Environmental Sustainability of Information and Communication Technology (ICT) for Smart Grids

An E-LCA Study of ICT in Smart Grids

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OUTLINE

1. Introduction
2. Exergy-based Life Cycle Assessment (E-LCA)
3. E-LCA of Advanced Metering Infrastructure (AMI)
4. E-LCA of ICT for Smart Grids
5. Conclusions

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The Promise of the Smart Grid

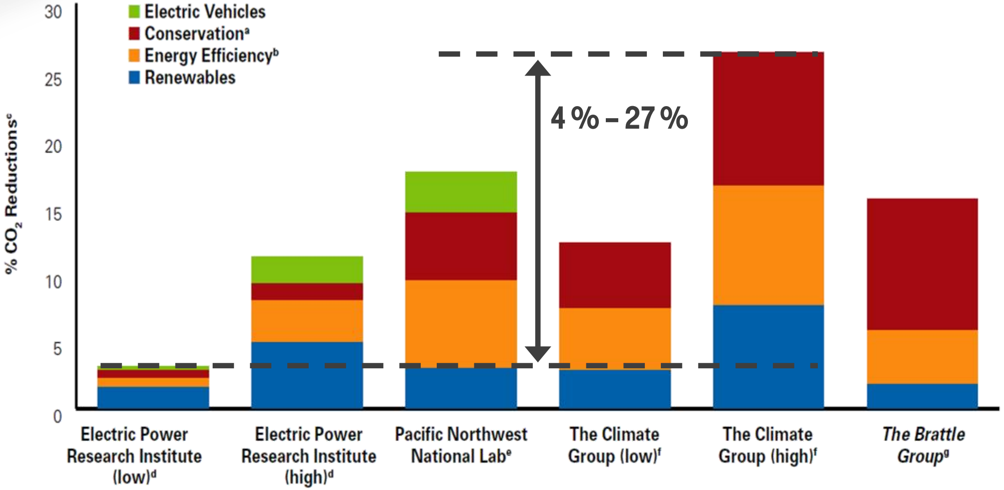
Goals

- Improvement of energy efficiency
- Integration of renewable energy sources
- Reduce peak demand

The Smart Grid concept is mainly driven by

- Distributed generation
- Energy storage systems
- Demand side management

Potential CO_2 Reductions (Results from 4 Studies)



Source: "The Promise of the Smart Grid: Goals, Policies, and Measurement Must Support Sustainability Benefits", Natural Resources Defense Council, 2012

ICT for Smart Grids

- Deployment of additional ICT equipment in various smart grid domains (e.g., customer, distribution, operations) will lead to a further increase in electricity consumption and additional e-waste

ADDITIONAL ICT EQUIPMENT

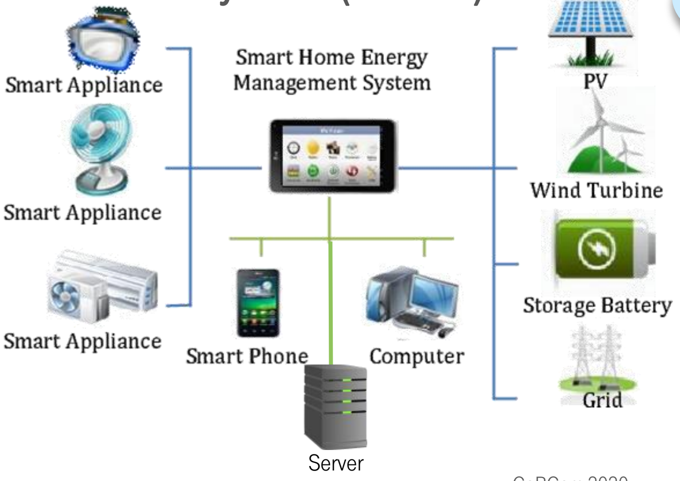
Smart Meters

- Hundred Millions in Europe
- Power Consumption ≈ 1 W - 5 W

Data Concentrators

- Hundreds of Thousands in Europe
- Power Consumption ≈ 10 W

Home Energy Management System (HEMS)



- Hundreds of Millions in Europe
- Power Consumption ≈ 10 W – 100 W

Communication Network Infrastructure

Data Centers

- Several small/medium size DCs
- Power Consumption ≈ kW - MW

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Comparison between Thermodynamic Indicators

Indicator Type	Advantage	Disadvantage
Energy analysis	• Enables energy assessment and evaluation by the use of the first law of thermodynamics	• Different forms of energy cannot be directly compared • Environmental effects cannot be directly assessed
Life cycle assessment (LCA)	• Allows a very detailed and thorough assessment of environmental effects	• Difficult to derive • Lack of a simple and unambiguous outcome for easy comparison purposes
Exergy-based life cycle assessment (E-LCA)	• Different forms of energy can be directly compared • Simpler to obtain than a LCA • Leads to a single value for easy comparison purposes	• Does not allow a thorough assessment of environmental effects

CRADLE-TO-GRAVE APPROACH

Most studies concentrate on the operation or use phase of ICT equipment only

Drawback: Other life cycle stages of ICT equipment not considered, such as:

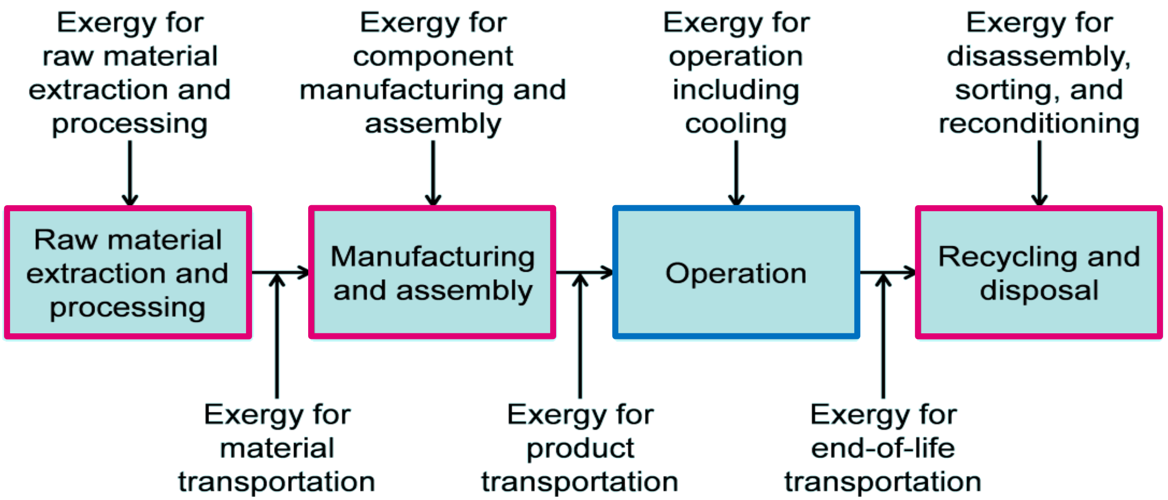
Raw material extraction and processing

Manufacturing and assembly

Disposal and recycling

Transportation

EXERGY CONSUMPTION IN DIFFERENT LIFE CYCLE STAGES



- Embodied exergy consumption (EEC): exergy consumed during *raw material extraction and processing, manufacturing and assembly, recycling and disposal, as well as transportation* of materials and products

- Operational exergy consumption (OEC): exergy consumed during the *operational or use phase* of the equipment

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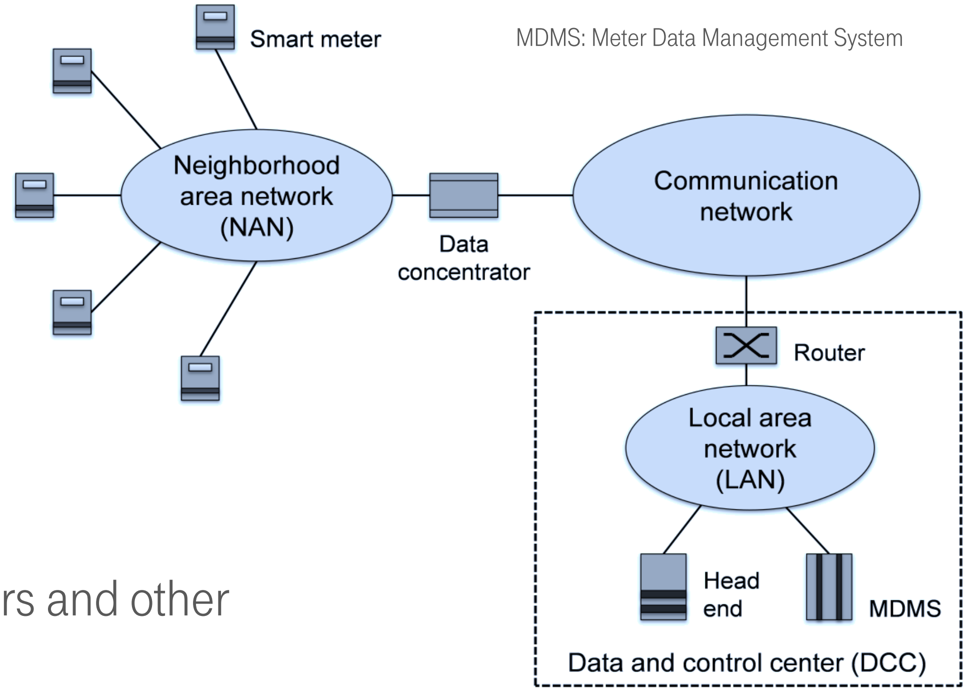
ADVANCED METERING INFRASTRUCTURE (AMI)

- Key enabling technology for Smart Grids
- Crucial component is the Smart Meter

- AMI enables:
  - two-way communication between the meter and the central system
  - better management of energy networks and more efficient consumption

- However, a large number of smart meters and other components have to be installed

MDMS: Meter Data Management System

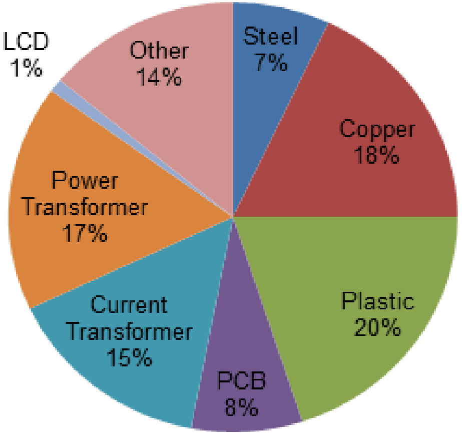


Smart Meters

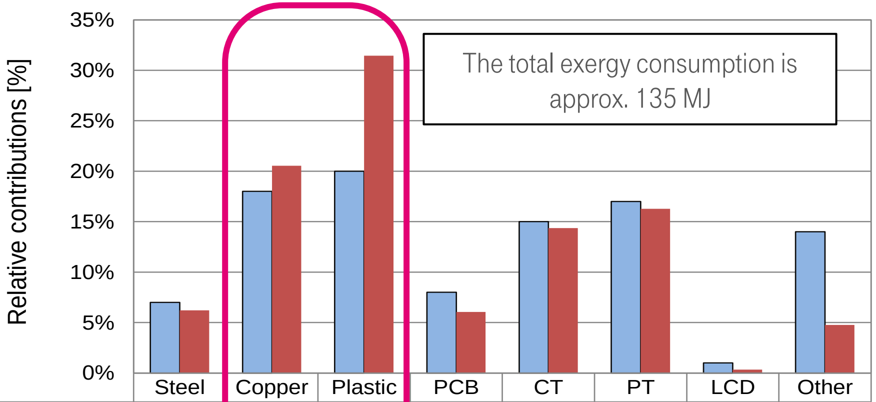
Row Material Extraction and Processing Phases

- First, we defined the typical material/component composition of smart meter
- Then, we applied a combined analytical and experimental analysis and used data from various sources with the aim to increase the data accuracy

Typical material/component composition



Relative contributions to weight and exergy consumption

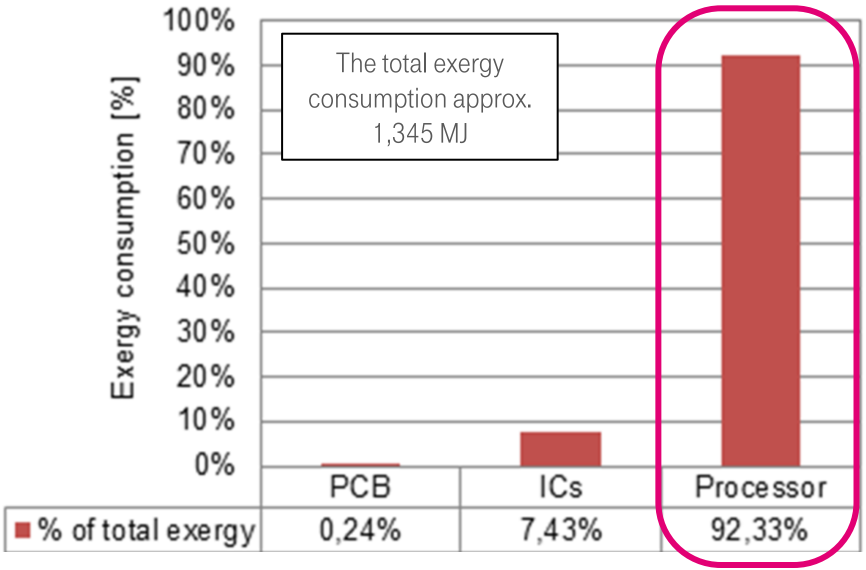


	Steel	Copper	Plastic	PCB	CT	PT	LCD	Other
% of total weight	7,00%	18,00%	20,00%	8,00%	15,00%	17,00%	1,00%	14,00%
% of total exergy	6,21%	20,55%	31,45%	6,04%	14,36%	16,27%	0,34%	4,77%

Smart Meters
Manufacturing and Assembly Phases

- The manufacturing of the processor accounts for more than 90% of the total exergy consumption in this life cycle stage

Relative contribution of some select manufacturing processes to the total exergy consumption of the manufacturing and assembly phase



SMART METERS

OPERATION AND TRANSPORTATION PHASES

- **Operation**

Main assumptions for the operation phase

Operational parameter [unit]	Value
Peak power consumption [W]	3
Average load [%]	50
Daily uptime [%]	100
Operational duration [years]	15

The total exergy consumption: 709.56 MJ

- **Transportation**

Main assumptions for transportation

Mode of transportation	Specific exergy [kJ/kg-km]
Air	22.41
Truck	2.096
Rail	0.253
Ship	0.296

The total exergy consumption: 351.7 MJ

Smart Meters

Recycling Phase and Total Exergy Consumption

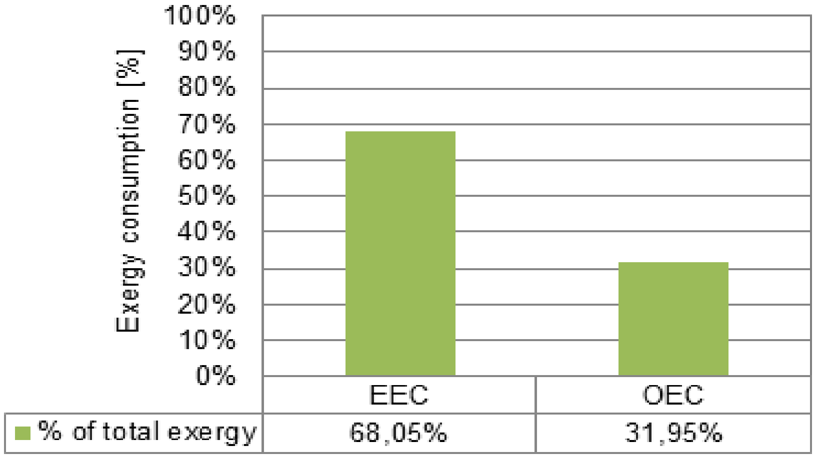
- Recycling and Disposal
  - An order of magnitude estimate approach was assumed
  - Exergy consumed: 520 kilo Joules per kilogram (kJ/kg)
  - The total exergy consumption approx. 1.2 MJ
- Overall Lifetime Exergy Consumption

Life cycle stage	Exergy consumption [MJ]	Exergy consumption [%]
Raw material extraction and processing	3rd 135	6.08
Material transportation	7.15	0.32
Manufacturing and assembly	1st 1,345.16	60.57
Product transportation	19.55	0.88
Operation	2nd 709.56	31.95
End-of-life transportation	3.25	0.15
Recycling and disposal	1.2	0.05
Total	**2,220.87**	**100**

SMART METERS

EMBODIED AND OPERATIONAL EXERGY

Lifetime embodied exergy consumption (EEC) and operational exergy consumption (OEC) distribution of the smart meter



- The embodied exergy consumption (EEC) is responsible for more than 68% of the total exergy consumption

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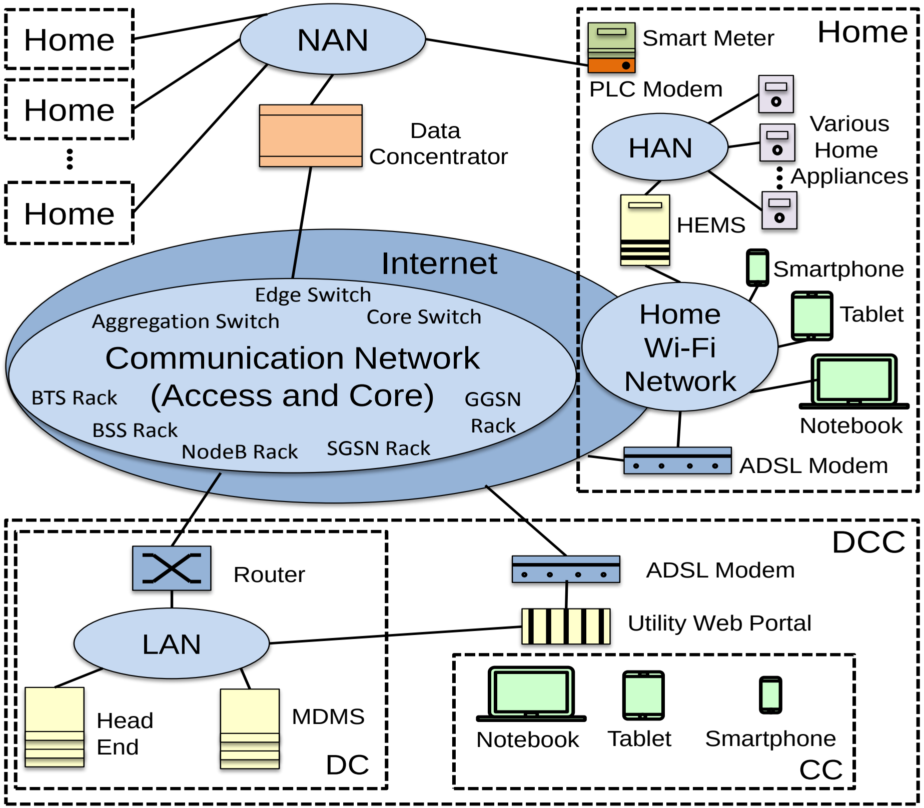
ICT FOR SMART GRIDS

OVERALL MODEL



PLC:	power line communication
HAN:	home area network
LAN:	local area network
WLAN:	wireless local area network
DSL:	digital subscriber line
HEMS:	home energy management system
NAN:	neighborhood area network
RAN:	radio access network
CN:	core network
MDMS:	meter data management system
UEMS:	utility energy management system
DC:	data center
CC:	control center
DCC:	data and control center

ICT FOR SMART GRIDS

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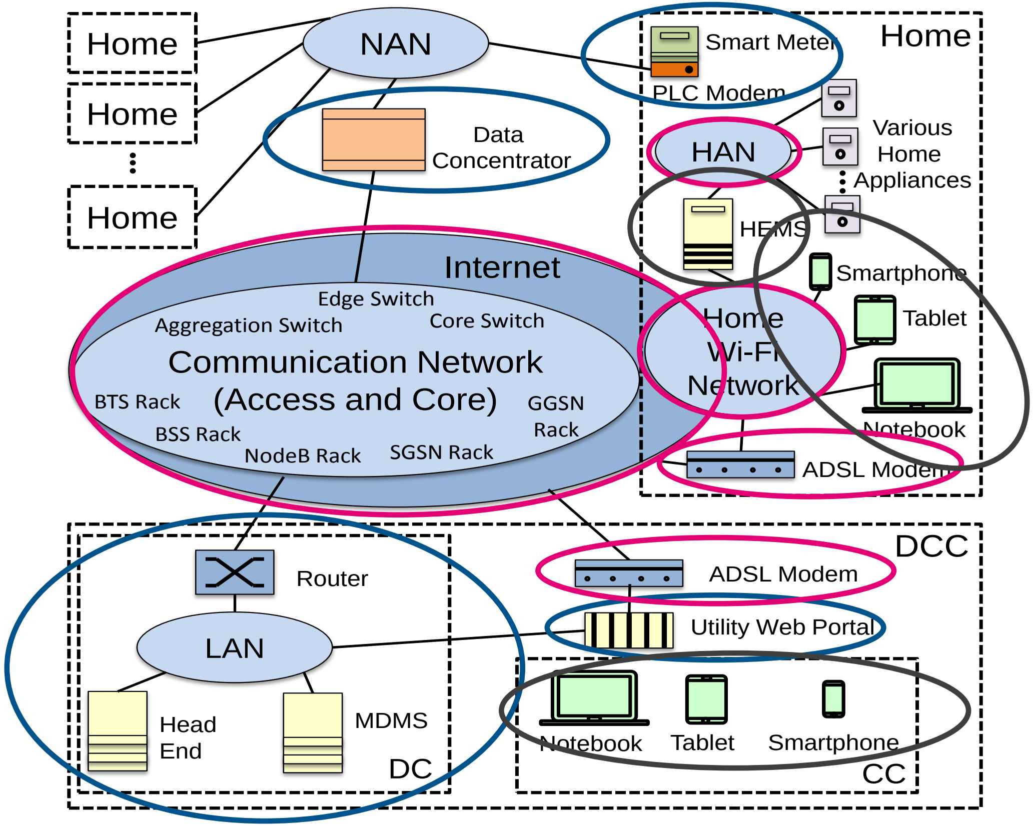
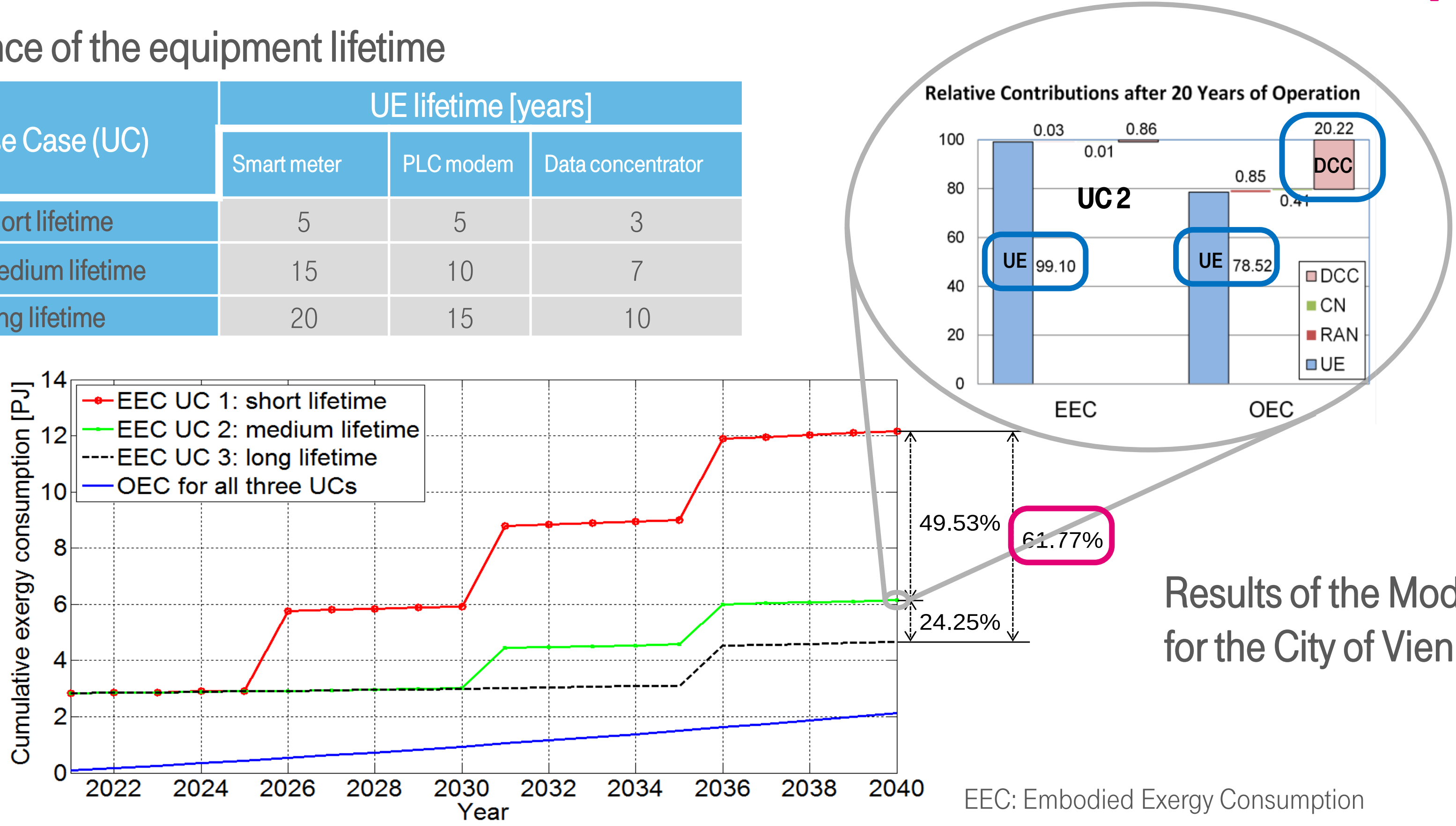


- Utility Equipment (UE):
  - smart meters
  - PLC modems
  - data concentrators
- Data and Control Center (DCC)
- Network Equipment:
  - BTS
  - BSC
  - Node B
  - RNC
  - Switches
  - Routers
  - Cables
- User Devices (UDs):
  - Smartphones
  - Tablets
  - Notebooks
  - HEMSs

SUSTAINABILITY OF ADVANCED METERING INFRASTRUCTURE (1)

Influence of the equipment lifetime

Use Case (UC)	UE lifetime [years]		
	Smart meter	PLC modem	Data concentrator
UC 1: short lifetime	5	5	3
UC 2: medium lifetime	15	10	7
UC 3: long lifetime	20	15	10



Results of the Model for the City of Vienna

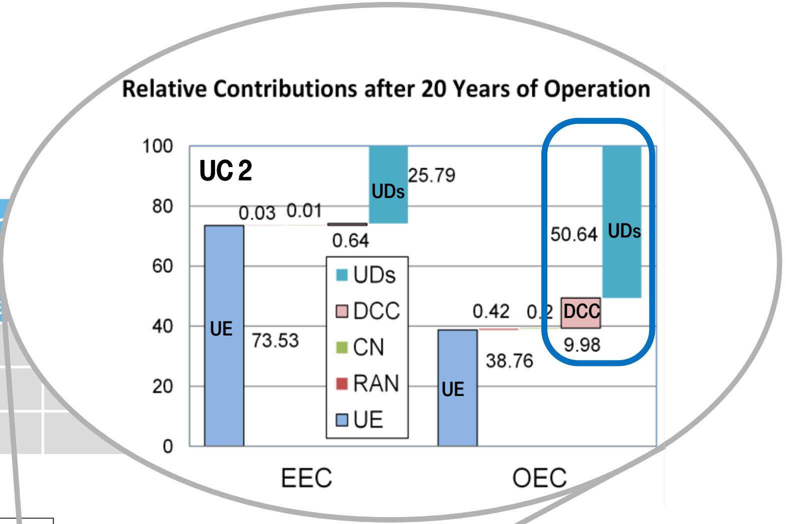
EEC: Embodied Exergy Consumption

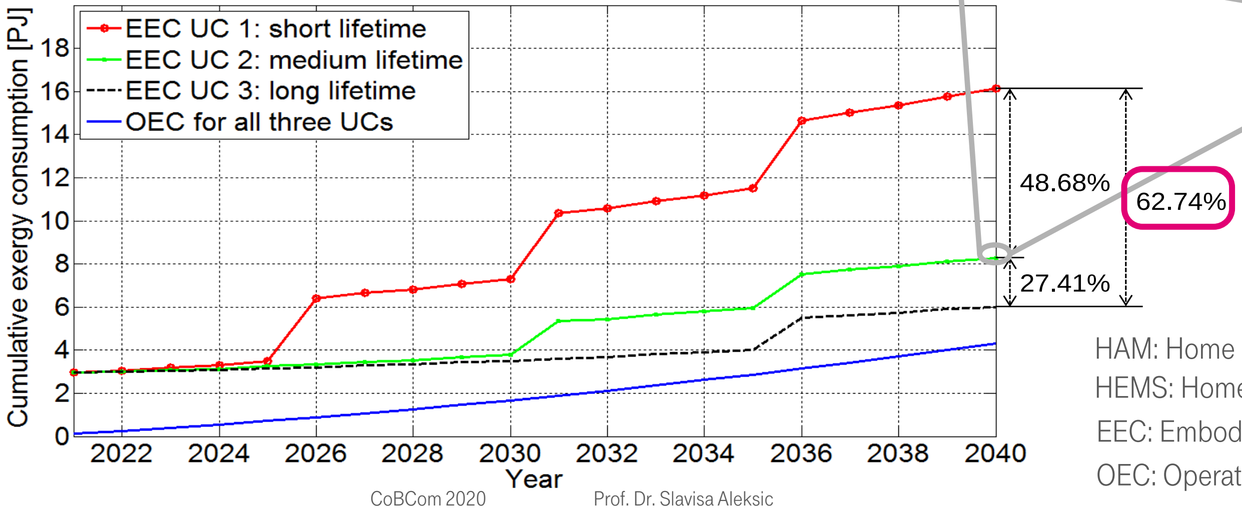
OEC: Operational Exergy Consumption

SUSTAINABILITY OF AMI/HAN

Influence of the equipment lifetime

Use Case (UC)	UDs lifetime [years]					UE lifeti	
	Smartphone	Tablet	Notebook	HEMS	DSL modem	Smart meter	PL mode
UC 1: short lifetime	1	1	2	2	3	5	5
UC 2: medium lifetime	2	2	3	4	5	15	10
UC 3: long lifetime	4	4	6	6	10	20	15





Results of the Model for the City of Vienna

HAM: Home Area Network
HEMS: Home Energy Management System
EEC: Embodied Exergy Consumption
OEC: Operational Exergy Consumption

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Conclusions (1)

- Smart Grids have the potential to improve the global energy efficiency
- The realization of the smart grid will only be possible by a pervasive deployment and use of information and communication technologies (ICT)
- However, additional ICT equipment will unavoidably lead to a higher energy consumption and an impact on the environment
- Embodied exergy consumption (EEC) is dominating
  - Almost 2 times higher than the operational exergy consumption (OEC)
  - Indicates the importance of considering the entire lifecycle

Conclusions (2)

- The most environmentally impacting lifecycle stage is the manufacturing and assembly phase
  - It accounts for 60% of the total exergy consumption
  - The manufacturing of the processor counts for more than 90% of the total exergy consumption in this life cycle stage
- The contribution of transportation is less than 2% of the total
- Increase of the equipment's lifetime can lead to a reduction of the cumulative embodied exergy consumption (EEC) by about 62%

Recommendations:

- Increase equipment's lifetime
- Improve efficiency of manufacturing and assembly processes
- Increase energy efficiency of servers and data centers

Thank you for your attention

Questions?

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