Architecting a Sustainable Planet

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Microsoft
Outline

- **Background on carbon emissions**
  - It is real & companies are listening
  - The little things add up

- **Data center history & analysis**
  - Bigger can be better: Efficiencies of scale
  - Breaking it down: Where does the carbon go?

- **Sustainability ideas**
  - Demand shaping: The when, where and how of running jobs
  - Sustainable Silicon

- **Innovative solutions & conclusion**
  - Thinking outside the box – May lead you back into a different box
  - The bigger picture
Facets of Sustainability
It is real & companies are listening
A planet-sized challenge
Annual total CO₂ emissions, by world region

This measures CO₂ emissions from fossil fuels and cement production only – land use change is not included.

Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)
Note: 'Statistical differences' included in the GCP dataset is not included here.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

10/29/2020
MICRO 2020 KEYNOTE
Data Centers

205TWh of electricity/year used†
Equivalent to 1 year of: *

- 31.3M cars
- 31,292 wind turbines
- 189.3M acres of forestland (Texas is ~172M acres)
- 145M metric tons CO2


* Based on EPA Greenhouse Gas Equivalences Calculator
Walmart aims for zero greenhouse gas emissions by 2040

Google, Facebook, Microsoft to Go Carbon-Free by 2030

Inside Apple's green revolution: Can it make a carbon neutral iPhone?
The little things add up
# Examples

<table>
<thead>
<tr>
<th>Monthly Active User</th>
<th># Monthly Active Users</th>
<th>Carbon/year (Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facebook (2019)*</td>
<td>~0.1 kg CO2e</td>
<td>2.38 Billion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost per hour (KWh)</th>
<th>Average Daily Hours</th>
<th>Tons CO2e/day</th>
<th>Carbon/year (Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netflix-2019† (Including Devices)</td>
<td>0.12 – 0.24</td>
<td>165,000,000</td>
<td>14,141-28,282</td>
</tr>
</tbody>
</table>

- † 86% renewable energy mix
Death by a billion swipes

“A cloud for everyone, on every device.”
Satya Nadella

Current World Population
7,810,981,656
As of September 10, 2020

World Internet Users
4.57 BILLION
As of July, 2020
Bigger can be better: Efficiencies of scale
Growth of hyperscale

• 2X increase in users
• 12X increase in traffic
• 6% increase in energy use

Benefits of hyperscale

Traditional enterprise data centers

- Multi-tenancy
- Dynamic allocation
- Efficient hardware
- Lower PUE (power usage effectiveness)
- Zero emission sources

“The carbon benefits of cloud computing: A study on the Microsoft Cloud in partnership with WSP”, Microsoft 2020
Hyperscale efficiencies

Google Data center PUE
Trailing 12 months from Q1’2020

https://www.google.com/about/datacenters/efficiency/

E. Sommer et. Al, “Cloud Jewels: Estimating kWh in the Cloud”.
Breaking it down: Where does the carbon go?
“If the cement industry were a country, it would be the third largest emitter in the world...”

Jocelyn Timperley, “Why cement emissions matter for climate change”
Data center equipment lifecycle

Material extraction & manufacturing
- CPU, GPU, FPGA
- DRAM
- HDD/SSD
- Power delivery unit (PDU)
- Networking equipment
- Cooling equipment
- Batteries

Component manufacturing
- Server
- Rack

Assembly

Use

EOL
- Shredding
- Recycling
- Smelting
Data center equipment lifecycle

**EMBODIED**
- Material extraction & manufacturing
  - Energy

**Component manufacturing**
- Energy
  - Emissions
- CPU, GPU, FPGA
- DRAM
- HDD/SSD
- Power delivery unit (PDU)
- Networking equipment
- Cooling equipment
- Batteries

**Assembly**
- Energy
  - Emissions
- Server
- Rack

**USE**
- Energy
  - Emissions
- Use

**EOL**
- Energy
  - Emissions
- Waste
  - Shredding
  - Recycling
  - Smelting

10/29/2020
MICRO 2020 KEYNOTE
1MW Data Center


10/29/2020
MICRO 2020 KEYNOTE
Not all electricity is created equal


Demand Shaping: The when, where, and how of running jobs
CA Energy Mix
April 19, 20, 21

Data from California Independent System Operator
CA Energy Mix
April 19, 20, 21

7X Variability in Carbon Intensity

Data from California Independent System Operator
Example: Time shifting demand

A Microsoft hackathon project showed that the carbon footprint of AZ batch service in the Netherlands can be reduced by:

- 11% for jobs < 24 hrs
- 10% - 27% savings for jobs < 5 hours
Load shifting complexities

Limited renewable availability

Overutilization of resources during low carbon intensity and/or in renewable friendly regions.

Underutilization in other data centers.

O. Hadary et al., “Protean: VM Allocation Service at Scale”, OSDI, 2020

VM Requests/hour
Averaged by day of week for 5 weeks

Carbon intensity from 10/4 – 10/11
Location, Location, Location
Take aways

VM power estimation
Demand shaping algorithm

Carbon intensity prediction
Job duration estimation

Checkpointing mechanisms
Delay tolerant applications

Customer requirements
Application needs

Renewable mix
Hardware availability

Data center utilization

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Sustainable silicon
Silicon manufacturing

TSMC (2019)
14.1M tons CO2e
75% electricity (7% renewable)
25% from chemicals with high global warming potential (GWP)

Increasing cost and complexity

Diminishing power and performance improvements

<table>
<thead>
<tr>
<th>Metric</th>
<th>16nm -&gt; 7nm</th>
<th>7nm -&gt; 5nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>65% ↓</td>
<td>30% ↓</td>
</tr>
<tr>
<td>Performance</td>
<td>35% ↑</td>
<td>15% ↑</td>
</tr>
<tr>
<td>Density</td>
<td>3.3X ↑</td>
<td>1.84X ↑</td>
</tr>
<tr>
<td>Wafer Cost †</td>
<td>2.34X ↑</td>
<td>1.82X ↑</td>
</tr>
</tbody>
</table>

* 7nm numbers from https://en.wikichip.org/wiki/7_nm_lithography_process

10/29/2020
MICRO 2020 KEYNOTE
Annual improvement in manufacturing energy efficiency

TSMC Corporate Social Responsibility Report, 2019
Key points

USE IT LONGER

MAKE IT CHEAPER
(IN TERMS OF CARBON)

DO MORE WITH LESS
(INCREASE UTILIZATION)
Hardware vs VM viewpoint

Hardware Perspective:
• 64+ cores
• Coherent LLC
• 8+ memory channels
• 256+ GB memory capacity
• Dual socket systems

85% of VMs are <= 4 virtual cores
70% of VMs require < 4GB memory

* E. Cortez et. Al, “Resource Central: Understanding and Predicting Workloads for Improved Resource Management in Large Cloud Platforms”, SOSP’17
Don’t throw the baby out with the bathwater

Resilient hardware and software

- Increase usability by adding spares or tolerating defects
  - Spare cores
  - Spare cache capacity

- Detect, isolate, and manage faulty components
  - Graceful repair and recovery
  - Remove faulty components

- Resource pooling & disaggregation
  - Pool SSDs, DRAM, accelerators

- Manage feature updates
  - Modular HW design
  - Software shim layer and/or microcode
Disaggregate the processor

Sustainability benefits of chiplets:
- Less waste due to defects
- Optimal process
- Higher re-use
Examine architectural decisions through the lens of sustainability
Thinking outside the box... might lead you to different box
Storage requirements

Usage data from "World Wide Waste", by Gerry McGovern
Sustainable storage

DNA promises to be significantly more sustainable than tape

Nguyen et al., Electronics Goes Green, 2020
Project Natick
864 servers

Sealed tank filled with nitrogen

Deployment took 1 day

117 feet underwater
AI for sustainability
1/8 the failure rate

- Very tight operating envelope
- No humidity and nitrogen filled tank
- Isolated conditions
Full Immersion

Liquid Immersion Optimized Servers

The bigger picture
In addition...

Water
- Reduce water use
- Restore wetlands
- Remove contaminants

Waste
- 56M metric tons of e-waste generated every year

Electricity distribution
- 24x7 carbon free
275 Million phones in US
Increase use from 28 to 36 months

Save 1M mTons CO2e annually

Apple 2018*:
25.2M metric tons CO2e
74% manufacturing, 19% use
~1/3 of all CO2e from ICs

Datacenters reimagined

DNA data storage  Green concrete  Biofueled electricity  Compostable electronics

Nguyen et al., Electronics Goes Green, 2020
Datacenters reimagined

DNA data storage

20W

Compostable electronics

Nguyen et al., Electronics Goes Green, 2020
“Problems cannot be solved with the same mindset that created them.”
— Albert Einstein
Materials

https://devblogs.microsoft.com/sustainable-software/


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