# Carbon-aware Networking

## An Environmental Impact use case for Time Variant Routing (TVR)

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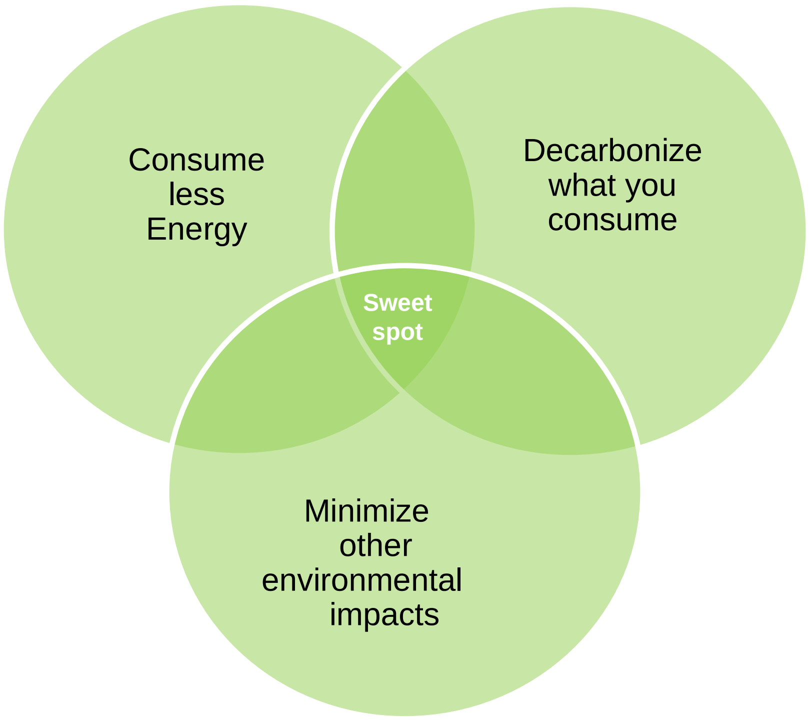
# The Backdrop

- Urgency to address UN IPCC recommendation re 1.5C degree threshold
- ICT contribution to GHG emissions sizeable and growing
  - Network impact rivals Data Center footprint
  - Must adopt renewables to get to NetZero?
- Will need 4x the amount of electricity currently generated to support the electrification of transportation, etc
  - Long arc of infrastructure roll-out …

# What is carbon-awareness?

- **Include energy carbon-intensity as a non-traditional QoS “cost” metric**
  - It is not enough to be energy efficient – i.e., to consume less energy
  - Must also decarbonize the energy consumed
  - Account for other environmental impacts
- **Inspired by DC adoption of Carbon-aware Computing**
  - Time- and space-shift workloads
  - Maximimize usage of renewable and clean energy
  - Consume excess renewable energy that would otherwise go wasted, to help stabilize the grid



# What is carbon-aware networking?

## Multiple facets

- **Carbon-aware routing**
  - Select routes with the greatest carbon efficiency
- **Carbon-aware transport**
  - Apply time- and space- shifting to 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 the network to be self-aware and to apply carbon-awareness to telemetry data stewardship

# Carbon-aware networking

## Overview

- **An example of use case 2: Operating efficiency**
  - when carbon-intensity is comprehended as part of the cost function of a link

- **Shades of use case 1: Resource preservation**
  - when the device/infrastructure opts for battery operation, e.g., when the battery is rated as having a mix of electricity whose carbon-intensity is less (which is better) than the carbon-intensity of the electricity coming out of the wall socket

- **Shades of Use case 3: Mobile devices**
  - when mobile distributed energy resources can be dispatched to places where needed

- Cause for the loss (re-appearance) of an adjacent link:
  - External environmental factors like the lack (abundance) of sun or wind or other clean energy sources
  - Threshold exceeded (met) for carbon-intensity

- Possible TVR Benefits
  - Expected loss of links are not seen as error conditions, but as optimizations
  - Expected resumption of a link does not always need to be rediscovered

# Use Case 2: Operating efficiency - revisited

## Assumptions and Expected TVR Benefits for Carbon-aware networking

### Assumptions

- **Cost Measureability.**
  - Infrastructure costs can be related to node functions.
- **Cost Predictability.**
  - Cost changes can be communicated in advance. More than just “the current cost at the moment”.
- **Cost Persistence.**
  - Cost changes are infrequent enough that behavior can be adjusted in response to their changing.
- **Cost Magnitude.**
  - The magnitude of cost savings justify the efforts required to optimize cost.
    - *Models of black-out aversion in CA in summer’22, if all EV batteries leveraged*

### Possible TVR Benefits

- **Link Filtering.**
  - Individual links can be filters based on cost to minimize the use of high-cost links unless needed by type of traffic (e.g. high priority).
    - *In the extreme, links are only up in the presence of clean energy*
- **Burst Planning.**
  - Where there is a cost savings associated with fewer longer transmissions (versus many smaller transmissions), nodes might accumulate a sufficient data volume exists to justify a transmission.
- **Environmental Measurement.**
  - If link quality is insufficient due to environmental conditions (such as clouds on an optical link or long distance RF transmission in a storm) the cost required to communicate over the link may be too much, even if access to infrastructure is otherwise in a less expensive time of day.
    - *Regulatory pressure, like carbon taxes?*

# Considerations

- Granularity, frequency, coverage of carbon-intensity measurement
- Interplay of stored electricity in battery and (live) electricity generation
- Justification function

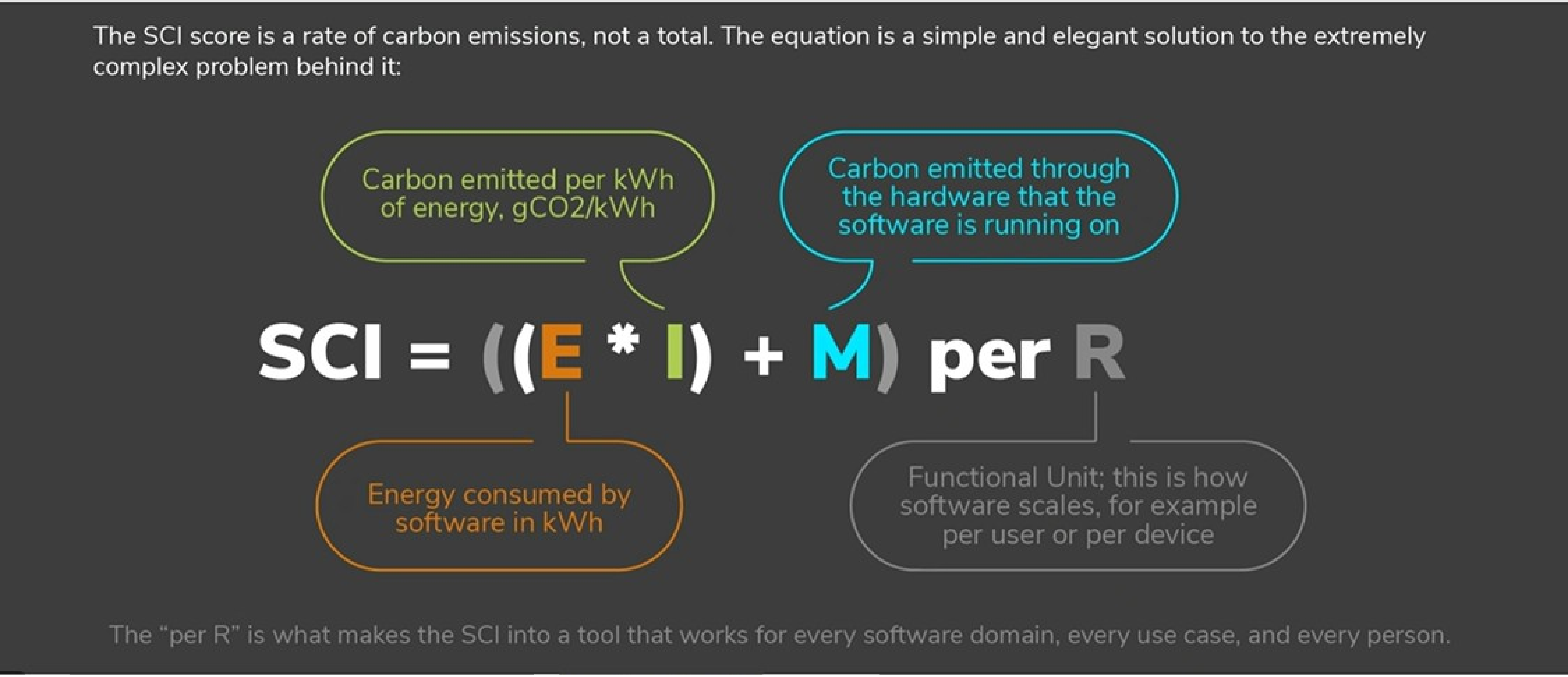
# Additional resources

- "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

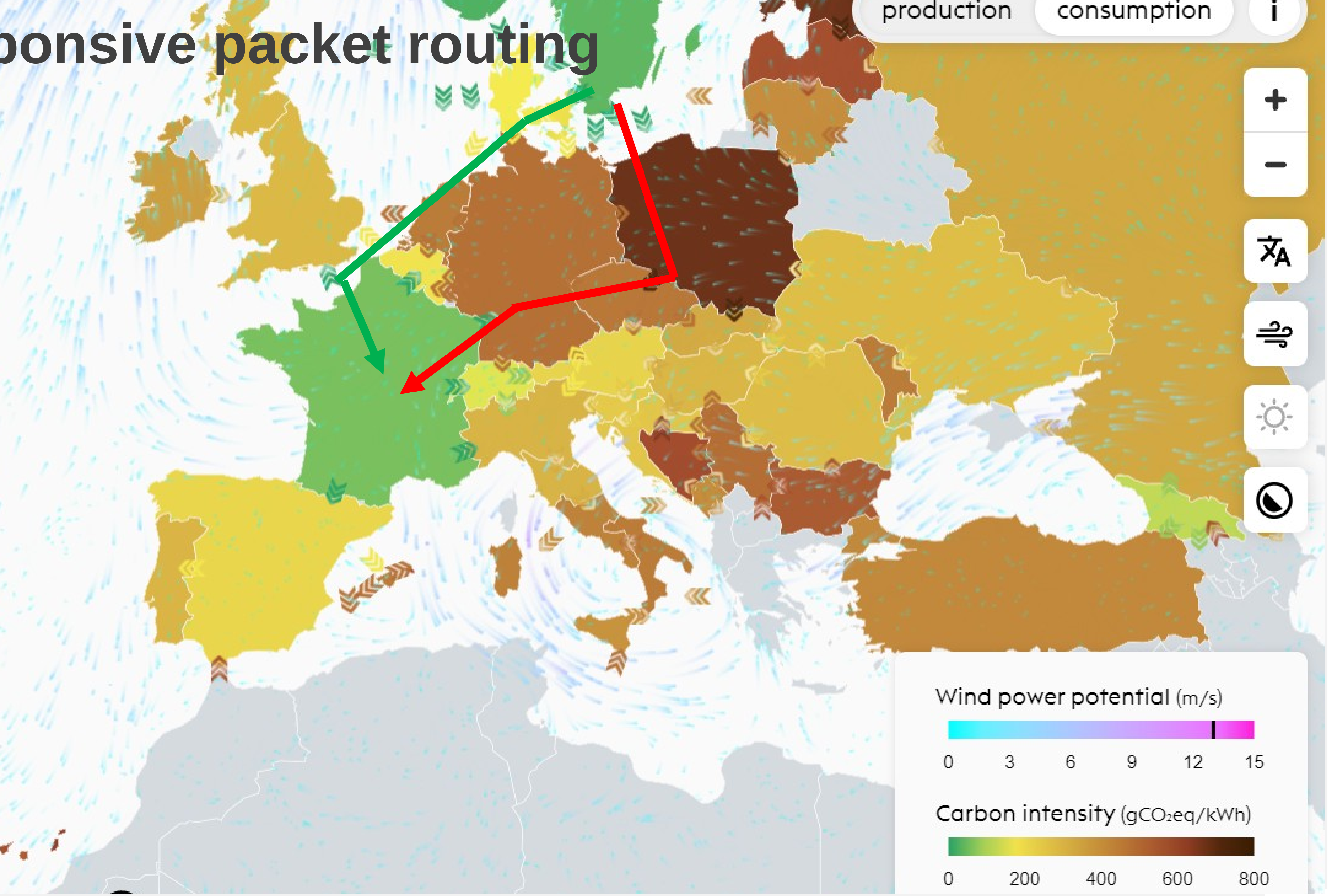
# BACKUP

# Green SW Foundation: Software Carbon Intensity




Source: https://grnsft.org/sci

# Carbon-responsive packet routing




Enabled by:

- Exposure of carbon-intensity data from eGrid
- Uptake of carbon-intensity in QoS-enabled routing protocols (and apps)

Image Source: Electricitymap.org