.sulpu.fi

Ground source heat pumps in Finland

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Year	Amount	Heating capacity [MW]	Generated heat [GWh]	Consumed electricity [GWh]	Utilized primary energy [GWh]
1995	14 077	300,10	1 042,00	359,30	682,70
1996	14 331	306,10	1 117,40	385,30	732,10
1997	14 731	314,70	1 131,90	390,30	741,60
1998	15 434	329,70	1 216,10	419,30	796,70
1999	16 339	350,10	1 237,40	426,70	810,70
2000	17 539	375,80	1 174,20	404,30	769,30
2001	19 016	406,80	1 441,00	480,30	960,70
2002	20 495	437,80	1 567,90	522,60	1 045,20
2003	22 695	484,90	1 710,20	570,10	1 140,10
2004	25 600	548,20	1 962,00	654,00	1 308,00
2005	29 106	624,30	2 104,30	701,40	1 402,90
2006	33 612	721,90	2 502,10	834,00	1 668,10
2007	38 906	831,00	2 815,00	983,00	1 877,00

http://www.sulpu.fi

Energy efficiency of the heating systems - Heat pumps

- Impacts of heat pumps on energy and power
  - In all cases, the consumption of primary energy decrease
  - When installed in electric heated building, heat pump decrease the demand of the electrical energy
  - In other than electric heated building, heat pump increase the demand of the electrical energy
  - In cold winter days, air-source heat pumps cannot generate heat => peak-load remain the same, or even increase
  - Ground source heat pumps (dimensioned for full power) can reduce also the peak-power demand
  - => full-power dimensioned heat pump best from the system viewpoint
- If energy demand decrease but power demand remain the same:
  - Savings in energy costs, but production capacity and grid dimensioning remain the same
  - Peak load production expensive and in many cases inefficient with high emission levels

Energy efficiency of the heating systems – System impacts of heat pumps

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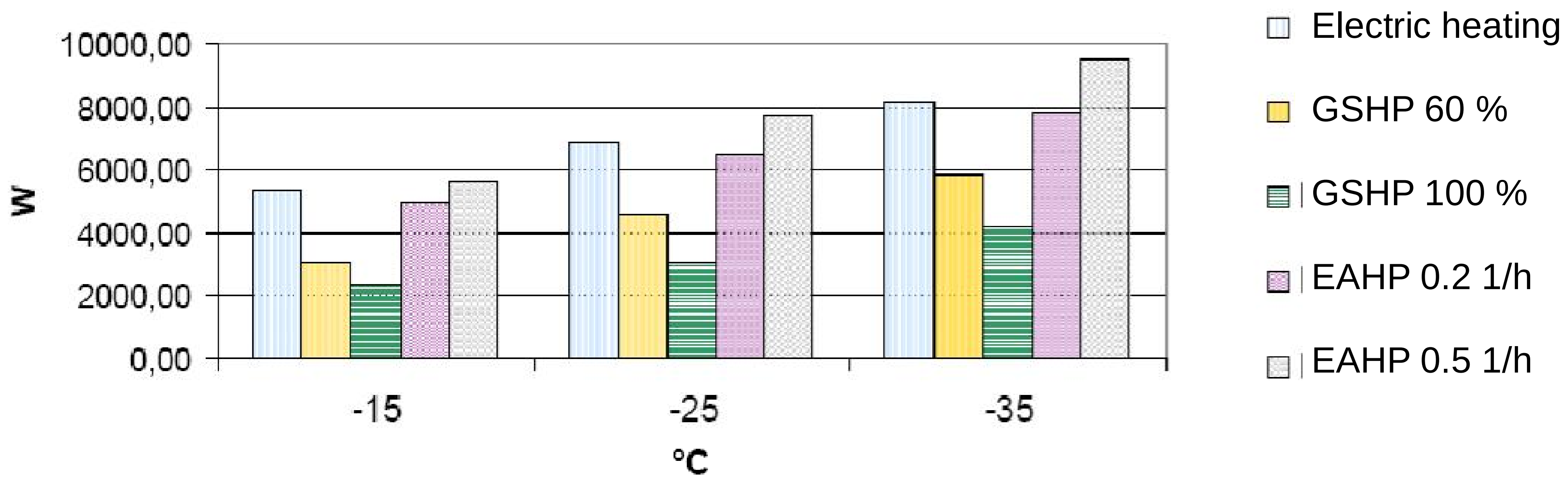
Electric power of 150 m^2 detached house (air and water heating and ventilation)



GSHP = Ground source heat pump

EAHP = Exhaust air heat pump

0.2 1/h and 0.5 1/h = ventilation rate of the building

Heljo, J. & Laine, H. *Sähkölämmitys ja lämpöpumput sähkönkäyttäjinä ja päästöjen tuottajina Suomessa*. TTY 2005

Energy efficiency of the heating systems - Heat pumps

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Significant efficiency increase compared to any other heating method; simplified comparison:

	Oil heating	**Heat pump**
Final heat demand	10 000 kWh	10 000 kWh
Efficiency of heating / SPF	90 %	3
Losses in electricity distribution & transmission		3 %
Efficiency of the electricity generation		40 %
Fuel demand	**11 111 kWh**	**8 591 kWh**
“Well-to-Wheel” efficiency	**90 %**	**116 %**

Energy efficiency of the cooling

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- Most efficient solution district cooling, where available
- Typical cool production methods in district cooling:
  - Free cooling, using e.g. seawater
  - Absorption, using surplus heat as a fuel for the process
  - Heat recovery from different sources by heat pumps

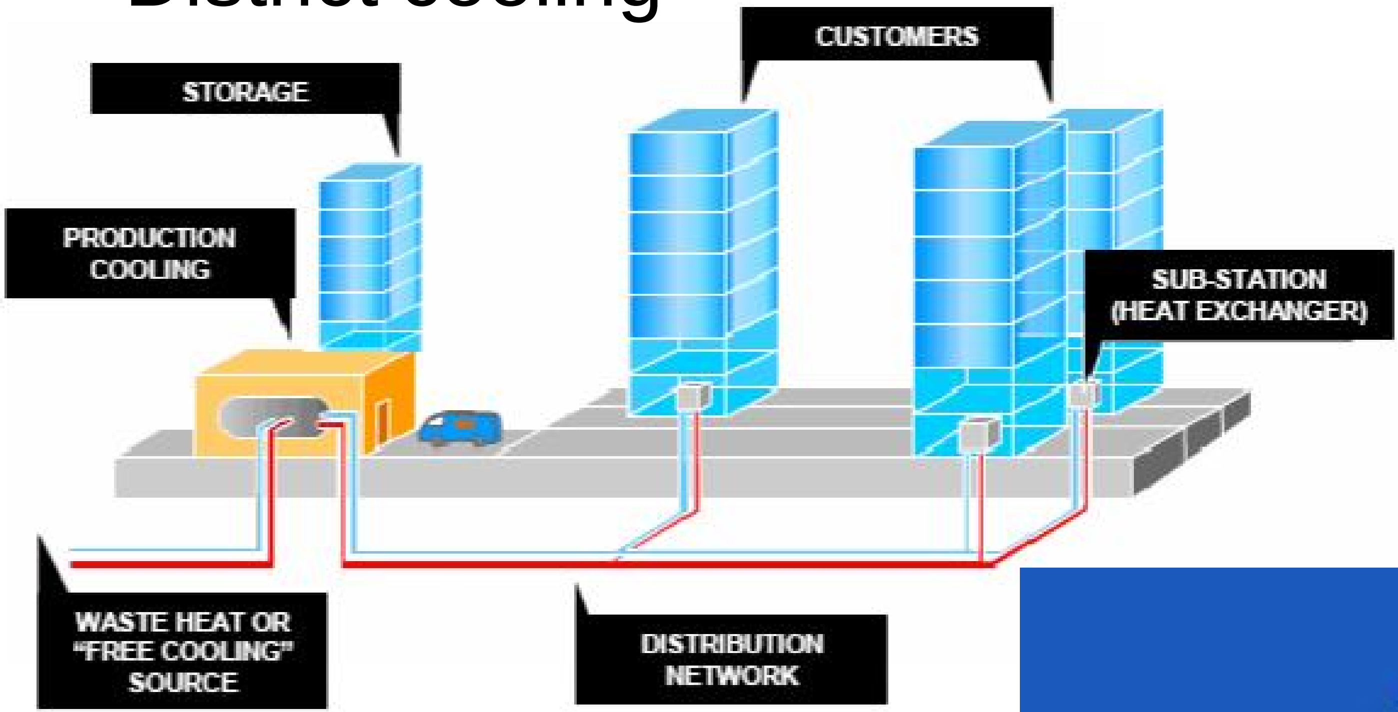
Solutions	EER	PRF
Conventional building bound solutions		
Conventional RAC and CAC	1,5-3,5	1,7-0,7
Conventional chillers combiened with aquifers	3-6	0,8-0,4
District cooling solutions		
Industrial chillers with efficient condenser cooling and/or recovered heat to DH	5-8	0,5-0,3
Free cooling / industrial chillers	8-25	0,3-0,1
Free cooling and cooling spills	25-40	0,1-0,06
Absorption chiller driven from heat from waste or renewable source	20-35	0,13-0,07

EER = Energy Efficiency Ratio (output of cooling energy / input of electrical energy)

PRF = Primary Resource Factor (the ratio of non-regenerative primary energy to final energy)

Ecoheatcool

Energy efficiency of the cooling - District cooling



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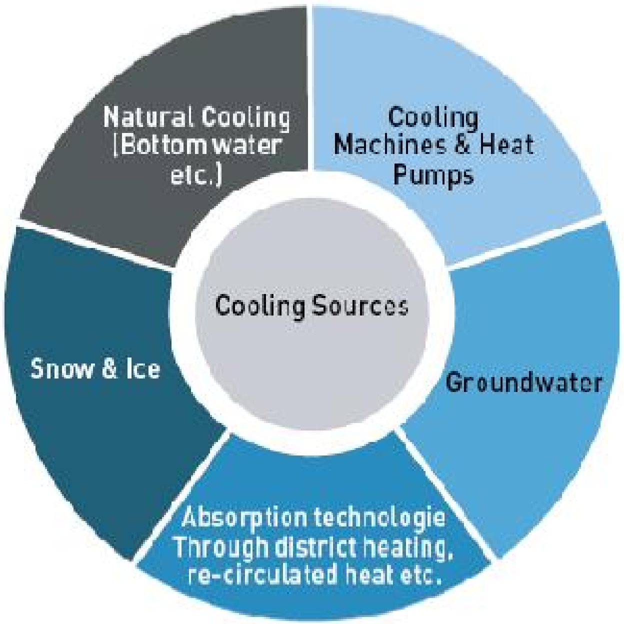
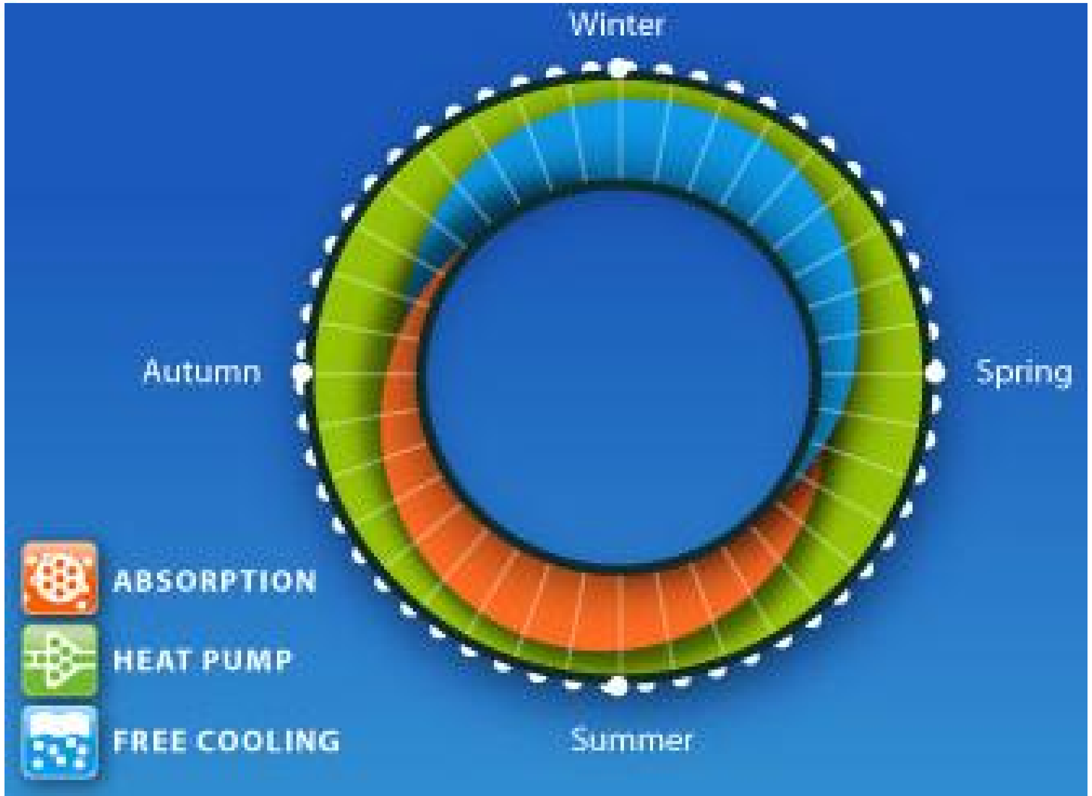
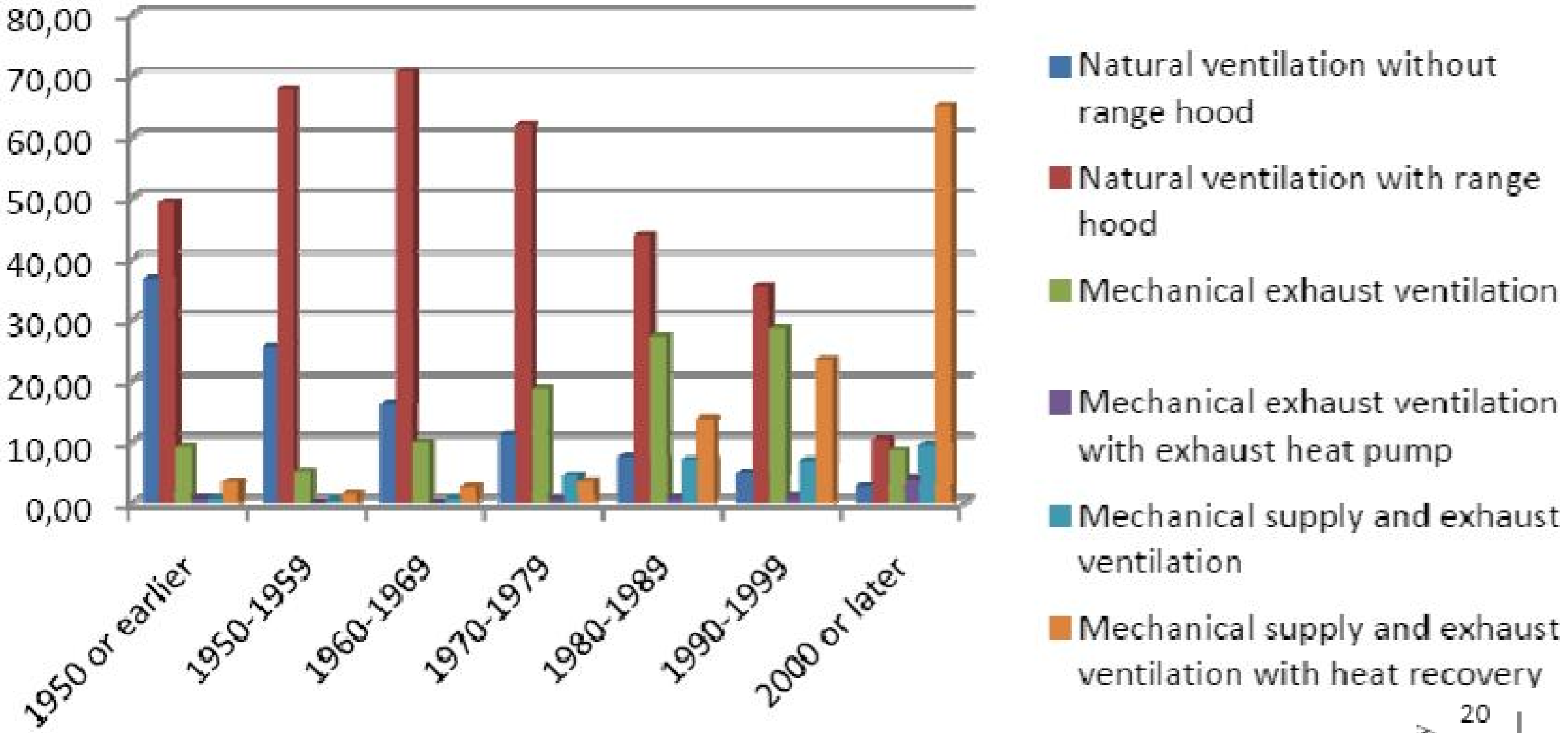
DHC+
Ecoheatcool
Helen

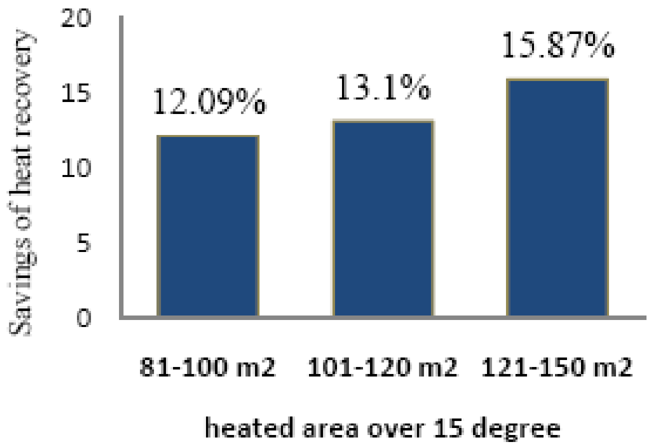




Energy efficiency in ventilation

Ventilation types in 3 351 households from Kainuu, Savo, and Vantaa area





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Household appliances – electricity demand of the Finnish households

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	1993 GWh/a		2006 GWh/a	
Refrigeration devices	2 215	30 %	1 461	13 %
Cooking	796	11 %	653	6 %
Dishwasher	125	2 %	261	2 %
Washing machine and dryers	316	4 %	391	4 %
TV and accessories	537	7 %	834	8 %
Computers			407	4 %
Sauna	606	8 %	852	8 %
HPAC	483	6 %	621	6 %
Electric floor heating	0	0 %	206	2 %
Pre-heating of the cars	226	3 %	218	2 %
Indoor lighting	1 541	21 %	2 427	22 %
Outdoor lighting			89	1 %
Other	623	8 %	2 572	23 %
In total	**7 468**	**100 %**	**10 992**	**100 %**




Adato 2006

Household appliances – energy efficiency potential

	Electricity demand of different appliances in year 2020 (GWh/a)		
Appliance	**Business-as-usual (BAU)**	**Best-available technology (BAT)**	**BAT/BAU**
Refrigeration devices	1 227	767	63 %
Cooking	693	577	83 %
Dishwasher	290	268	92 %
Washing machine and dryers	423	347	82 %
TV and accessories	1 076	860	80 %
Computers	240	87	36 %
Sauna	971	971	100 %
HPAC	809	566	70 %
Electric floor heating	227	227	100 %
Pre-heating of the cars	225	225	100 %
Indoor lighting	2 002	845	42 %
Outdoor lighting	99	22	22 %
Other	2 650	2 650	100 %
In total	**10 931**	**8 412**	**77 %**

Adato 2006

Energy efficiency in household appliances

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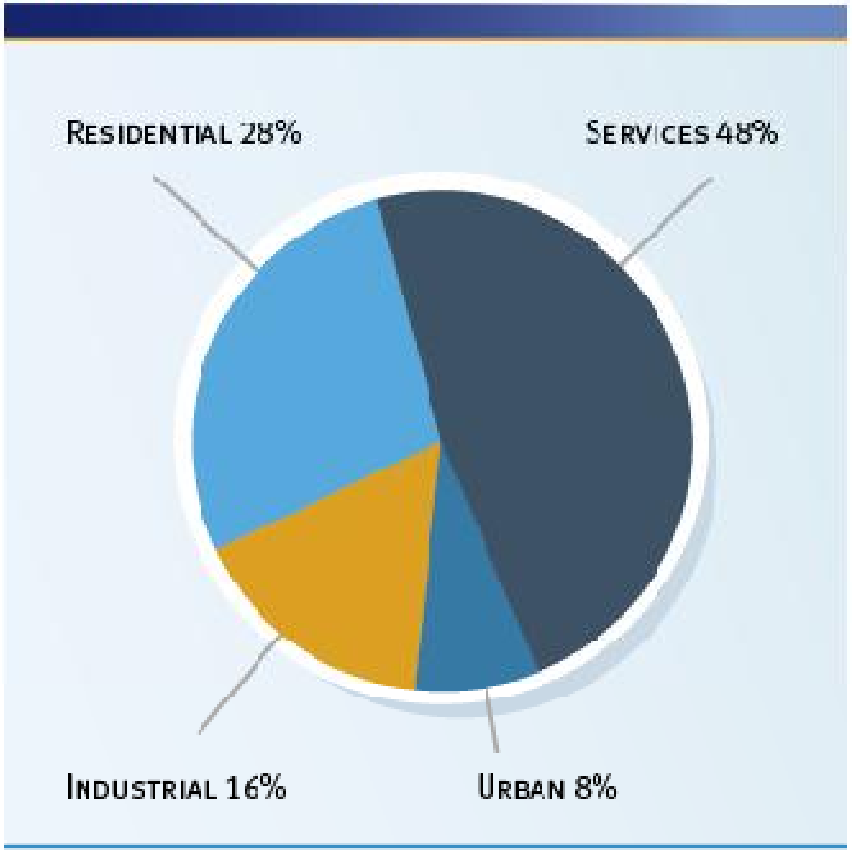
- Increasing living standards increase the demands for energy service => demand for more efficient use of energy

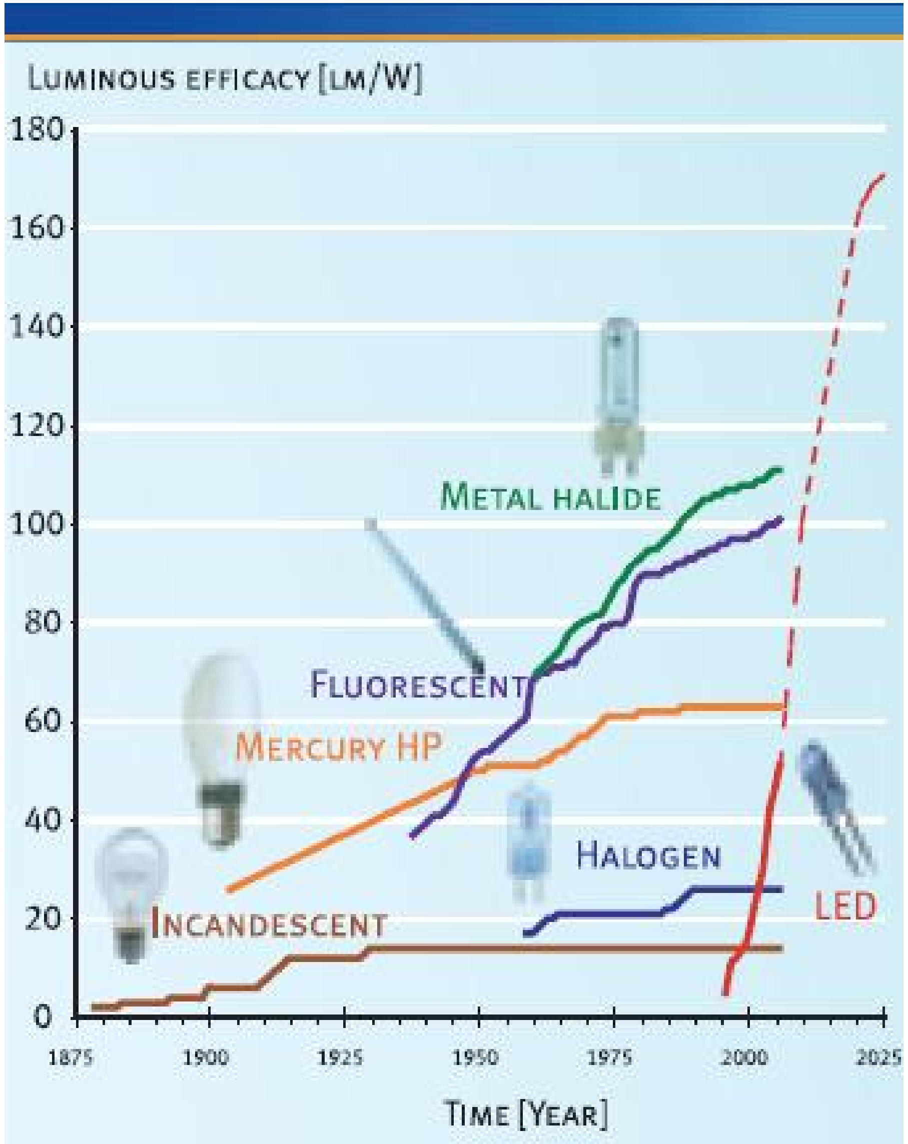
Figure 1. Norweigian integrated kitchen from 18th century.

Figure 2. Finnish integrated kitchen from 21th century.

Lighting

FIGURE 19: ENERGY CONSUMPTION FOR LIGHTING, BY SECTOR





Eurelectric. The Role of Electricity. Brussels 2007

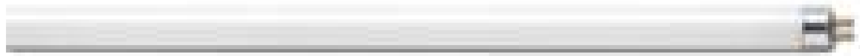
Lighting

- Incandescent lamps
  - Tungsten filament lamp (Incandescent Light Bulb, ILB)

    - Oldest type of the electric lamp (since 1878)
    - Based on heating of the tungsten filament => radiation (only partly in the visible wavelength)
    - Low luminous efficacy; 7 - 15 lm/W (efficiency 1 - 2 %)
    - Life-time 1 000 hours
  - Halogen lamps

    - Tungsten filament lamps where the bulb is filled by halogen gas
    - Efficacy 15 - 24 lm/W (efficiency 2 - 3,5 %)
    - Life-time 1 000 – 3 000 hours
    - Typical as spot-lights and in decorative lighting

Lighting

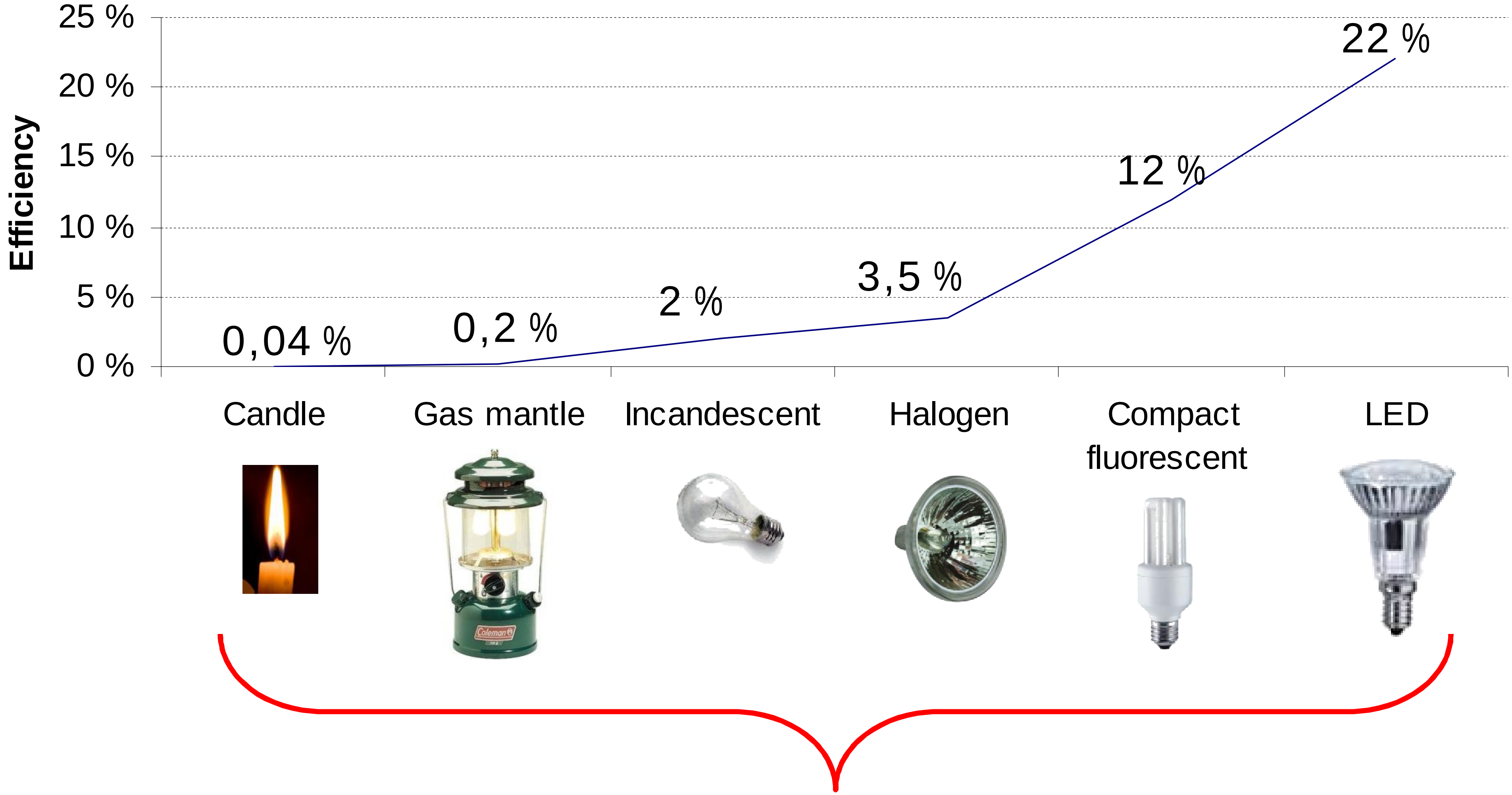
- Fluorescent lamps 
  - Low-pressure gas filled tube (argon and mercury) and glass wall coated with phosphor
    - Electric charge between the electrodes => Mercury vapor emits UV-radiation => Phosphor emits visible light
    - Efficacy ~80 lm/W (efficiency 12 %)
    - Life-time up to 12 000 hours
    - Needs ballast
    - Contains mercury => toxic waste
  - Compact Fluorescent Lamp (CFL) also called as energy-saving lamps
    - Similar operating principles as in other fluorescent lamps
    - Integrated ballast with screw-in fitting => can be used in same lighting devices as ILBs

Lighting

- High-pressure discharge lamps
  - Efficacy 100 - 150 lm/W (efficiency 15 – 22 %)
  - Typical in lighting of the large areas (e.g. road lighting, warehouses, etc.)

- LED (Light Emitting Diode)
  - Typical efficacy 40-50 lm/W (efficiency 6-7 %), even 161 lm/W (24 %) in laboratory tests
  - Long life-time (15 000 – 25 000 hours)
  - Developing fast from the indicator light to lighting source
  - Flexible for decorative purposes

Lighting – development of energy efficiency



Efficiency has increased significantly, still over 75 % of electricity is converted into heat instead of light

Lighting – improving the energy efficiency

- Lighting technology
  - CFL, LED
    - E.g. changing ILB to CFL => possibilities for instant changes
- Efficiency of the auxiliary devices
  - Ballasts, luminaries
  - Increase the efficiency and life-time of the lamp by electronic ballasts
- Lighting design and control
  - Optimal amount of light in right time and place
  - Choosing the optimal light source
  - Intelligent control of the lighting

Lighting – improving the energy efficiency

- Lighting design
  - Possibility for energy saving … or threat for energy wasting
  - Energy saving by using natural light as much as possible
    - Depends on the design of the building => slow changes
  - Trend is to use lighting for decorative purposes and use halogen lamps also as general lights
    - Typical “traditional” lighting in the bathroom 18 W fluorescent lamp
    - Renovation => 5 x 35 W halogen => power demand of the lighting increase to 175 W
  - Increasing amount of the lighting devices in the households

- Intelligent control of the lighting
  - Controlling the intensity of the lighting based on the demands and natural lighting conditions
  - Timers or detectors for natural light conditions and human presence

Lighting – improving the energy efficiency

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Life-cycle energy demand (10 years, 2.5 h/day)

Lamp-type	**Life-time**	**Energy demand in manufacturing**	**Energy demand during the operation**	**Total energy demand**
CFL 15 W	10 000 h	3,4 kWh	136,9 kWh	140,3 kWh
ILB 60 W	1 000 h	0,9 kWh * 10 = 9 kWh	547,5 kWh	556,5 kWh

Lamp-type	**Price**	**Investment costs during the 10 years**	**End-use energy costs (10 snt/kWh)**	**Total costs during 10 years**
CFL 15 W	10 €	10 €	13,7 €	23,7 €
ILB 60 W	0,5 €	0,5 € * 10 = 5 €	54,8 €	59,8 €

Lighting – system level impacts

- Replacing ILBs with CFLs
  - Decreased electricity demand in lighting
  - Decreased heat generation of the lighting appliances
    - => Increased heating demand during winter
    - => Decreased cooling demand during summer
  - Increased reactive power and harmonic distortions in the power grid
  - Life-cycle impacts
    - CFLs contain mercury => used lamps are toxic waste and detrimental for health => Needs (and possibilities) to improve the recycling
    - Life time of CFL significantly longer than ILB => Less produce of waste and demand of raw-material
- Total effects
  - Case dependent
    - Is there need for heating or cooling?
    - Efficiency and emissions from the heating/cooling vs. efficiency and emissions of the electricity
    - Life-cycle impacts!

Annual temperatures in different parts of Europe

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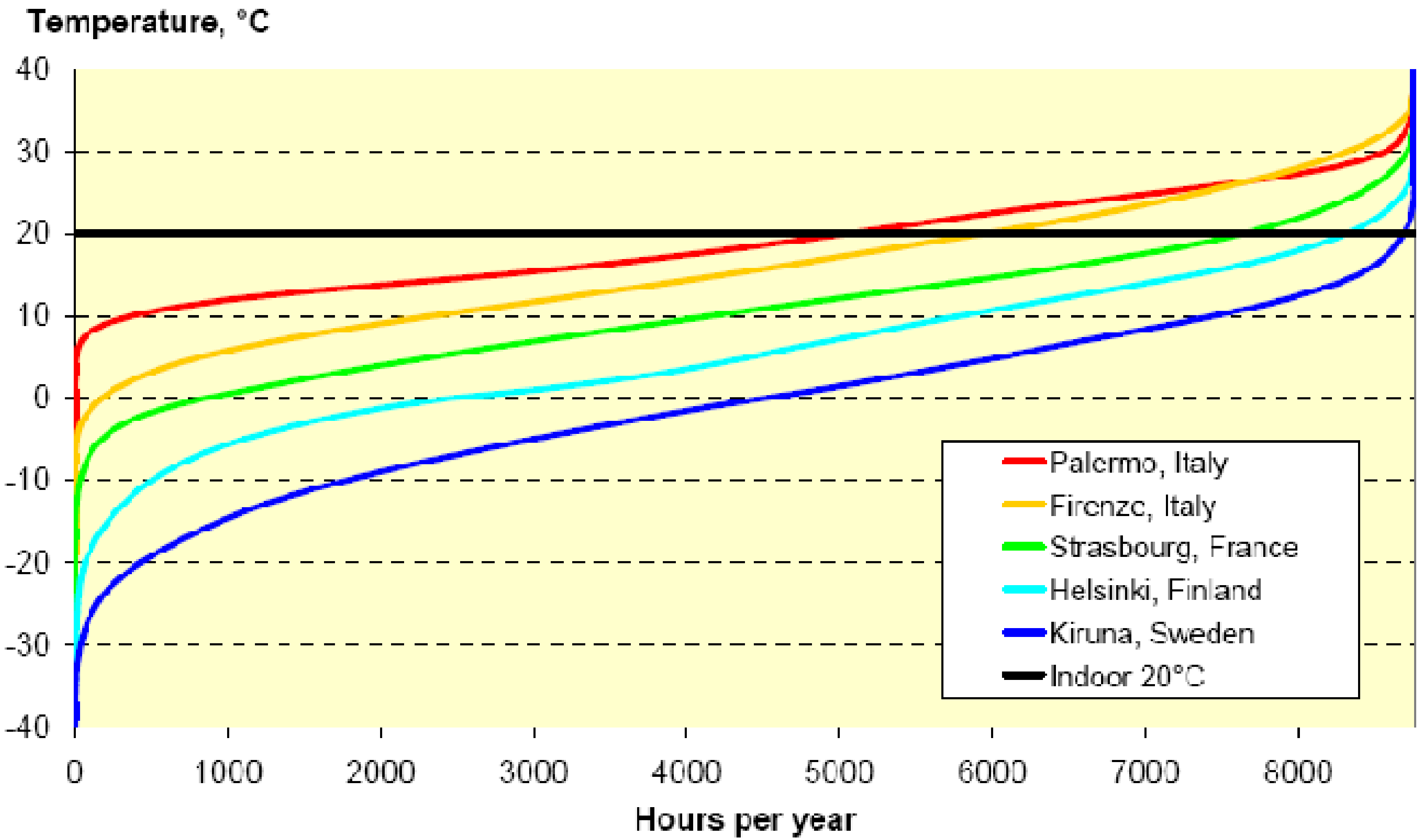

Ecoheatcool

Lighting – system level impacts

- Electricity appliances typically generate heat
  - Decrease the heating demand or increase the cooling demand
  - Possibilities to utilize generated heat depend also on the controllability of the heating system
    - Decrease in heat demand or increase in room temperature
    - It is estimated that ~70 % of such heat can be utilized in the heating in Finland
  - System level impacts depend also on the heating type
    - District heating, heat pumps, oil, electricity, wood…
- In Finland: cold, dark, and long winter
  - Major lighting demand during the heating season => Possibilities to gain from the heat generated by the electrical appliances
- High demand for cooling in southern countries
  - => Heat generated by the electrical appliances increase the cooling energy demand

Lighting – system level impacts

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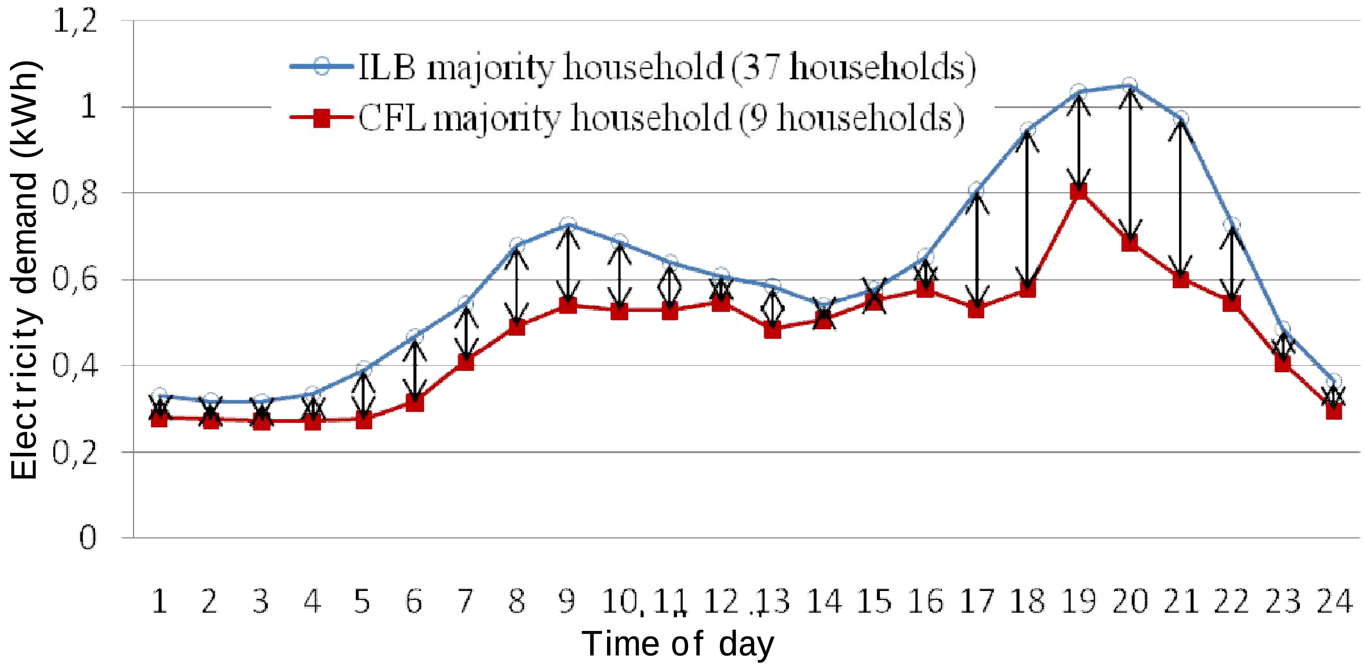


- Replacing of ILBs with CFLs saves 13 – 17 % from the electricity consumption of a household (without electric heating)
- However, total impact in the directly electric heated house is minor, because of the increased heat demand

Lehtonen, M., Aalto-university

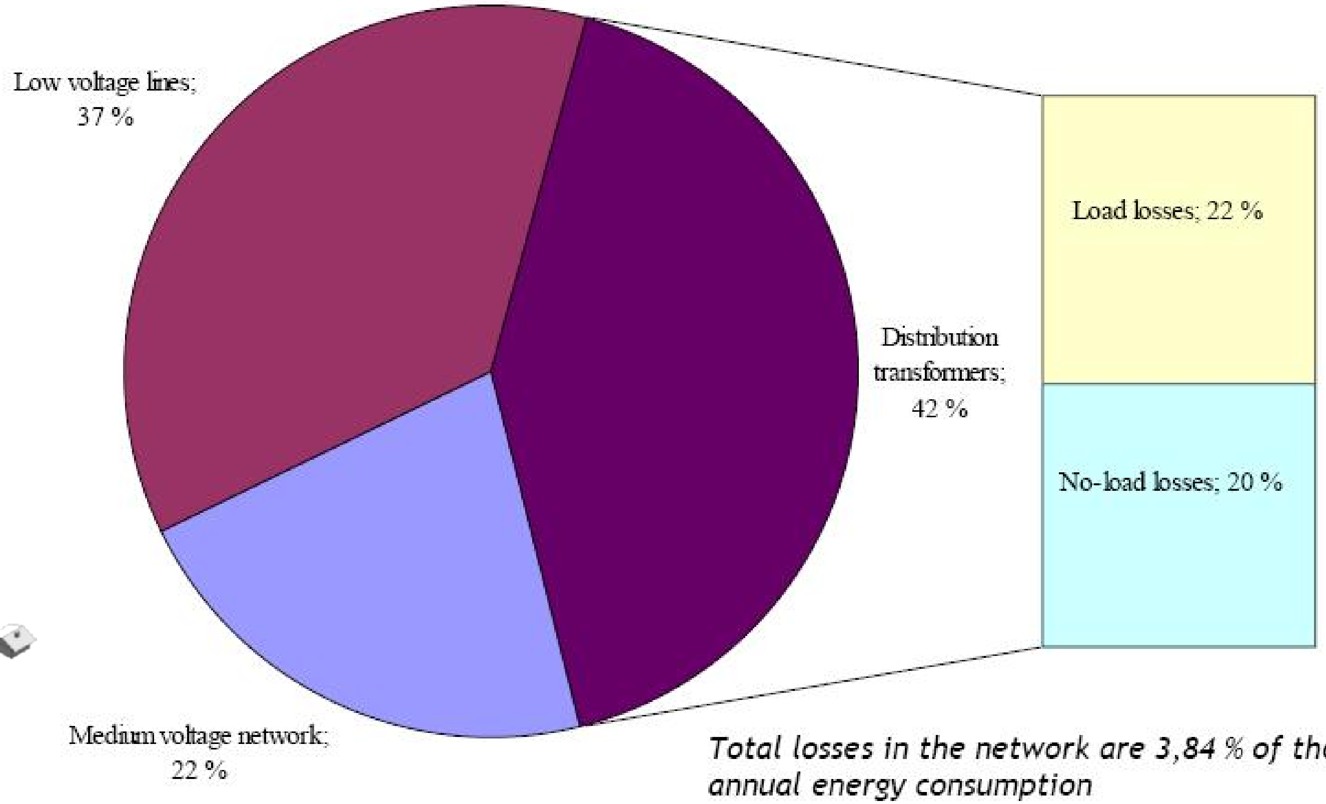
Energy efficiency in households

End-use type	Action	Impacts
Ground-source heat pump (GSHP)	Replacing direct electric heating with GSHP	Savings of 27.45 % – 47.0 % of heating electricity consumption
Air-source heat pump (ASHP)	Using ASHP as supportive heating for direct electric heating	Savings of 7.8 % – 25.6 % of heating electricity consumption
Ventilation	Incorporating heat recovery system in ventilation	In average 13.6 % savings in household's total electricity consumption
Thermostat type	Installing and using of the programmable thermostats	Average savings of 14.7 % in heating electricity consumption
Thermostat setting	Lowering indoor temperature by 1 degree during heating season	Average saving of 3.43 % of total household's electricity consumption
Stand-by consumption		An average saving potential 46.2 W per household
Energy saving lamp	Replacing every ILB with energy saving lamp	Savings of 13.62 % - 17.06 % of total household electricity consumption (other than heating consumption)

Electricity distribution and transmission

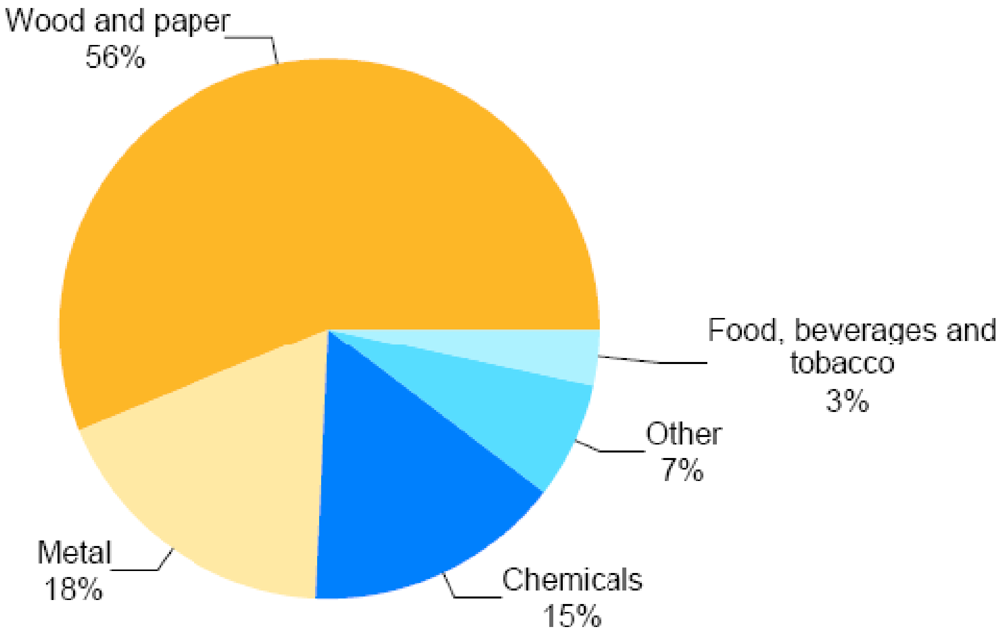
- Total losses in distribution and transmission in Finland is about 4 % of the distributed energy

Distribution of the energy losses in typical electricity distribution network in Southern Finland

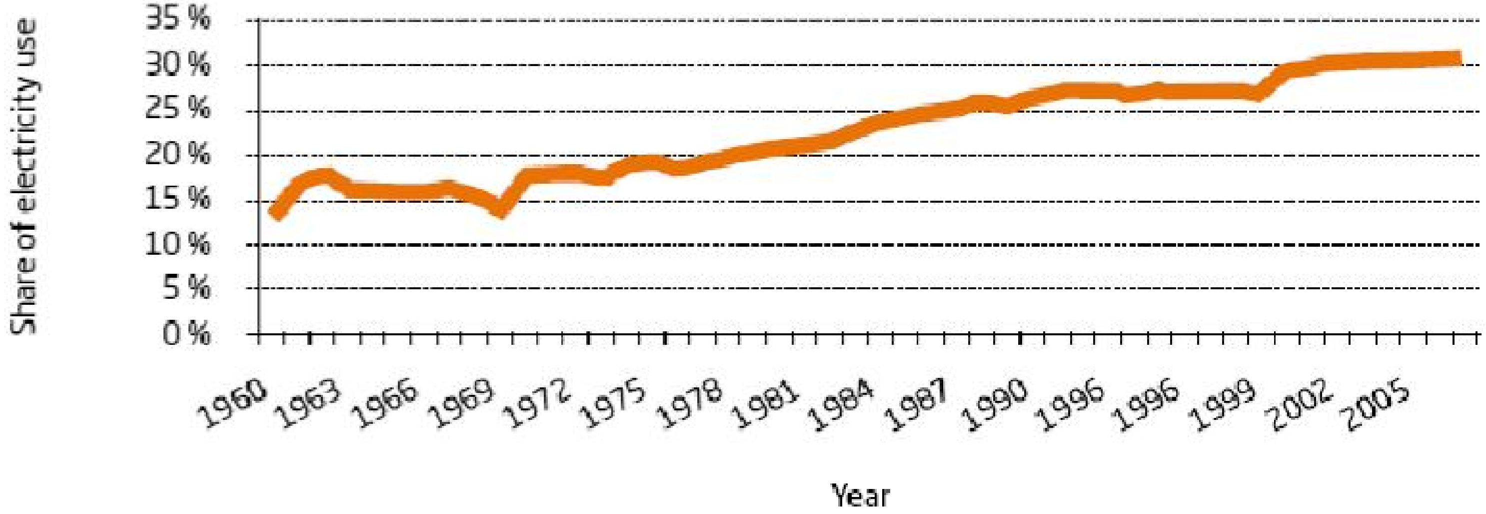


Total losses in the network are 3,84 % of the regional annual energy consumption

Electricity consumption in Finnish industrial sector



Share of electricity in industrial energy use in Finland

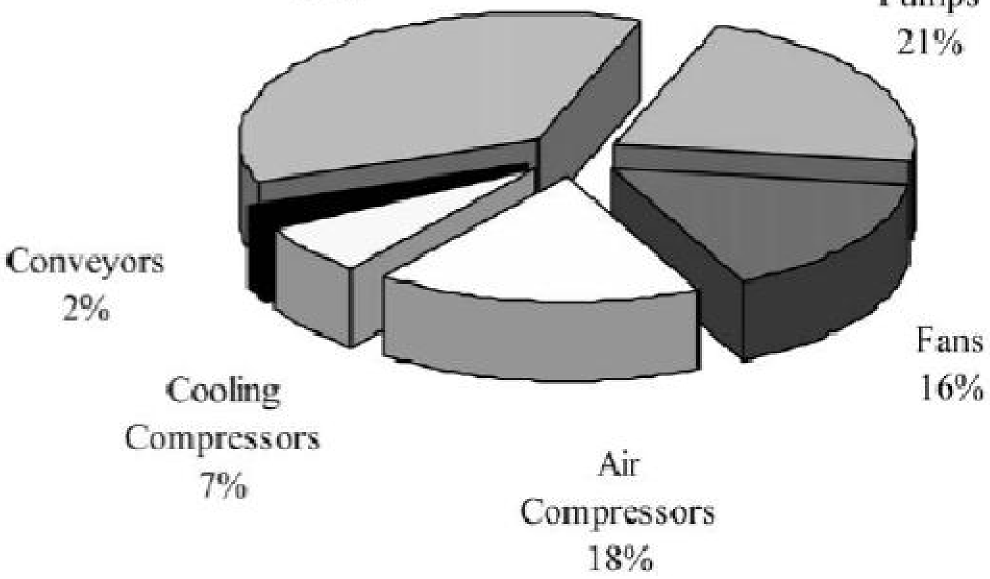


Statistics Finland

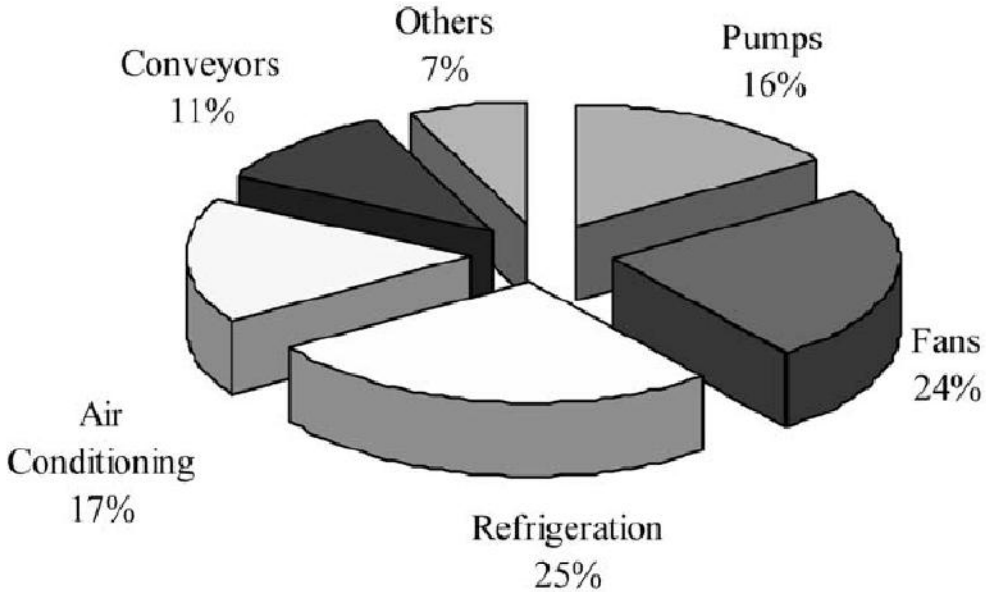
Electrical drives and motors

- In EU's service sector, 38 % (186 TWh/a) of the electrical energy is consumed in motor systems
- In industrial sector, 69 % of electricity is consumed in motor systems, corresponding 575 TWh/a

Industrial sector

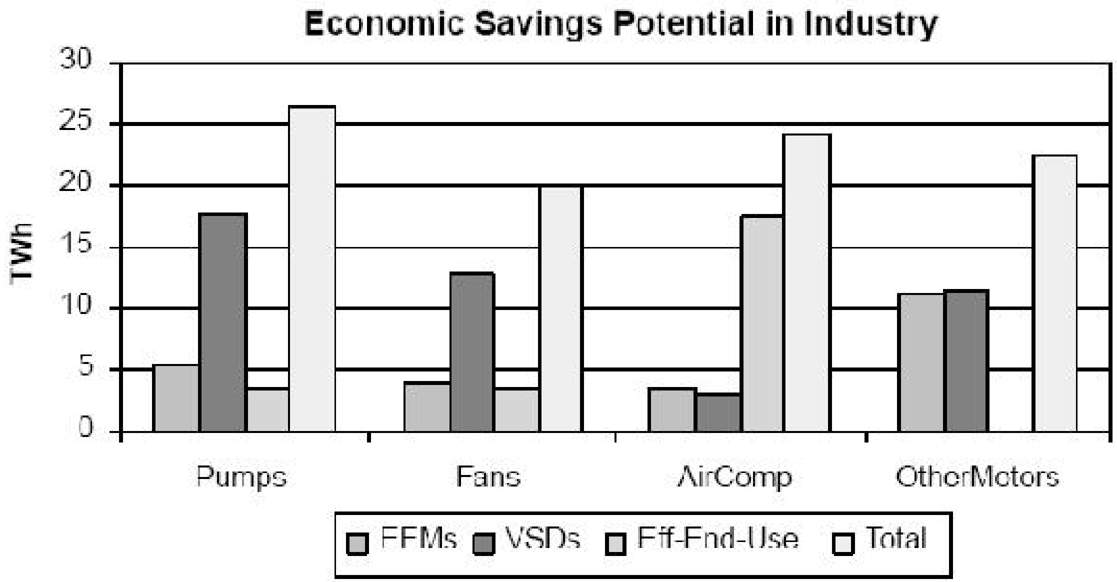


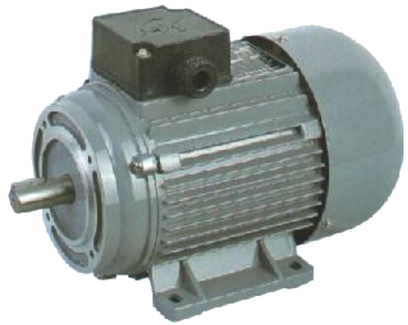
Service sector



de Almeida et al. (2003)

Economic saving potential in electric drives in EU

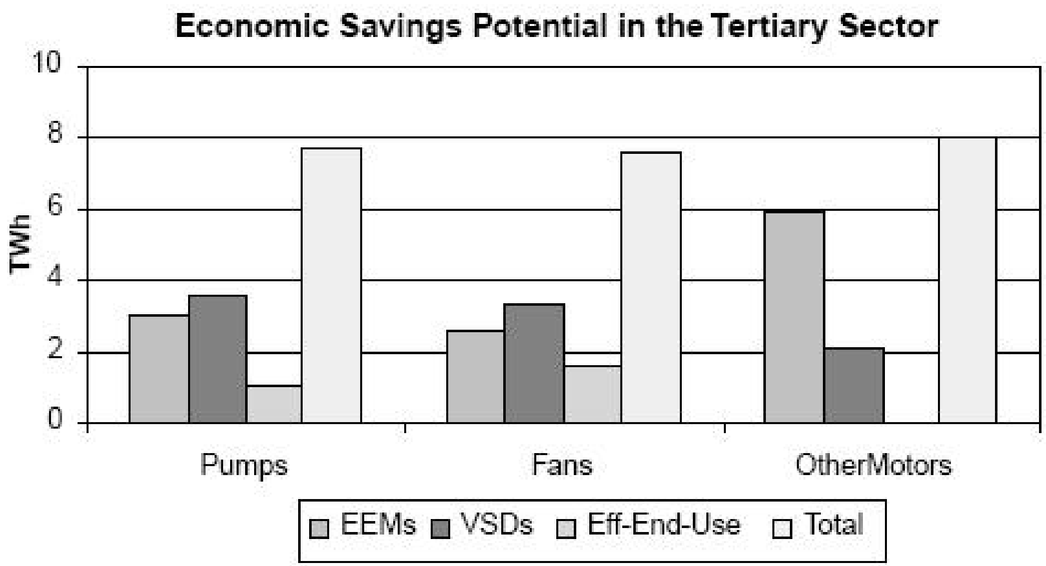




EEM = Energy-efficient motor

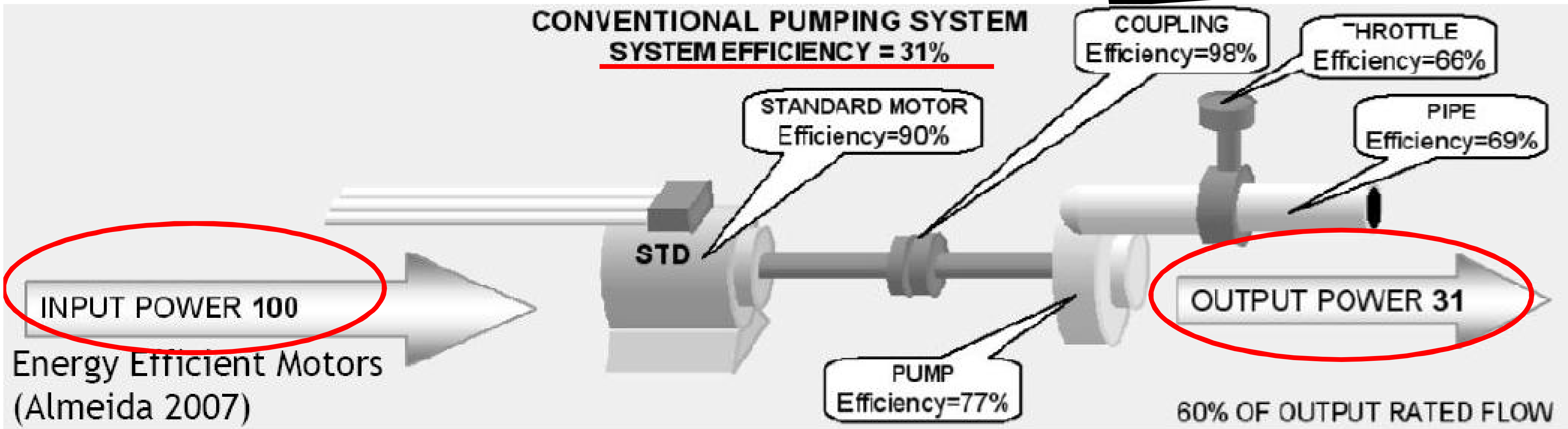
VSD = Variable speed drives

Efficient end use = efficient pumps, fans, and compressors

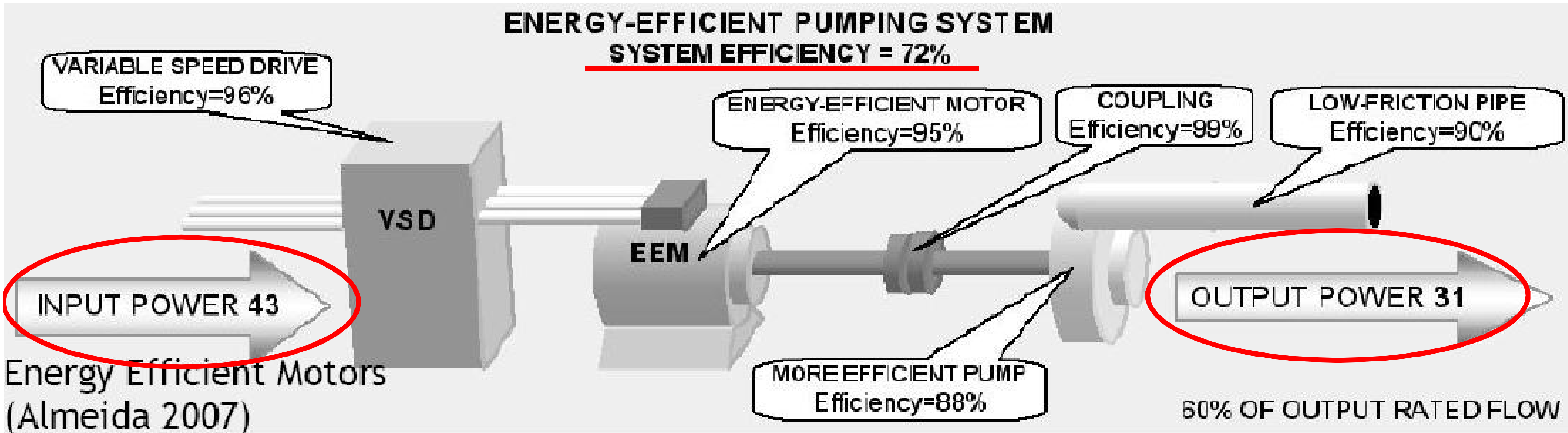


de Almeida et al. (2003)

Energy efficiency in pumping systems



Energy Efficient Motors (Almeida 2007)



Energy Efficient Motors (Almeida 2007)

Energy consumption in transportation sector in Finland

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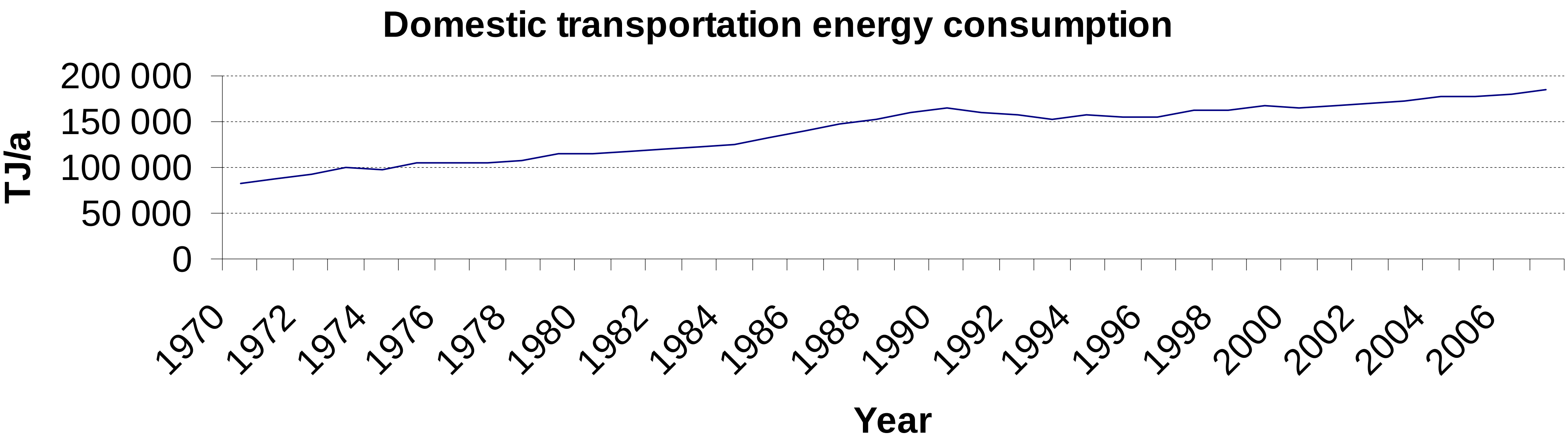

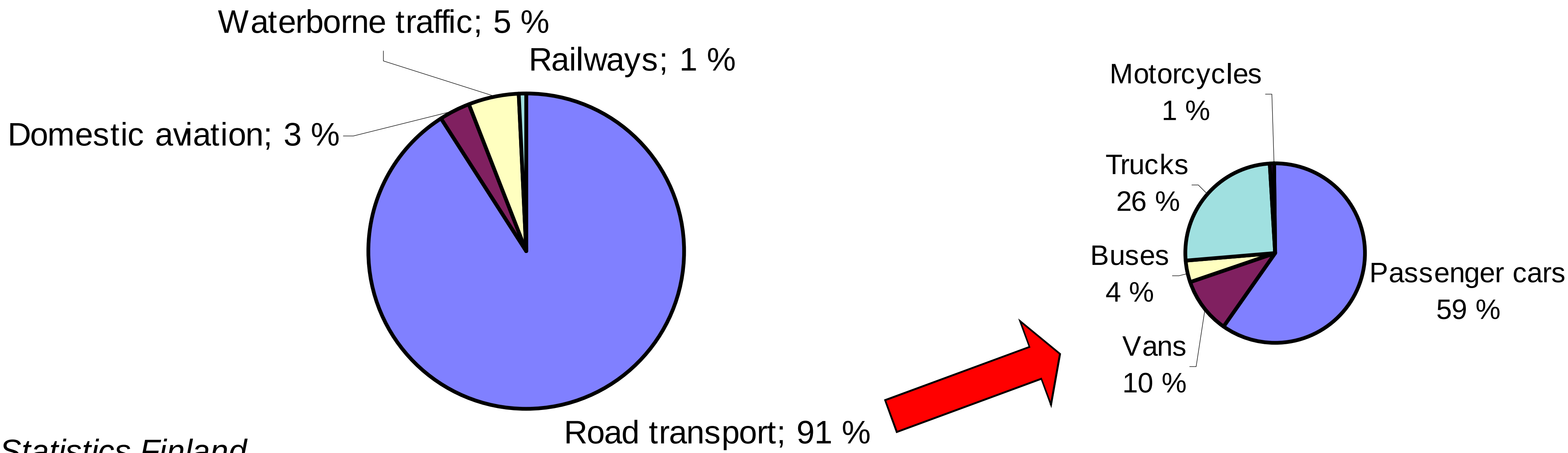

Statistics Finland

Energy efficiency potential in transportation sector

- More efficient vehicles
  - **Replacing internal combustion engine with electric motor!**
  - Materials, aerodynamics, friction of tires
- More efficient ways of transportation
  - Public transportation
  - Navigation to minimize traveled distance and avoiding traffic jams
- Attitudes of the drivers
  - For instance, 20 % saving potential is estimated to be achieved in the energy consumption of the truck vehicles by education of the drivers for energy saving driving habits
- Biofuels
  - However, holistic impacts varies significantly based on the source and production methods of the fuel
- Transportation needs of the persons and goods
  - Impacts of the community planning

Electric vehicles – penetration impacts in Finland

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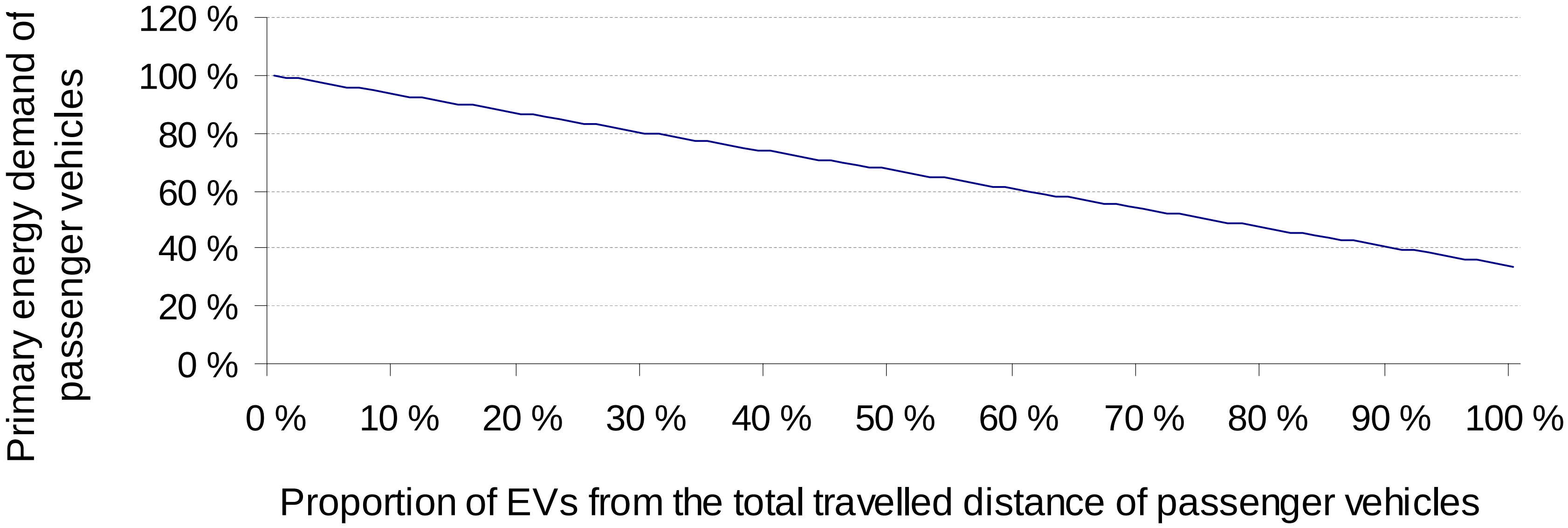

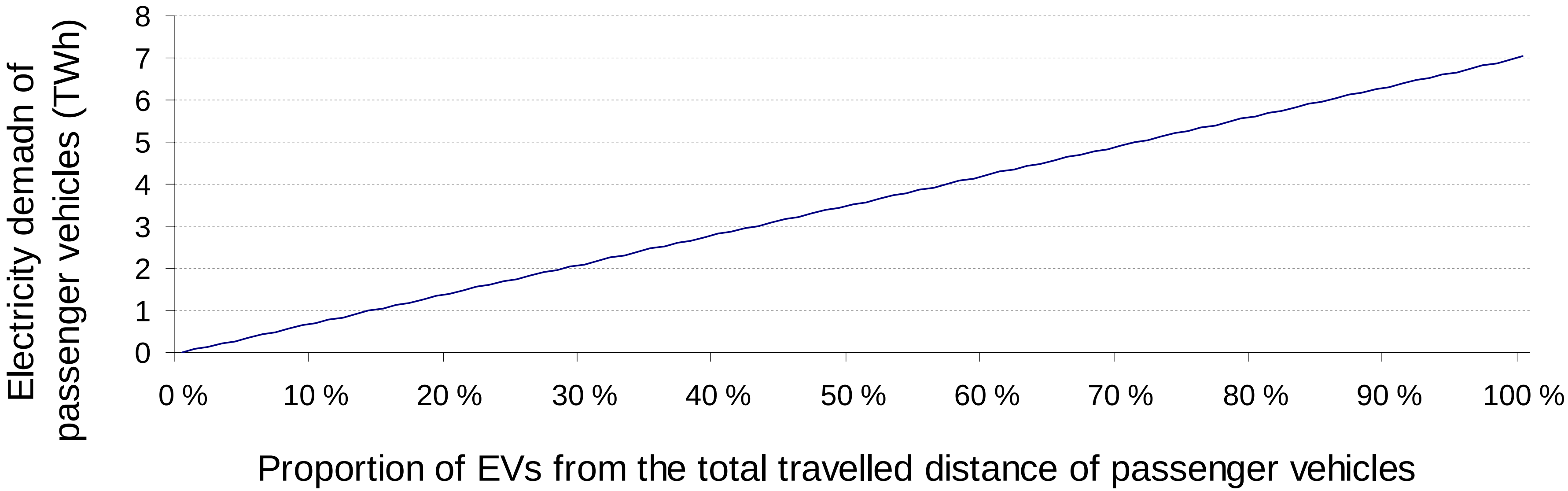

Conclusions

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- Increase of the energy efficiency decrease not only the primary energy demand, but typically also the life-cycle costs
  - Reducing the CO_2 emissions with negative costs

- Increasing energy efficiency in end-use will result to many times higher savings in the primary energy consumption than similar efficiency increase in production, because of the losses in the every step of the energy chain

- Most significant end-use energy efficiency potential (in Finland) is in the heating of the buildings and transportation, as well as in the industrial energy use and lighting

- System level and life-cycle impacts are important => partial optimization may lead to increasing energy demand

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