A Perspective on
Carbon-Aware Networking

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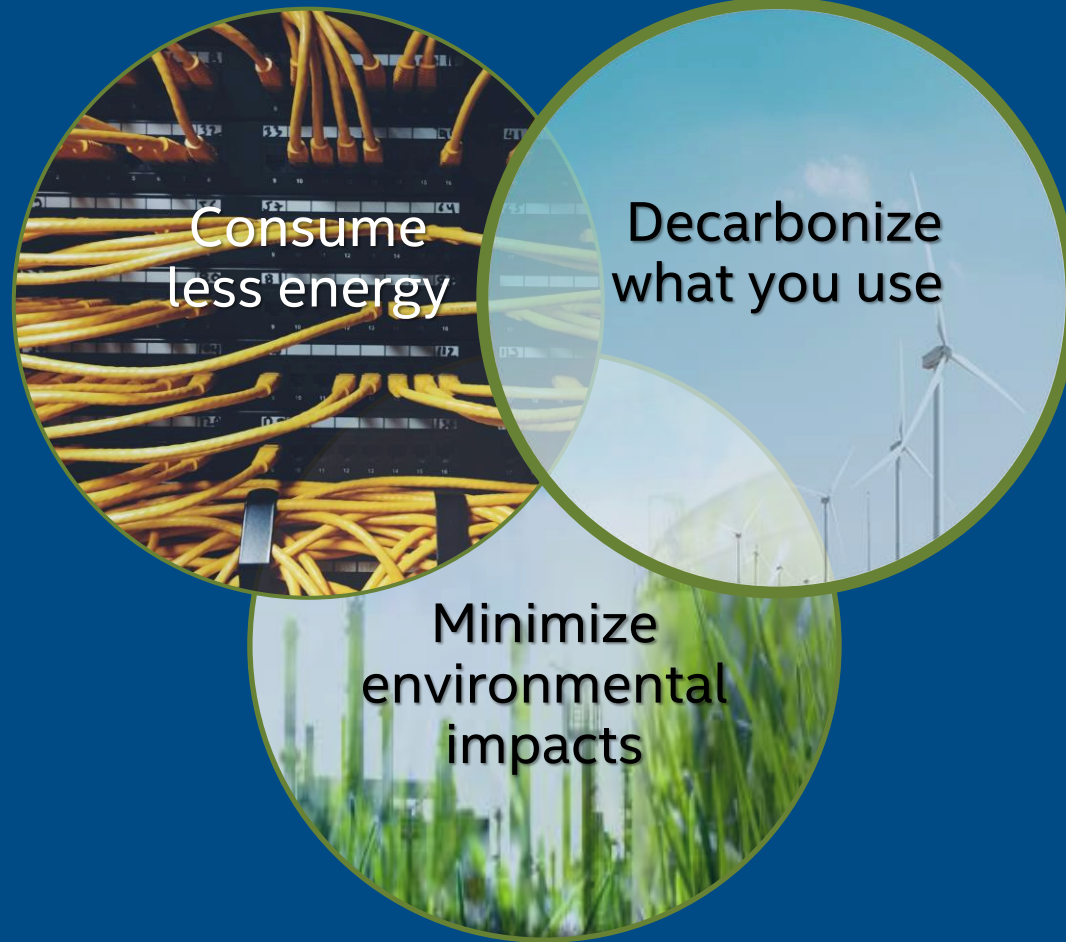
December 5th, 2022

Sustainable ICT

Consume less energy
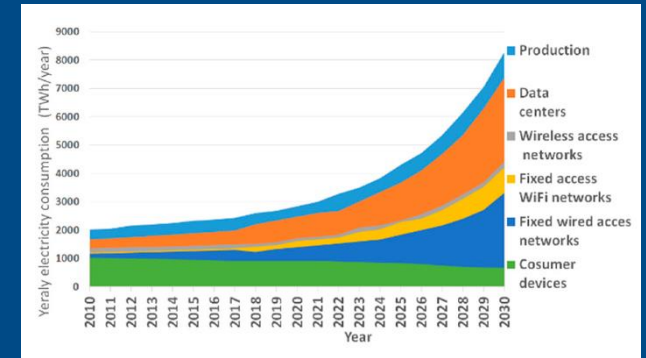
Decarbonize what you use
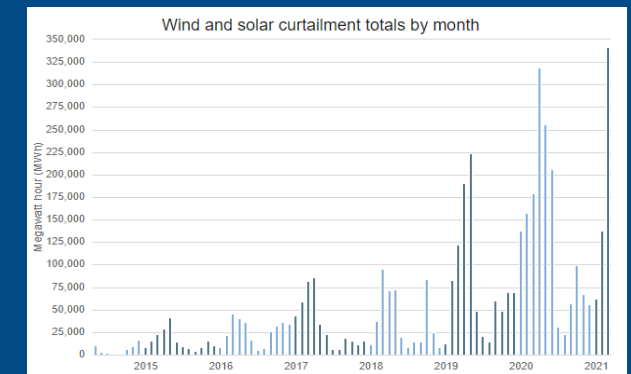
Minimize environmental impacts

Carbon-awareness

- **Inspired by DC Carbon-aware computing**
  - **Time- and space-shift** workloads
  - Maximize usage of (excess) renewable energy
    - Lower carbon footprint
    - Avoid energy wasted & stabilize grid

- **Apply carbon awareness everywhere**
  - Edge-to-cloud continuum, infrastructure roll-out → co-lo w/renewables
  - Compute, storage, network → **carbon-intensity cost metric**
  - HW/FW/SW – horizontally/vertically → APIs

ICT electricity usage growing; Network on par with DC

Variability/Excess of renewable energy

Source: Lorincz et al, Greener, energy-efficient and sustainable networks: state-of-the-art and new trends", Sensors, (2019): 4864.
Source: CAISO - California Independent System Operator (2021)

Carbon-Aware Networking
From an IETF Perspective

- **Carbon-aware Routing**

  - Select routes with the greatest carbon efficiency, comprehend time-variant links

- **Carbon-aware Transport**

  - Apply time- and space-shifting to schedule network data transmission *– DTN-like*

- **Carbon-aware Traffic engineering**

  - Guarantee carbon efficiency thresholds along paths through the network, possibly reserving resources along the way *– DetNet-inspired*

- **Carbon-aware Telemetry**

  - Instrument observability, apply carbon-awareness to telemetry data stewardship

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Preview: Challenges / Opportunities

- Reporting real-time electricity consumption

- Reporting finer-grain electricity carbon intensity

- Discovering and collating energy usage and carbon efficiency of network paths ➜ of applications and services

- Reacting in (near) RT to carbon-related info

Additional Readings

- "[Toward carbon-aware networking](#)", Noa Zilberman, Eve M. Schooler, Uri Cummings, Rajit Manohar, Dawn Nafus, Robert Soule, Rick Taylor, *HotCarbon'22 (July 2022)*

- "[Carbon-responsive computing: Changing the nexus between energy and computing](#)", Dawn Nafus, Eve M. Schooler, Karly Ann Burch, *Energies 14 (Oct 2021)*

Thank You

Food for Thought

- ~4x Electricity generation needed by 2050

  - Massive growth in eGrid infrastructure to support

- Edge-ification of eGrid from renewables

  - Decentralization of assets and ownership

- ICT players are large purchasers of clean energy RECs

  - Key stakeholders/influencers/owners/designers of future eGrid?

2x

~4x

When 100% EVs + electrification of other transportation
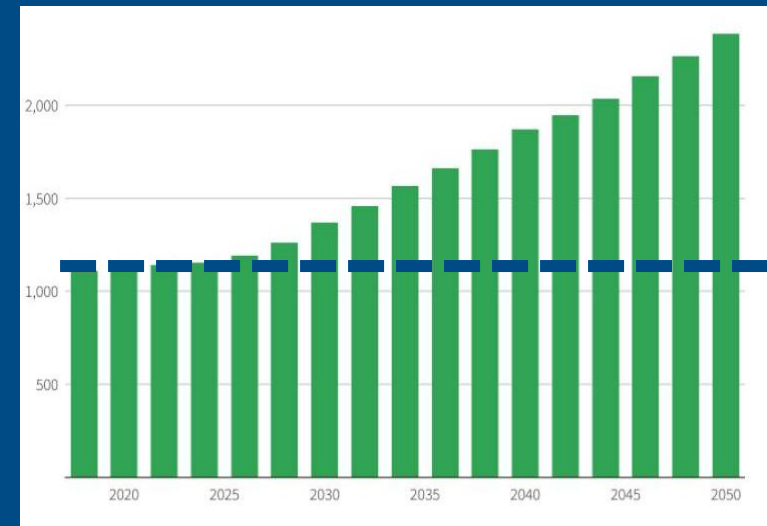
US Grid capacity to double when 66% of cars are EVs (2050)

ICT Electricity Usage is Growing Significantly

US consumes ~4000TWh/year

Germany consumes ~500TWh/year
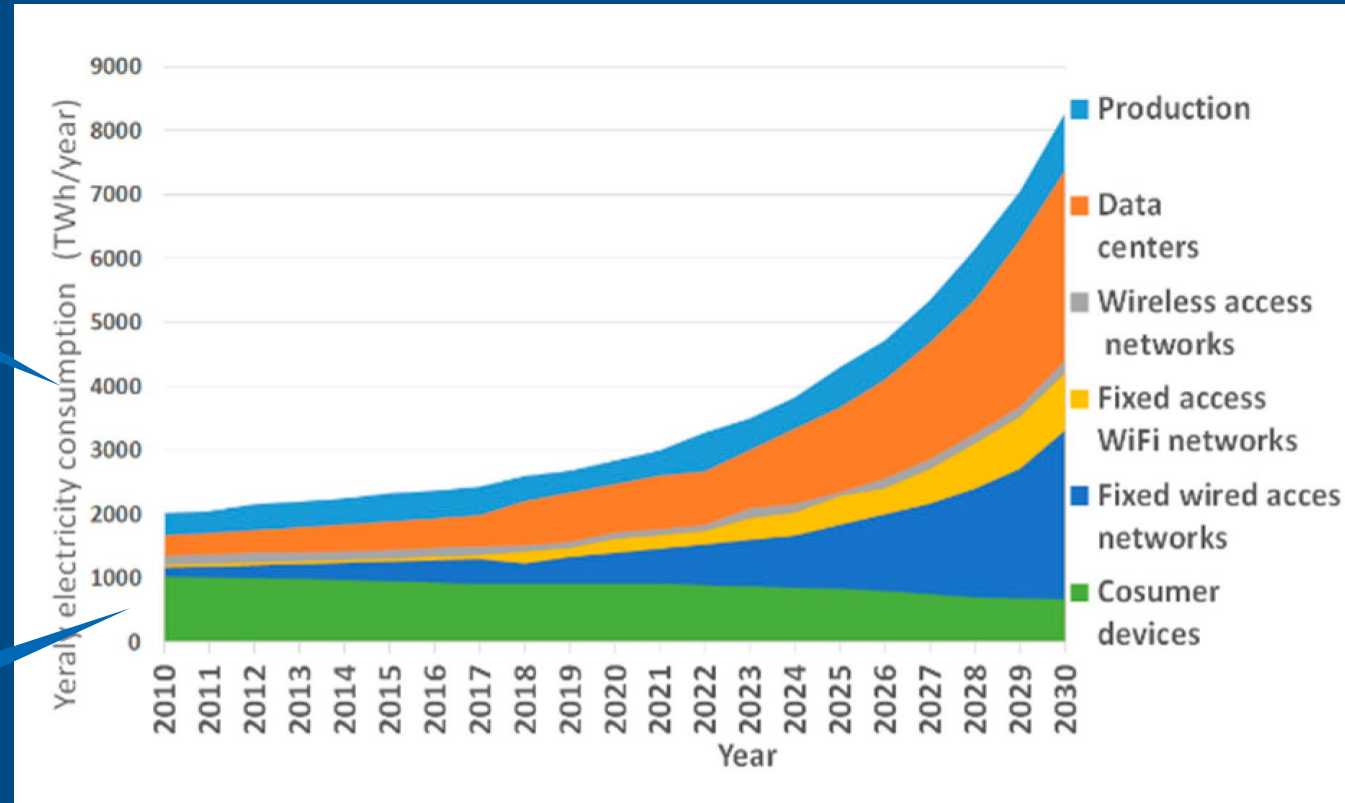
Info/Comm/Tech projected energy usage as a percentage of total electricity **is notable!**
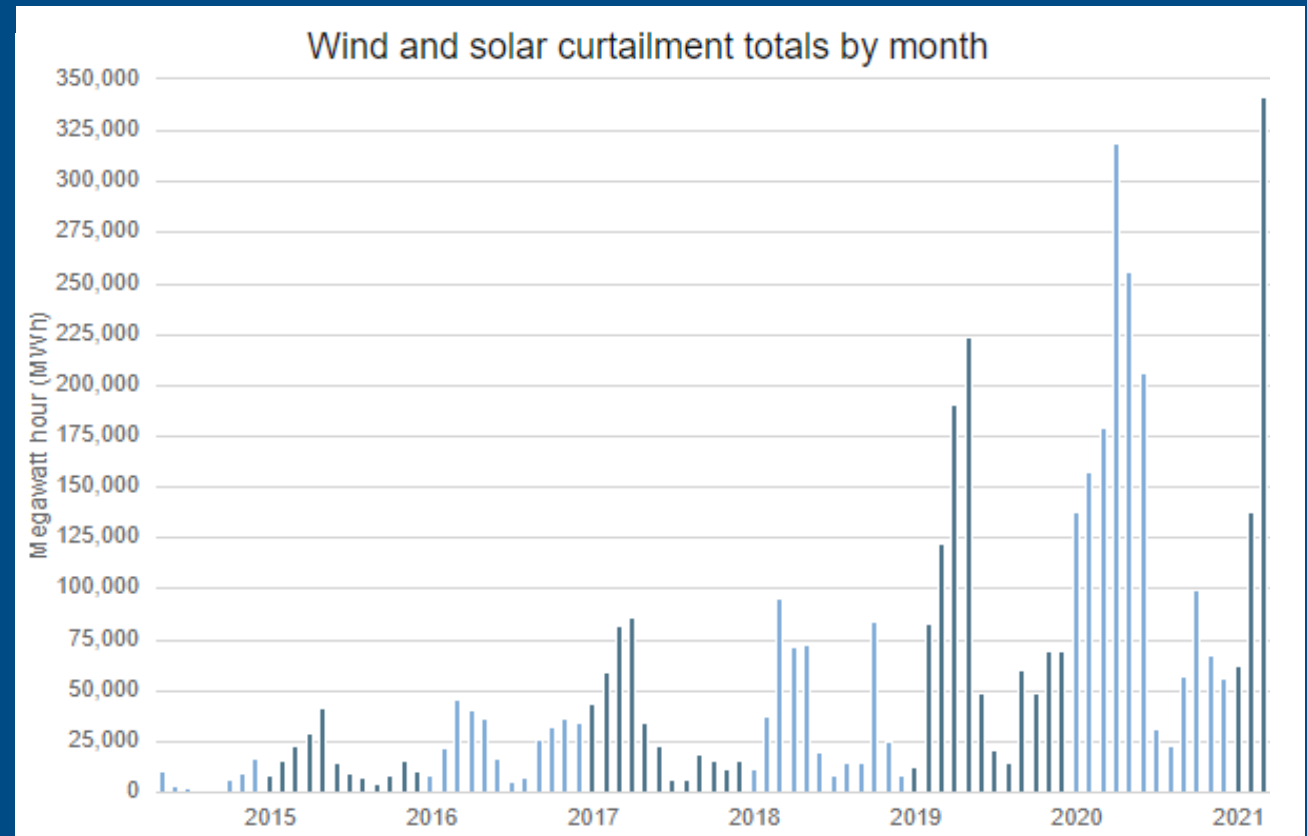
(2%-24% forecasts)

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# Renewable Energy Integration Mandated

Opportunity: Key strategy to offset increased ICT demand...

Challenge: out-of-sync nature of supply & demand...

...leading to more and more excess or *Stranded energy*

California Stranded Energy Trend

Wind and solar curtailment totals by month

Source: California Independent System Operator

Estimated US Grid Capacity to Double
If 66% of all cars are EVs by 2050

2x

↓

~4x

When
100% EVs
+
electrification
of other
transportation

Source: The National Renewable Energy (NREL) Lab's Electrification Futures Study, Jan 2021

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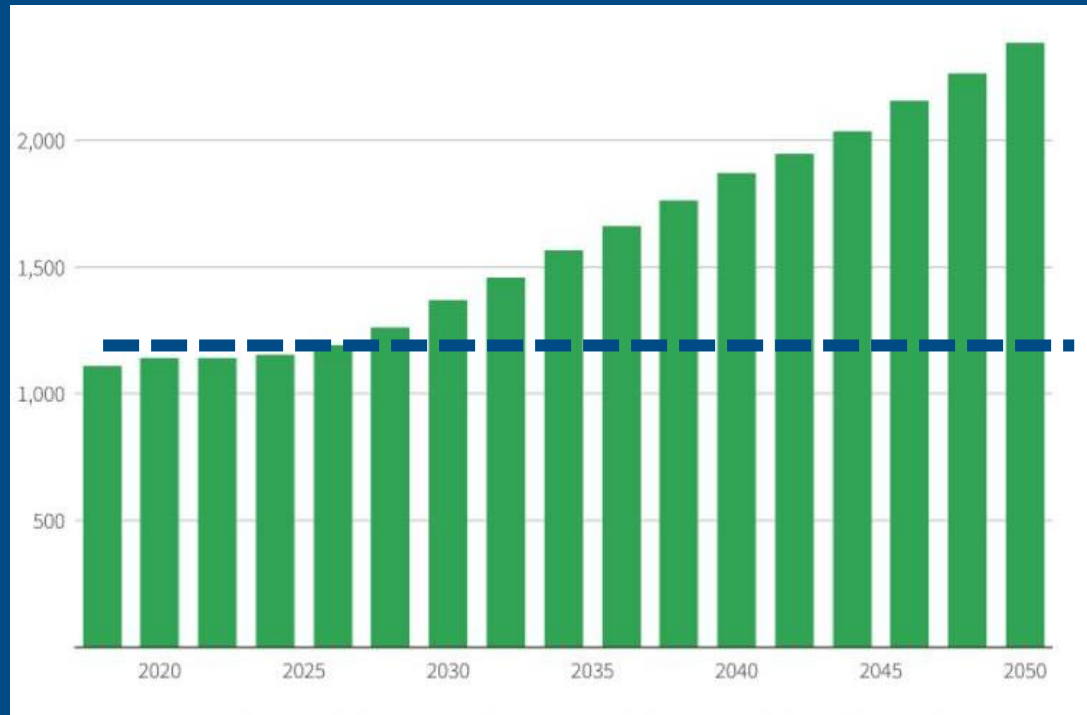
Green SW Foundation:
Software Carbon Intensity Score

The SCI score is a rate of carbon emissions, not a total. The equation is a simple and elegant solution to the extremely complex problem behind it:

Carbon emitted per kWh of energy, gCO2/kWh

Carbon emitted through the hardware that the software is running on

$$SCI = ((E * I) + M) \text{ per } R$$

Energy consumed by software in kWh

Functional Unit; this is how software scales, for example per user or per device
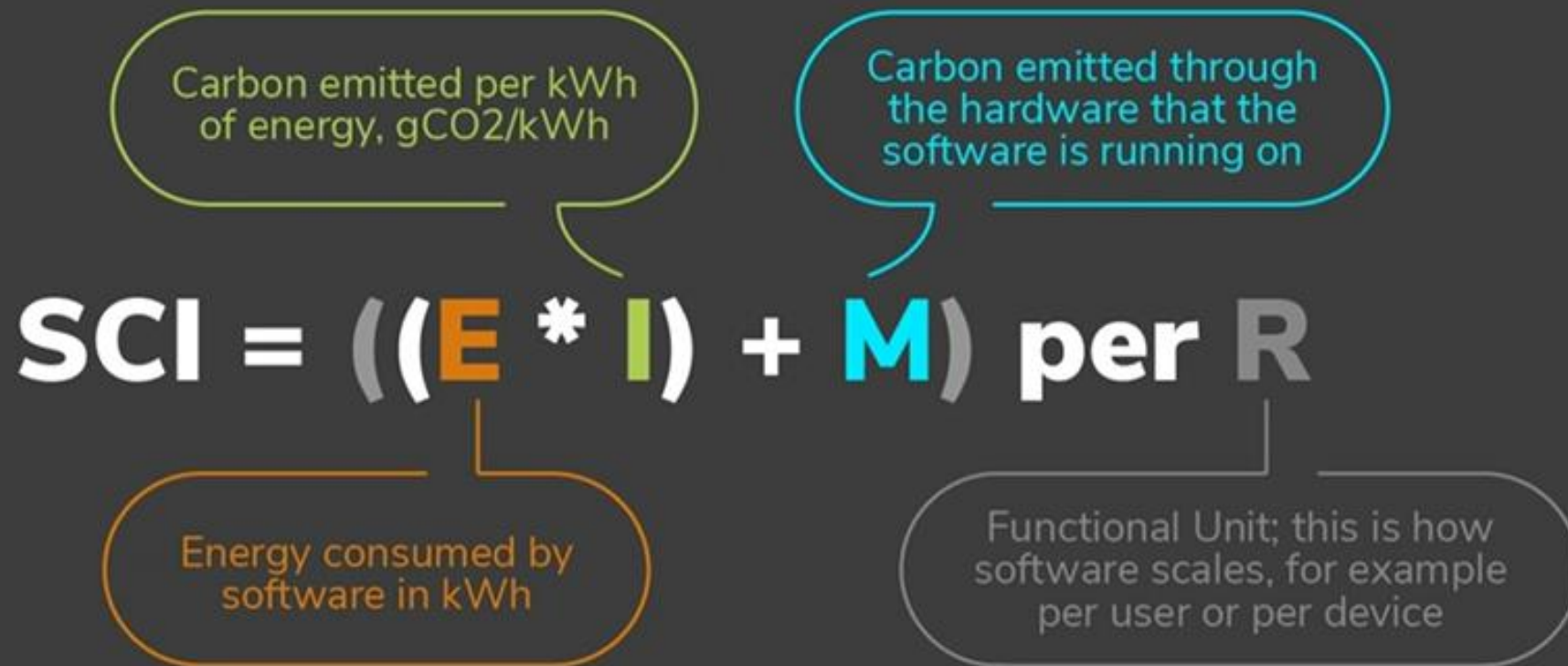
The "per R" is what makes the SCI into a tool that works for every software domain, every use case, and every person.

Source: https://grnsft.org/sci

Beaming Clean Energy from Space

https://www.caltech.edu/about/news/space-solar-power