Digital Sustainability

How Can We Build Software With the Planet in Mind?

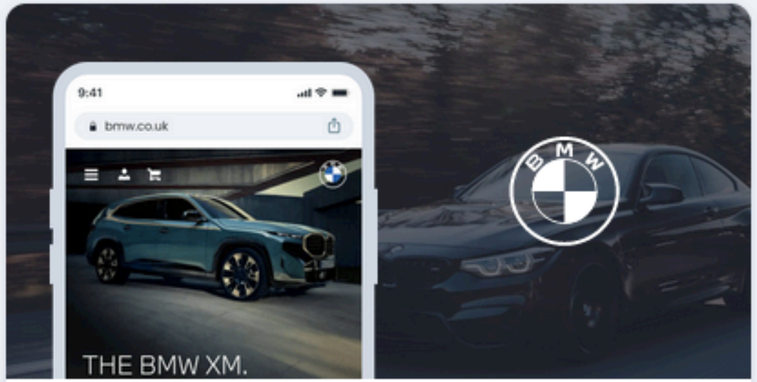
Brian Louis Ramirez

Web Performance Engineer

Speed Kit

CUSTOMER SUCCESS STORIES

Speed Kit makes leading brands faster

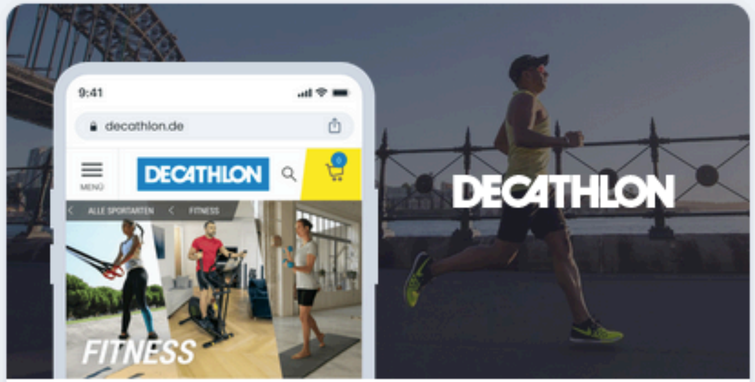


„Speed Kit has been rolled out for **118 countries** and achieved a **1.5x faster LCP**."

BMW (Bayerische Motoren Werke AG)

33%
Faster FCP

65%
Less Image Data

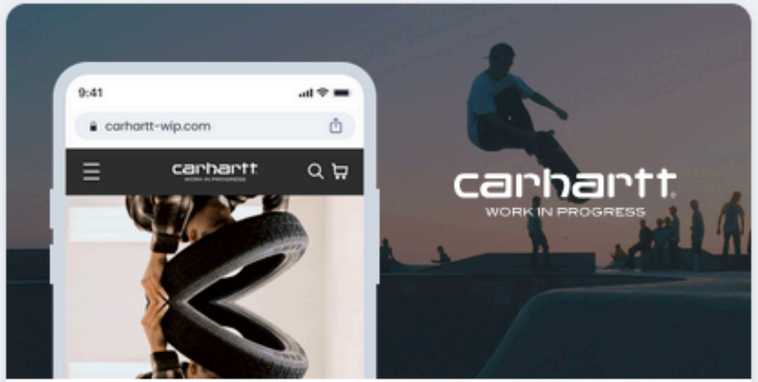


„Speed Kit accelerated our site by **2.5x** […]. There is no doubt about the **great ROI**."

Florian Bischoff, Director E-Commerce

2.5x
Faster FCP

2 Weeks
Until ROI Achieved



„We were able to go **live within a matter of days** […] across our three biggest markets."

Marc Lohausen, Head of E-Commerce

1.9x
Faster FCP

1 Week
Until Go Live


The Internet is
the largest machine
ever built.

The Internet Machine

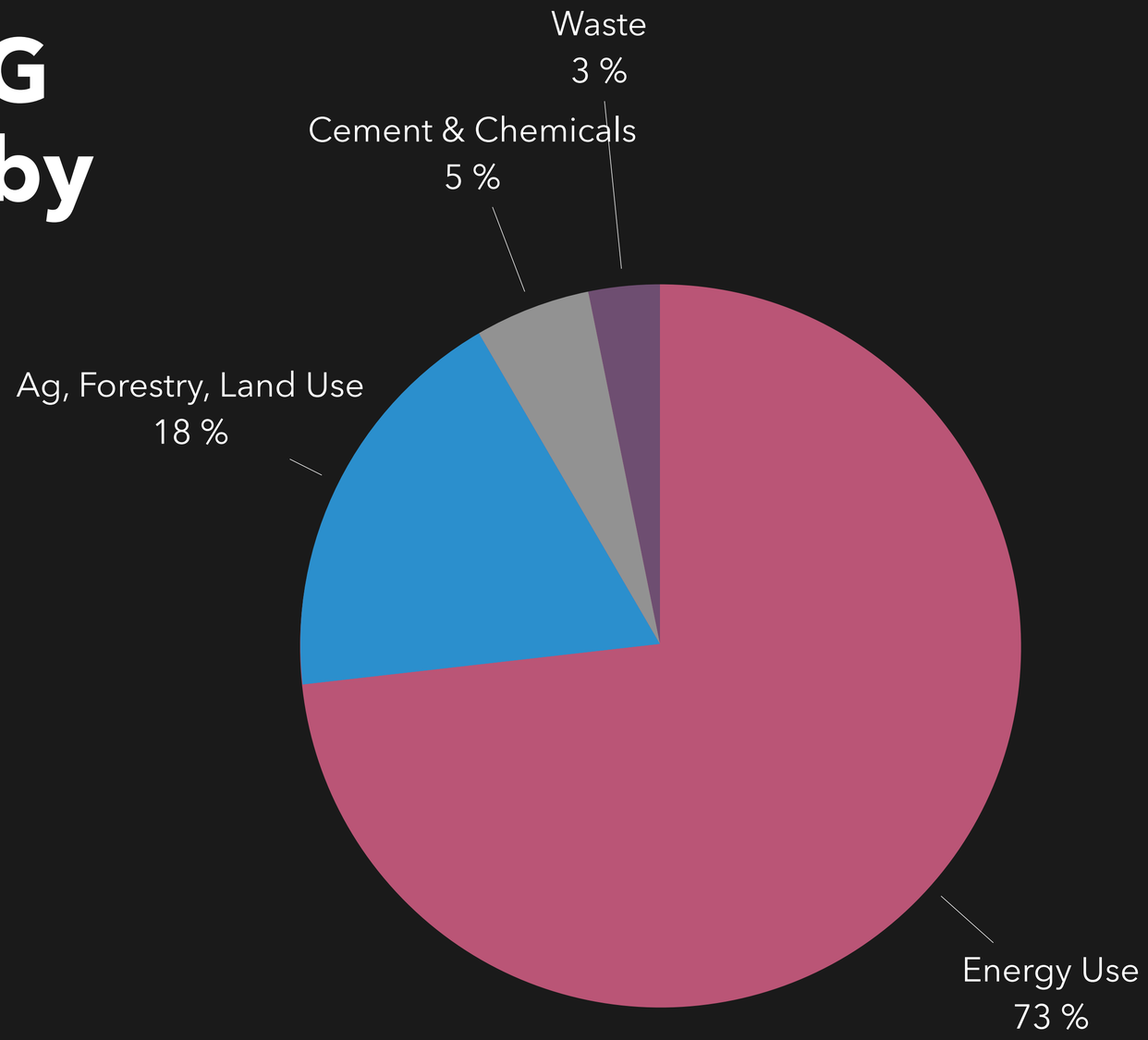
Energy,
Land,
Water,
Resources

Data Centers

Networks

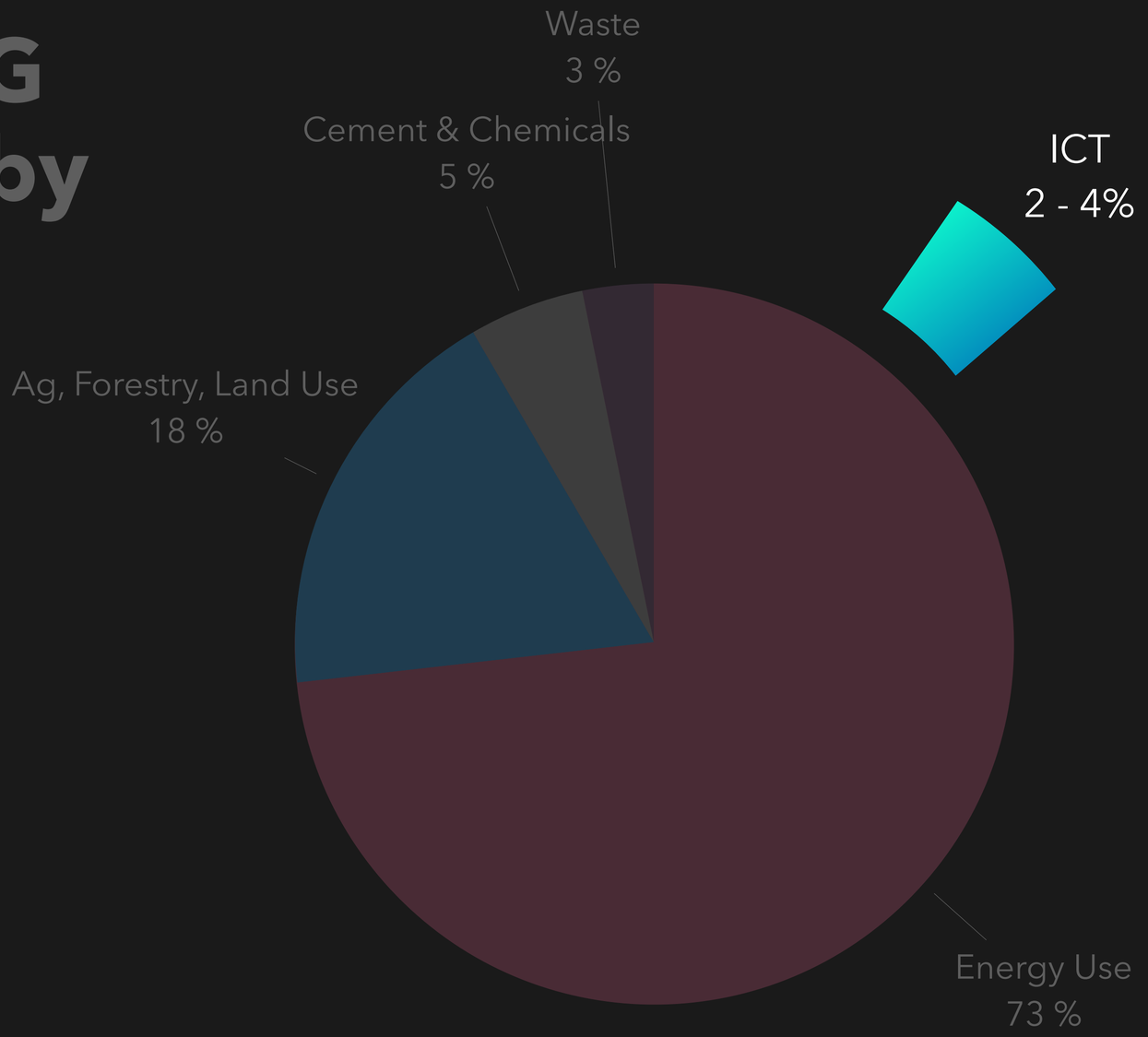
Devices

Global GHG Emissions by Sector



Source: ourworldindata.org/ghg-emissions-by-sector

Global GHG Emissions by Sector



Source: ourworldindata.org/ghg-emissions-by-sector

Patterns

CellPress
OPEN ACCESS

Review

The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations

Charlotte Freitag,[1] Mike Berners-Lee,[1] Kelly Widdicks,[2,*] Bran Knowles,[2] Gordon S. Blair,[2] and Adrian Friday[2]
[1]Small World Consulting, Gordon Manley Building, Lancaster Environment Centre, Lancaster University, Lancaster, Lancashire LA1 4YQ, UK
[2]School of Computing and Communications, InfoLab21, Lancaster University, Lancaster, Lancashire LA1 4WA, UK
*Correspondence: k.v.widdicks@lancaster.ac.uk
https://doi.org/10.1016/j.patter.2021.100340

THE BIGGER PICTURE To avoid catastrophic consequences from climate change, all sectors of the global economy, including *Information Communication Technology* (*ICT*), must keep their greenhouse gas (GHG) emissions in line with the Paris Agreement. We examine peer-reviewed estimates of ICT's GHG emissions, which put ICT's share of global GHG emissions at 1.8%–2.8%. We find pronounced differences and much debate concerning the underlying assumptions behind the peer-reviewed studies, which could suggest that global emissions from ICT are as high as 2.1%–3.9%. All study analysts agree that ICT emissions *will not reduce* without major concerted political and industrial efforts, and we provide three reasons for anticipating that ICT emissions are actually going to *increase* without intervention. Our analysis suggests not all ICT carbon pledges are ambitious enough to meet climate targets, and that policy mechanisms for enforcing sector-wide climate target compliance are lacking. Without a global carbon constraint, sector-wide regulations are required to keep ICT's carbon footprint aligned with the Paris Agreement. With a global carbon constraint, ICT would be a greater enabler of productivity and utility, creating opportunity for the sector to be financially successful as a critical part of a global net zero society.

SUMMARY

In this paper, we critique ICT's current and projected climate impacts. Peer-reviewed studies estimate ICT's current share of global greenhouse gas (GHG) emissions at 1.8%–2.8% of global GHG emissions; adjusting for truncation of supply chain pathways, we find that this share could actually be between 2.1% and 3.9%. For ICT's future emissions, we explore assumptions underlying analysts' projections to understand the reasons for their variability. All analysts agree that ICT emissions will not reduce without major concerted efforts involving broad political and industrial action. We provide three reasons to believe ICT emissions are going to increase barring intervention and find that not all carbon pledges in the ICT sector are ambitious enough to meet climate targets. We explore the underdevelopment of policy mechanisms for enforcing sector-wide compliance, and contend that, without a global carbon constraint, a new regulatory framework is required to keep the ICT sector's footprint aligned with the Paris Agreement.

Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.

Patterns

CellPress
OPEN ACCESS

Review

The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations

Charlotte Freitag,[1] Mike Berners-Lee,[1] Kelly Widdicks,[2,*] Bran Knowles,[2] Gordon S. Blair,[2] and Adrian Friday[2]
[1]Small World Consulting, Gordon Manley Building, Lancaster Environment Centre, Lancaster University, Lancaster, Lancashire LA1 4YQ, UK
[2]School of Computing and Communications, InfoLab21, Lancaster University, Lancaster, Lancashire LA1 4WA, UK
*Correspondence: k.v.widdicks@lancaster.ac.uk
https://doi.org/10.1016/j.patter.2021.100340

THE BIGGER PICTURE To avoid catastrophic consequences from climate change, all sectors of the global economy, including *Information Communication Technology* (*ICT*), must keep their greenhouse gas (GHG) emissions in line with the Paris Agreement. We examine peer-reviewed estimates of ICT's GHG emissions, which put ICT's share of global GHG emissions at 1.8%–2.8%. We find pronounced differences and much debate concerning the underlying assumptions behind the peer-reviewed studies, which could suggest that global emissions from ICT are as high as 2.1%–3.9%. All study analysts agree that ICT emissions *will not reduce* without major concerted political and industrial efforts, and we provide three reasons for anticipating that ICT emissions are actually going to *increase* without intervention. Our analysis suggests not all ICT carbon pledges are ambitious enough to meet climate targets, and that policy mechanisms for enforcing sector-wide climate target compliance are lacking. Without a global carbon constraint, sector-wide regulations are required to keep ICT's carbon footprint aligned with the Paris Agreement. With a global carbon constraint, ICT would be a greater enabler of productivity and utility, creating opportunity for the sector to be financially successful as a critical part of a global net zero society.

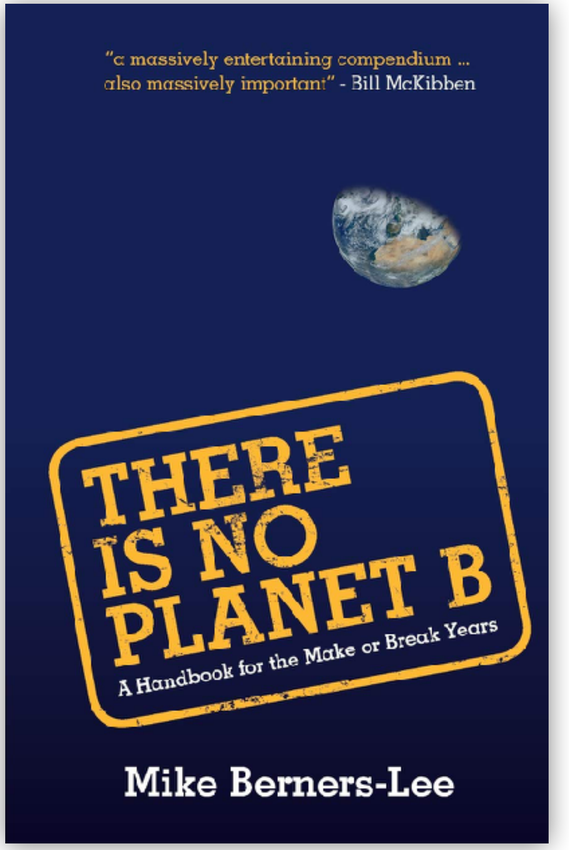
SUMMARY

In this paper, we critique ICT's current and projected climate impacts. Peer-reviewed studies estimate ICT's current share of global greenhouse gas (GHG) emissions at 1.8%–2.8% of global GHG emissions; adjusting for truncation of supply chain pathways, we find that this share could actually be between 2.1% and 3.9%. For ICT's future emissions, we explore assumptions underlying analysts' projections to understand the reasons for their variability. All analysts agree that ICT emissions will not reduce without major concerted efforts involving broad political and industrial action. We provide three reasons to believe ICT emissions are going to increase barring intervention and find that not all carbon pledges in the ICT sector are ambitious enough to meet climate targets. We explore the underdevelopment of policy mechanisms for enforcing sector-wide compliance, and contend that, without a global carbon constraint, a new regulatory framework is required to keep the ICT sector's footprint aligned with the Paris Agreement.

INTRODUCTION

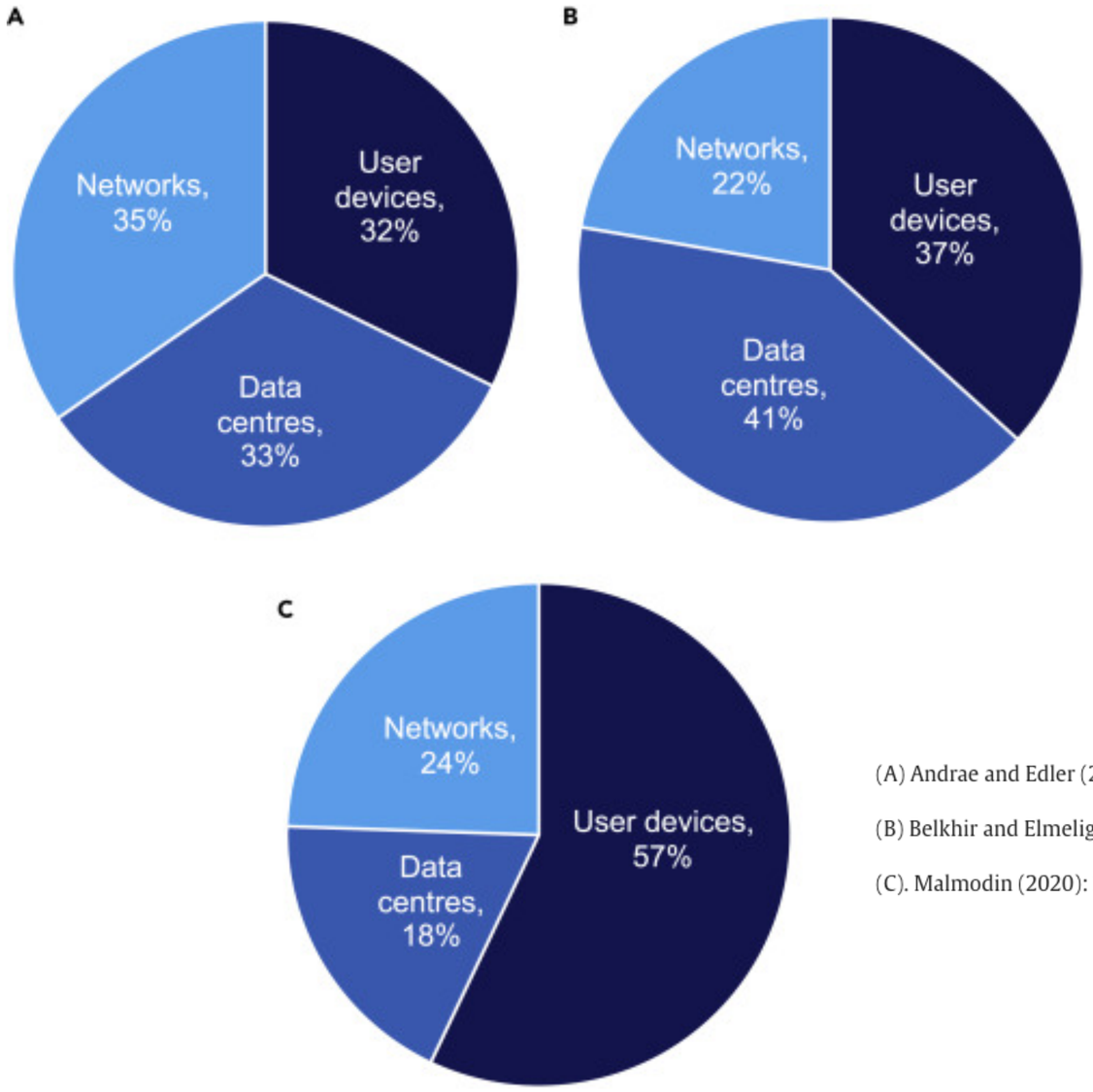
The Information and Communication Technology (ICT) sector

and end-of-life emissions (disposal). Yet estimates of ICT's footprint and whether it is in fact growing in impact, or held stable or



Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.

Estimates of ICT GHG emissions in 2020



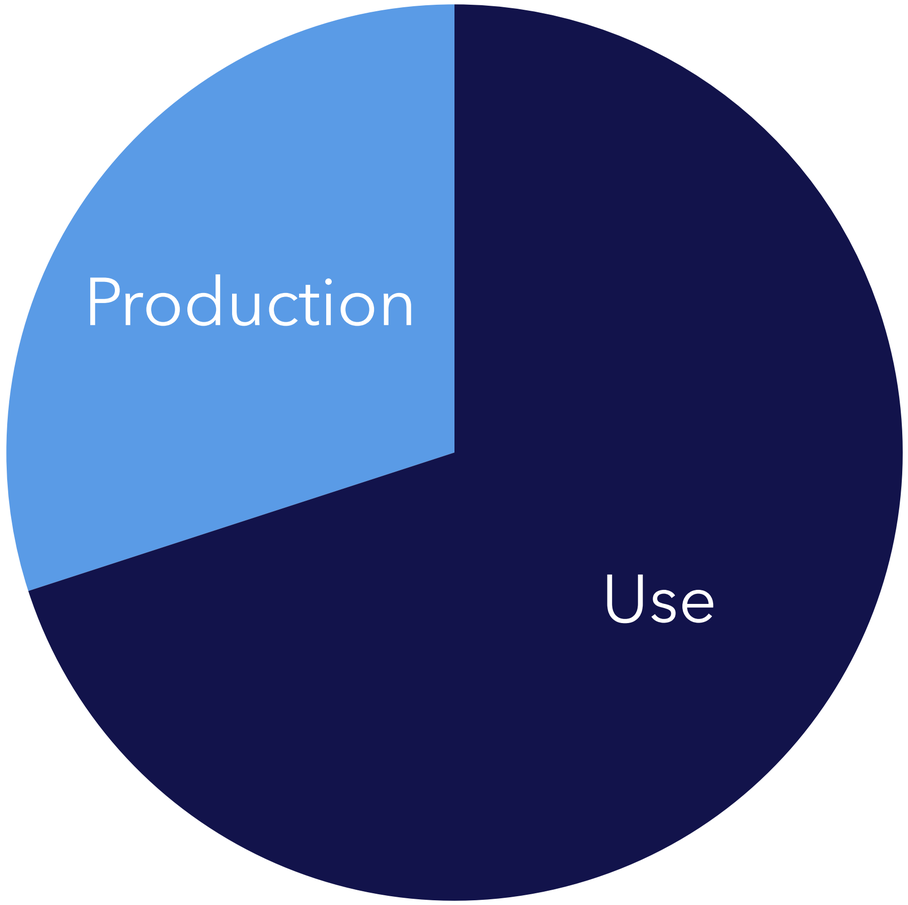
(A) Andrae and Edler (2015): 2020 best case (total of 623 $MtCO_2e$).

(B) Belkhir and Elmeligi (2018): 2020 average (total of 1,207 $MtCO_2e$).

(C). Malmodin (2020): 2020 estimate (total of 690 $MtCO_2e$).

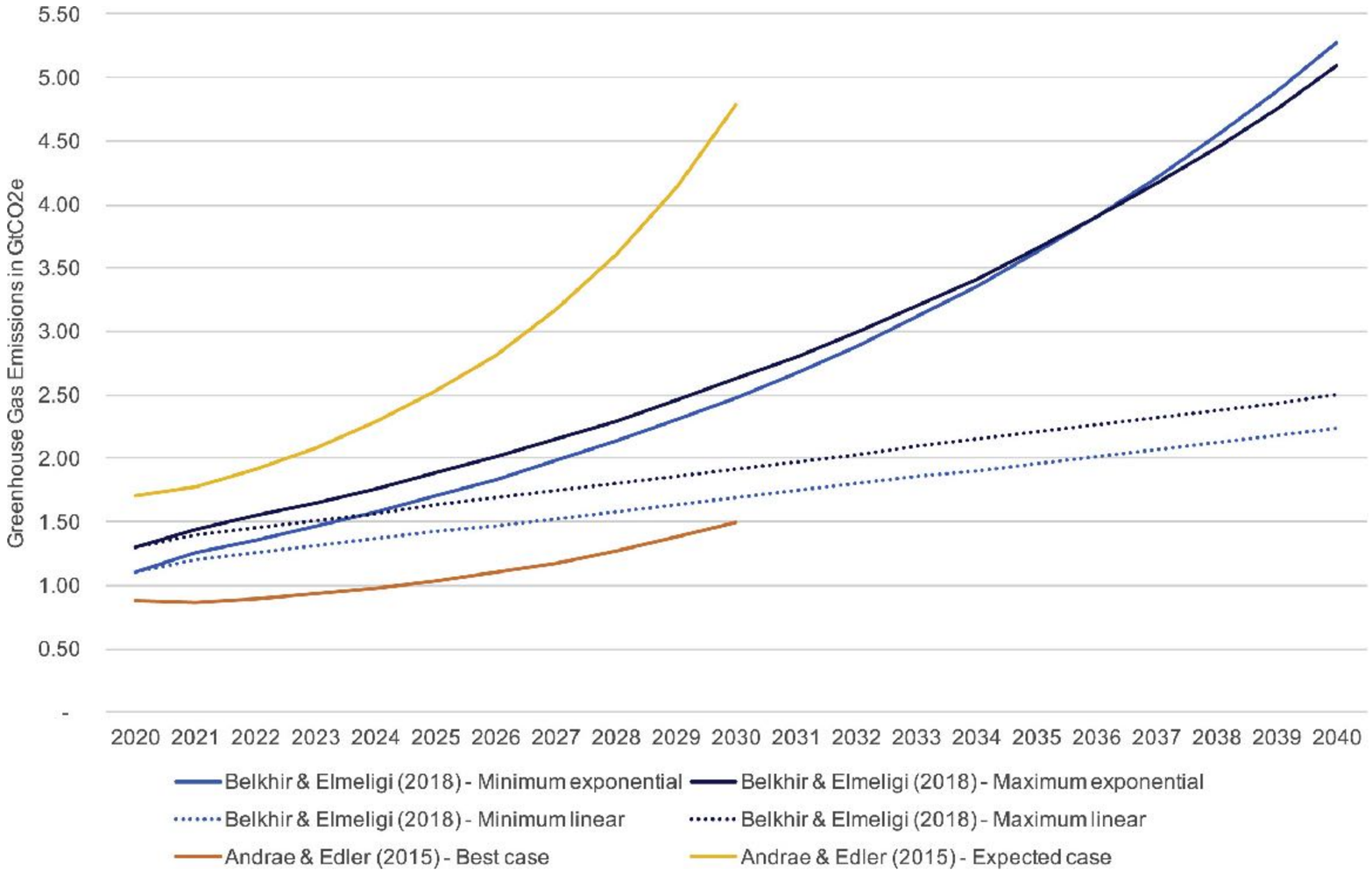
Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.

Around 70% of ICT's footprint is due to use



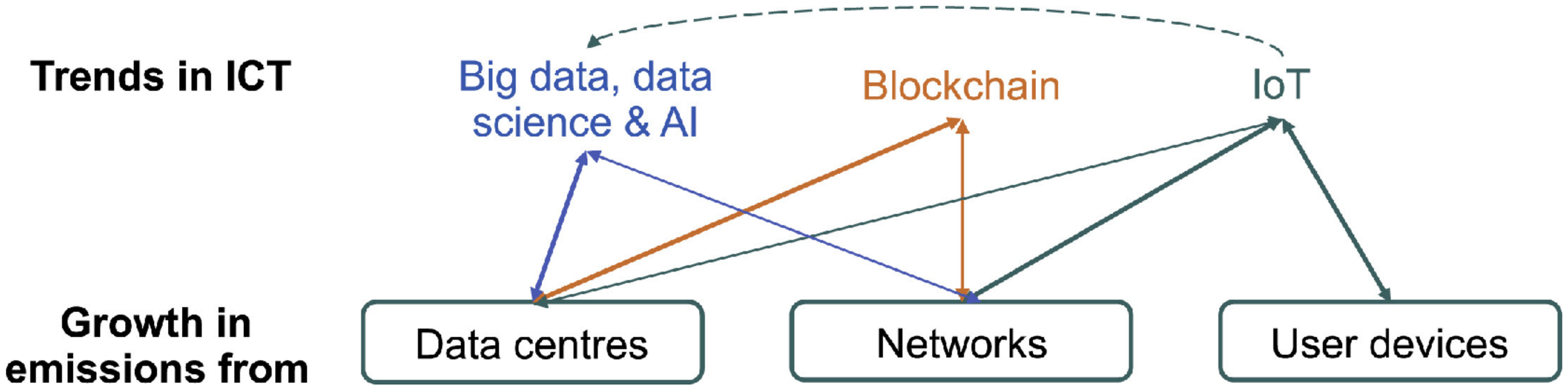
Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.

Projected GHG emissions from ICT

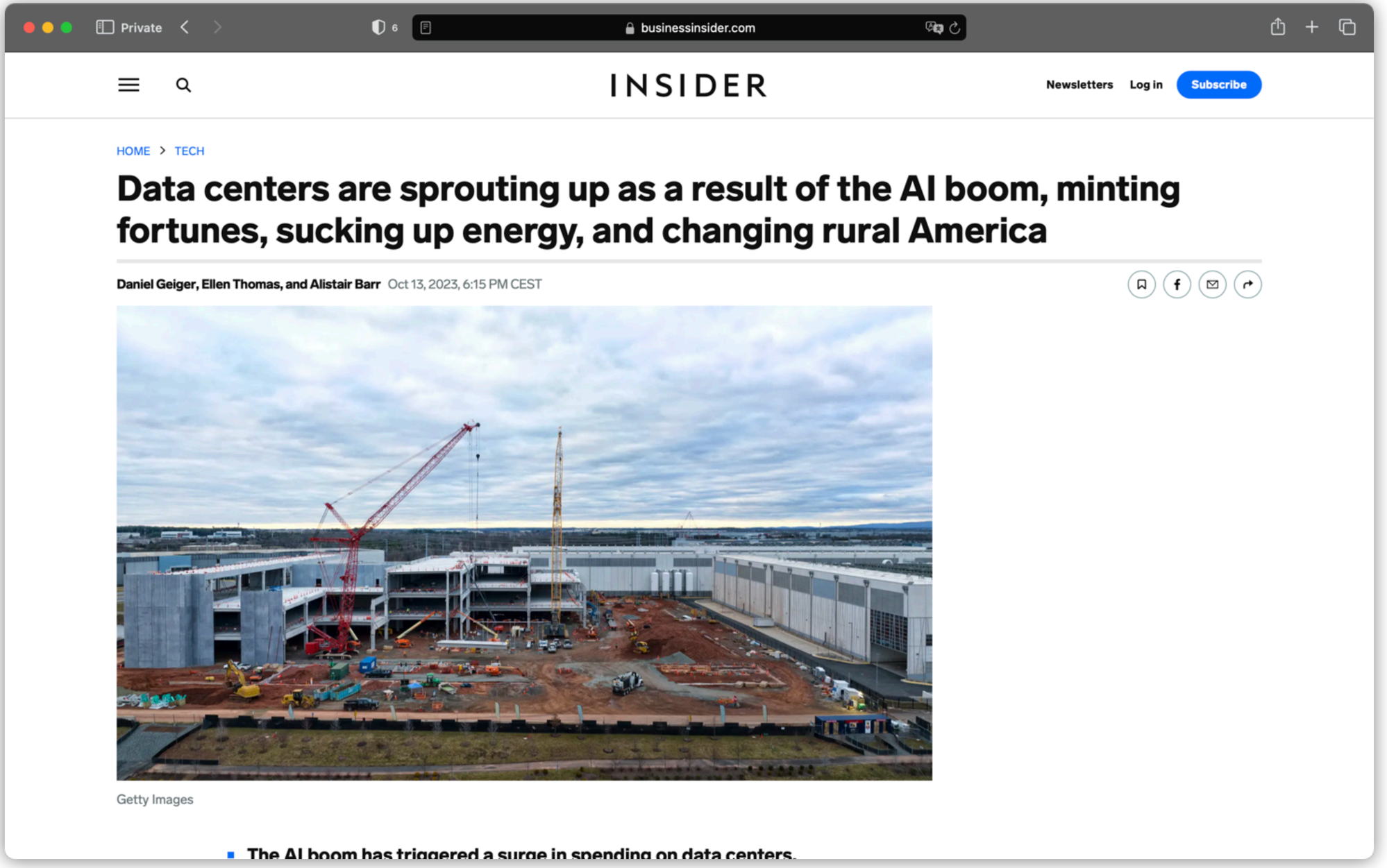


Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.

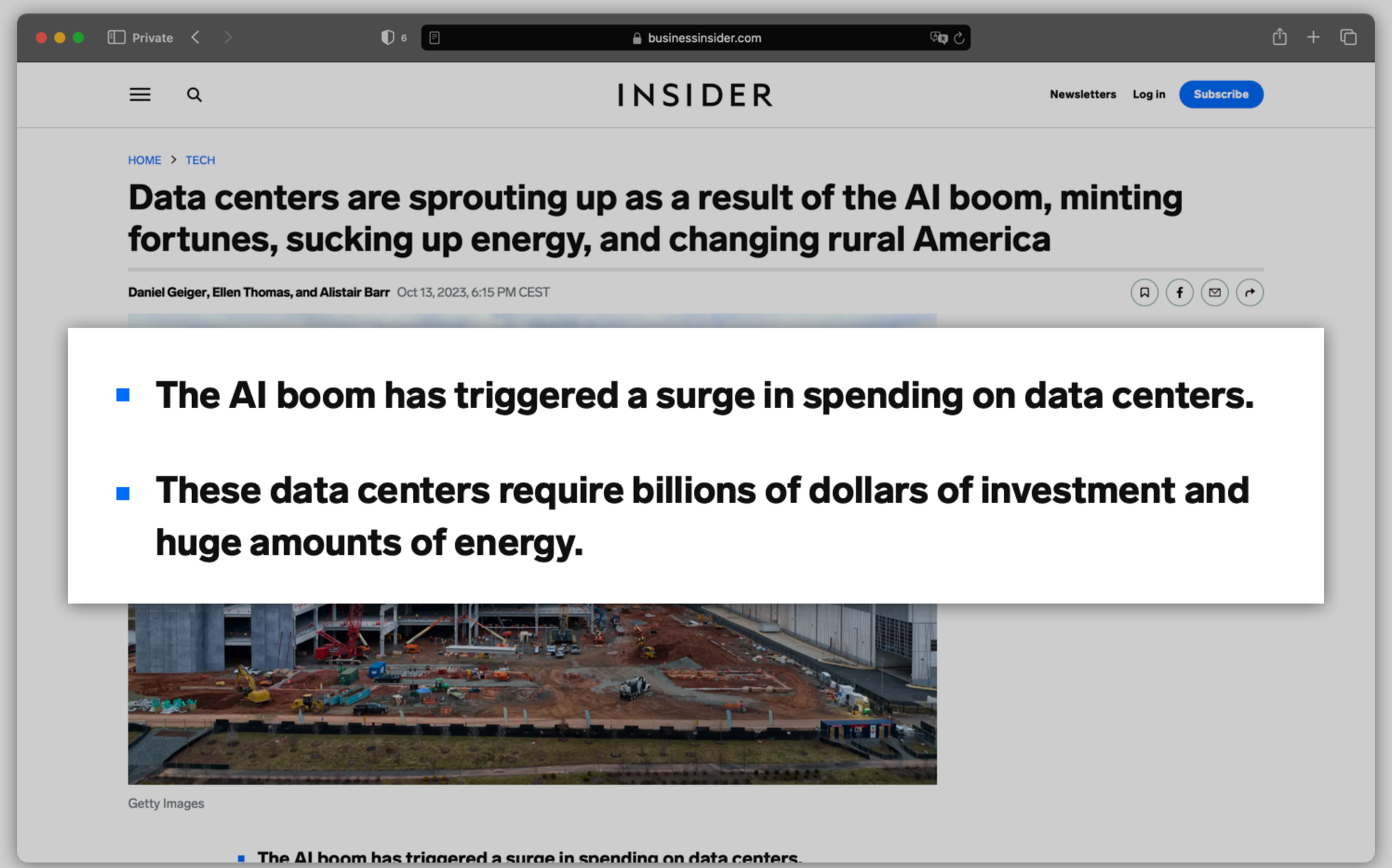
Trends in ICT



Source: "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" (2021) by Charlotte Freitag, Mike Berners-Lee, et al.



Source: "Data centers are sprouting up as a result of the AI boom, minting fortunes, sucking up energy, and changing rural America" (Oct. 13, 2023), businessinsider.com



Source: "Data centers are sprouting up as a result of the AI boom, minting fortunes, sucking up energy, and changing rural America" (2023), businessinsider.com

80% of all digital data
is never accessed
or used again
after it is stored.

Gerry McGovern, *World Wide Waste*

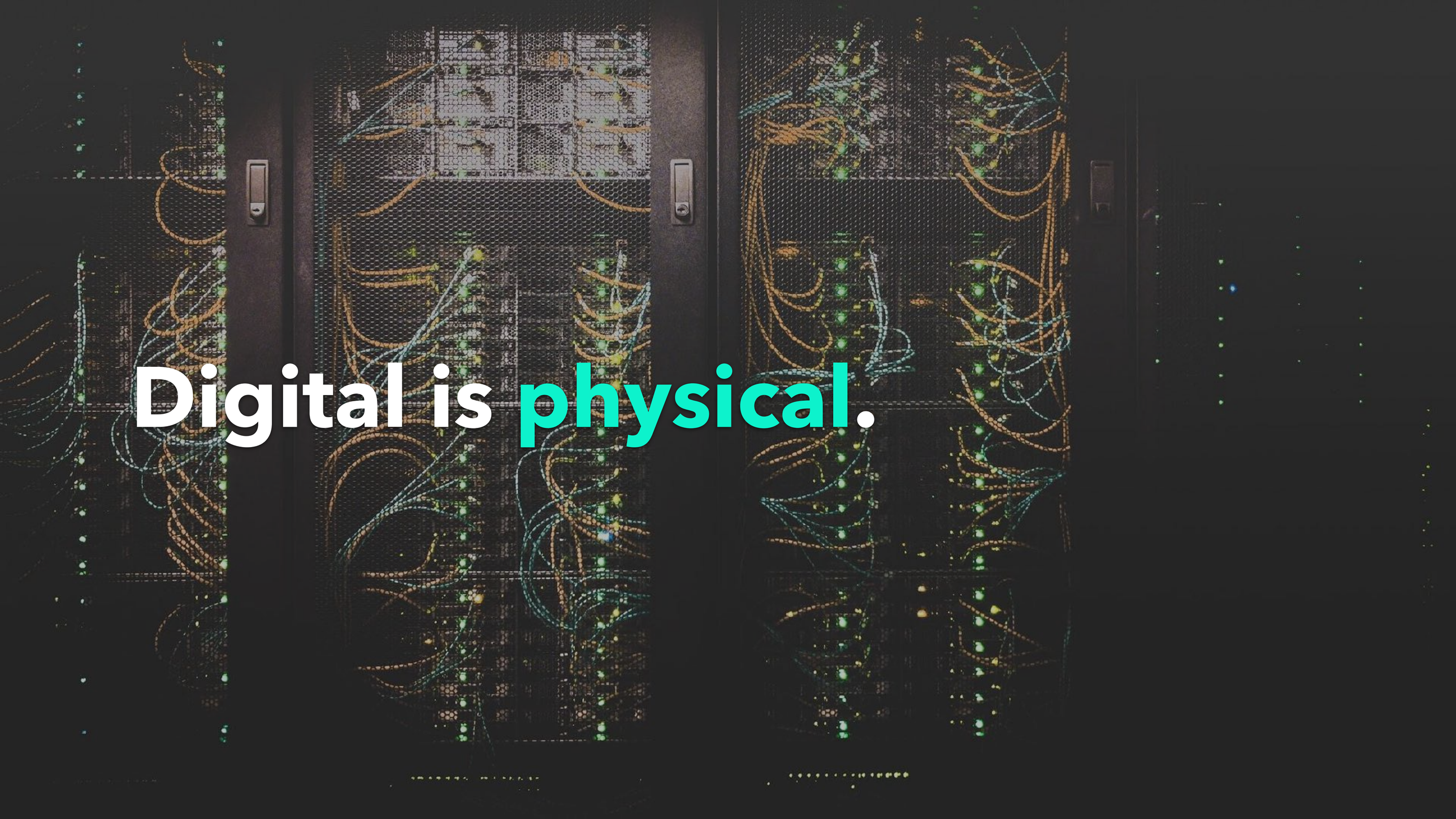
In 2020, there were
14 billion mobile devices worldwide

Source: Statista

By 2025, there could be
18.2 billion mobile devices worldwide

Source: Statista


The more we consume,
the more resources use.

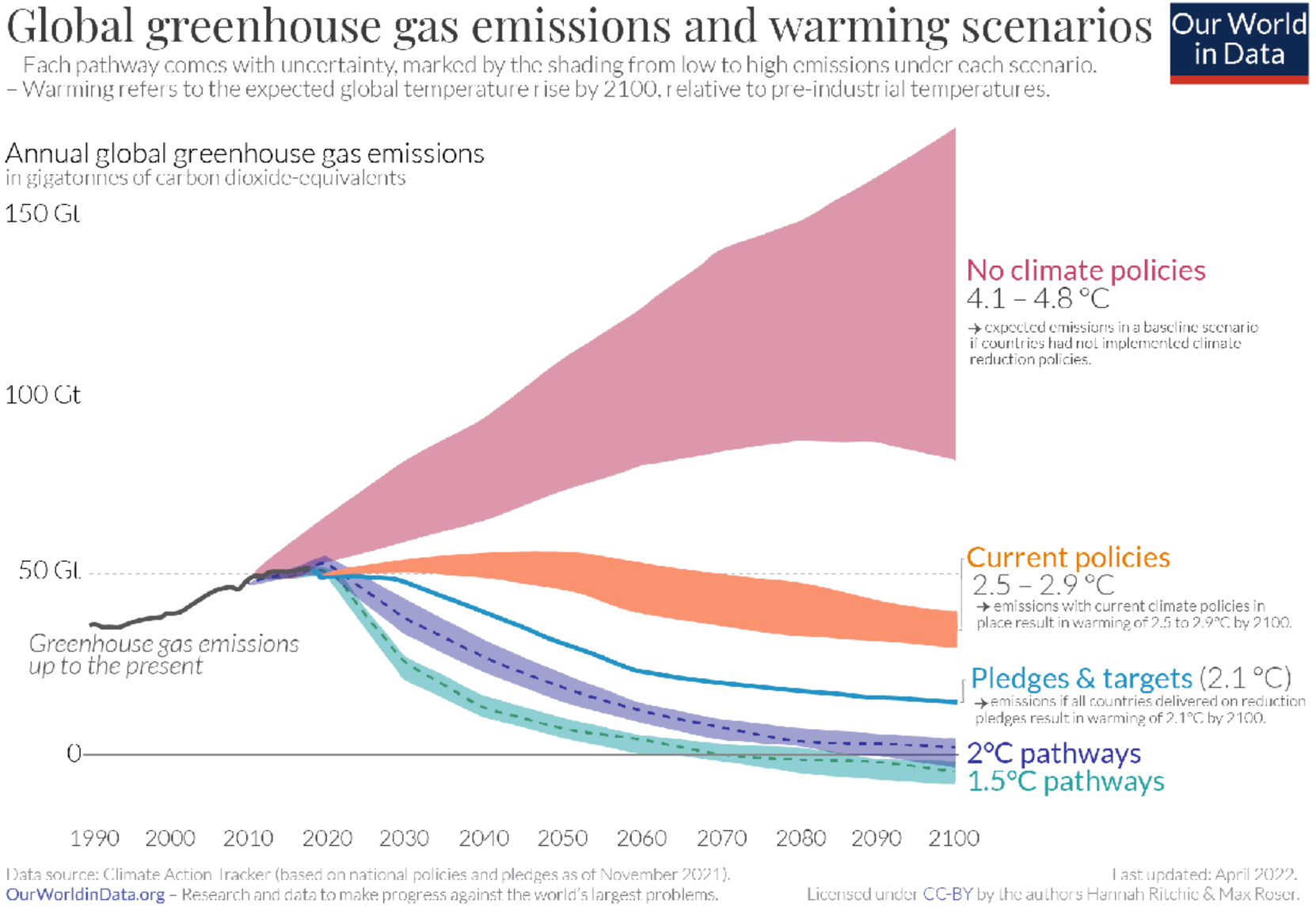

Digital is physical.

Digital is social.

https://www.ft.com/content/c6909812-9ce4-11e9-9c06-a4640c9feebb

ICT is part of the climate problem

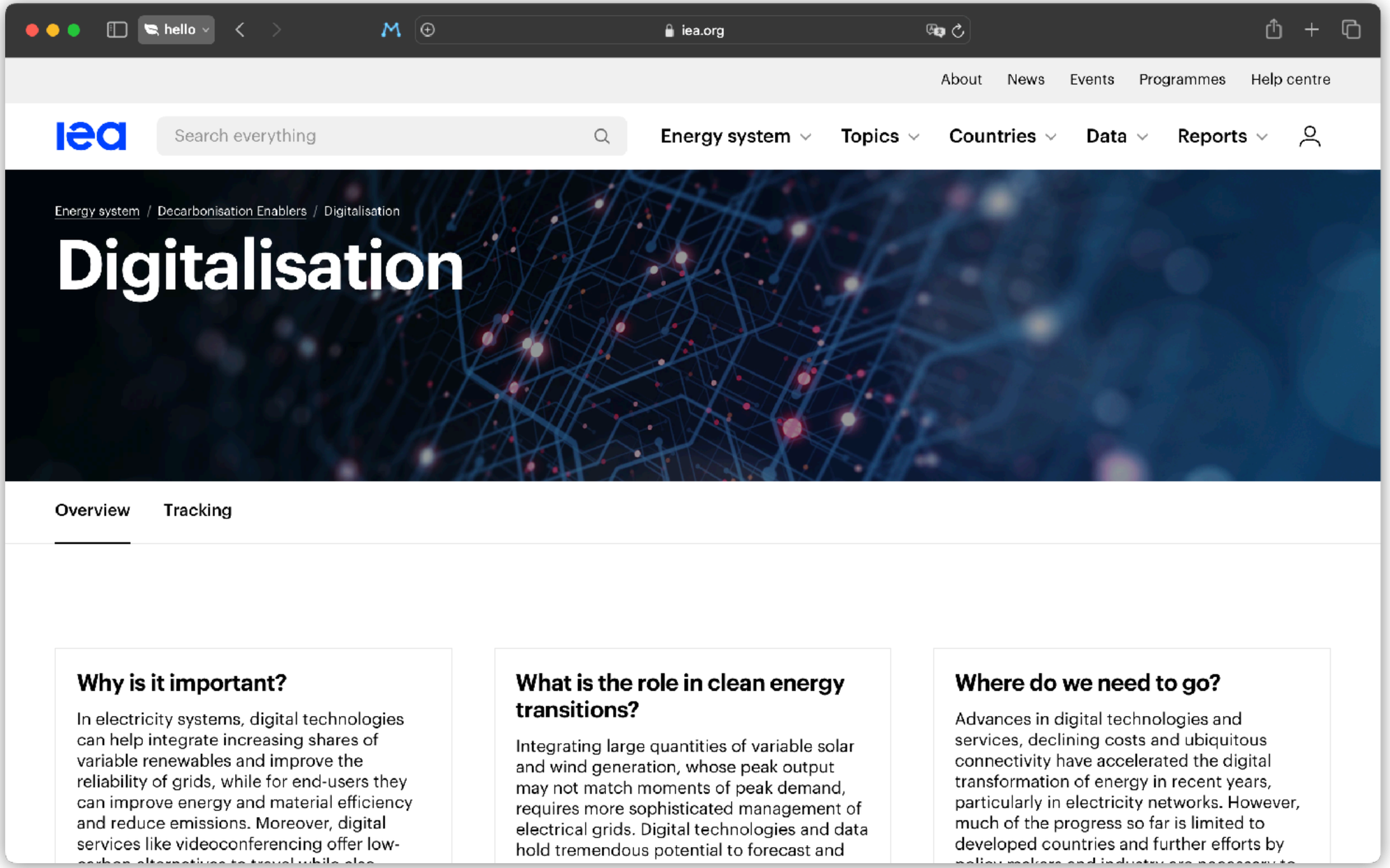
Our targets



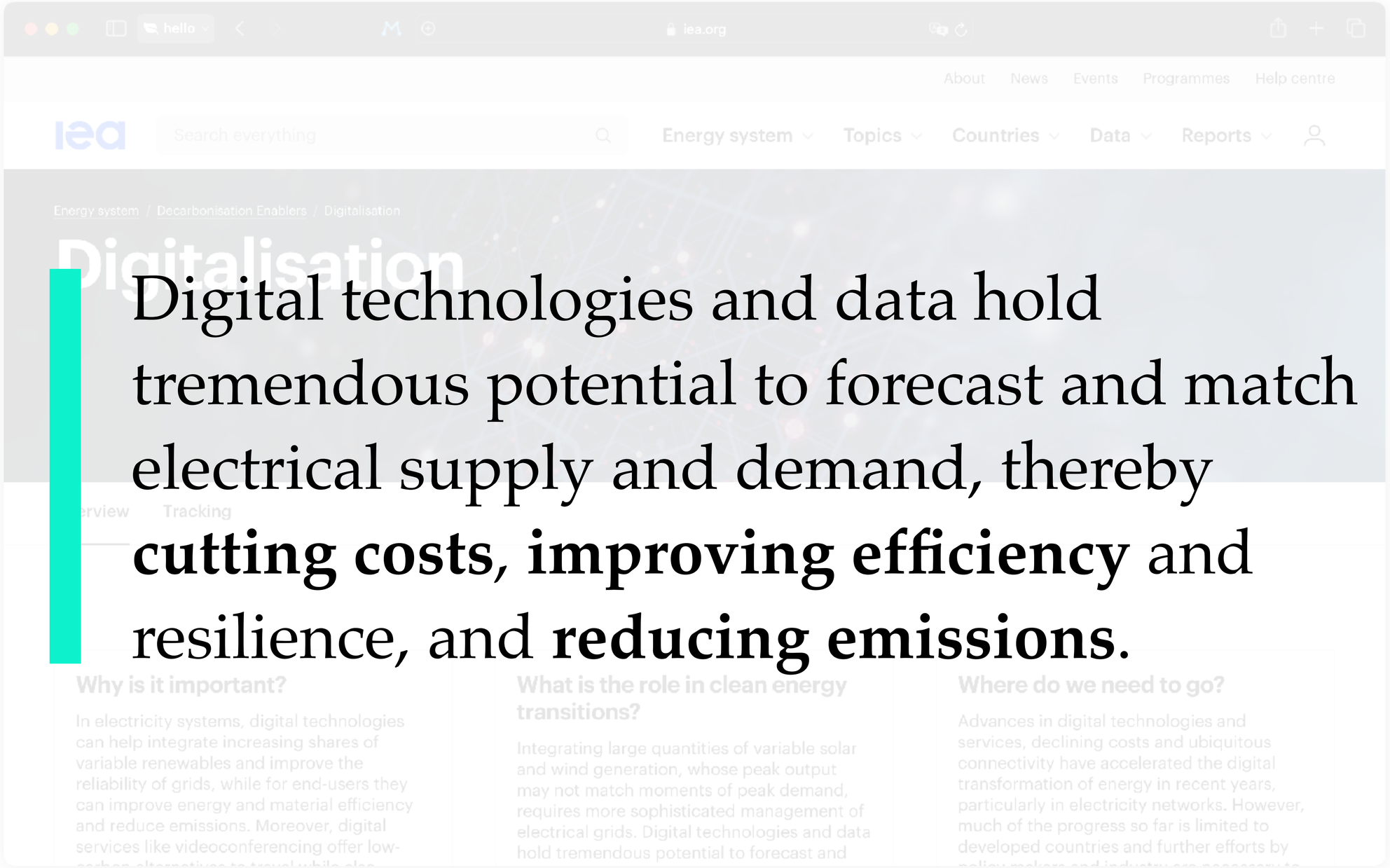
Source: ourworldindata.org

Source: formulapedia.com

…but ICT can be part of climate solutions



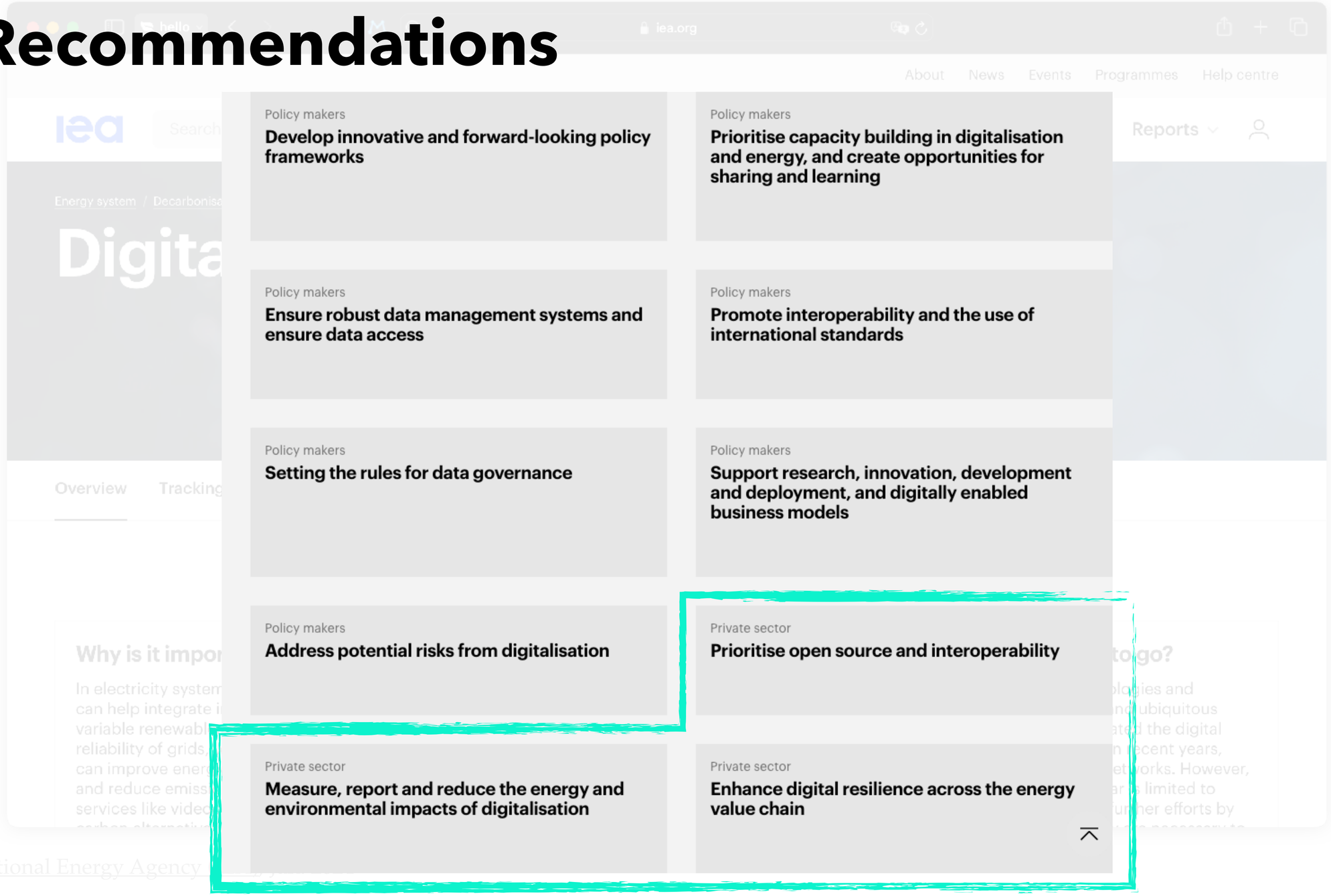
Source: International Energy Agency (IEA), Jan. 2024



Digital technologies and data hold tremendous potential to forecast and match electrical supply and demand, thereby **cutting costs**, **improving efficiency** and resilience, and **reducing emissions**.

Source: International Energy Agency (IEA), Jan. 2024

IEA Recommendations



Policy makers

Develop innovative and forward-looking policy frameworks

Policy makers

Prioritise capacity building in digitalisation and energy, and create opportunities for sharing and learning

Policy makers

Ensure robust data management systems and ensure data access

Policy makers

Promote interoperability and the use of international standards

Policy makers

Setting the rules for data governance

Policy makers

Support research, innovation, development and deployment, and digitally enabled business models

Policy makers

Address potential risks from digitalisation

Private sector

Prioritise open source and interoperability

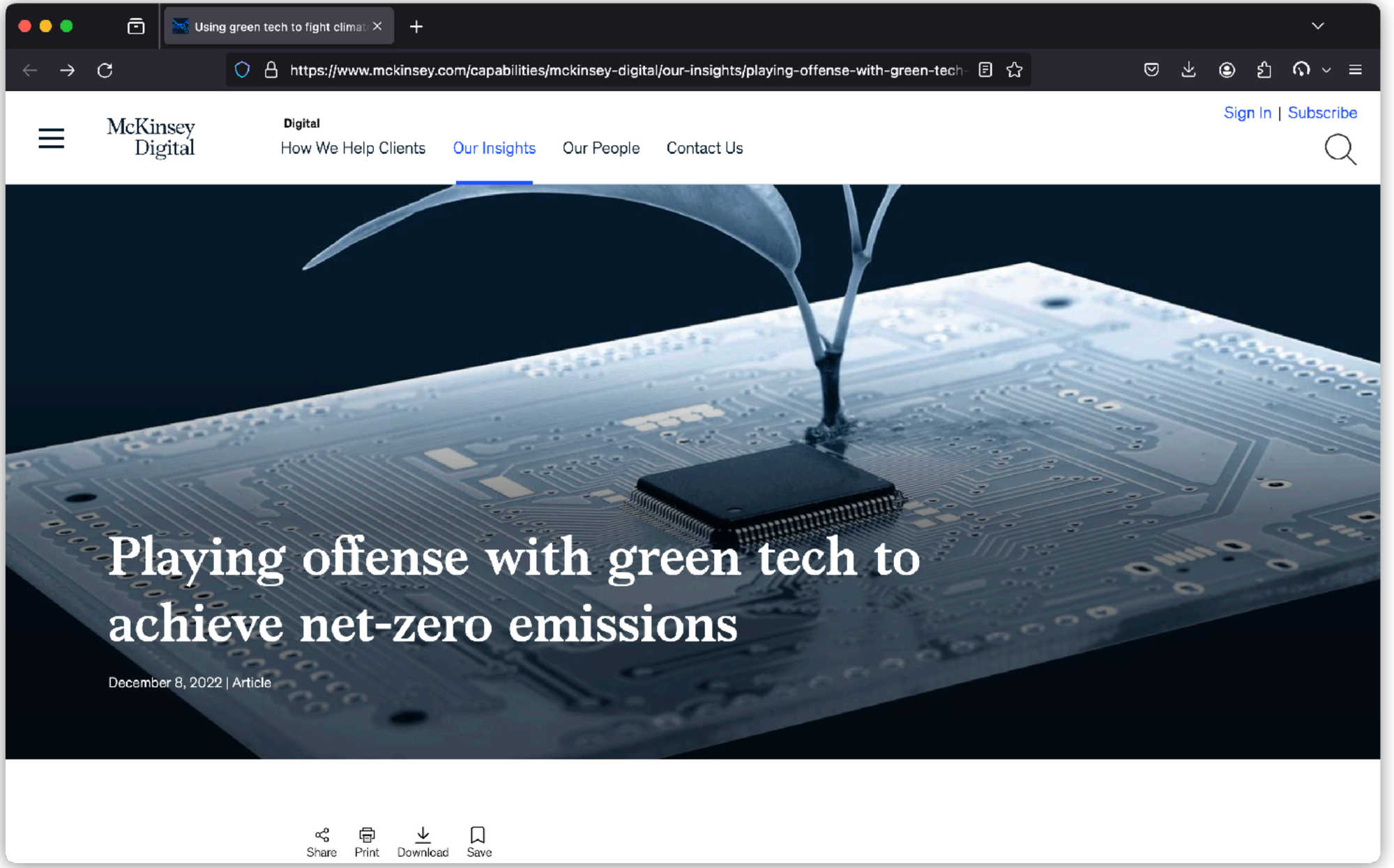
Private sector

Measure, report and reduce the energy and environmental impacts of digitalisation

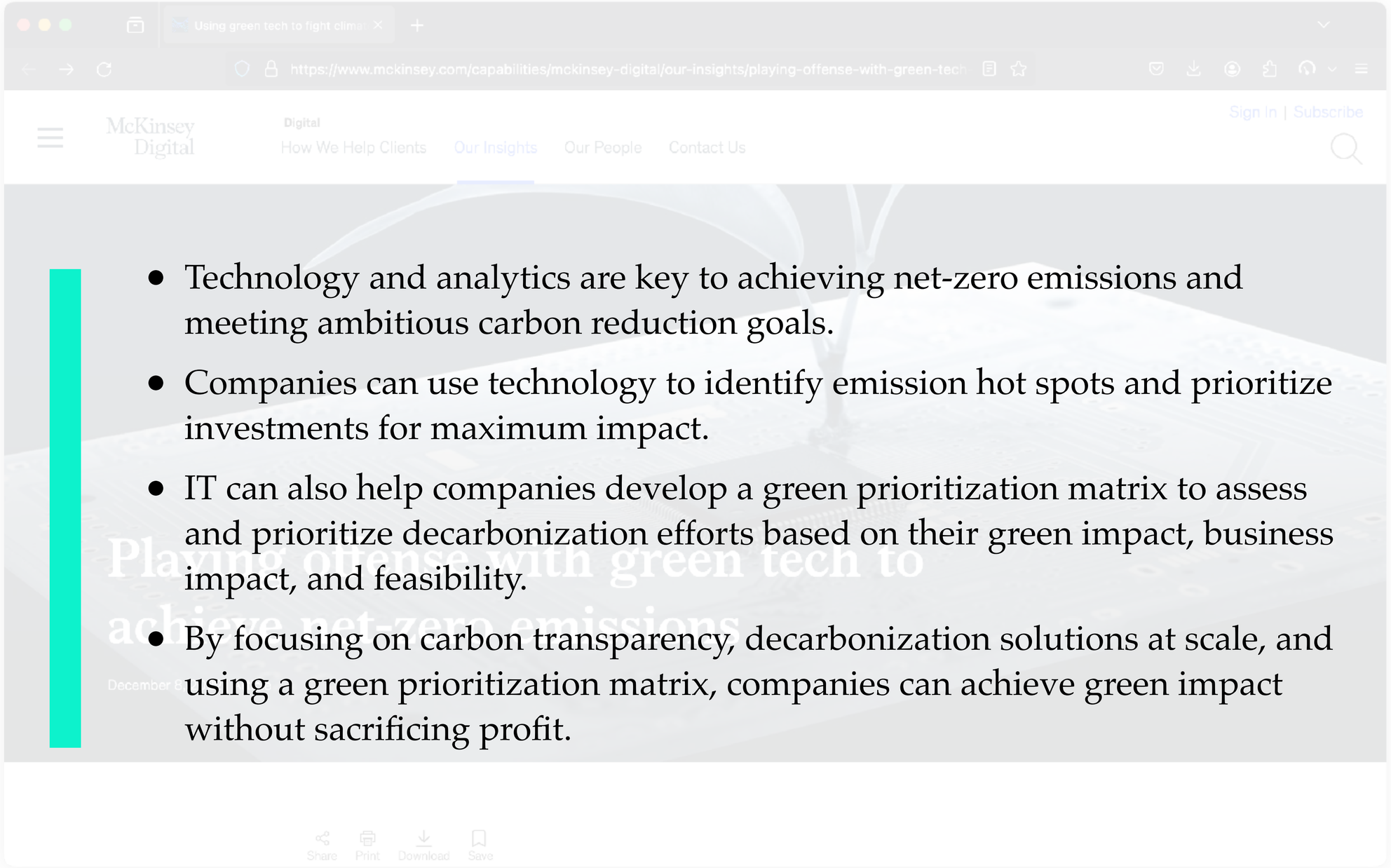
Private sector

Enhance digital resilience across the energy value chain

Source: International Energy Agency



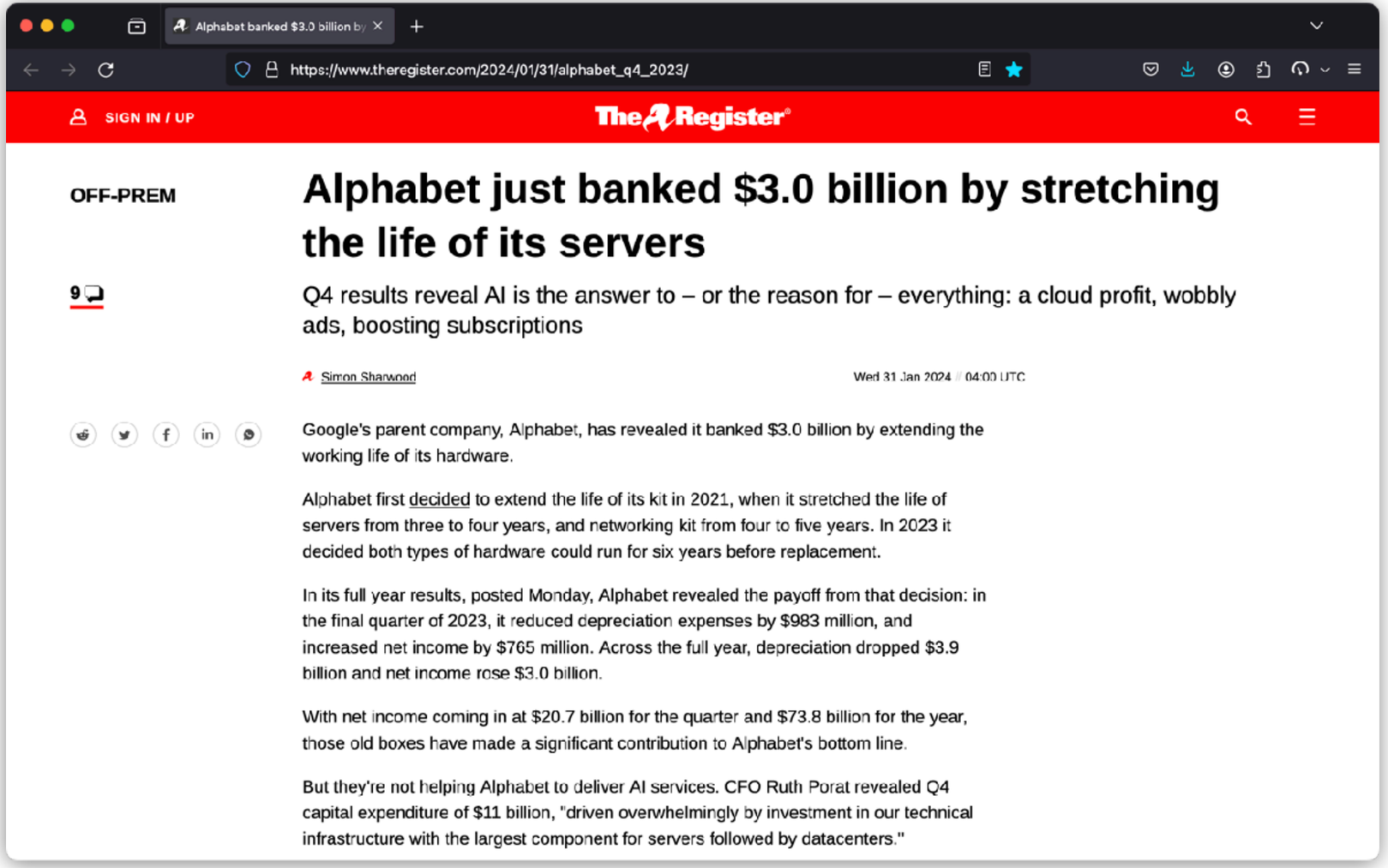
Source: "Playing offense with green tech to achieve net-zero emissions" (Dec. 8, 2022) by McKinsey Digital



- Technology and analytics are key to achieving net-zero emissions and meeting ambitious carbon reduction goals.
- Companies can use technology to identify emission hot spots and prioritize investments for maximum impact.
- IT can also help companies develop a green prioritization matrix to assess and prioritize decarbonization efforts based on their green impact, business impact, and feasibility.
- By focusing on carbon transparency, decarbonization solutions at scale, and using a green prioritization matrix, companies can achieve green impact without sacrificing profit.

Source: "Playing offense with green tech to achieve net-zero emissions" (Dec. 8, 2022) by McKinsey Digital

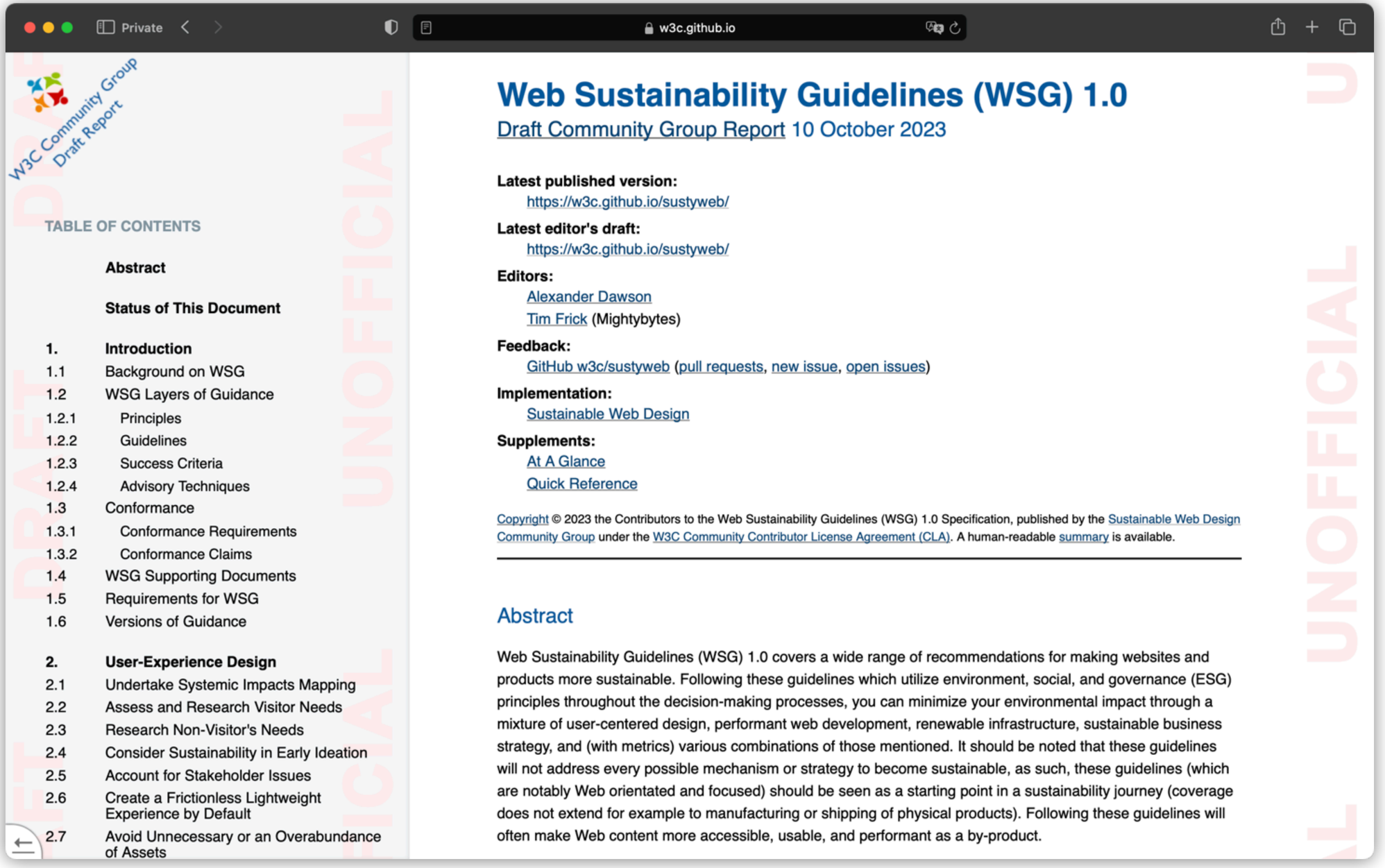
Extending server life saves money



Source: "Alphabet just banked $3.0 billion by stretching the life of its servers" by Simon Sharwood on *The Register*, Jan. 31, 2024

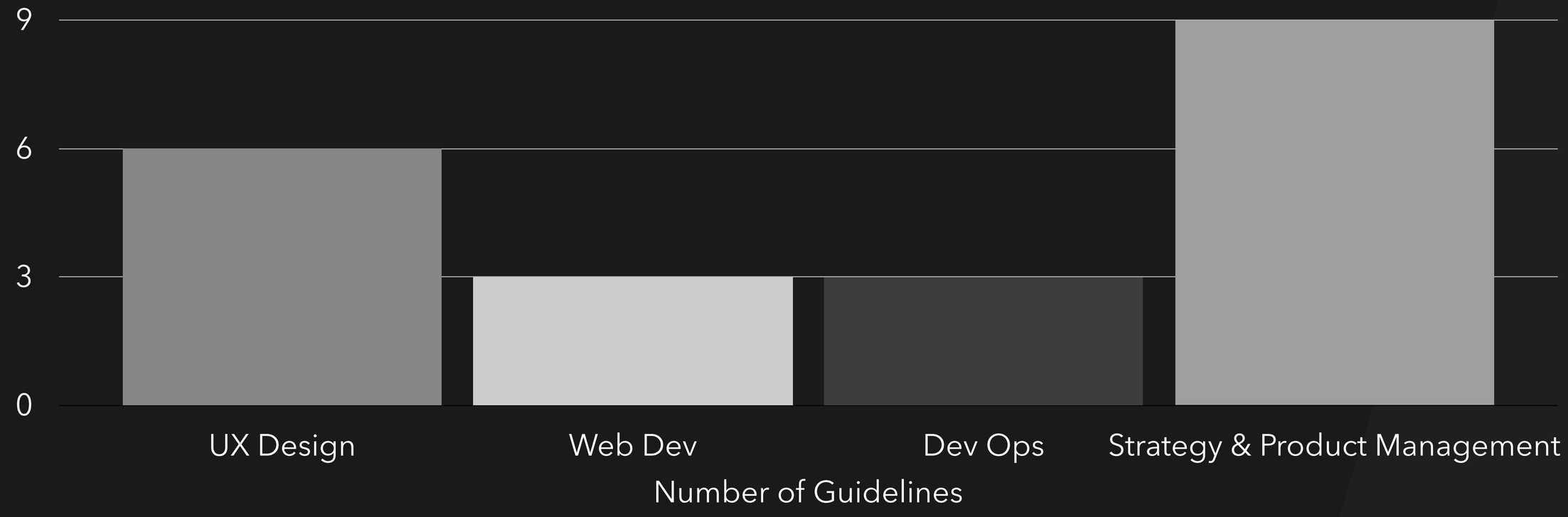
Software can enable decarbonization, but it needs to do so sustainably.

What can we do to make the Web more sustainable?



Source: https://w3c.github.io/sustyweb/

Web sustainability guidelines
High Impact, Low-/Medium Effort



Source: “Web Sustainability Guidelines: Getting Started” by Brian Louis Ramirez, based on Web Sustainability Guidelines, v1, 2023

Web sustainability guidelines
High Impact, Low- or Medium-Effort

BUSINESS STRATEGY & PRODUCT MANAGEMENT

Establish if a Digital Product or Service Is Necessary

Follow a Product Management and Maintenance Strategy

Implement Sustainability Onboarding Guidelines

Create One or More Impact Business Models

Share Economic Benefits

Promote Responsible Data Practices

Promote Responsible Emerging Technology Practices

Include Organizational Philanthropy Policies

Include E-Waste, Right-To-Repair, and Recycling Policies

UX

Take a More Sustainable Approach to Image Assets

Avoid Unnecessary or an Overabundance of Assets

Avoid Manipulative Patterns

Take a More Sustainable Approach to Media Assets

Create a Stakeholder-Focused Testing & Prototyping Policy

Incorporate Compatibility Testing Into Each Release-Cycle

WEB DEV

Ensure Your Solutions Are Accessible

Rigorously Assess Third-Party Services

Use Beneficial JavaScript and Its API's

DEV OPS

Compress Your Files

Choose a Sustainable Hosting Provider

Automate To Fit the Needs

Web sustainability guidelines
High Impact, Low- or Medium-Effort

BUSINESS STRATEGY & PRODUCT MANAGEMENT

Establish if a Digital Product or Service Is Necessary

Follow a Product Management and Maintenance Strategy

Implement Sustainability Onboarding Guidelines

Create One or More Impact Business Models

Share Economic Benefits

Promote Responsible Data Practices

Promote Responsible Emerging Technology Practices

Include Organizational Philanthropy Policies

Include E-Waste, Right-To-Repair, and Recycling Policies

UX

Take a More Sustainable Approach to Image Assets

Avoid Unnecessary or an Overabundance of Assets

Avoid Manipulative Patterns

Take a More Sustainable Approach to Media Assets

Create a Stakeholder-Focused Testing & Prototyping Policy

Incorporate Compatibility Testing Into Each Release-Cycle

WEB DEV

Ensure Your Solutions Are Accessible

Rigorously Assess Third-Party Services

Use Beneficial JavaScript and Its API's

DEV OPS

Compress Your Files

Choose a Sustainable Hosting Provider

Automate To Fit the Needs

The biggest problems

Too much energy

Too many devices

The biggest problems

Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults

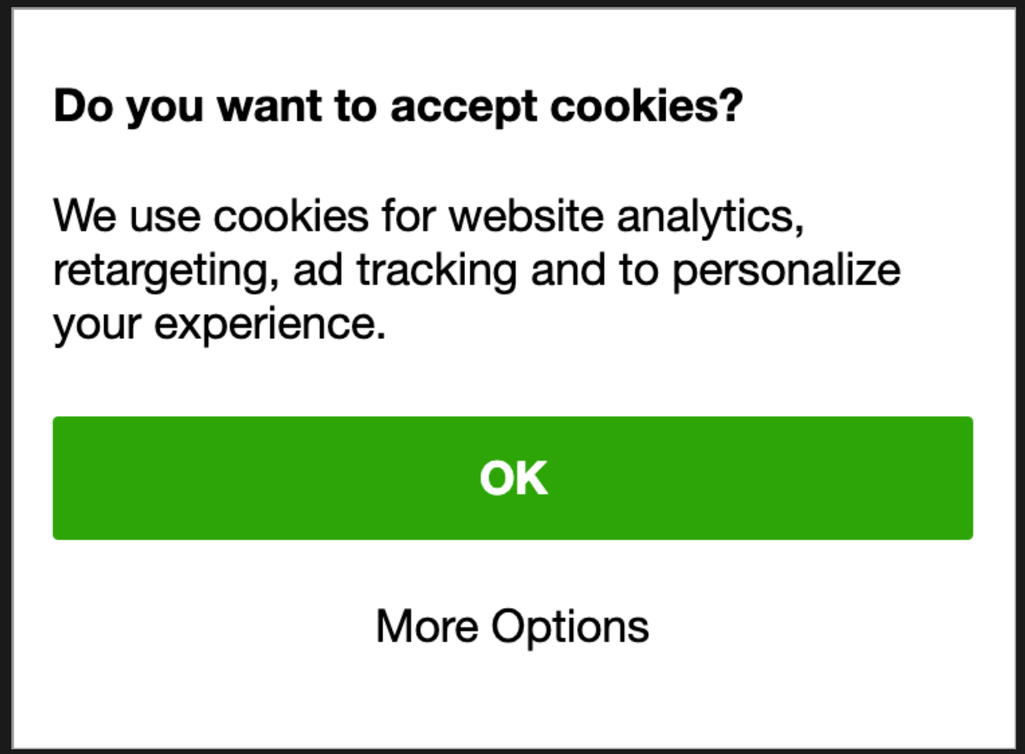
Too many devices

Default effect

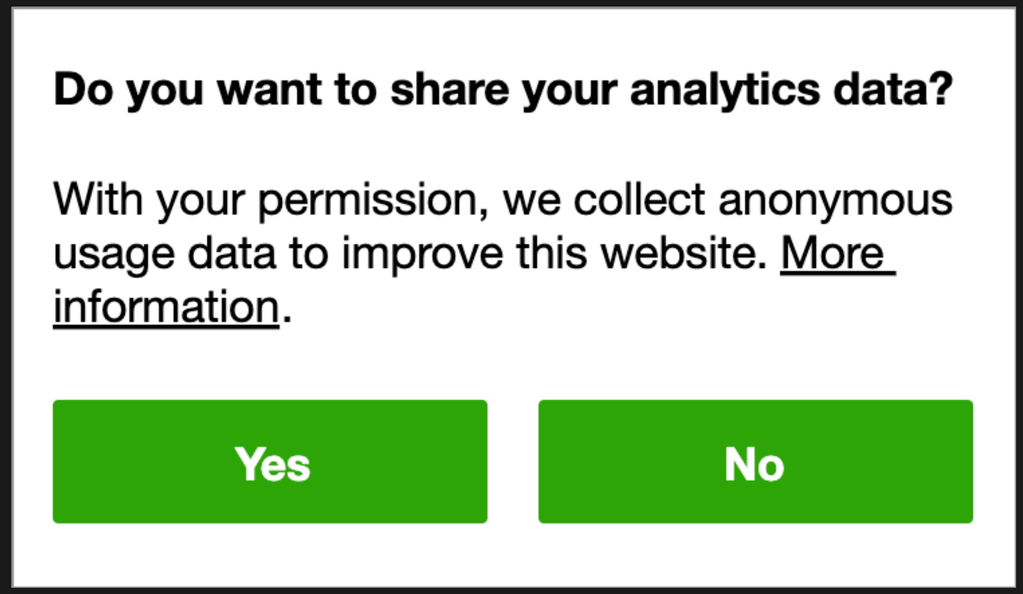
The tendency to favor the default option when given a choice between several options.

Ask:

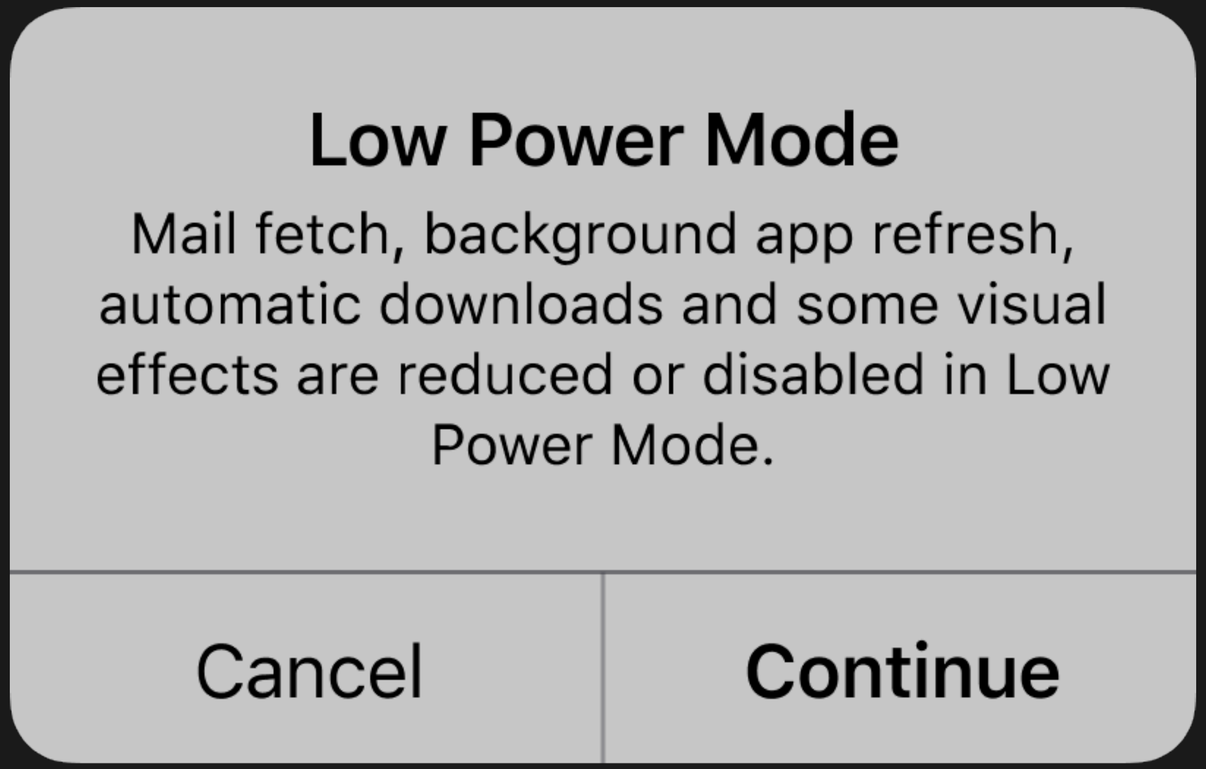
Are the defaults set to maximize efficiency and minimize consumption?


Do you want to accept cookies?
We use cookies for website analytics, retargeting, ad tracking and to personalize your experience.
OK
More Options

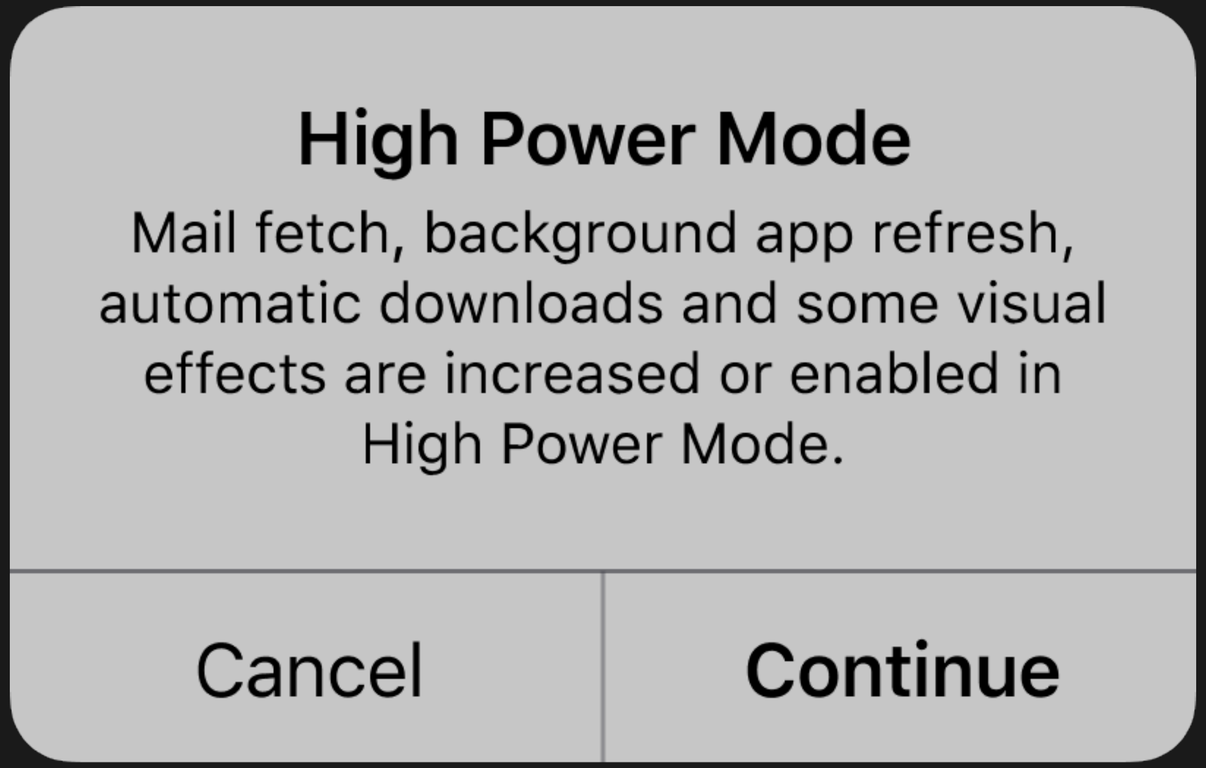
DON'T


Do you want to share your analytics data?
With your permission, we collect anonymous usage data to improve this website. More information.
Yes
No

DO


Low Power Mode
Mail fetch, background app refresh, automatic downloads and some visual effects are reduced or disabled in Low Power Mode.
Cancel
Continue

DON’T


High Power Mode
Mail fetch, background app refresh, automatic downloads and some visual effects are increased or enabled in High Power Mode.
Cancel
Continue

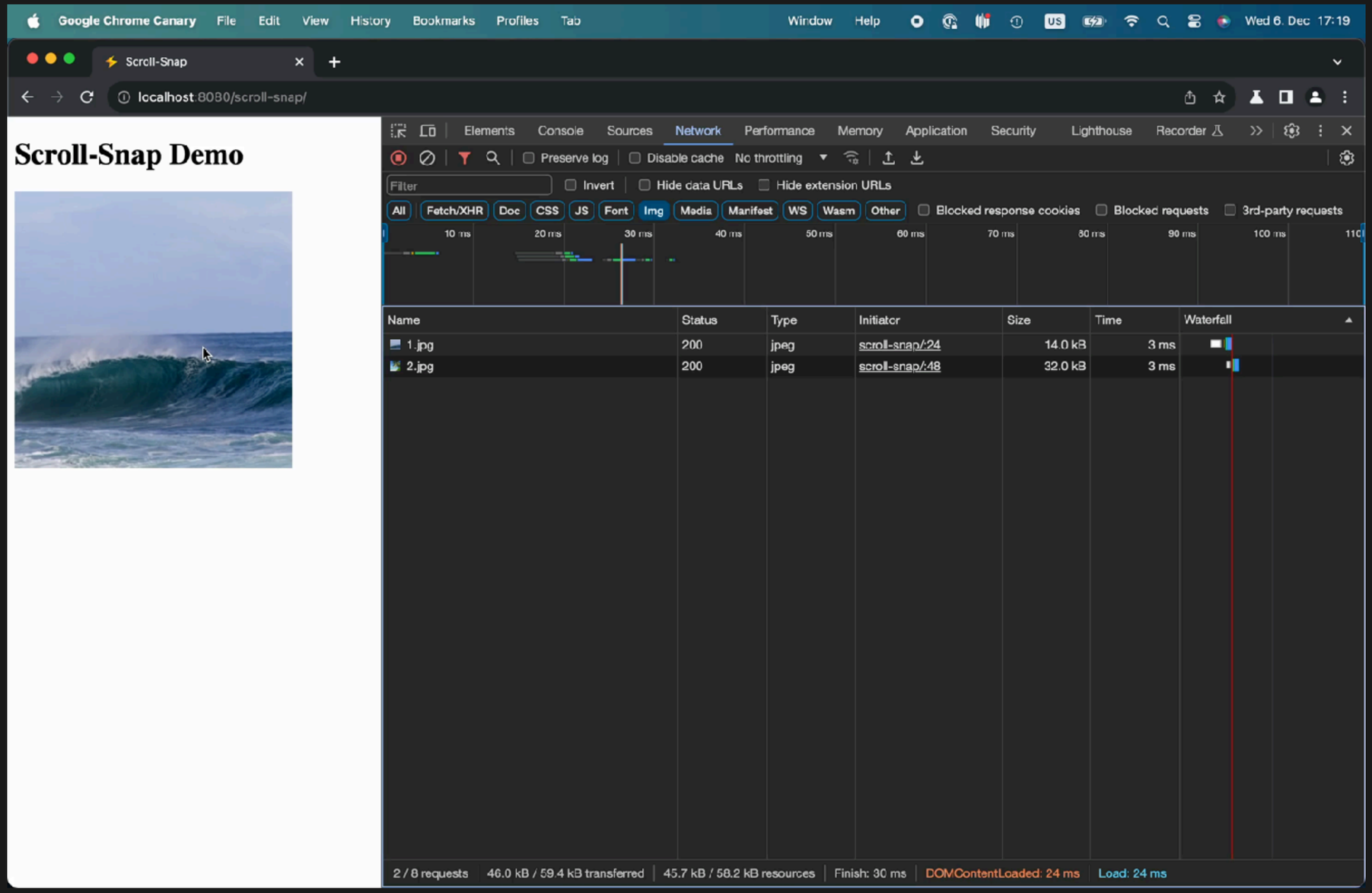
DO

The biggest problems

Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults
- Lazy-load, use façades

Too many devices


Google Chrome Canary File Edit View History Bookmarks Profiles Tab Window Help Wed 6. Dec 17:19
Scroll-Snap
localhost:8080/scroll-snap/
Scroll-Snap Demo
Elements Console Sources Network Performance Memory Application Security Lighthouse Recorder
Preserve log Disable cache No throttling
Filter Invert Hide data URLs Hide extension URLs
All Fetch/XHR Doc CSS JS Font Img Media Manifest WS Wasm Other Blocked response cookies Blocked requests 3rd-party requests
10 ms 20 ms 30 ms 40 ms 50 ms 60 ms 70 ms 80 ms 90 ms 100 ms
Name Status Type Initiator Size Time Waterfall
1.jpg 200 jpeg scroll-snap/:24 14.0 kB 3 ms
2.jpg 200 jpeg scroll-snap/:48 32.0 kB 3 ms
2 / 8 requests 46.0 kB / 59.4 kB transferred 45.7 kB / 58.2 kB resources Finish: 30 ms DOMContentLoaded: 24 ms Load: 24 ms

DO

they don't shove megabytes worth of product images onto customers' devices like other shops usually do. Instead they apply the "pull principle" very effectively – and very in-line with an ethical brand – by only showing simple SVG silhouettes by default. If the grid is currently green enough, the user can decide to click on a silhouette to load a real product image, like so:

Click on the placeholder image (1.1 KB) to load the real image (23 - 65 KB, depending on browser)

The next best way to minimize image data is by not loading images until the user scrolls to then (i.e. lazy loading). For performance reasons however, any above-the-fold images

DO

The biggest problems

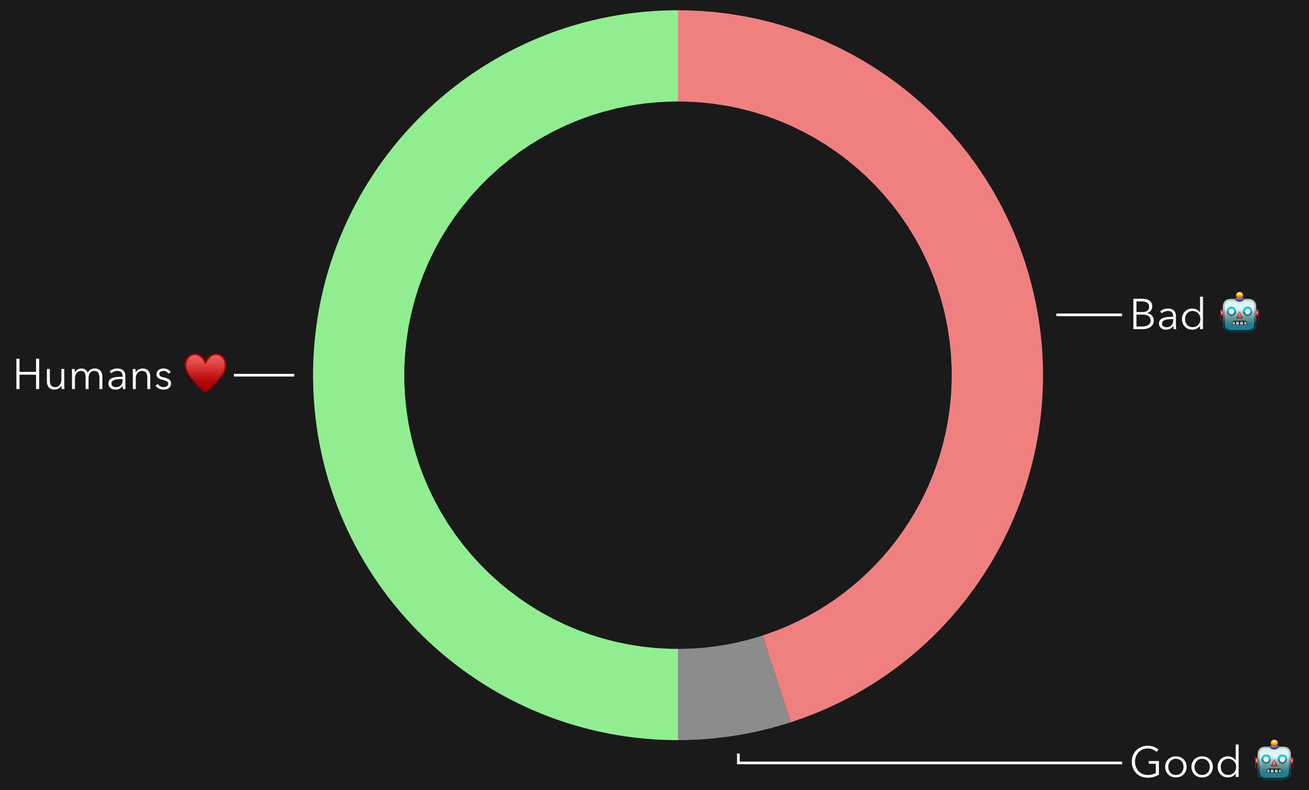
Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults
- Lazy-load, use façades
- Optimize images, media
- Optimize perf
- Performance budgets
- Carbon-aware coding

Too many devices

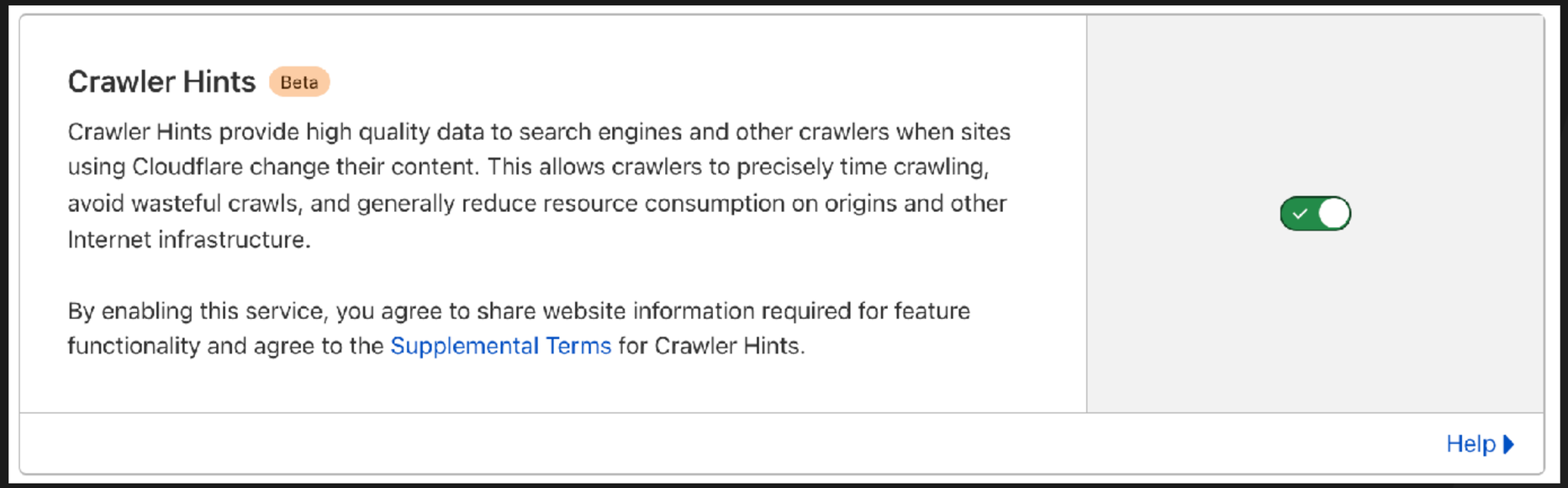
- HTML standards > JS
- Support legacy, progressively
- a11y
- Sourcing & recycling policies
- Optimize cloud

Internet Traffic Sources



Source: Cloudflare, “Crawler Hints: How Cloudflare Is Reducing The Environmental Impact Of Web Searches”, 2021.

Internet Traffic Sources



Source: Cloudflare, "Crawler Hints: How Cloudflare Is Reducing The Environmental Impact Of Web Searches", 2021.

The biggest problems

Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults
- Lazy-load, use façades
- Optimize images, media
- Optimize perf
- Performance budgets
- Carbon-aware coding

Too many devices

- HTML standards > JS
- Support legacy, progressively
- a11y
- Sourcing & recycling policies
- Optimize cloud

The biggest problems

Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults
- Lazy-load, use façades
- Optimize images, media
- Optimize perf
- Performance budgets
- Carbon-aware coding

Too many devices

- HTML standards > JS
- Support legacy, progressively
- a11y
- Sourcing & recycling policies
- Optimize cloud

Human behavior

The biggest problems

Too much energy

- Build what's needed, delete what's not
- Use green hosts & cloud
- Minify, compress, cache
- Use green defaults
- Lazy-load, use façades
- Optimize images, media
- Optimize perf
- Performance budgets
- Carbon-aware coding

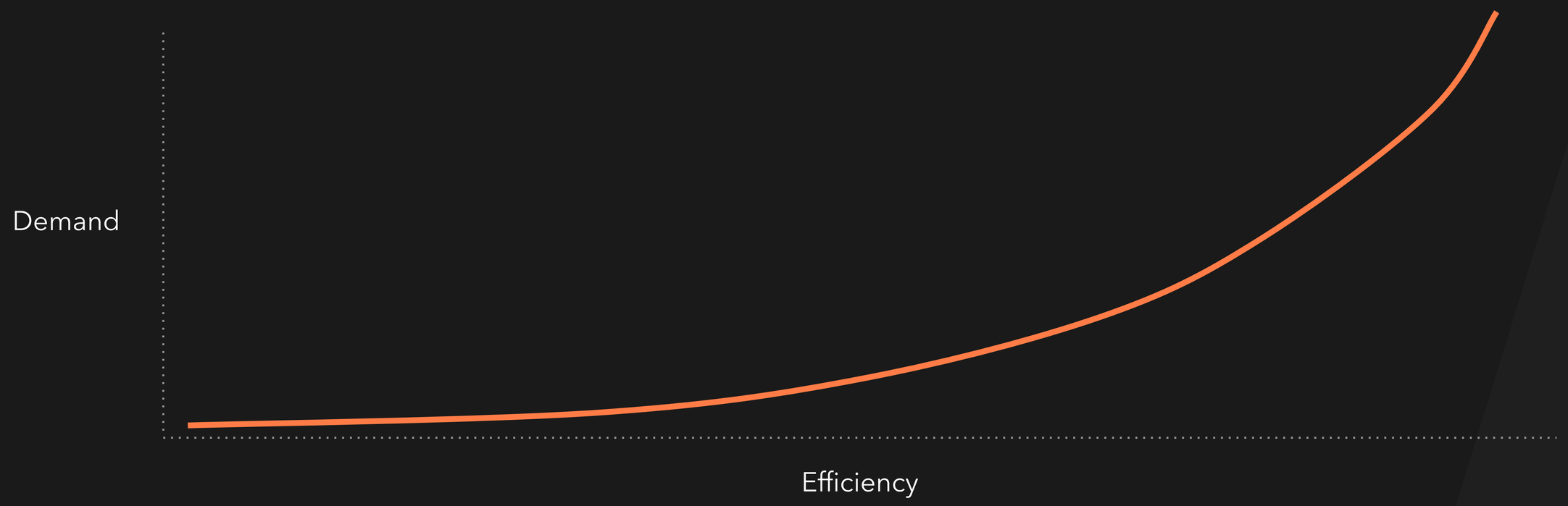
Too many devices

- HTML standards > JS
- Support legacy, progressively
- a11y
- Sourcing & recycling policies
- Optimize cloud

Human behavior

- Talk about sustainability
- Green software training
- Set targets & limits
- Grassroots action & community participation
- Policy

The Jevons Paradox
Increasing efficiency enables increased use

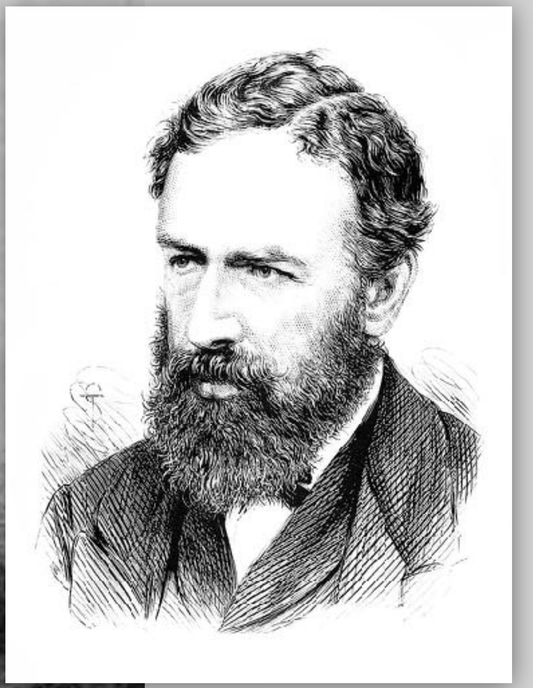


Source: Wikipedia

The Jevons Paradox

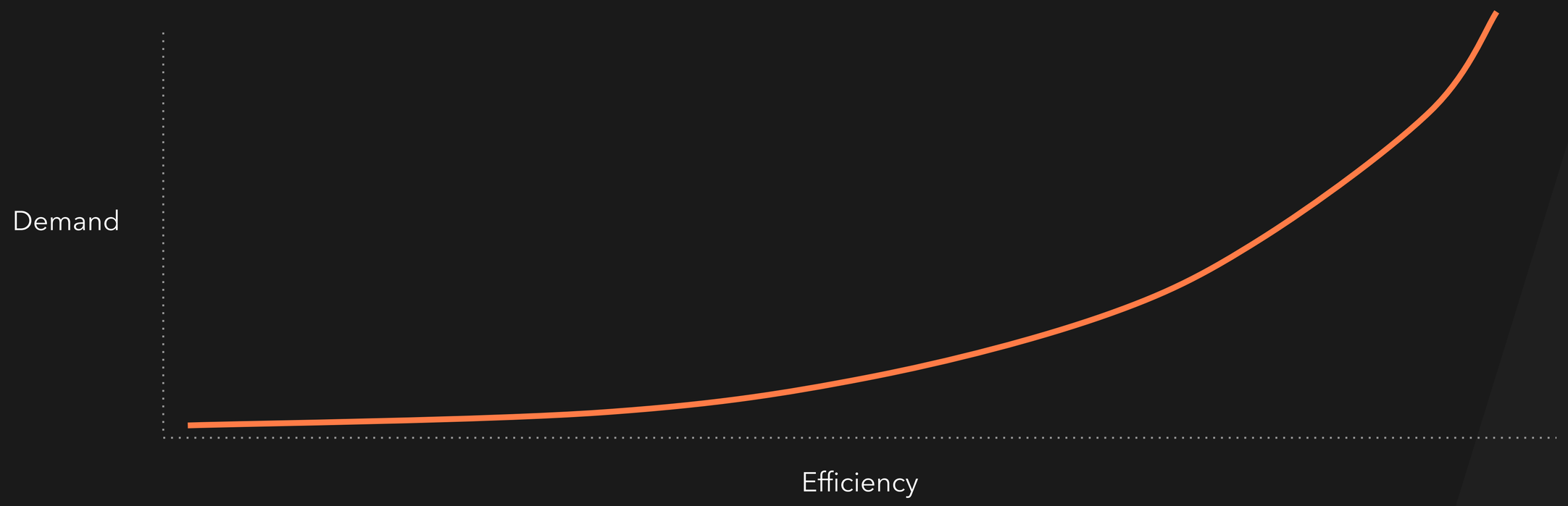
Increasing
enables i

Demand



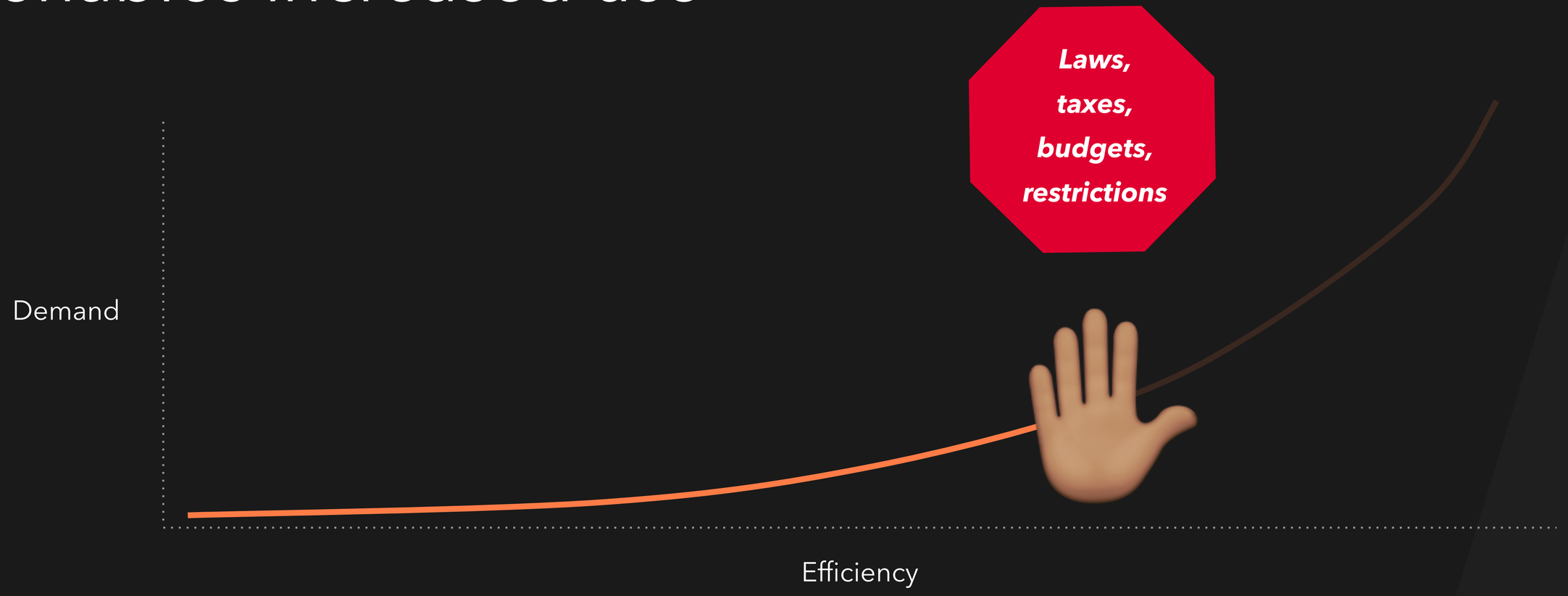
Source: Wikipedia

The Jevons Paradox
Increasing efficiency enables increased use



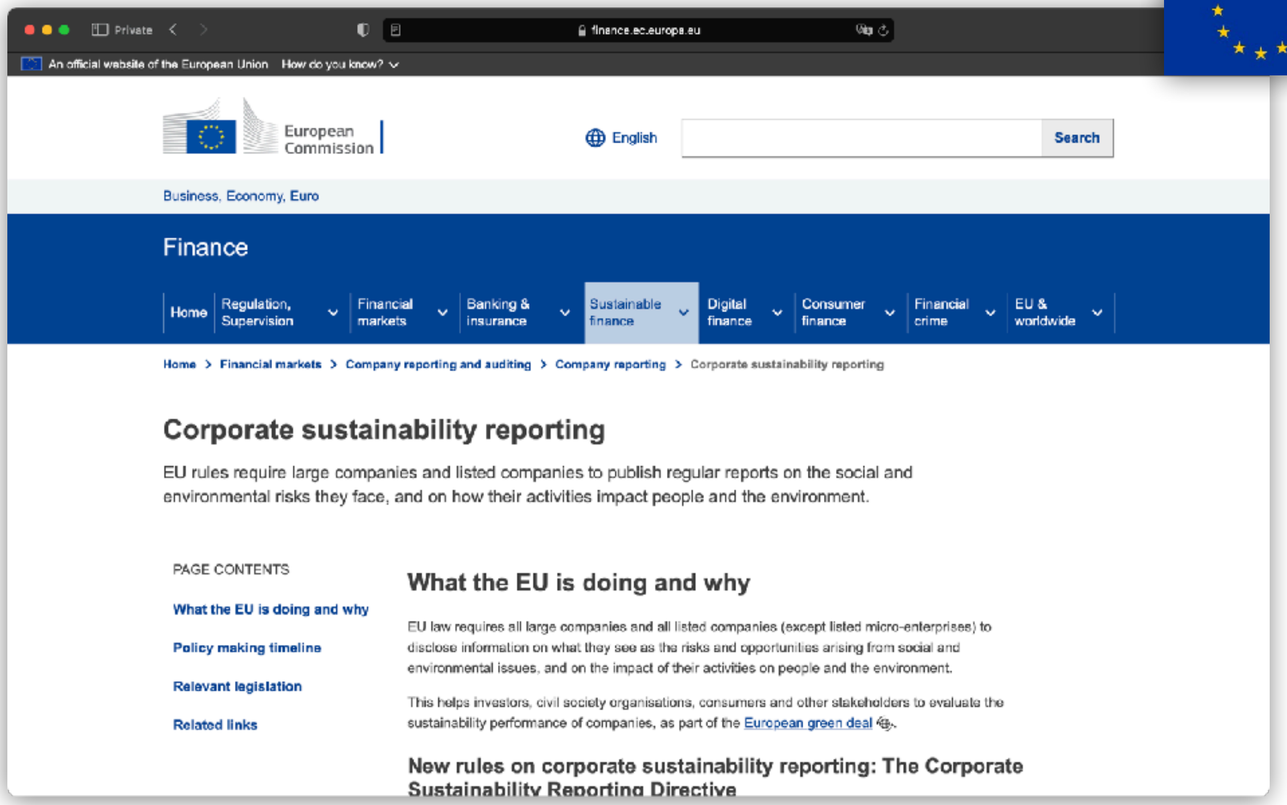
Source: Wikipedia

The Jevons Paradox
Increasing efficiency enables increased use

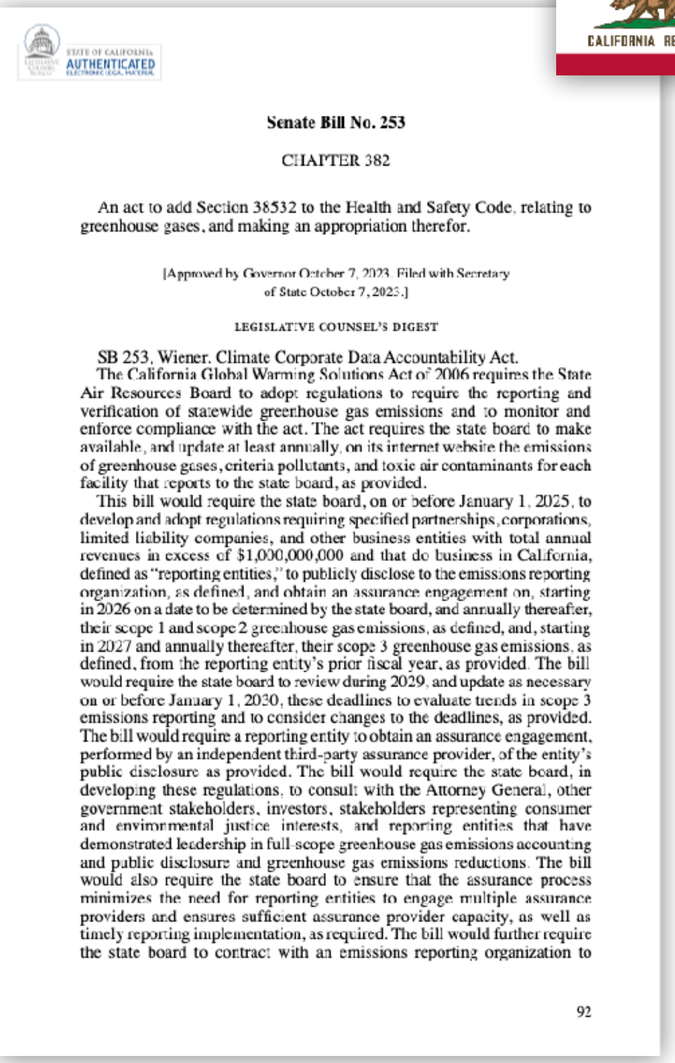


Source: Wikipedia

CSRD



CCDAA



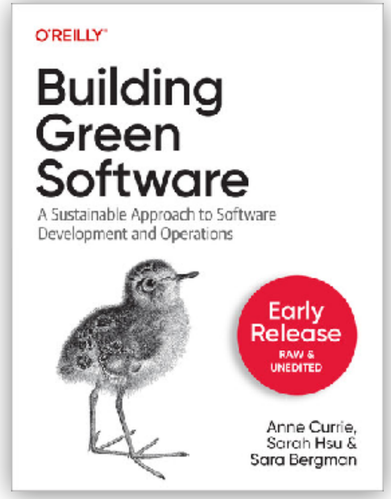
The EU's Corporate Sustainability Reporting Directive (CSRD); California's SB 253, the Climate Corporate Data Accountability Act (CCDAA)

How to measure impact?

Source: Techspot

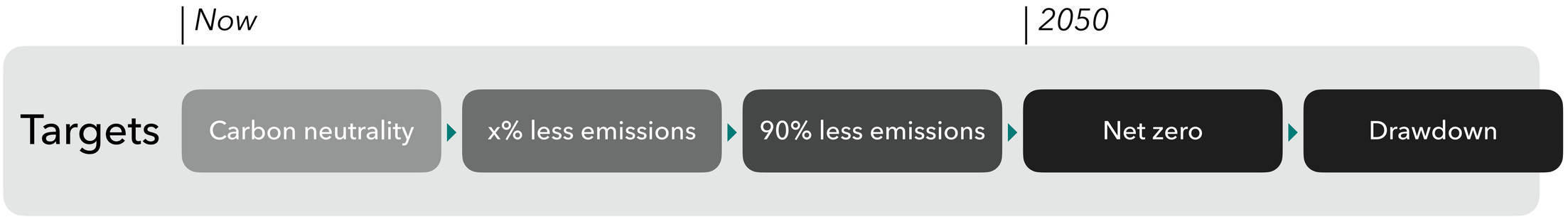
The perfect green metric

> The perfect source of energy data for our software would be in real time and able to scope to the granularity you currently desired.



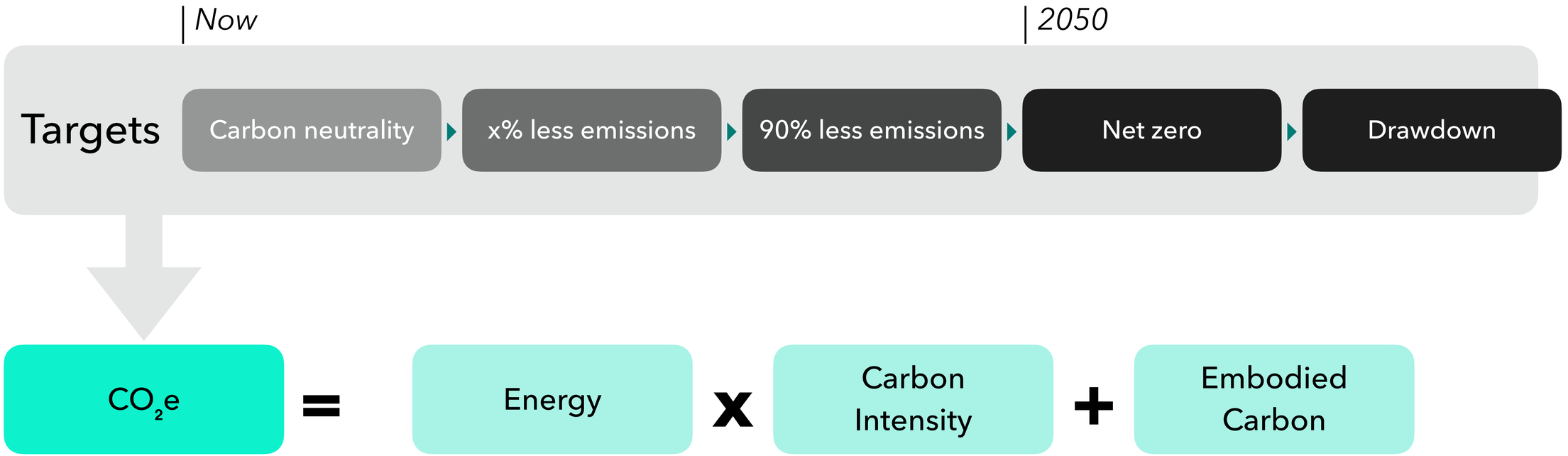
Source: Building Green Software (2024, preview) by Anne Currie, Sarah Hsu, Sara Bergman

The perfect green metric



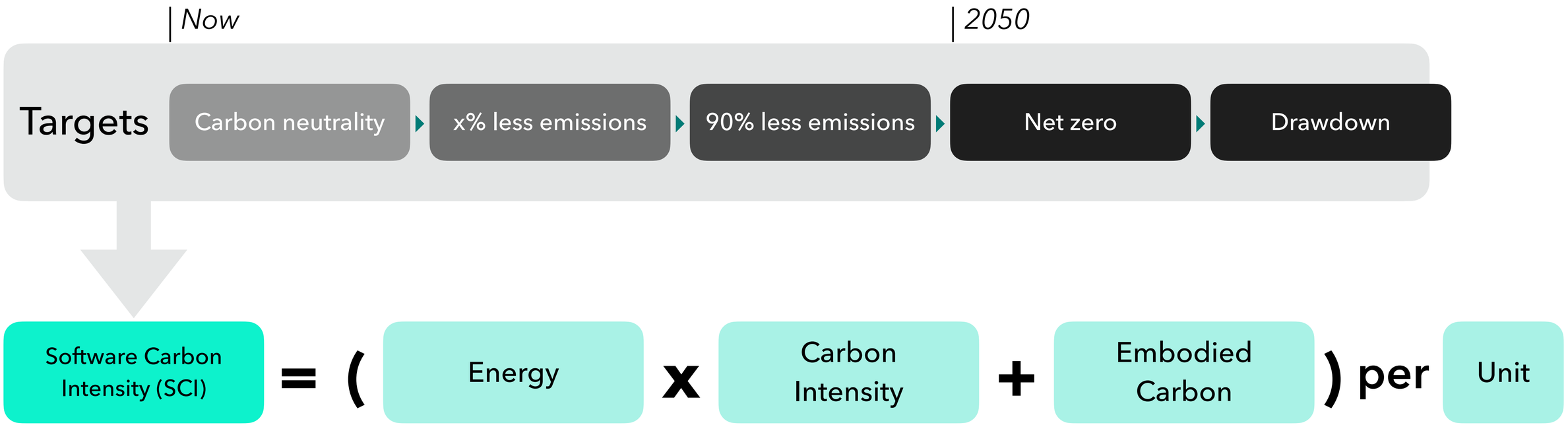
References: Building Green Software (2024, preview) by Anne Currie, Sarah Hsu, Sara Bergman. "Why do estimates for internet energy consumption vary so drastically?" by Tom Greenwood. Green Software Practitioner by the Green Software Foundation. "Calculating Digital Emissions" on sustainablewebdesign.org.

The perfect green metric



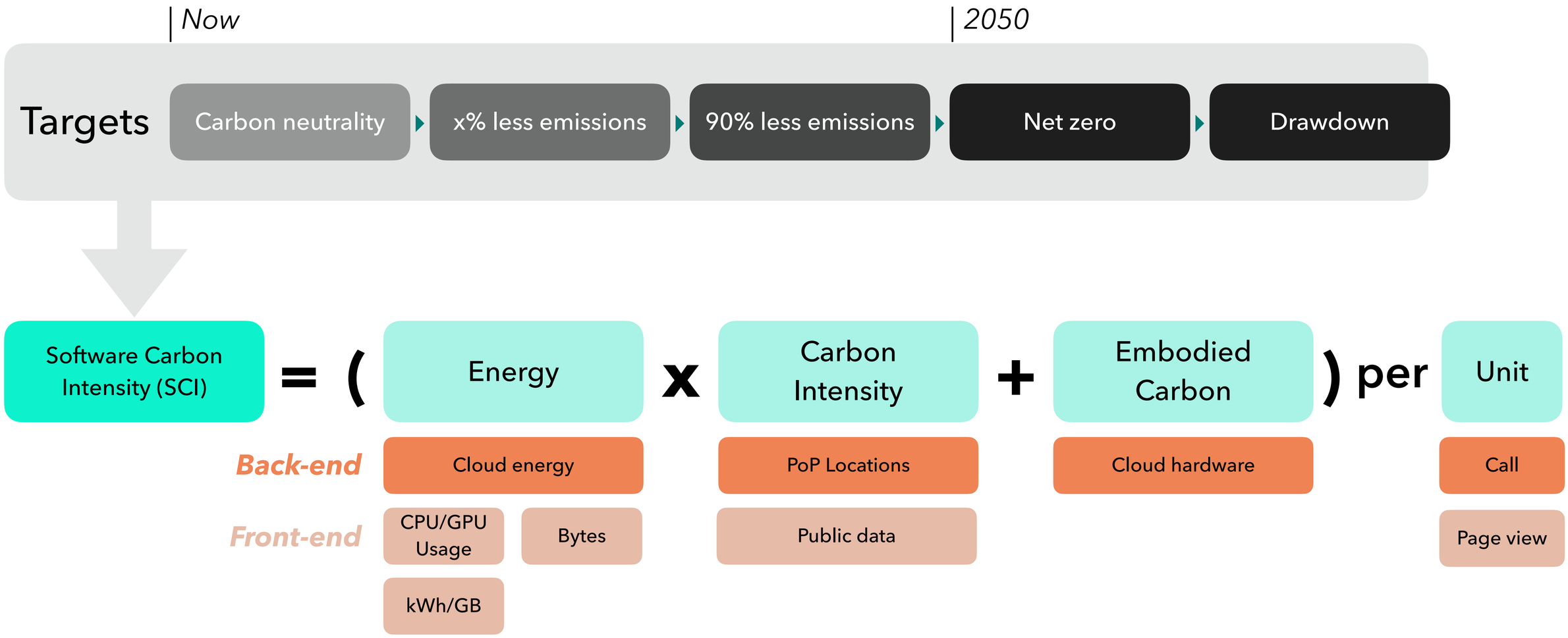
References: Building Green Software (2024, preview) by Anne Currie, Sarah Hsu, Sara Bergman. "Why do estimates for internet energy consumption vary so drastically?" by Tom Greenwood. Green Software Practitioner by the Green Software Foundation. "Calculating Digital Emissions" on sustainablewebdesign.org.

A *good-enough* green metric



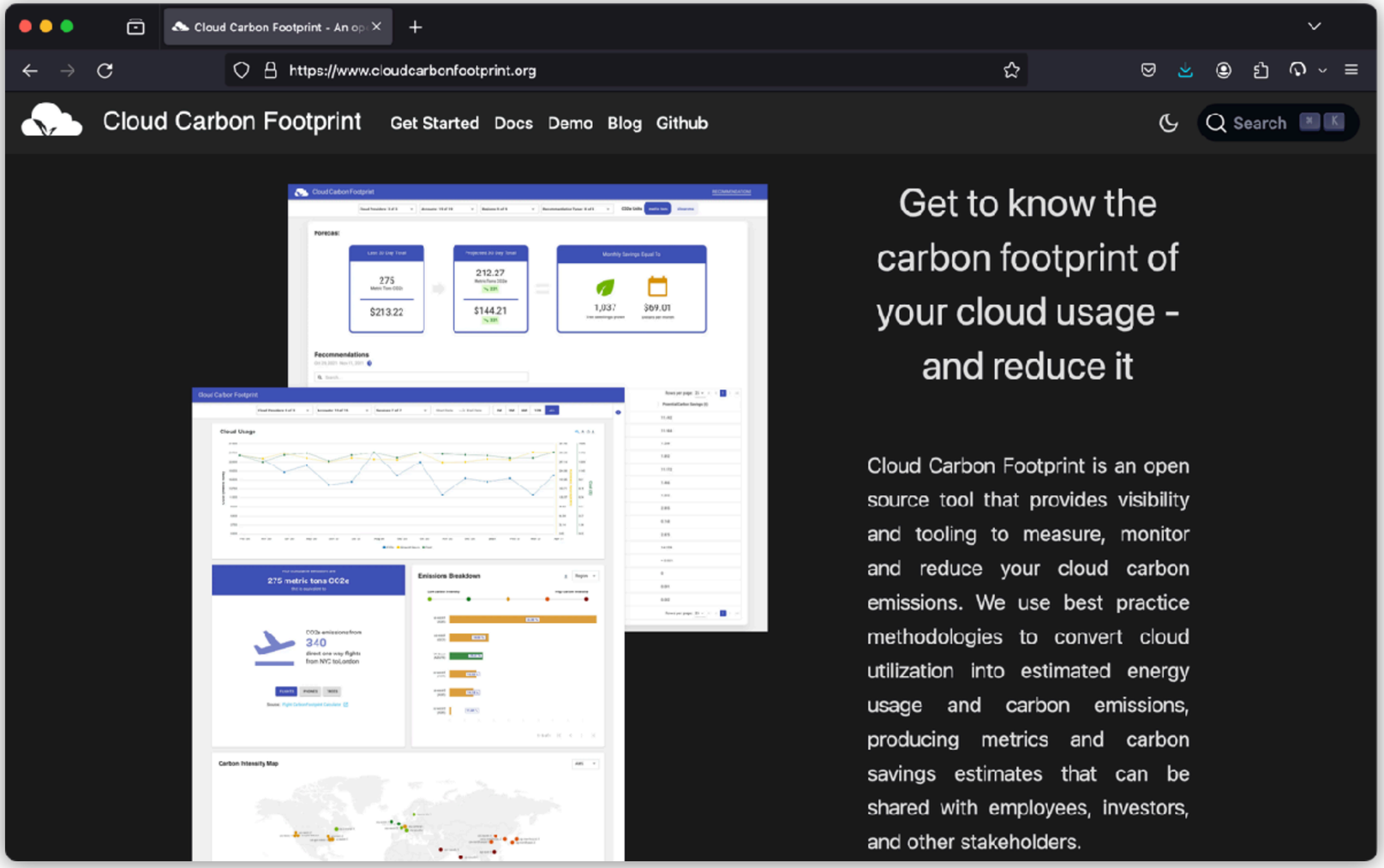
References: Building Green Software (2024, preview) by Anne Currie, Sarah Hsu, Sara Bergman. "Why do estimates for internet energy consumption vary so drastically?" by Tom Greenwood. Green Software Practitioner by the Green Software Foundation. "Calculating Digital Emissions" on sustainablewebdesign.org.

A *good-enough* green metric



References: Building Green Software (2024, preview) by Anne Currie, Sarah Hsu, Sara Bergman. "Why do estimates for internet energy consumption vary so drastically?" by Tom Greenwood. Green Software Practitioner by the Green Software Foundation. "Calculating Digital Emissions" on sustainablewebdesign.org.

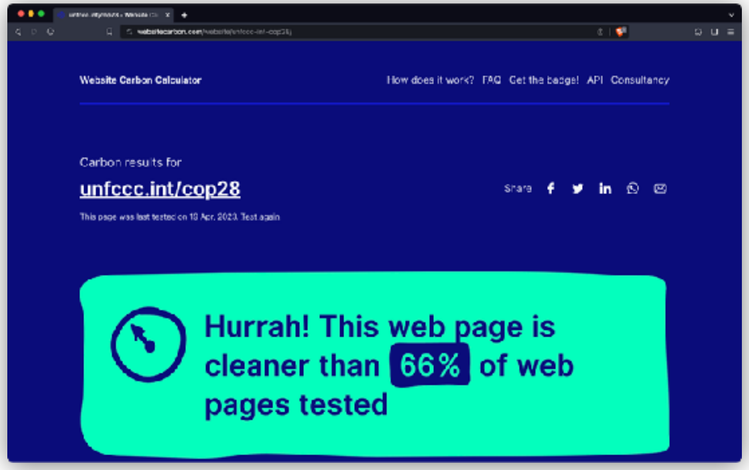
Measuring the Cloud



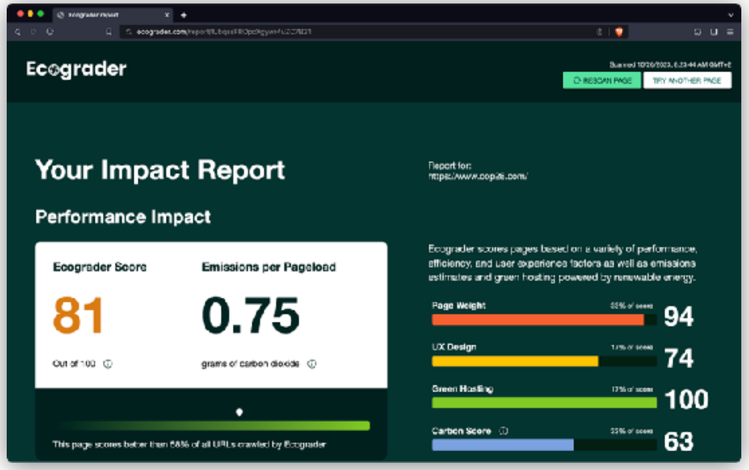
https://www.cloudcarbonfootprint.org/

Measuring the Front-End

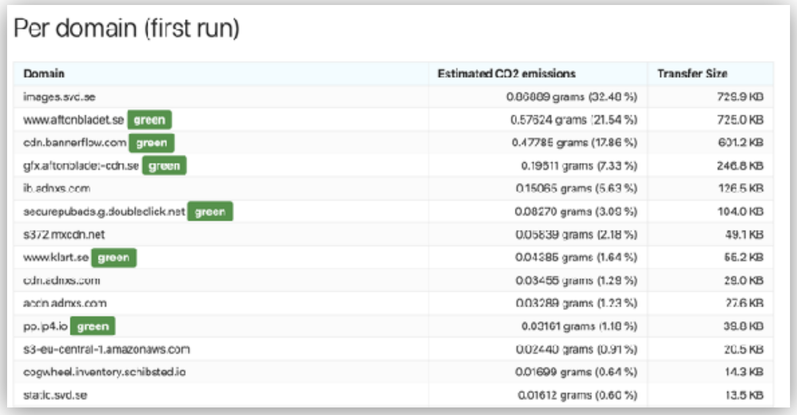
websitecarbon.com



ecograder.com



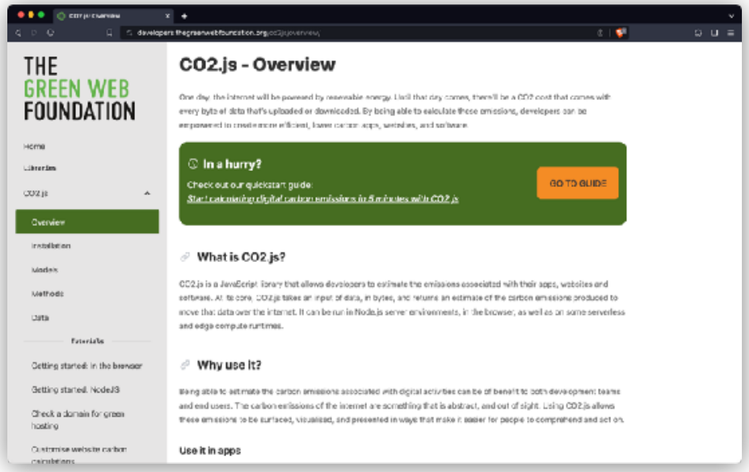
sitespeed.io



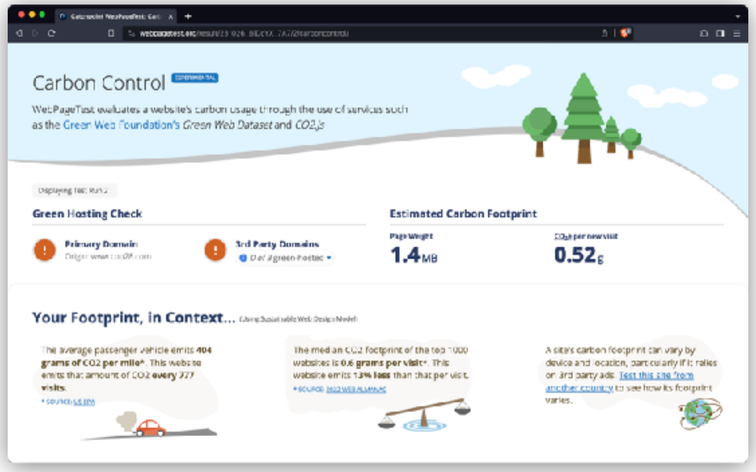
Per domain (first run)

Domain	Estimated CO2 emissions	Transfer Size
images.svc.se	0.06089 grams (32.40 %)	729.9 KB
www.aftonbladet.se green	0.57824 grams (21.54 %)	725.0 KB
cdn.bannerflow.com green	0.47786 grams (17.86 %)	601.2 KB
gfx.aftonbladet-cdn.se green	0.19511 grams (7.33 %)	246.8 KB
ib.adnxs.com	0.15065 grams (5.63 %)	126.5 KB
securepubads.g.doubleclick.net green	0.08270 grams (3.09 %)	104.0 KB
s372.mxcdn.net	0.05839 grams (2.18 %)	49.1 KB
www.klart.se green	0.04385 grams (1.64 %)	55.2 KB
cdn.ednxs.com	0.03455 grams (1.29 %)	29.0 KB
acdn.adnxs.com	0.03289 grams (1.23 %)	27.6 KB
pp.p4.io green	0.02161 grams (1.10 %)	39.0 KB
s3-eu-central-1.amazonaws.com	0.02440 grams (0.91 %)	20.5 KB
cogwheel.inventory.schibsted.io	0.01699 grams (0.64 %)	14.3 KB
static.svd.se	0.01612 grams (0.60 %)	13.5 KB

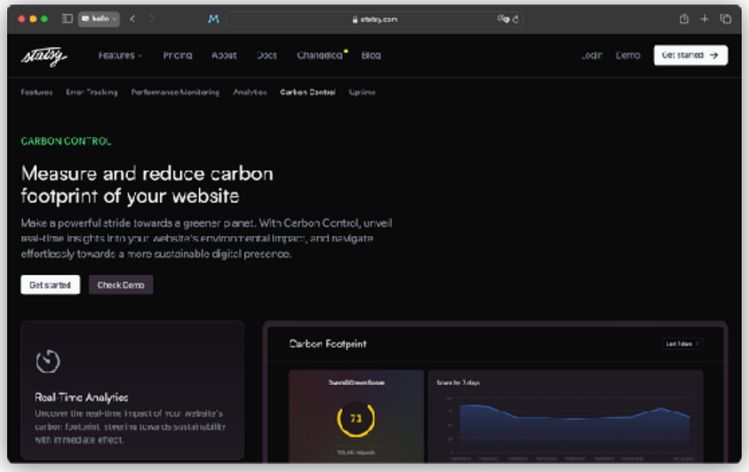
CO2.js



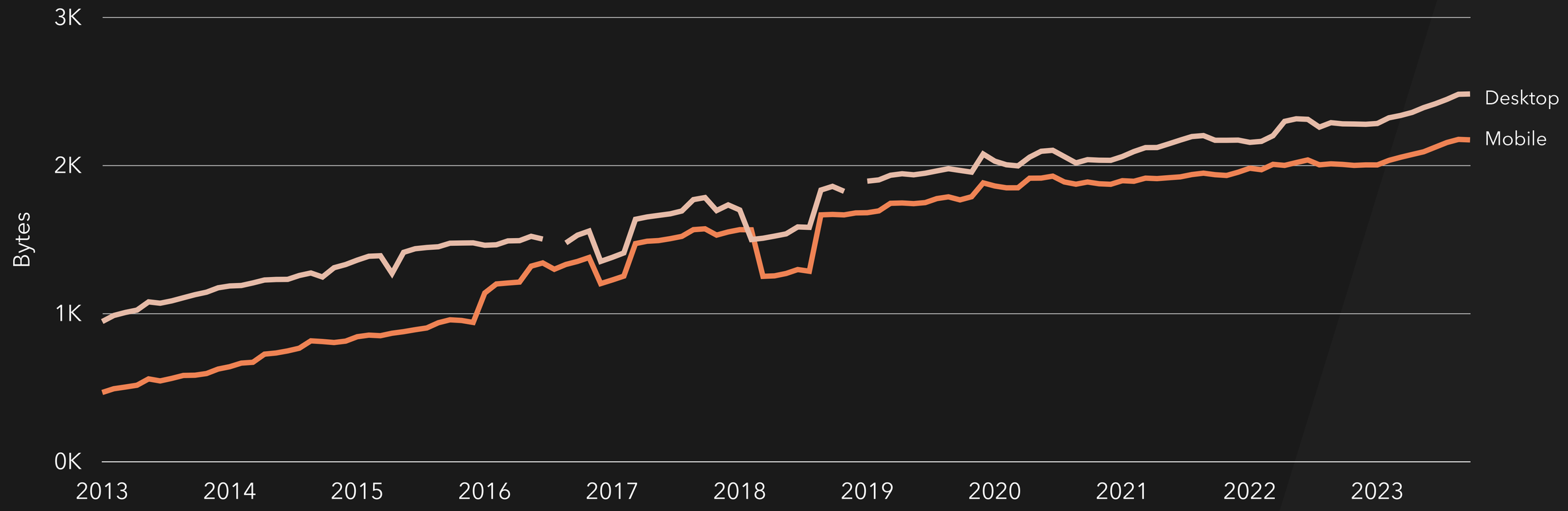
WebPageTest Carbon Control



Statsy

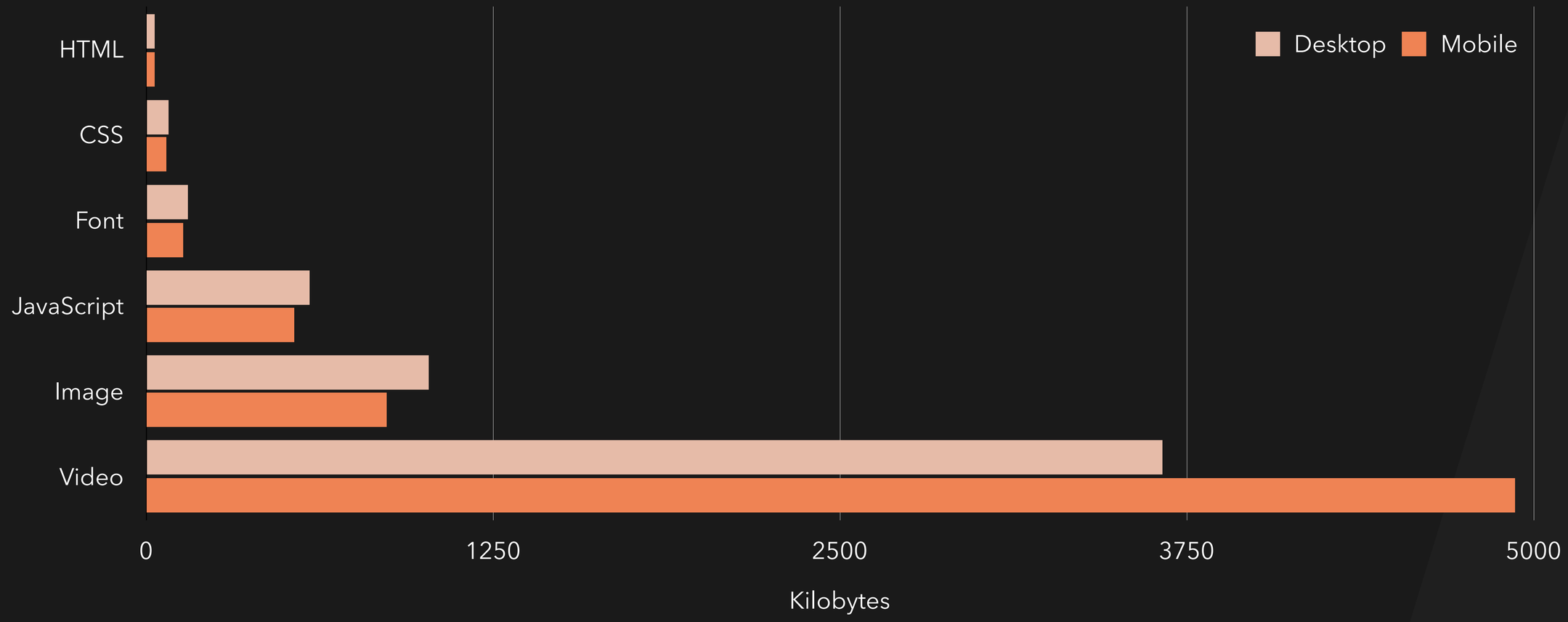


Webpages keep getting heavier



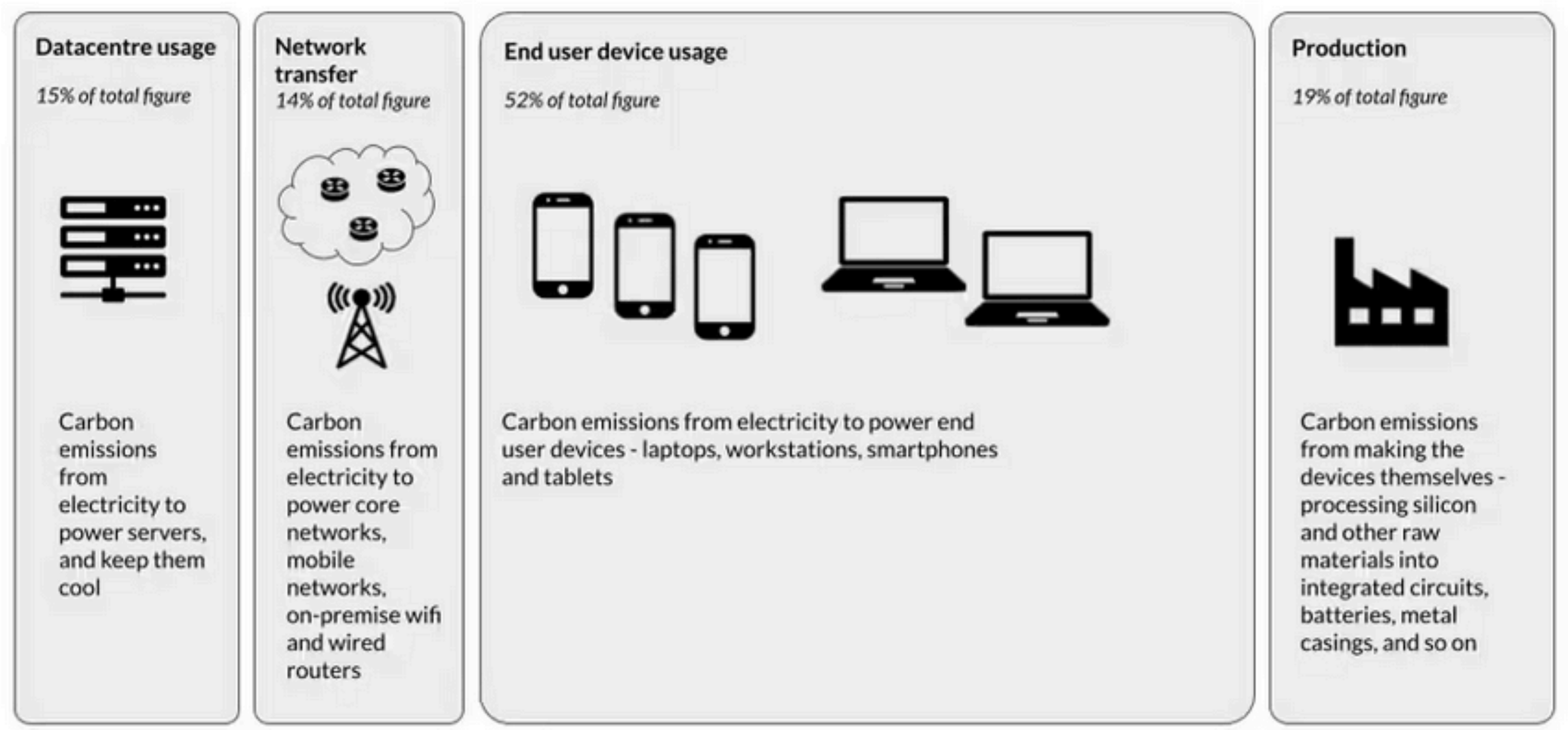
Source: HTTP Archive, Aug 2013 - Sept 2023, no lens

Median resource weight



Source: HTTP Archive, September 2022 - September 2023

The Sustainable Web Design Model

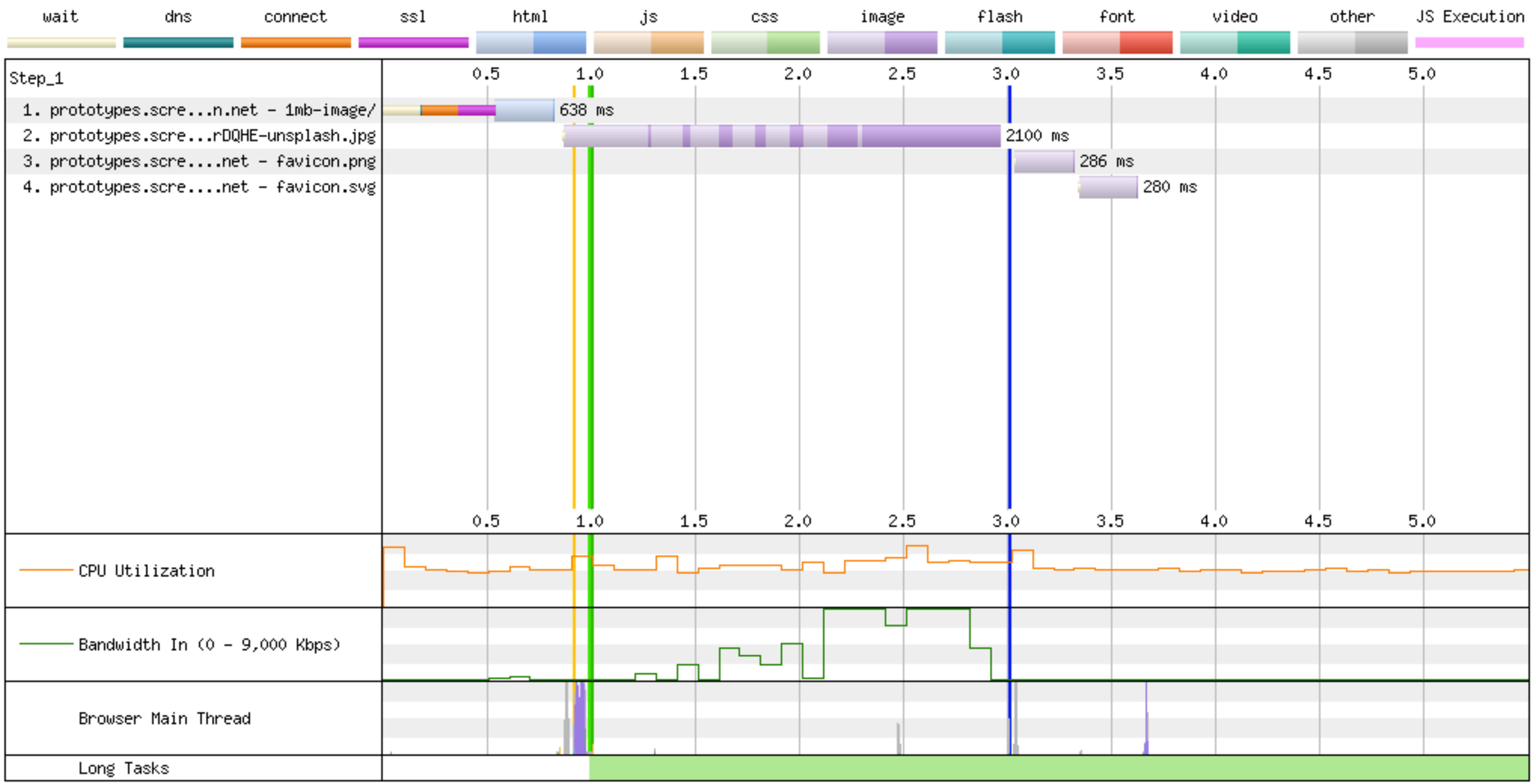


Source: "Methodologies for calculating website carbon" explainer by The Green Web Foundation; see also SustainableWebDesign.org

Data transfer is a (weak) proxy for CO_2e

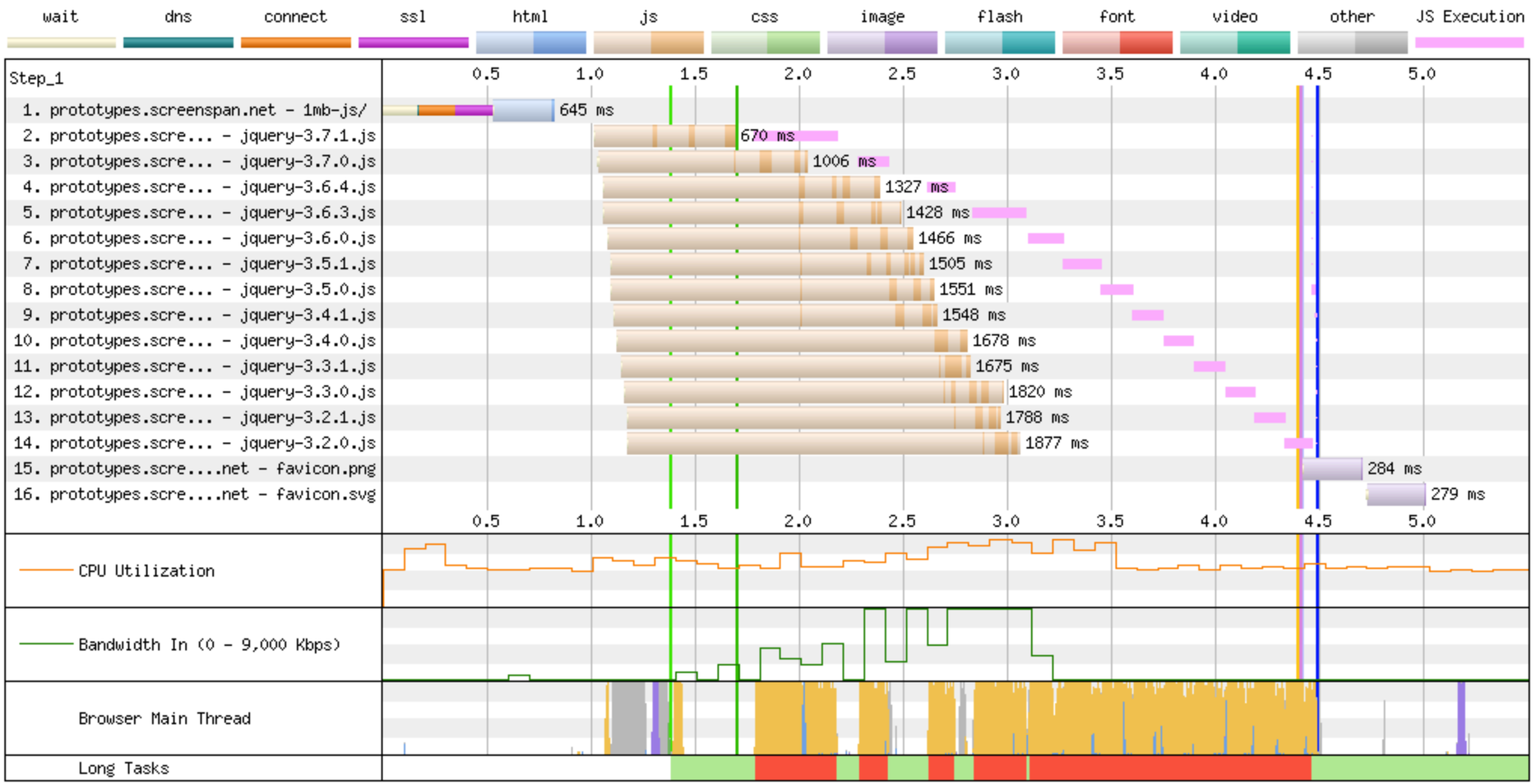
More info: “Why We Don’t Report Website Carbon Emissions” by DebugBear (Oct. 31, 2023);
“Why web perf tools should be reporting website carbon emissions” by Fershad Irani (Dec. 5, 2023)

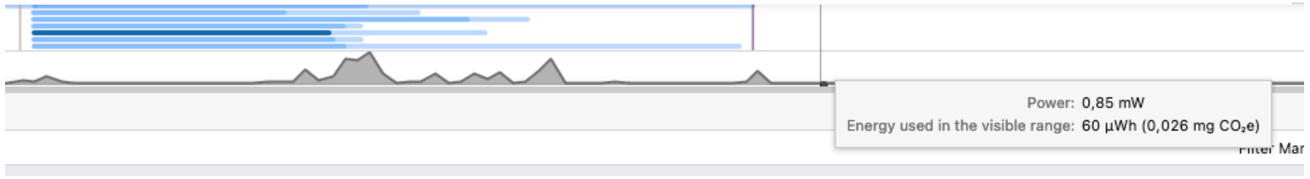
1 MB image file



Source: WebPageTest, Firefox Power Profiler

1 MB of JavaScript





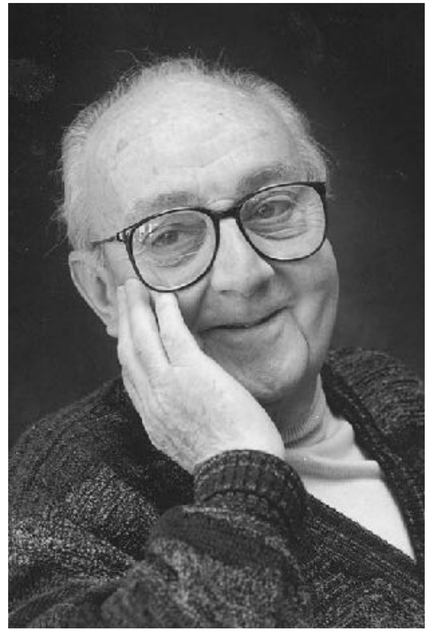
Source: WebPageTest, Firefox Power Profiler

We need APIs that help us measure sustainability

```
Navigator = {
    deviceAge: 2,
    embodiedCarbon: 8,
    // ...
}

PerformanceSessionTiming = {
    totalTransferSize: 2220, // including request and response headers
    totalTransferredJS: 750,
    // ...
}

PerformanceMeasure = {
    detail: {
        cpuTime: 2342,
        gpuTime: 366,
        energyImpact: .66,
        watts: 0.00014
    }
}
```

On models

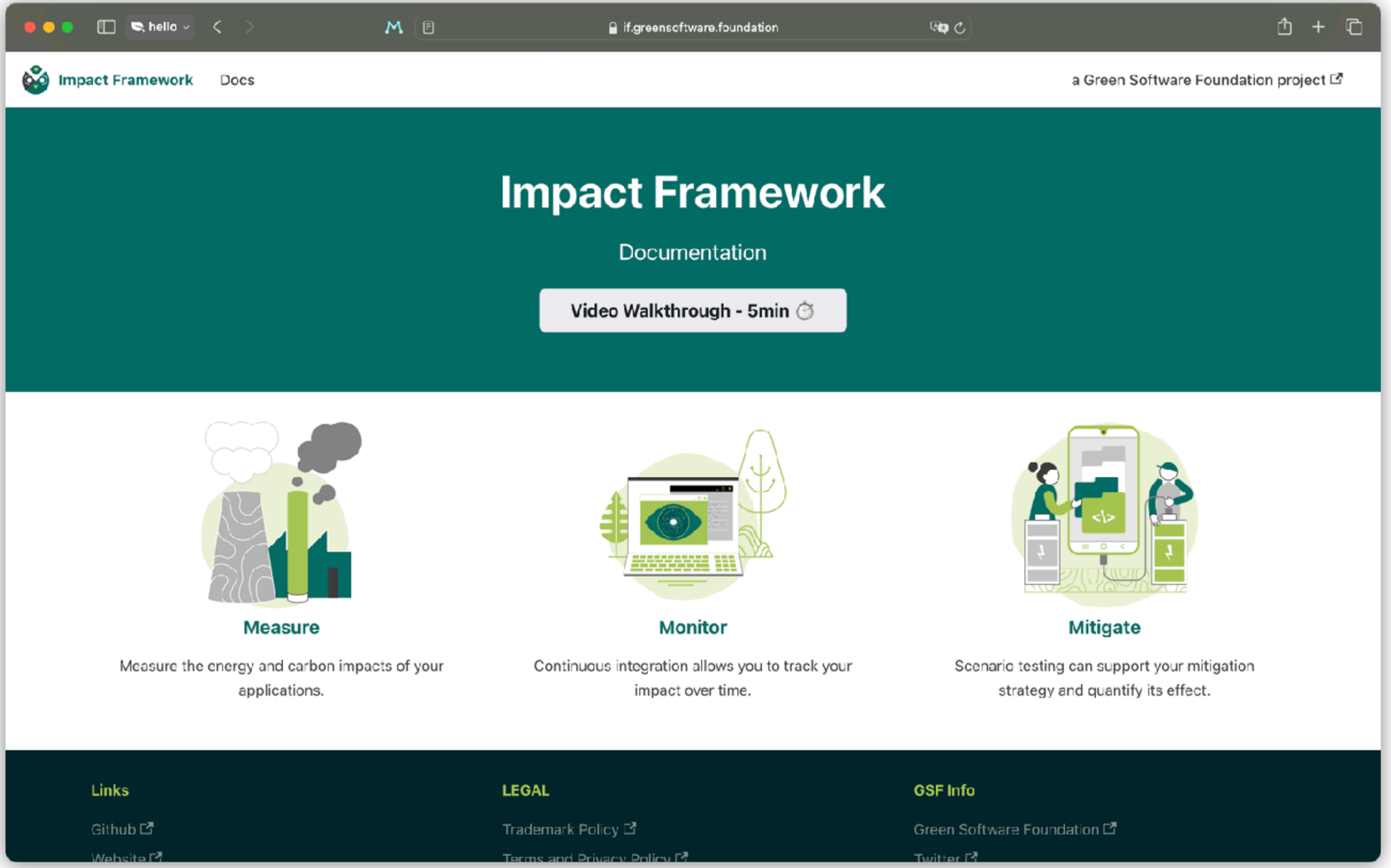
> All models are wrong
> but some models are useful.



George Box
Statistician

Info: Wikipedia

The Impact Framework



Info: https://if.greensoftware.foundation/

Use different models, working with the data you've got

```yaml
name: example
description: a simple example manifest
tags:
initialize:
  models:
    - name: teads-curve
      model: TeadsCurveModel
      path: "@grnsft/if-unofficial-models"
    - name: sci-e
      model: SciEModel
      path: "@grnsft/if-models"
    - name: sci-m
      path: "@grnsft/if-models"
      model: SciMModel
    - name: sci-o
      model: SciOModel
      path: "@grnsft/if-models"
    - name: sci
      model: SciModel
      path: "@grnsft/if-models"
graph:
  children:
    child: # an advanced grouping node
      pipeline:
        - teads-curve
        - sci-e
        - sci-m
        - sci-o
        - sci
      config:
        teads-curve:
          thermal-design-power: 65
```

Info: https://if.greensoftware.foundation/

```yaml
      model: SciModel
      path: "@grnsft/if-models"
graph:
  children:
    child: # an advanced grouping node
      pipeline:
        - teads-curve
        - sci-e
        - sci-m
        - sci-o
        - sci
      config:
        teads-curve:
          thermal-design-power: 65
        sci-m:
          total-embodied-emissions: 251000 # gCO2eq
          time-reserved: 3600 # 1 hour in s
          expected-lifespan: 126144000 # 4 years in seconds
          resources-reserved: 1
          total-resources: 1
        sci-o:
          grid-carbon-intensity: 457 # gCO2/kwh
        sci:
          functional-unit-duration: 1
          functional-duration-time: ''
          functional-unit: requests # factor to convert per tim
      inputs:
        - timestamp: '2023-07-06T00:00'
          duration: 10
          cpu-util: 50
          e-net: 0.000811 #kwh
          requests: 380
```

```yaml
    model: SciModel
    path: "@grnsft/if-models"
graph:
  children:
    child: # an advanced grouping node
      pipeline:
        - teads-curve
        - sci-e
        - sci-m
        - sci-o
        - sci
      config:
        teads-curve:
          thermal-design-power: 65
        sci-m:
          total-embodied-emissions: 251000 # gCO2eq
          time-reserved: 3600 # 1 hour in s
          expected-lifespan: 126144000 # 4 years in seconds
          resources-reserved: 1
          total-resources: 1
        sci-o:
          grid-carbon-intensity: 457 # gCO2/kwh
        sci:
          functional-unit-duration: 1
          functional-duration-time: ''
          functional-unit: requests # factor to convert per tim
      inputs:
        - timestamp: '2023-07-06T00:00'
          duration: 10
          cpu-util: 50
          e-net: 0.000811 #kwh
          requests: 380
```

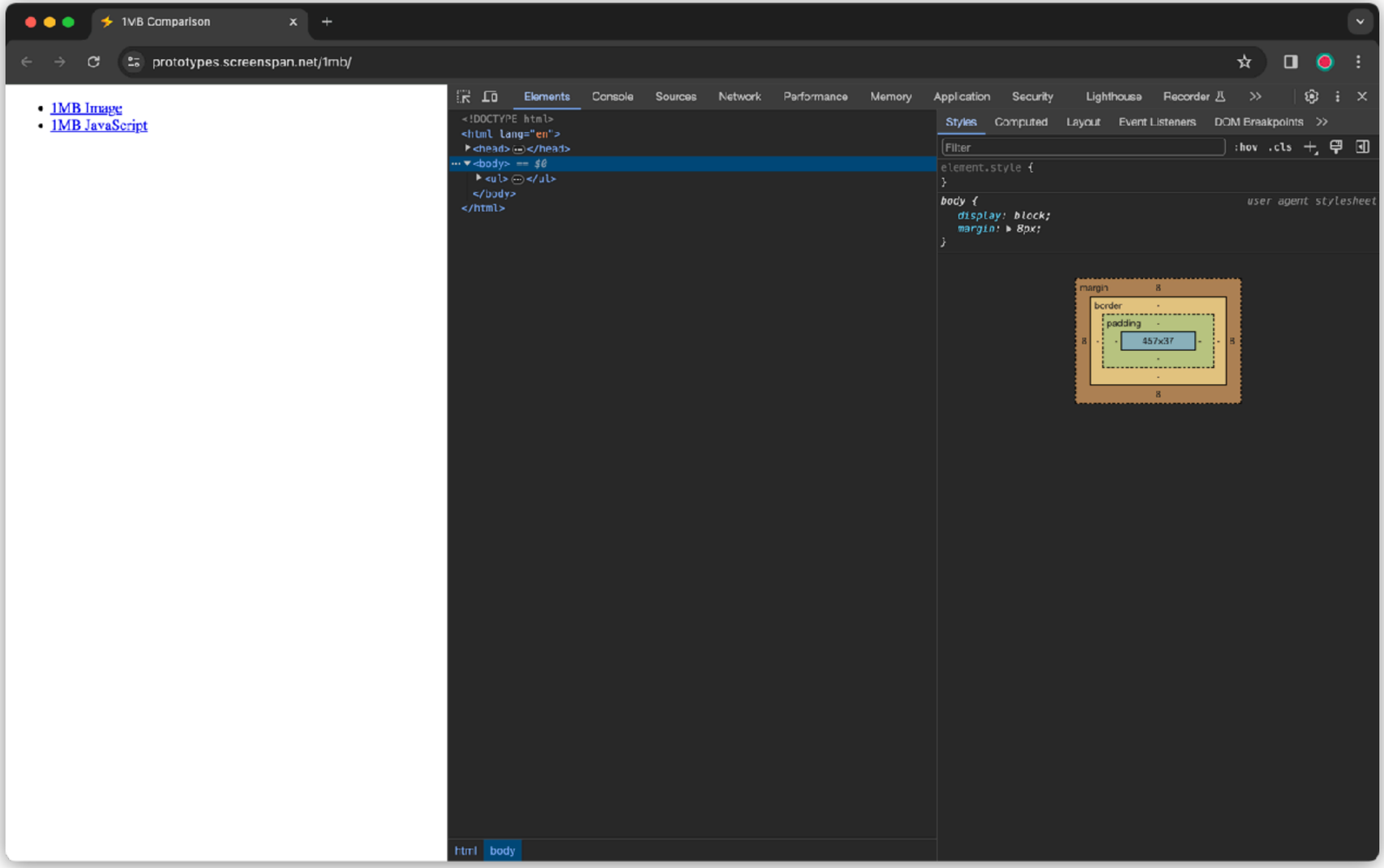
```yaml
          functional-duration-time: ''
          functional-unit: requests
      inputs:
        - timestamp: 2023-07-06T00:00
          duration: 10
          cpu-util: 50
          e-net: 0.000811
          requests: 380
      outputs:
        - timestamp: 2023-07-06T00:00
          duration: 10
          cpu-util: 50
          e-net: 0.000811
          requests: 380
          thermal-design-power: 65
          total-embodied-emissions: 251000
          time-reserved: 3600
          expected-lifespan: 126144000
          resources-reserved: 1
          total-resources: 1
          grid-carbon-intensity: 457
          functional-unit-duration: 1
          functional-duration-time: ''
          functional-unit: requests
          energy-cpu: 0.00013541666666666666
          energy: 0.00013541666666666666
          embodied-carbon: 7.16324200913242
          operational-carbon: 0.061885416666666665
          carbon: 0.7225127425799086
          sci: 0.001901349322578707
```

Start with the basics, focus on high-impact, add more granular data where possible

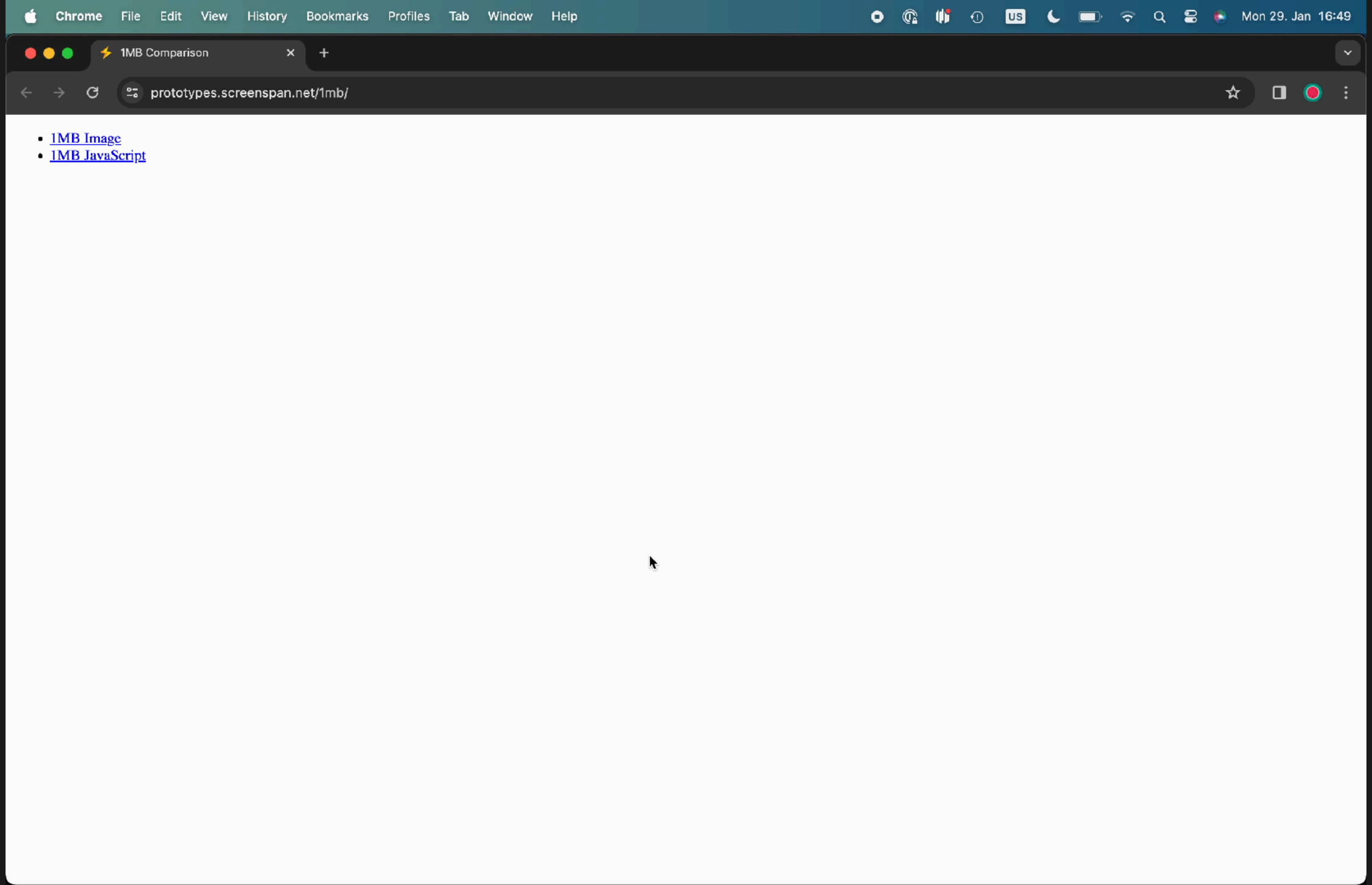
Fill in columns A, B and F only		*Using energy factor of 1.8kWh/GB. Can be easily adjusted with data from new studies.*	*Using gloval IEA figure of 475g/kWh. Adjust for relevant region or country*	*Adjusted to only power data centre by renewables (33.4g/kWh)*			
Website	**Page transfer size (MB)**	**Energy consumption per page view (kWh)**	**CO2 per page view from standard grid energy (kg)**	**CO2 per page view with 100% renewable hosting (kg)**	**Annual page views**	**Annual CO2 from standard grid energy (kg)**	**Annual CO2 with 100% renewable hosting (kg)**
Average website 2020	3.17	0.00571	0.00271	**0.00160**	120000	325.24	191.62
		0.00000	0.00000	**0.00000**		0.00	0.00

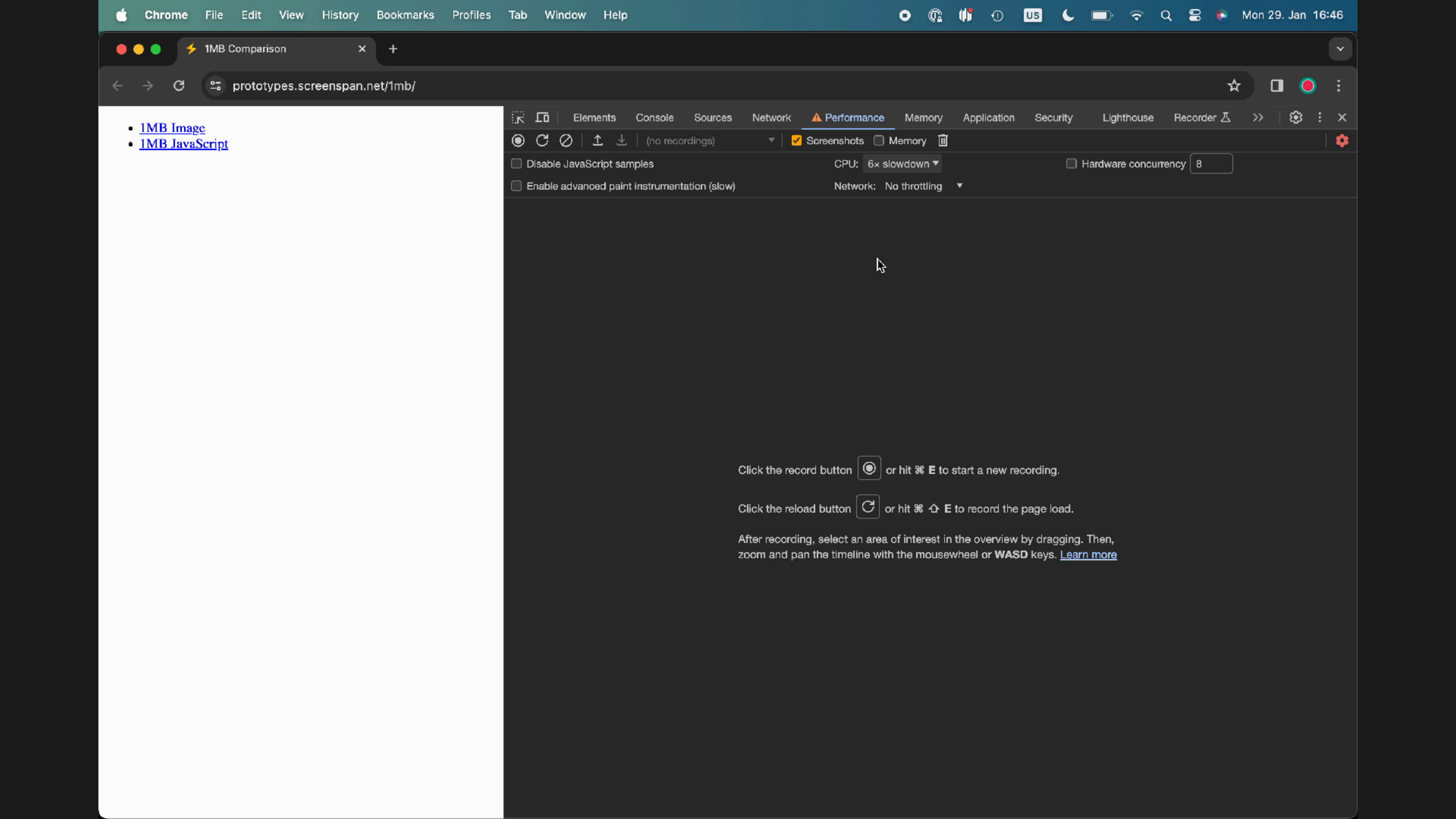
How to optimize?

Chrome Developer Tools

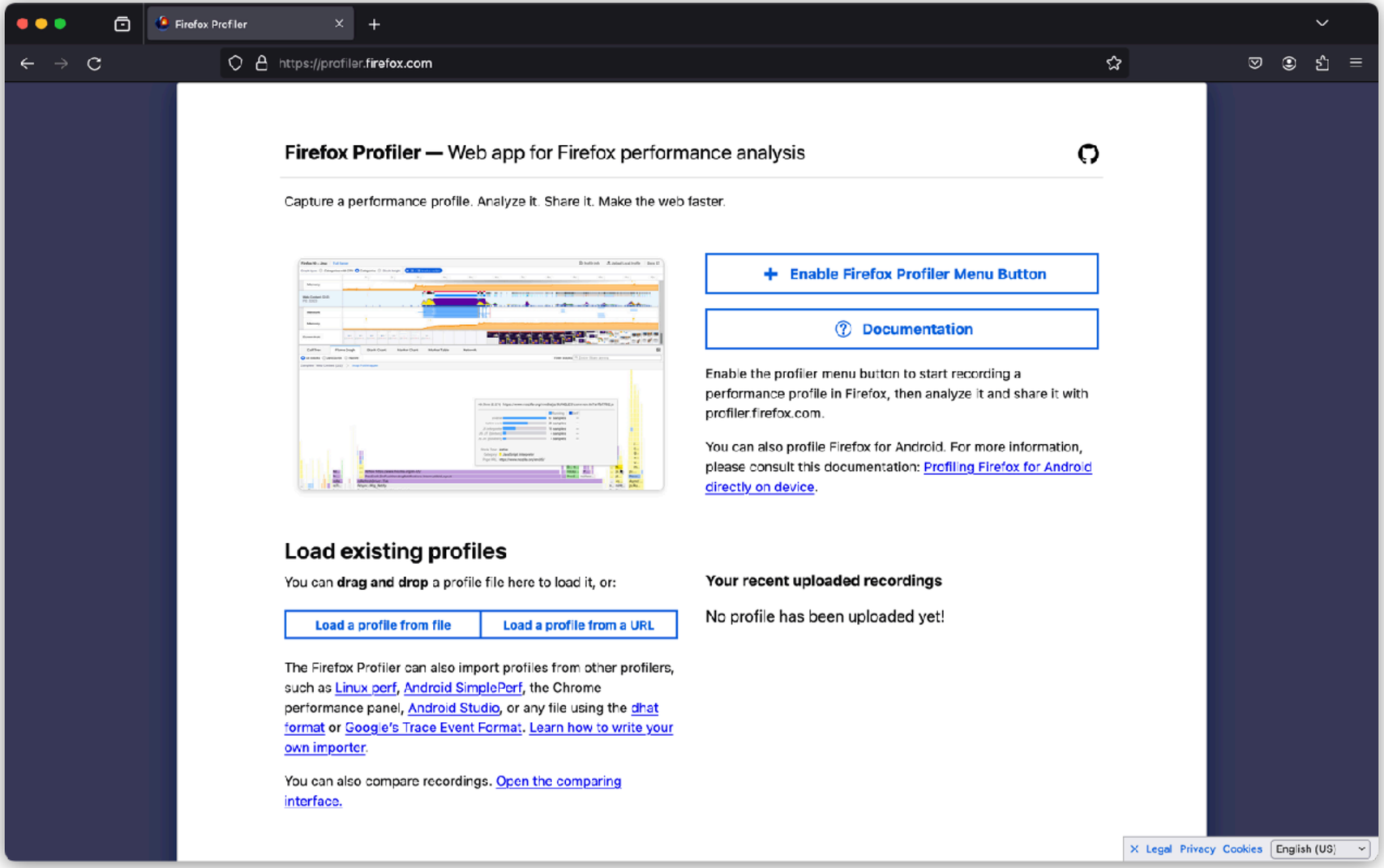


More info: "Analyze runtime performance" at Chrome for Developers

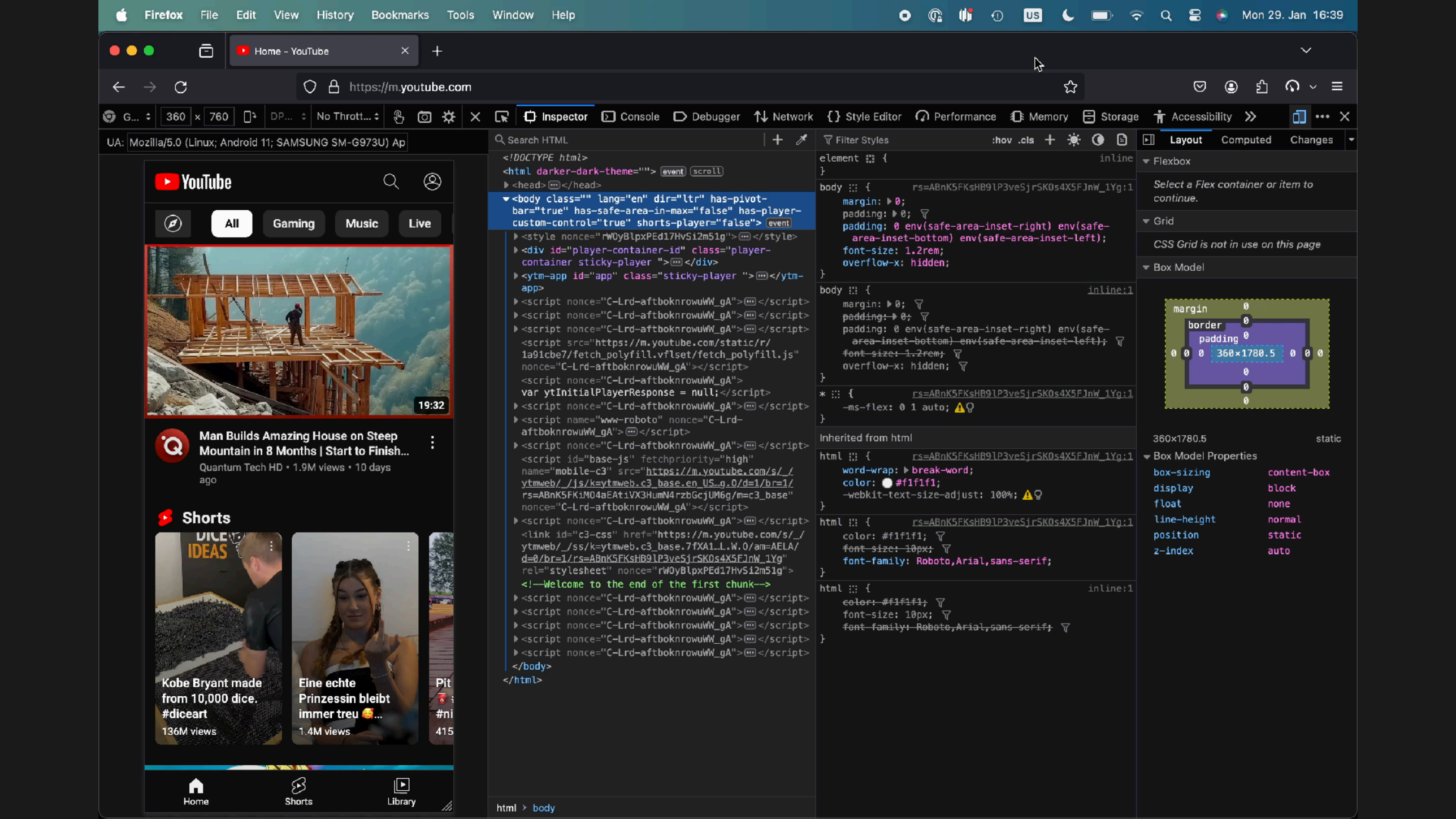

Chrome File Edit View History Bookmarks Profiles Tab Window Help
Mon 29. Jan 16:49
1MB Comparison
prototypes.screenspan.net/1mb/
1MB Image
1MB JavaScript


Chrome File Edit View History Bookmarks Profiles Tab Window Help
Mon 29. Jan 16:46
1MB Comparison
prototypes.screenspan.net/1mb/
1MB Image
1MB JavaScript
Elements Console Sources Network Performance Memory Application Security Lighthouse Recorder
(no recordings)
Screenshots
Memory
Disable JavaScript samples
CPU: 6× slowdown
Hardware concurrency 8
Enable advanced paint instrumentation (slow)
Network: No throttling
Click the record button or hit ⌘ E to start a new recording.
Click the reload button or hit ⌘ ⇧ E to record the page load.
After recording, select an area of interest in the overview by dragging. Then, zoom and pan the timeline with the mousewheel or WASD keys. Learn more

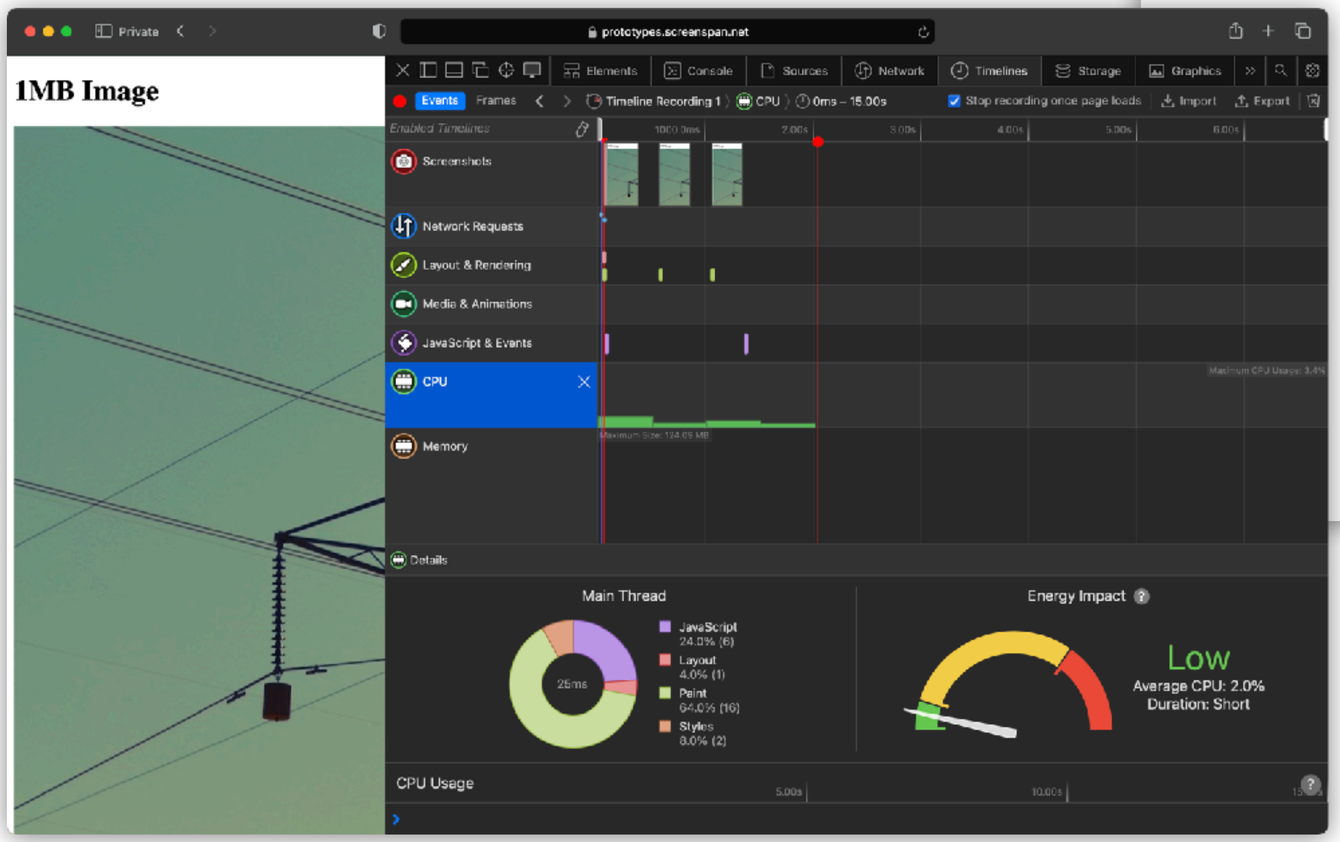
Firefox Power Profiler

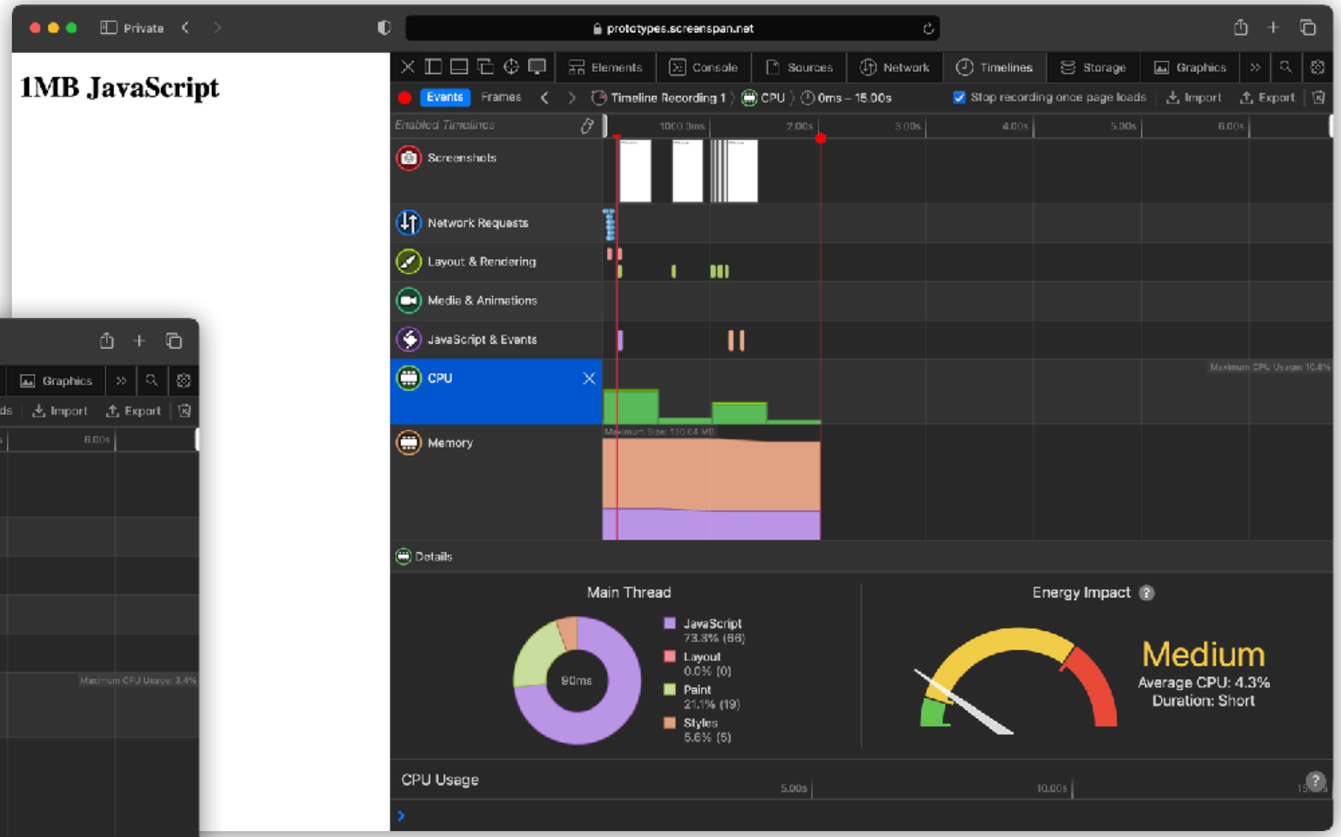


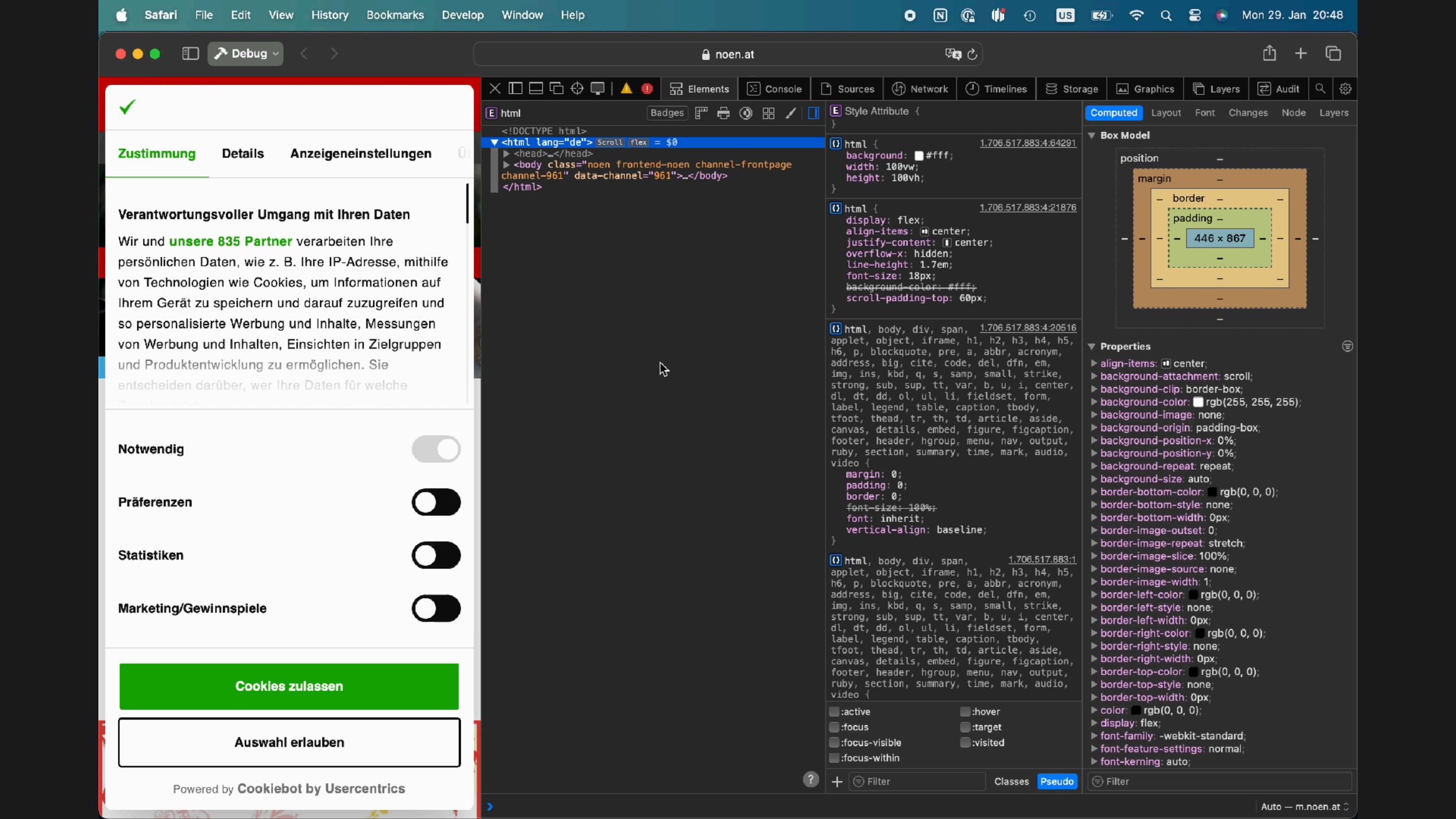
Info: https://profiler.firefox.com/

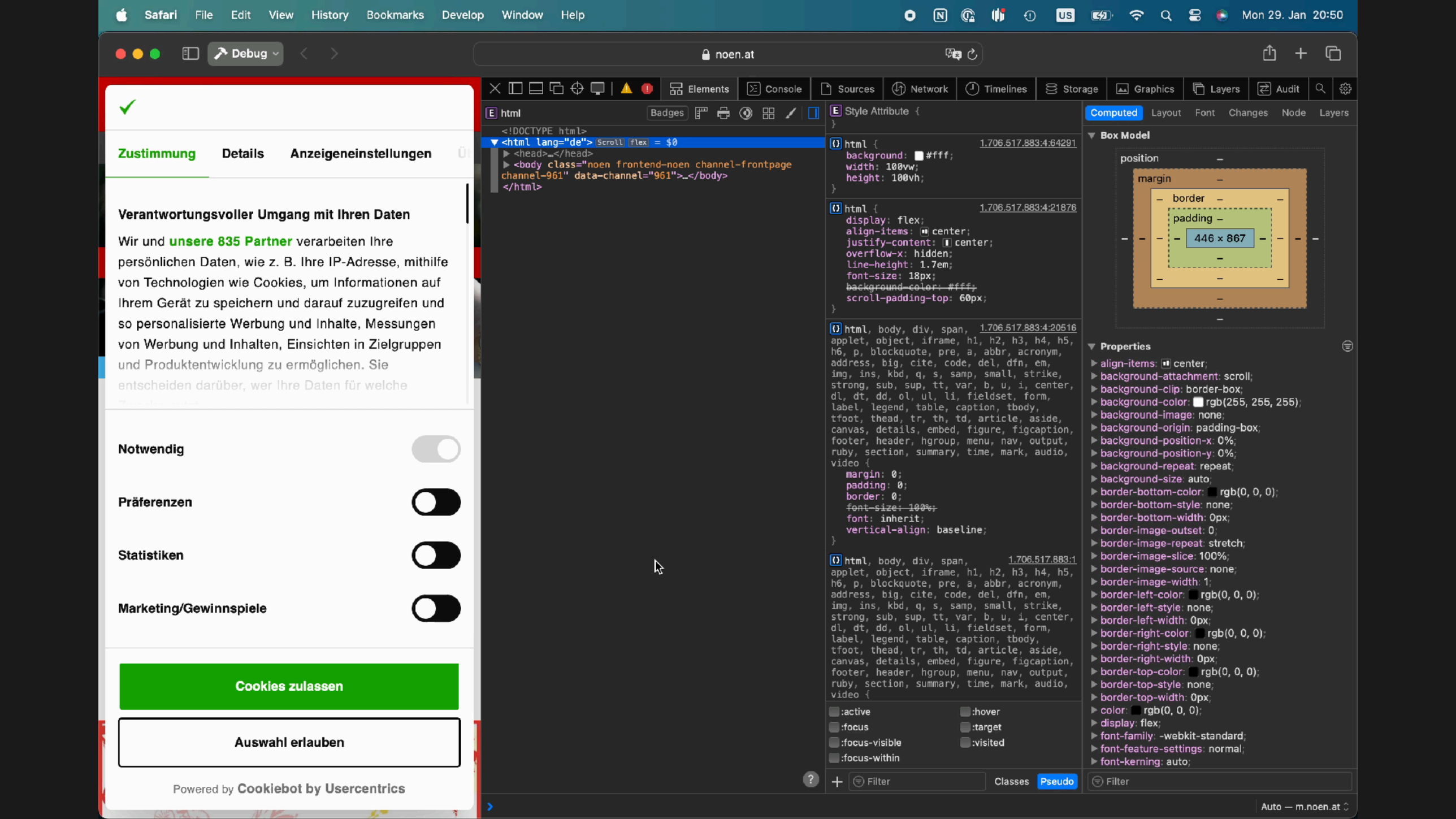

Firefox File Edit View History Bookmarks Tools Window Help
Mon 29. Jan 16:39
Home - YouTube
https://m.youtube.com
Inspector Console Debugger Network Style Editor Performance Memory Storage Accessibility
UA: Mozilla/5.0 (Linux; Android 11; SAMSUNG SM-G973U) Ap
YouTube
All Gaming Music Live
19:32
Man Builds Amazing House on Steep Mountain in 8 Months | Start to Finish...
Quantum Tech HD • 1.9M views • 10 days ago
Shorts
Kobe Bryant made from 10,000 dice. #diceart
136M views
Eine echte Prinzessin bleibt immer treu 🥰...
1.4M views
Home Shorts Library
Search HTML
Filter Styles
Layout Computed Changes
Flexbox
Select a Flex container or item to continue.
Grid
CSS Grid is not in use on this page
Box Model
margin border padding 360×1780.5
360×1780.5 static
Box Model Properties
box-sizing content-box
display block
float none
line-height normal
position static
z-index auto
Inherited from html
html › body

Safari Web Inspector

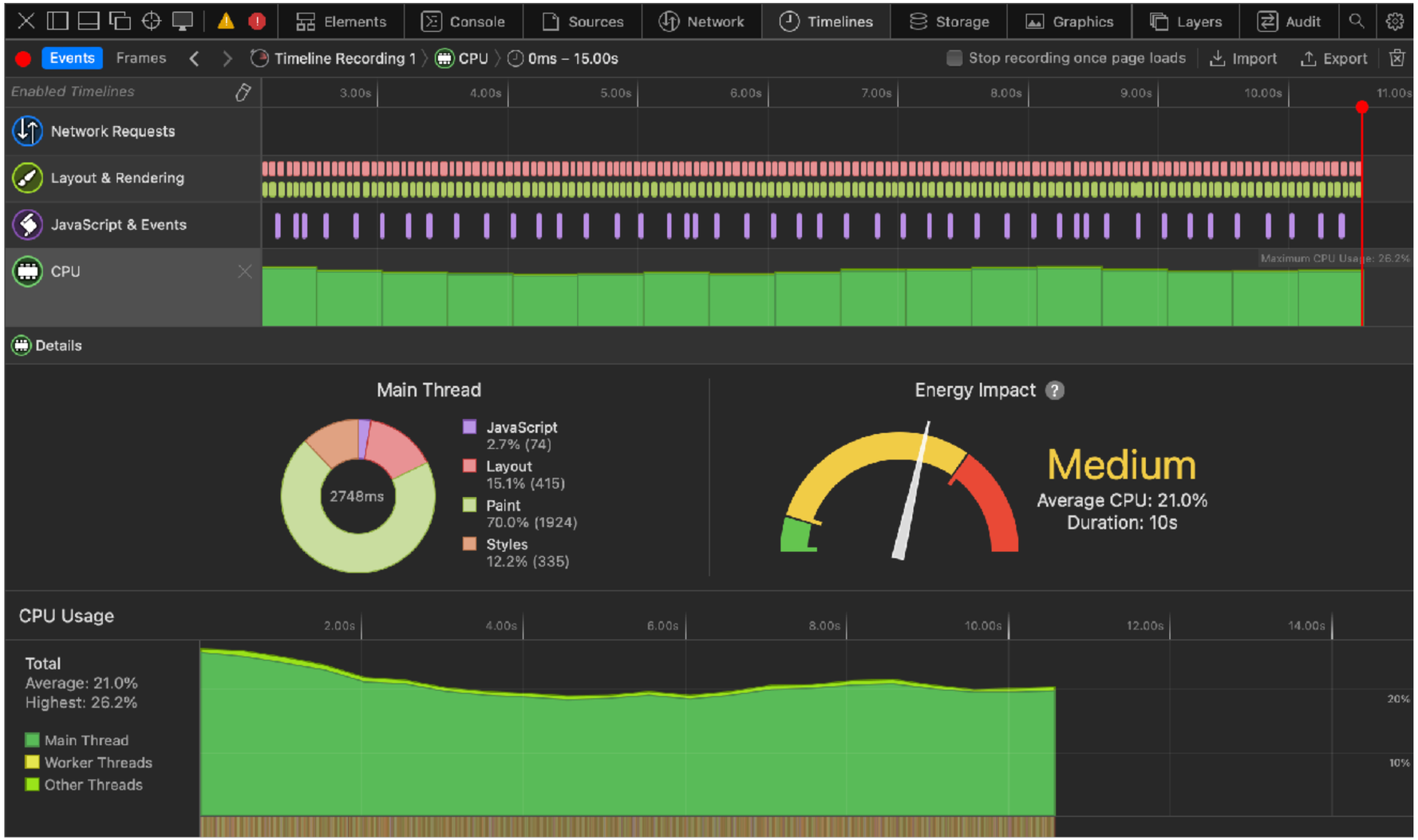




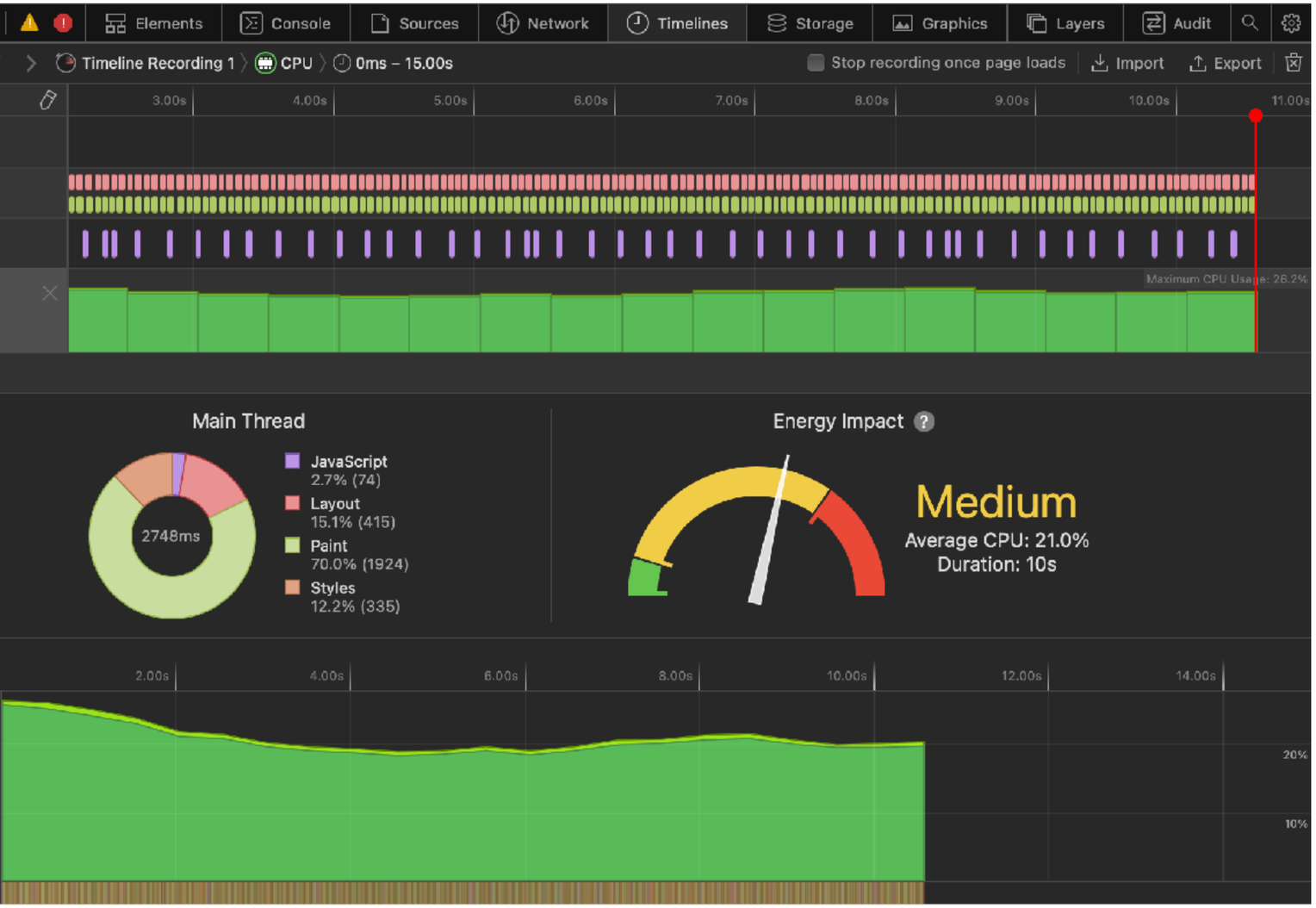

Safari File Edit View History Bookmarks Develop Window Help
Mon 29. Jan 20:48
Debug
noen.at
Elements Console Sources Network Timelines Storage Graphics Layers Audit
Zustimmung Details Anzeigeneinstellungen
Verantwortungsvoller Umgang mit Ihren Daten
Wir und unsere 835 Partner verarbeiten Ihre persönlichen Daten, wie z. B. Ihre IP-Adresse, mithilfe von Technologien wie Cookies, um Informationen auf Ihrem Gerät zu speichern und darauf zuzugreifen und so personalisierte Werbung und Inhalte, Messungen von Werbung und Inhalten, Einsichten in Zielgruppen und Produktentwicklung zu ermöglichen. Sie entscheiden darüber, wer Ihre Daten für welche
Notwendig
Präferenzen
Statistiken
Marketing/Gewinnspiele
Cookies zulassen
Auswahl erlauben
Powered by Cookiebot by Usercentrics
<!DOCTYPE html>
<html lang="de"> Scroll flex = $0
<head>…</head>
<body class="noen frontend-noen channel-frontpage channel-961" data-channel="961">…</body>
</html>
Style Attribute {
html { 1.706.517.883:4:64291
background: #fff;
width: 100vw;
height: 100vh;
html { 1.706.517.883:4:21876
display: flex;
align-items: center;
justify-content: center;
overflow-x: hidden;
line-height: 1.7em;
font-size: 18px;
background-color: #fff;
scroll-padding-top: 60px;
html, body, div, span, 1.706.517.883:4:20516
applet, object, iframe, h1, h2, h3, h4, h5, h6, p, blockquote, pre, a, abbr, acronym, address, big, cite, code, del, dfn, em, img, ins, kbd, q, s, samp, small, strike, strong, sub, sup, tt, var, b, u, i, center, dl, dt, dd, ol, ul, li, fieldset, form, label, legend, table, caption, tbody, tfoot, thead, tr, th, td, article, aside, canvas, details, embed, figure, figcaption, footer, header, hgroup, menu, nav, output, ruby, section, summary, time, mark, audio, video {
margin: 0;
padding: 0;
border: 0;
font-size: 100%;
font: inherit;
vertical-align: baseline;
html, body, div, span, 1.706.517.883:1
applet, object, iframe, h1, h2, h3, h4, h5, h6, p, blockquote, pre, a, abbr, acronym, address, big, cite, code, del, dfn, em, img, ins, kbd, q, s, samp, small, strike, strong, sub, sup, tt, var, b, u, i, center, dl, dt, dd, ol, ul, li, fieldset, form, label, legend, table, caption, tbody, tfoot, thead, tr, th, td, article, aside, canvas, details, embed, figure, figcaption, footer, header, hgroup, menu, nav, output, ruby, section, summary, time, mark, audio, video {
:active :hover
:focus :target
:focus-visible :visited
:focus-within
Filter Classes Pseudo
Computed Layout Font Changes Node Layers
Box Model
position
margin
border
padding
446 × 867
Properties
align-items: center;
background-attachment: scroll;
background-clip: border-box;
background-color: rgb(255, 255, 255);
background-image: none;
background-origin: padding-box;
background-position-x: 0%;
background-position-y: 0%;
background-repeat: repeat;
background-size: auto;
border-bottom-color: rgb(0, 0, 0);
border-bottom-style: none;
border-bottom-width: 0px;
border-image-outset: 0;
border-image-repeat: stretch;
border-image-slice: 100%;
border-image-source: none;
border-image-width: 1;
border-left-color: rgb(0, 0, 0);
border-left-style: none;
border-left-width: 0px;
border-right-color: rgb(0, 0, 0);
border-right-style: none;
border-right-width: 0px;
border-top-color: rgb(0, 0, 0);
border-top-style: none;
border-top-width: 0px;
color: rgb(0, 0, 0);
display: flex;
font-family: -webkit-standard;
font-feature-settings: normal;
font-kerning: auto;
Filter
Auto — m.noen.at


Safari File Edit View History Bookmarks Develop Window Help
Mon 29. Jan 20:50
Debug
noen.at
Elements Console Sources Network Timelines Storage Graphics Layers Audit
Zustimmung Details Anzeigeneinstellungen
Verantwortungsvoller Umgang mit Ihren Daten
Wir und unsere 835 Partner verarbeiten Ihre persönlichen Daten, wie z. B. Ihre IP-Adresse, mithilfe von Technologien wie Cookies, um Informationen auf Ihrem Gerät zu speichern und darauf zuzugreifen und so personalisierte Werbung und Inhalte, Messungen von Werbung und Inhalten, Einsichten in Zielgruppen und Produktentwicklung zu ermöglichen. Sie entscheiden darüber, wer Ihre Daten für welche
Notwendig
Präferenzen
Statistiken
Marketing/Gewinnspiele
Cookies zulassen
Auswahl erlauben
Powered by Cookiebot by Usercentrics
<!DOCTYPE html>
<html lang="de"> Scroll flex = $0
<head>…</head>
<body class="noen frontend-noen channel-frontpage channel-961" data-channel="961">…</body>
</html>
Style Attribute
html { 1.706.517.883:4:64291
background: #fff;
width: 100vw;
height: 100vh;
html { 1.706.517.883:4:21876
display: flex;
align-items: center;
justify-content: center;
overflow-x: hidden;
line-height: 1.7em;
font-size: 18px;
background-color: #fff;
scroll-padding-top: 60px;
html, body, div, span, 1.706.517.883:4:20516
applet, object, iframe, h1, h2, h3, h4, h5, h6, p, blockquote, pre, a, abbr, acronym, address, big, cite, code, del, dfn, em, img, ins, kbd, q, s, samp, small, strike, strong, sub, sup, tt, var, b, u, i, center, dl, dt, dd, ol, ul, li, fieldset, form, label, legend, table, caption, tbody, tfoot, thead, tr, th, td, article, aside, canvas, details, embed, figure, figcaption, footer, header, hgroup, menu, nav, output, ruby, section, summary, time, mark, audio, video {
margin: 0;
padding: 0;
border: 0;
font-size: 100%;
font: inherit;
vertical-align: baseline;
html, body, div, span, 1.706.517.883:1
applet, object, iframe, h1, h2, h3, h4, h5, h6, p, blockquote, pre, a, abbr, acronym, address, big, cite, code, del, dfn, em, img, ins, kbd, q, s, samp, small, strike, strong, sub, sup, tt, var, b, u, i, center, dl, dt, dd, ol, ul, li, fieldset, form, label, legend, table, caption, tbody, tfoot, thead, tr, th, td, article, aside, canvas, details, embed, figure, figcaption, footer, header, hgroup, menu, nav, output, ruby, section, summary, time, mark, audio, video {
:active :hover
:focus :target
:focus-visible :visited
:focus-within
Filter Classes Pseudo
Computed Layout Font Changes Node Layers
Box Model
position
margin
border
padding
446 × 867
Properties
align-items: center;
background-attachment: scroll;
background-clip: border-box;
background-color: rgb(255, 255, 255);
background-image: none;
background-origin: padding-box;
background-position-x: 0%;
background-position-y: 0%;
background-repeat: repeat;
background-size: auto;
border-bottom-color: rgb(0, 0, 0);
border-bottom-style: none;
border-bottom-width: 0px;
border-image-outset: 0;
border-image-repeat: stretch;
border-image-slice: 100%;
border-image-source: none;
border-image-width: 1;
border-left-color: rgb(0, 0, 0);
border-left-style: none;
border-left-width: 0px;
border-right-color: rgb(0, 0, 0);
border-right-style: none;
border-right-width: 0px;
border-top-color: rgb(0, 0, 0);
border-top-style: none;
border-top-width: 0px;
color: rgb(0, 0, 0);
display: flex;
font-family: -webkit-standard;
font-feature-settings: normal;
font-kerning: auto;
Filter
Auto — m.noen.at

Watch out for infinite animations!



Watch out for infinite animations!

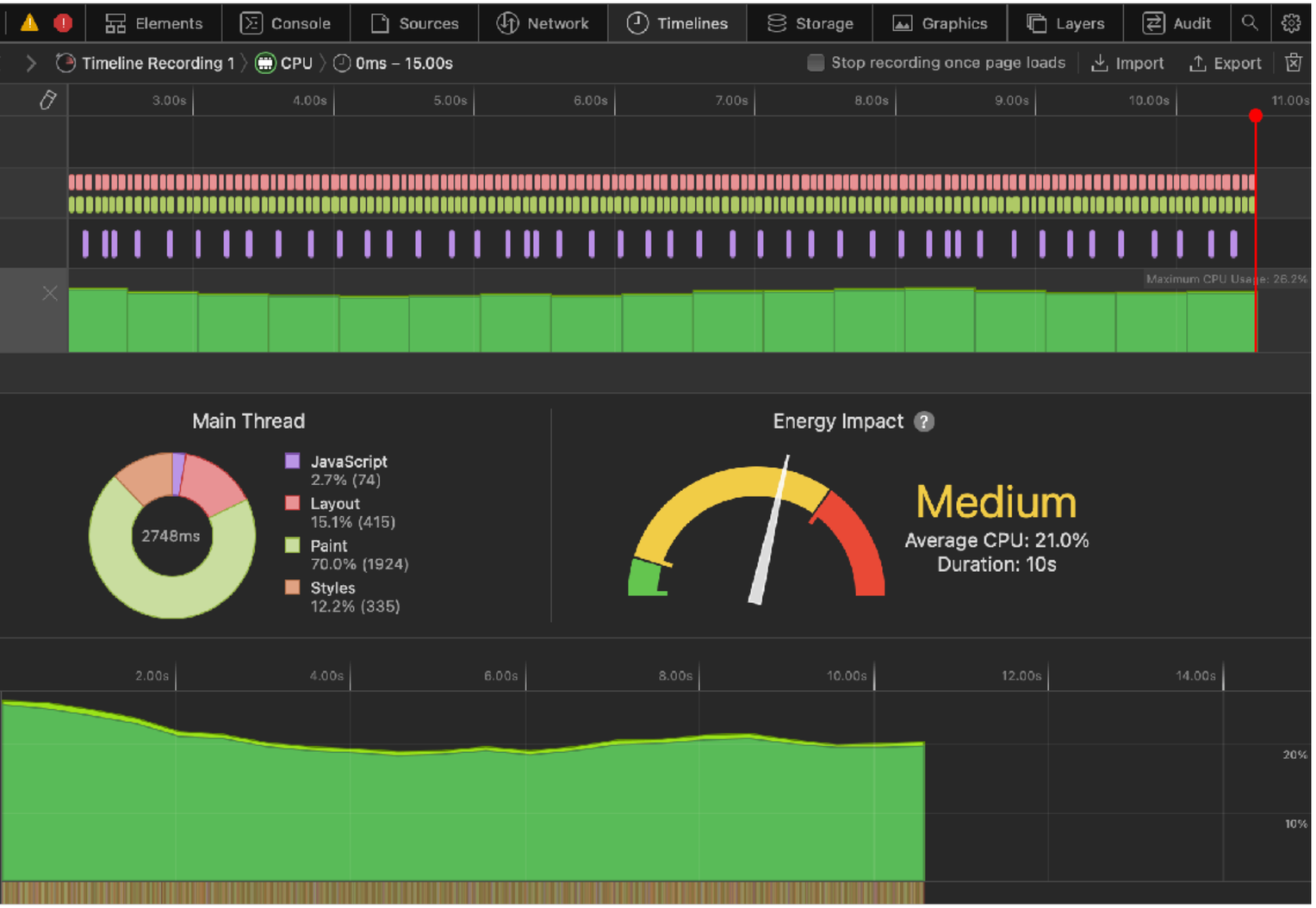


Pseudo-Element ::after

product-grid.css:736

```
.product-grid-slider
.preloader:after {
  animation: shine 2s linear infinite;
  background: linear-
  gradient(110deg,#eaeaea 8%,#f5f5f5
  18%,#eaeaea 33%);
  background-size: 300% 100%;
  content: "";
  display: block;
  height: 100%;
  left: 0;
  position: absolute;
  top: 0;
  width: 100%;
}
```

Watch out for infinite animations!



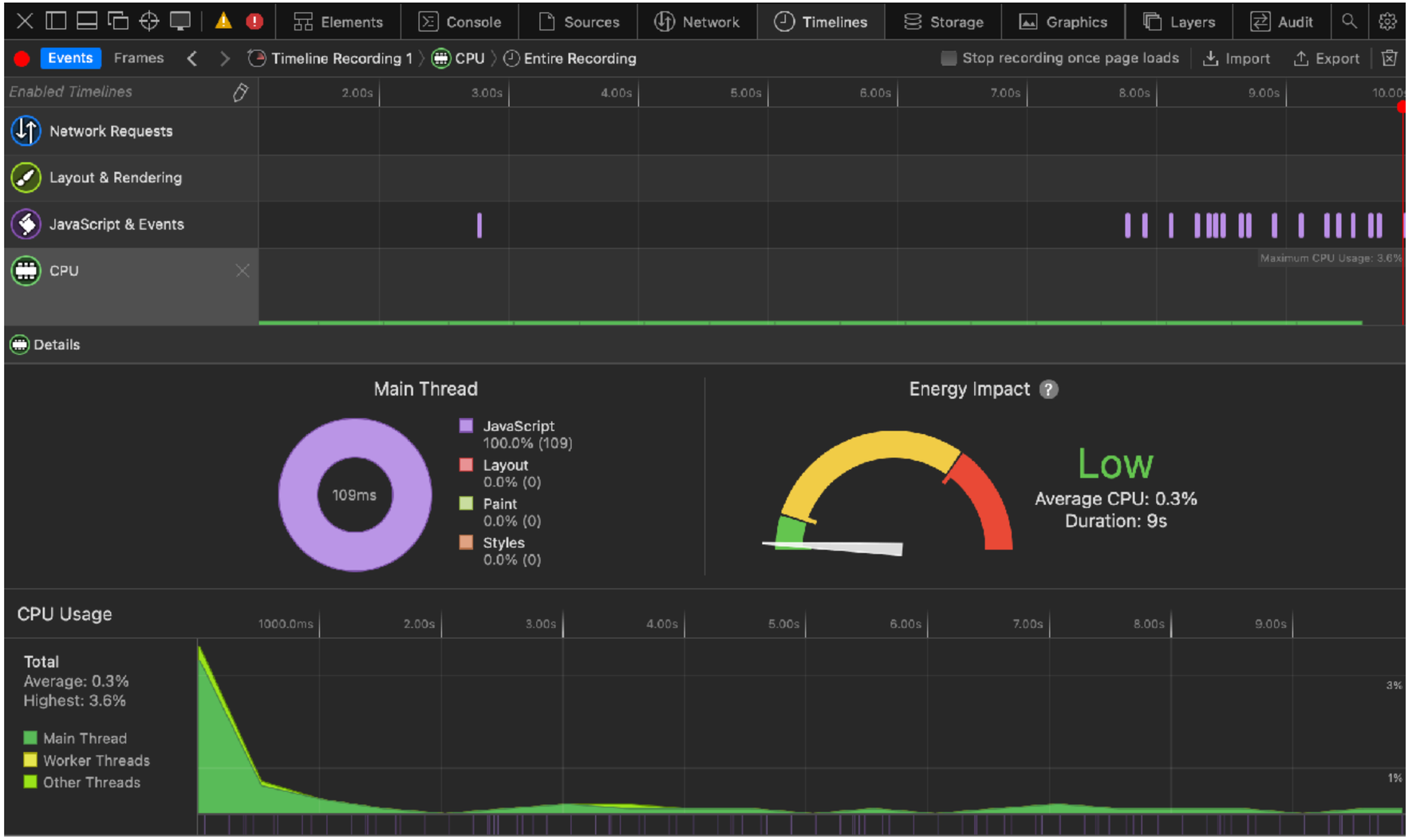
Pseudo-Element ::after

.product-grid-slider .preloader:after { product-grid.css:736

```
/* animation: shine 2s linear infinite;
*/
background: linear-gradient(110deg,#eaeaea 8%,#f5f5f5 18%,#eaeaea 33%);
background-size: 300% 100%;
content: "";
display: block;
height: 100%;
left: 0;
position: absolute;
top: 0;
width: 100%;
}
```

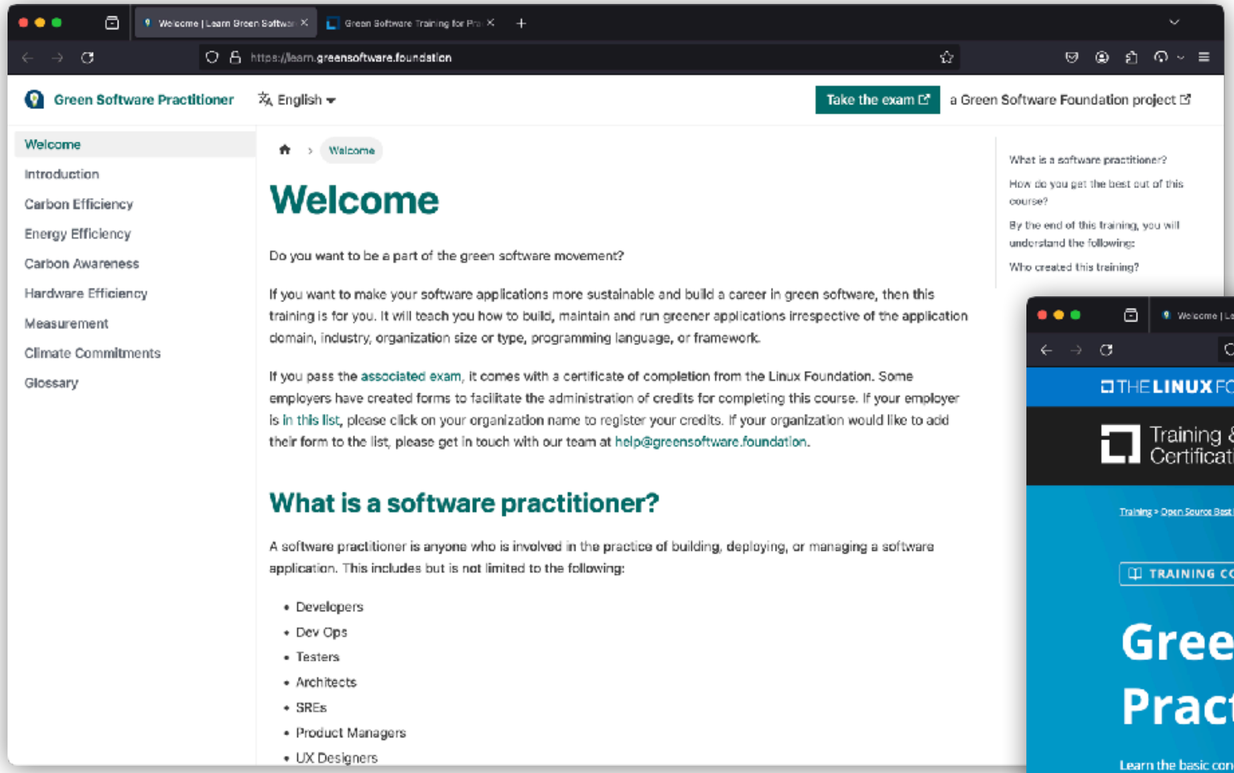
Watch out for infinite animations!

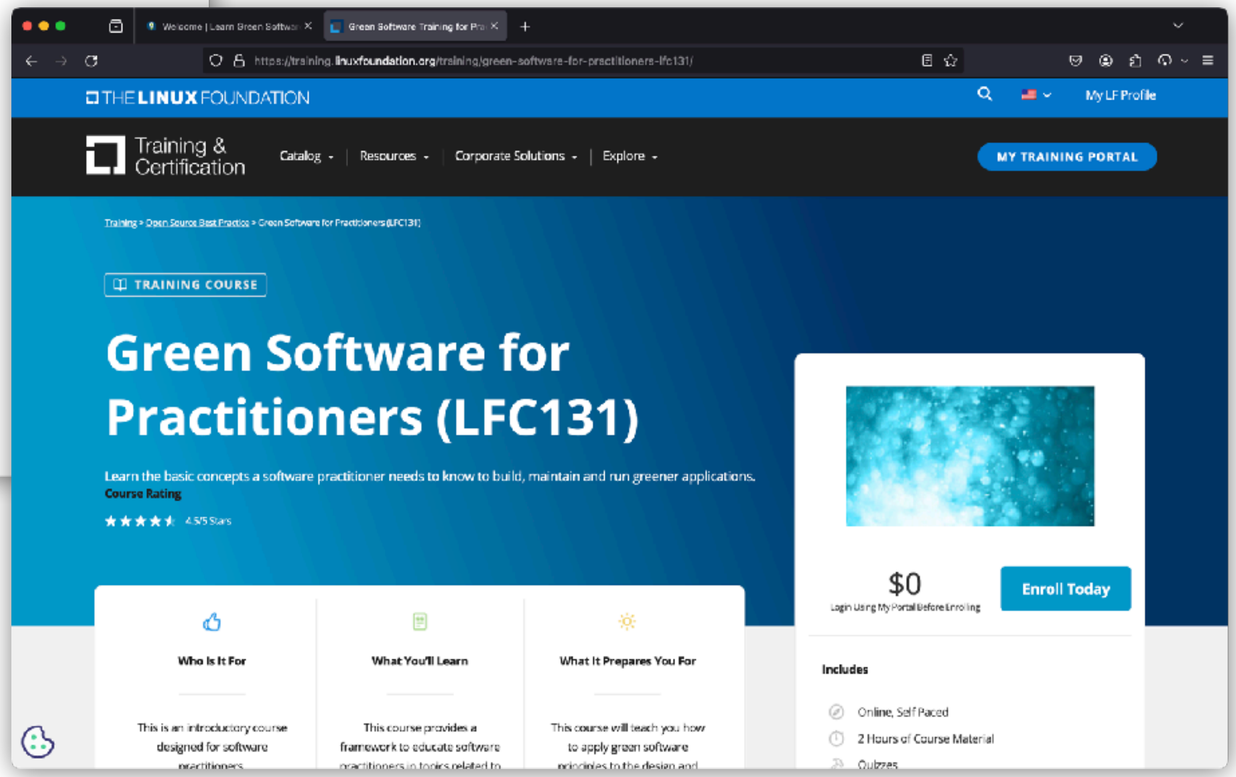
```
lement ::after
uct-grid-slider          product-grid.css:736
er:after {
imation: shine 2s linear infinite;

round: linear-
ent(110deg,#eaeaea 8%,#f5f5f5
eaeaea 33%);
round-size: 300% 100%;
nt: "";
ay: block;
t: 100%;
 0;
ion: absolute;
0;
: 100%;
```



Where to go from here?

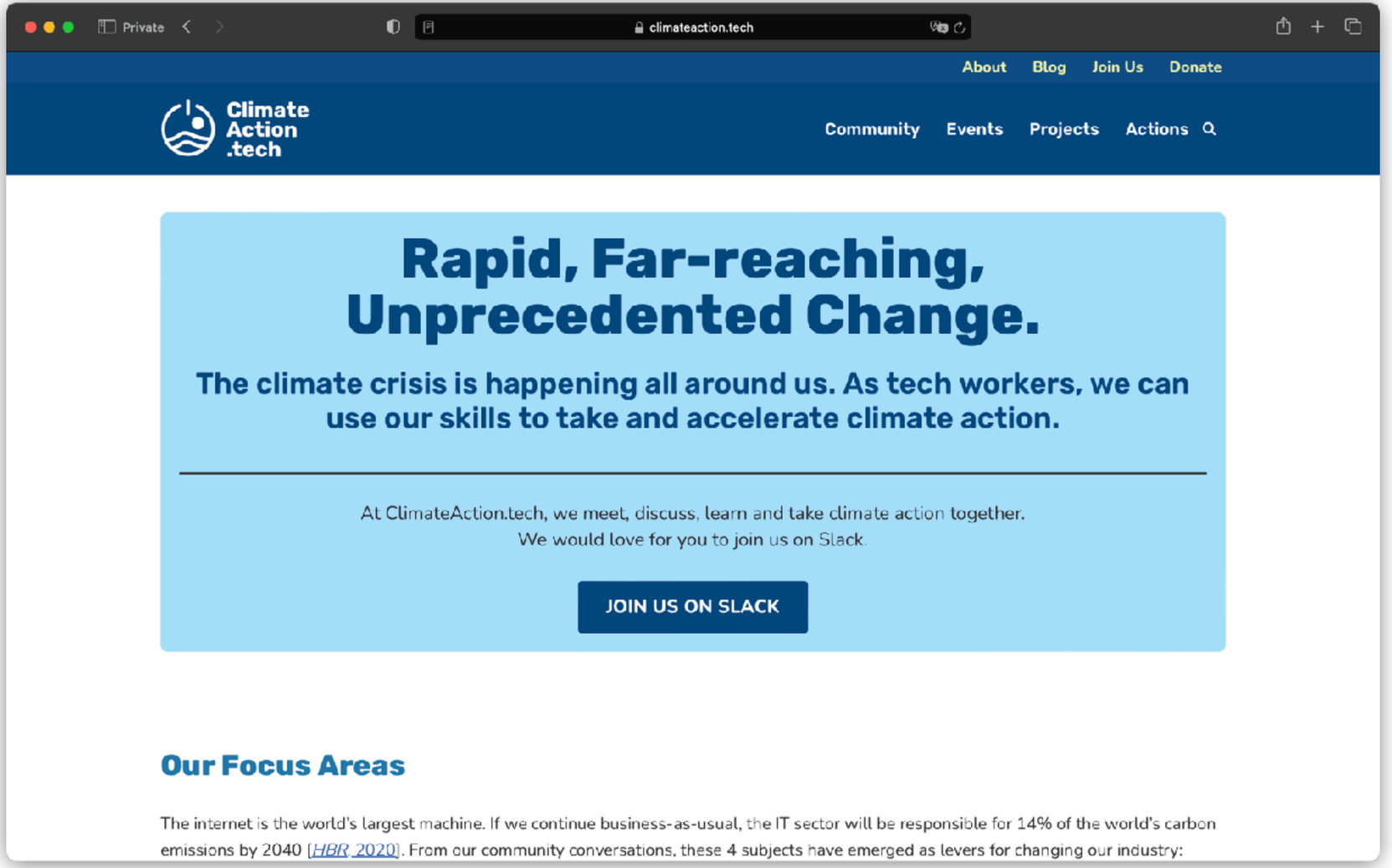
Online Training





Green Software Practitioner courses by the Green Software Foundation and The Linux Foundation

Online Community



Source: climateaction.tech

Podcasts

Environment Variables podcast; Green IO podcast

Follow on Social

SUSTAINABLE DIGITAL INFRASTRUCTURE ALLIANCE

Green Software Foundation

GREEN WEB FOUNDATION

Sustainable Digital Infrastructure Alliance; Green Software Foundation; The Green Web Foundation

Let’s wrap it up…

Key Points

AWARENESS

ICT has an environmental cost

Software enables savings in other sectors, but it needs to do so sustainably

Talk to others about digital sustainability

BUILD SUSTAINABLY

Only build what's needed and delete what's no longer needed

Use green hosts & cloud

Ship less code, cache, compress, minify

Focus on performance and accessibility

Lazy-load and use façades for what's not immediately needed

Optimize media and images

Rely on HTML standards instead of JavaScript frameworks and libraries

MEASURE

Establish performance budgets

Measure and monitor performance

Try out the Impact Framework

OPTIMIZE

Debug memory leaks, JavaScript performance and excessive rendering work and animations

Thanks!

Notes, Links, Slides:

screenspan.net/talks/digital-sustainability/