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Environmental Performance Indicators for Data Centers

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Table of contents

Climate Crisis and Data Centers

- Energy demand of IT industry
  - Substantial portion of total energy usage (probably >10%)[1]
  - Increasing
- Need for very efficient Data Centers
- Need for Performance Indicators

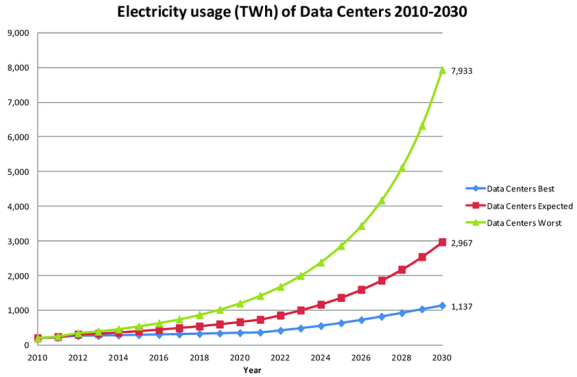

Figure: Combined global electricity usage of data centers is rising [2].

Traditional Performance Indicators for Data Centers

- Economic Performance Indicators
  - Create competition
  - Should lead to more efficient Data Centers
  - Example: Power Usage Effectiveness (PUE) [3]

$$\text{PUE} = \frac{\text{total Facility Energy}}{\text{IT Equipment Energy}}$$

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What are problems of the PUE?

Traditional Performance Indicators for Data Centers

- Example: Power Usage Effectiveness (PUE) [3]

$$\text{PUE} = \frac{\text{total Facility Energy}}{\text{IT Equipment Energy}}$$

  - Does not show energy usage
  - Does not show specific problems
  - Depends on site location
  - Assumes that all IT load is good
  - Misused for marketing purposes [4]
  - Does not lead to more efficient IT processes [3]

Traditional Ecological Performance Indicators for Data Centers

- Too many Performance Indicators
- No "gold standard"
- Data Centers **were** not interested

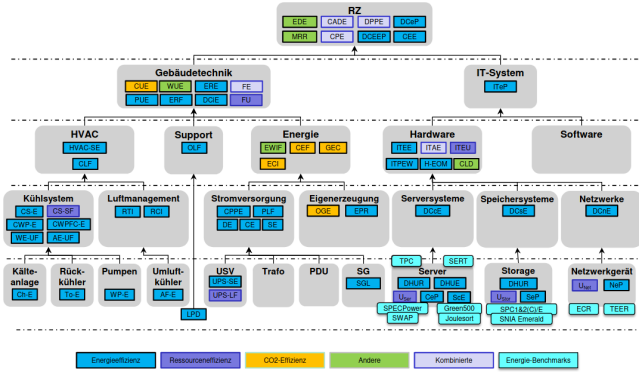

Figure:
Subset of >100 ecological Performance Indicators [5].

Key Performance Indicators for Data Centers *(KPI4DC)*

- "*Kennzahlen und Indikatoren für die Beurteilung der Ressourceneffizienz von Rechenzentren und Prüfung der praktischen Anwendbarkeit*"[6]
  Translated: Key figures and indicators for assessing the resource efficiency of data centers and testing their practical applicability
  - 261 pages report
  - Published in February 2018
  - Commissioned by German Environmental Agency
  - Tries to solve problems from above
  - EXCEL Sheet to calculate KPI4DC
    - not accessible

Resource Efficiency

$$\text{Resource Efficiency} = \frac{\text{Data Center Performance (Output)}}{\text{Consumption of Natural Resources (Input)}}$$

Building Infrastructure Resource Efficiency

- Is treated separately from IT Resource Efficiency
  - Management is often separated
  - Works for Colocation Data Center
- Measured similar to *Data Center Infrastructure Efficiency (DCIE)*[7]

$$\text{DCIE} = \frac{1}{\text{PUE}} = \frac{\text{IT Equipment Energy}}{\text{total Facility Energy}}$$

  - Here:

$$\text{Building Infrastructure Resource Efficiency} = \frac{\text{IT Resource Usage}}{\text{Facility Resource Usage}}$$

Data Center Performance

$$\text{Resource Efficiency} = \frac{\textbf{Data Center Performance (Output)}}{\text{Consumption of Natural Resources (Input)}}$$

How would you measure the Performance of a Data Center?

Data Center Performance

- Difficult to measure
  - Data Centers are very different
  - Performance depends on use case
    - HPC Data Center
    - Netflix Data Center
    - Dropbox Data Center

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    - HPC Data Center ⇒ Computation
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  - Performance depends on use case
    - HPC Data Center ⇒ Computation
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    - Dropbox Data Center ⇒ Data Storage
- Measured at the physical infrastructure level -> IT Performance
  - Ensures comparability

IT Performance in the Report

- 3 performance dimensions:
  - Computation:
    - *SPECint_rate* $\times$ usage
  - Data Storage (HDD and SSD):
    - Number of read/write operations
    - Data throughput of read/write operations
    - Used storage space
  - Data Transmission:
    - Amount of data transmitted between Data Center and the world

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    - Amount of data transmitted between Data Center and the world
- No aggregation rules due to loss of transparency and objectivity

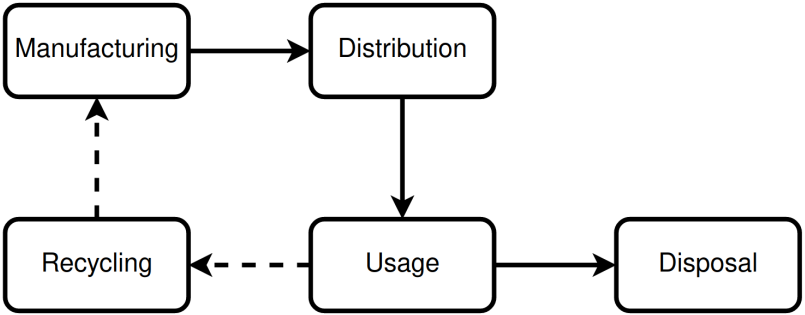
Consumption of Natural Resources

$$\text{Resource Efficiency} = \frac{\text{IT Performance (Output)}}{\textbf{Consumption of Natural Resources (Input)}}$$

What are Natural Resources used by a Data Center?

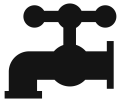
Consumption of Natural Resources

- Measured over entire life cycle of Data Center



Consumption of Natural Resources

- Water Consumption
  - Unit: m^3 Water per year
  - Very relevant in areas with water shortage



Consumption of Natural Resources

- Water Consumption
  - Unit: m^3 Water per year
  - Very relevant in areas with water shortage
- Abiotic resources Depletion Potential (ADP)
  - Raw material consumption
  - Unit: kg *Sb* (Antimony) equivalents per year
  - Focus of the report
  - Not yet finalized (data is changing a lot)

Consumption of Natural Resources

- Cumulative Energy Expenditure
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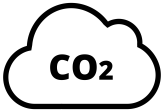
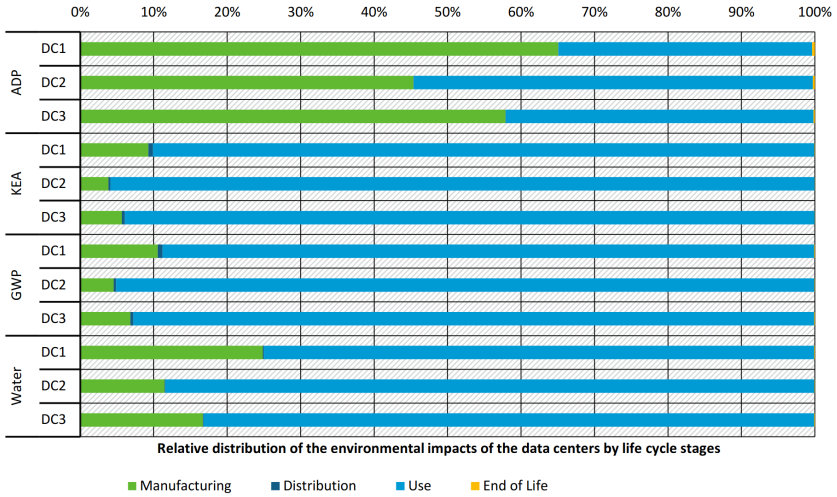
Consumption of Natural Resources

- Cumulative Energy Expenditure
  - Combined renewable and non-renewable energy
  - Unit: MJ per year
- Global Warming Potential
  - Unit: kg CO_2 equivalents per year
  - Depends heavily on electricity mixture



Relative environmental impact of life cycle phases



Short Recap

$$\text{Resource Efficiency} = \frac{\text{IT Performance (Output)}}{\text{Consumption of Natural Resources (Input)}}$$

- IT Performance
  - measured at physical Infrastructure Level
  - Computation, Data Storage, Data Transmission
- Consumption of Natural Resources
  - Measured over whole life cycle
  - Manufacturing and Use phase have greatest impact
  - Water, Raw Materials, Energy Usage, Green House Gas Emissions

Emmy

- 2020: rank 47 on TOP500 list [8]
- 2022: rank 91 on TOP500 list [9]
- 120k Cores, 500TB RAM [9]
- 5.95 PFlop/s LINPACK Performance Benchmark [9]
- PUE of 1.03 [8]

Performance Indicator for Emmy

- Try to calculate Resource Efficiency of Emmy
- **ONLY USE PHASE!**

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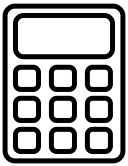
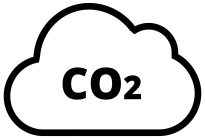
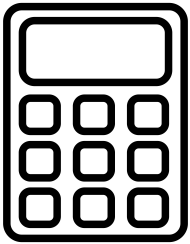
- Try to calculate Resource Efficiency of Emmy
- **ONLY USE PHASE!**
- use computation and Global Warming Potential





IT Performance - computing power

- Required by the report[6]:
  - SPECint_rate benchmark
    - Not available
    - Approx. cost: *25 000 €* electricity bill
    - Will use LINPACK instead (5.95 PFlop/s)[9]



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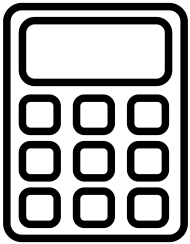

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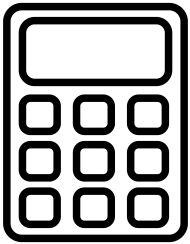

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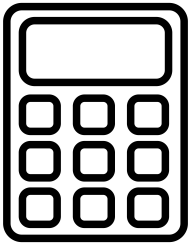

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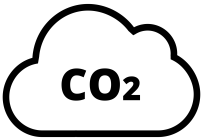
- like 1 operation per second for 150 838 521 years

Global Warming Potential

- Electricity per year:
  - $1\ MW \times 1\ \text{year} = 8\ 760\ 000\ kWh$
  - like 2625 Lower Saxony households[10]

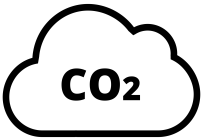
Global Warming Potential

- In 2021:
  - electricity mix of the University
  - 0.287 $kg\ CO_2/kWh$ (Source: facility management)
  - 8 760 000 $kWh \times 0.287\ kg\ CO_2/kWh = 2\ 514\ 120\ kg\ CO_2$
- $\approx$ 12 500 000 km in a VW Golf (2020, 2.0l Gasoline)[11]



Global Warming Potential

- In 2022:
  - green electricity[12]
  - Monitored in "Herkunftnachweisregister" of the German Environmental Agency[13]
    - GWDG could check CO_2 Emissions
  - 233 940 $kg\ CO_2$
    - "CO_2-Calculator" of the German Environmental Agency[14]



Thoughts

- difficult to get the data
- useful to find inefficiencies
  - Resource Efficiency(2021) $\approx 1.9 \frac{GFlop/s}{kg\ CO_2}$
  - Resource Efficiency(2022) $\approx 20 \frac{GFlop/s}{kg\ CO_2}$
- useful to compare Data Centers
  - missing SPECint_rate $\Rightarrow$ comparison not possible

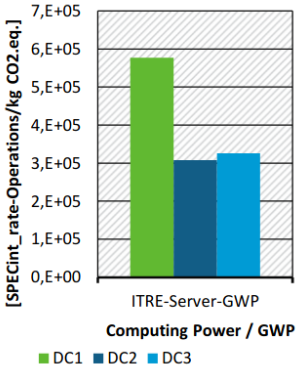


Figure: Comparison of 3 Data Centers from [6].

Outlook

Ongoing effort of the German Environmental Agency:

- *KPI4DC 2.0* started in 2018 [15]
- *Green Cloud Computing*, report 2021 [16]
  - Examine cloud computing scenarios with KPI4DC

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- Blue Angel
  - Environmental certificate in many fields
  - In Data Center context
    - Required to get e.g. government contracts
    - *DE-UZ 161* Energy-Efficient Data Center Operation[17]
    - *DE-UZ 214* Climate Friendly Colocation Data Centers [18]
    - *Blue Angel for Data Centers* will combine DE-UZ 161 and 214[19]

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  - Role model for *European Flower*

Summary

- KPI4DC Report

$$\text{Resource Efficiency} = \frac{\text{IT Performance (Output)}}{\text{Consumption of Natural Resources (Input)}}$$

  - IT Performance
    - Measured at physical Infrastructure Level
  - Consumption of Resources
    - Measured over whole life cycle
- Calculated Resource Efficiency for Emmy

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