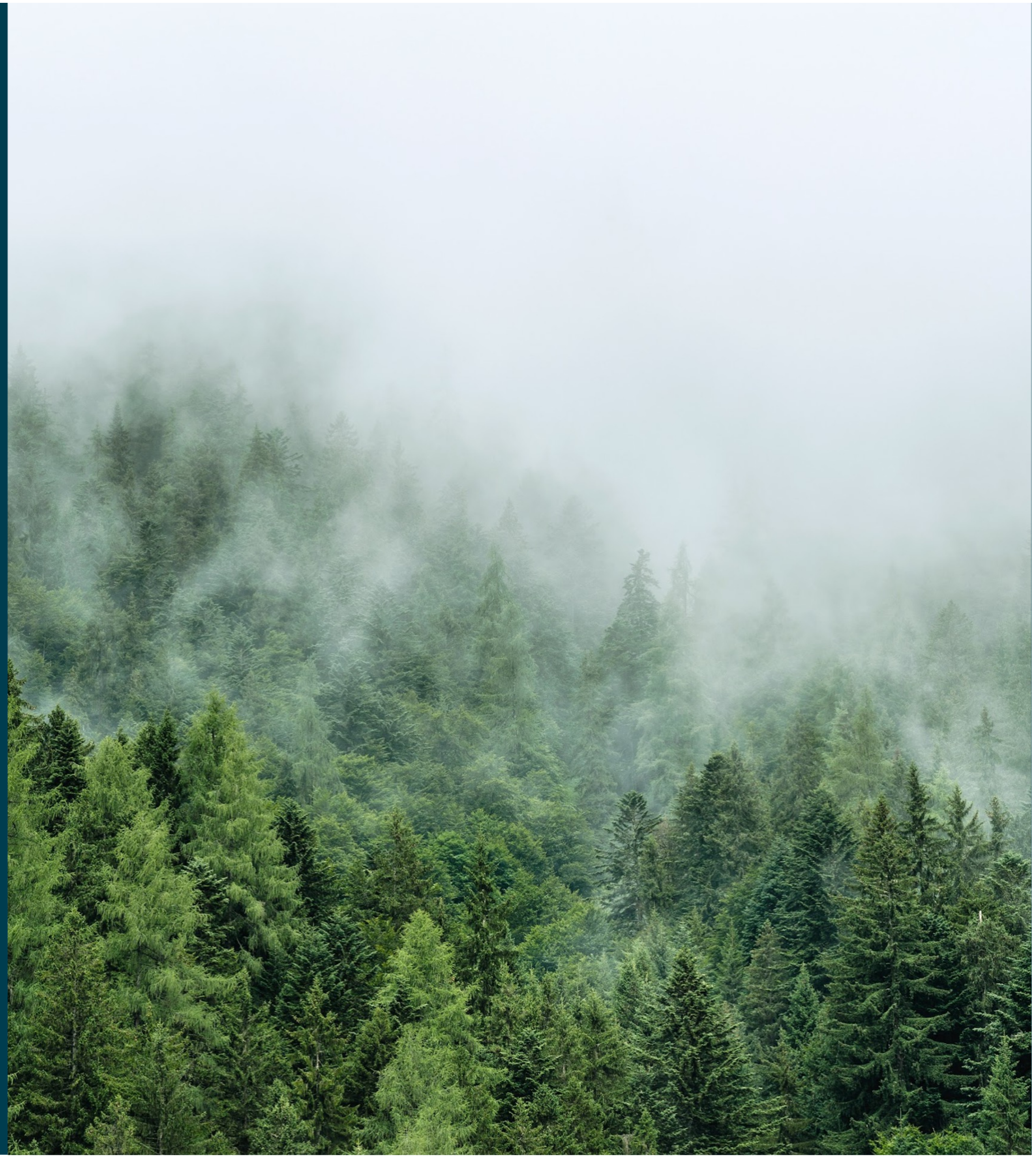
Green Cloud :
A step towards a Sustainable Future

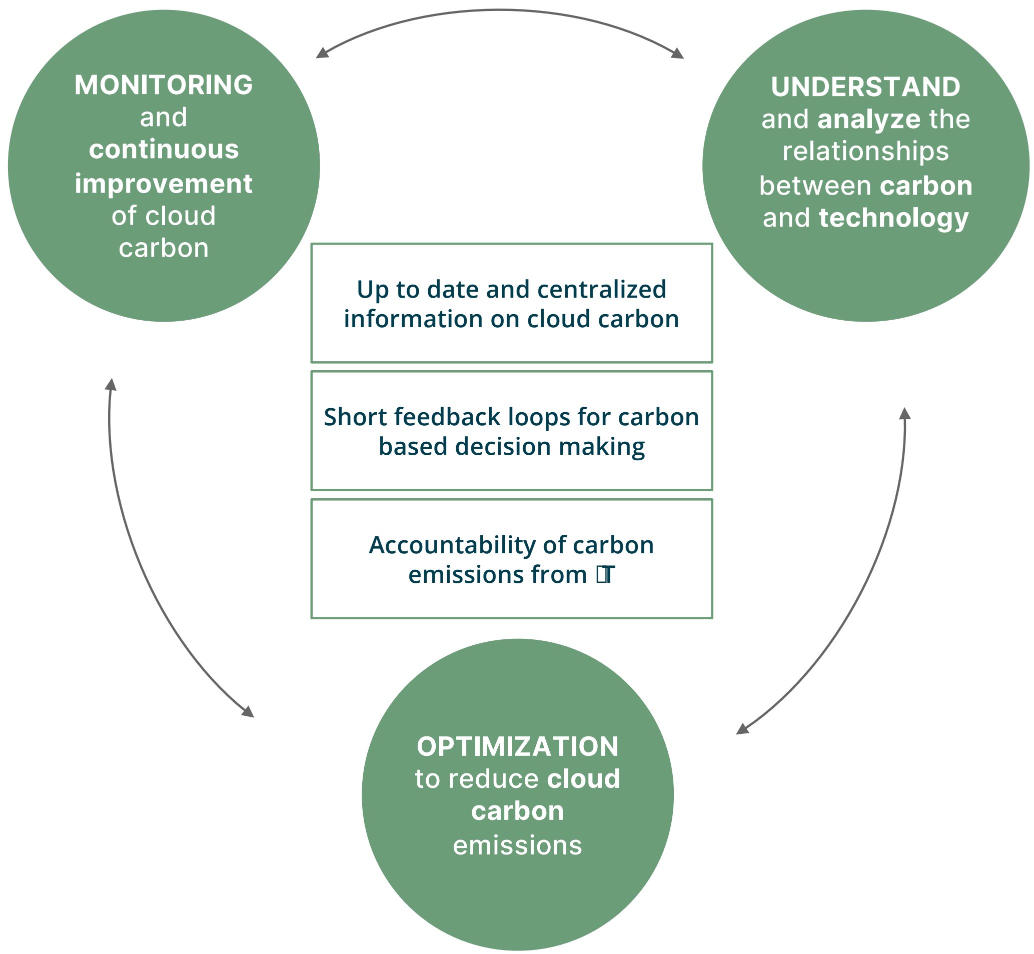
Sudhanshu Garg
Thoughtworks Deutschland



Sustainability of IT through GreenOps

Mindset, Metrics and Management

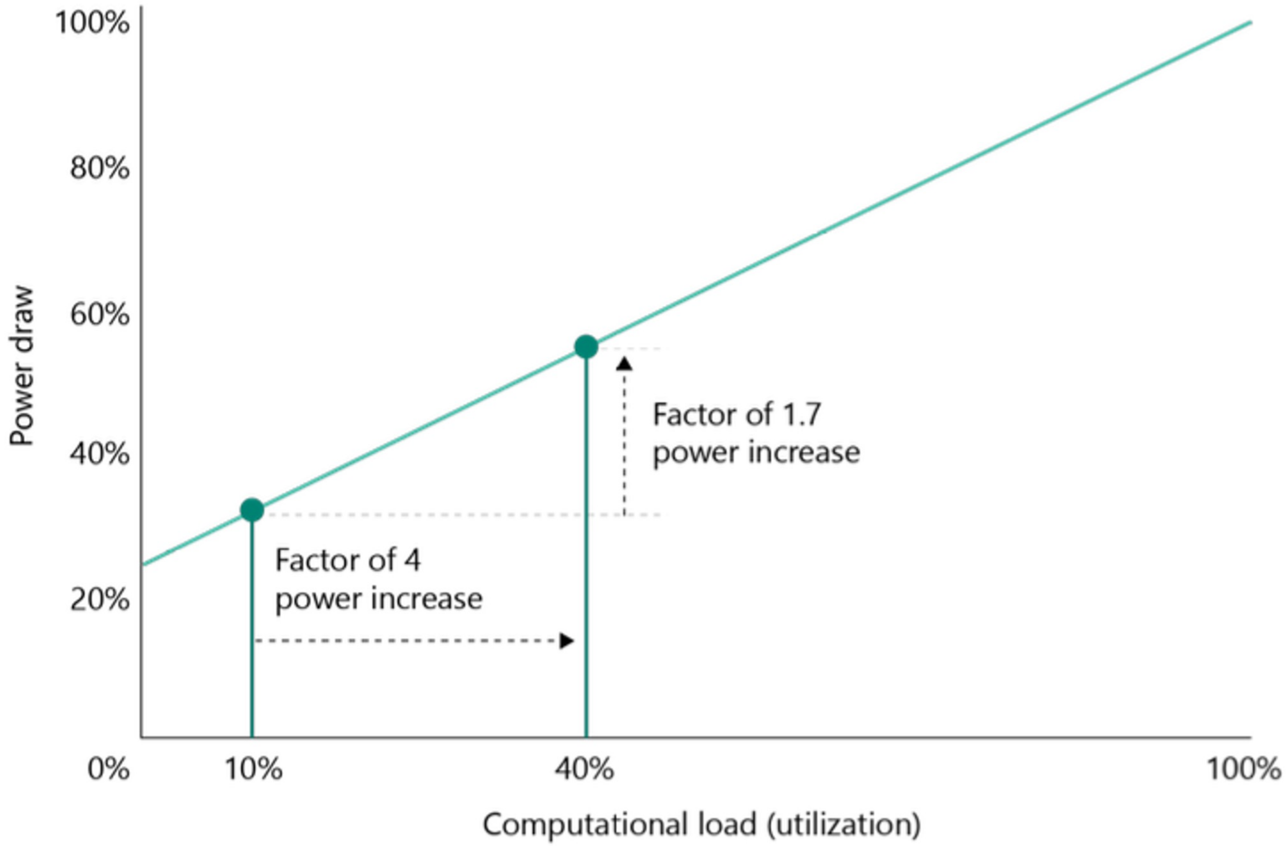
GreenOps is a **data-driven discipline** and **cultural practice** that enables optimization of the cloud for carbon intensity.



Advantages & Pillars of Green Cloud

Elastic Usage

Energy proportionality



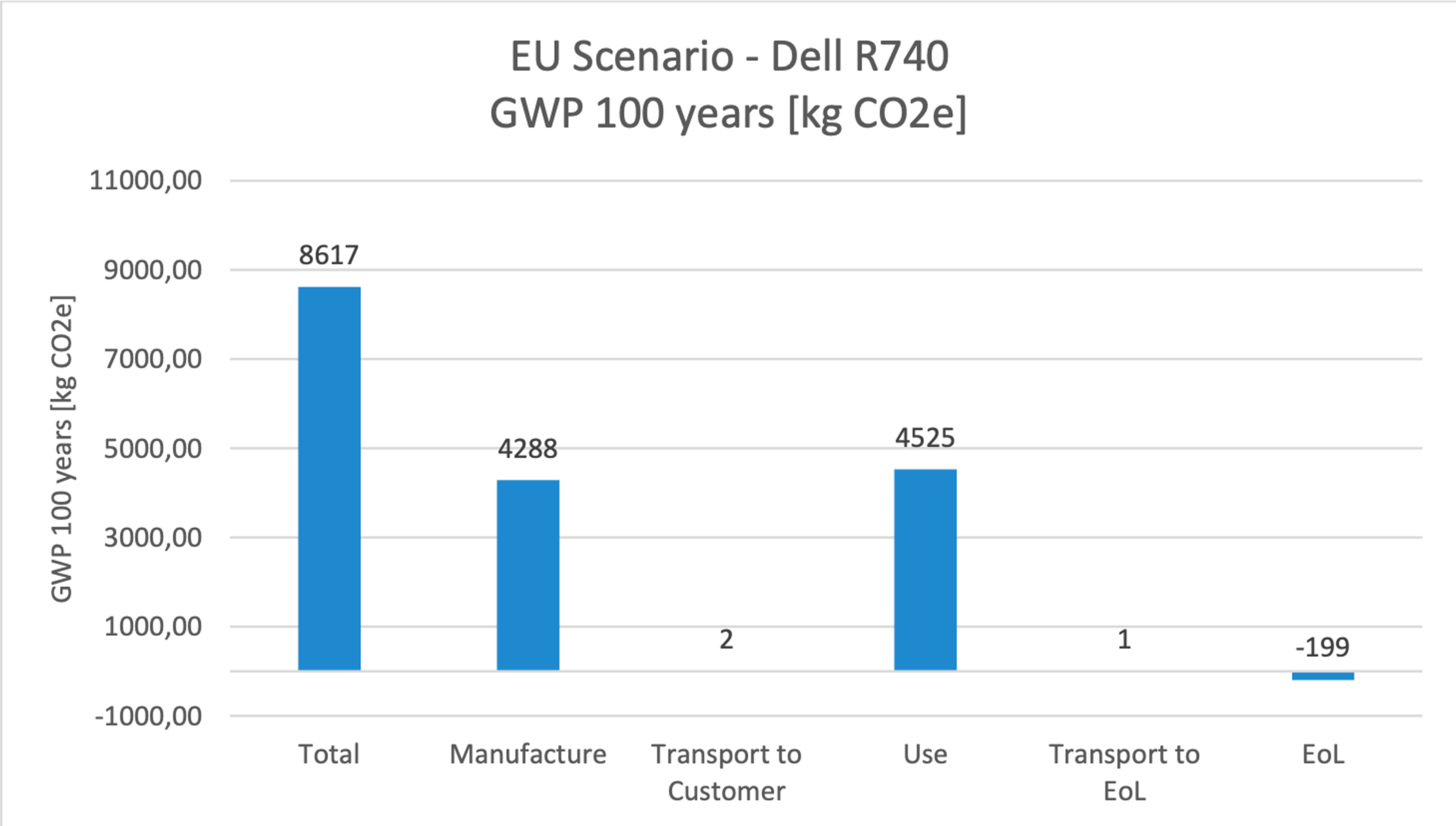
The carbon benefits of cloud computing. Microsoft study. Updated 2020.

Carbon Efficiency - Greenhouse gases (GHG)

CO2e

(carbon dioxide equivalent)

Lifecycle CO_2e Emissions



Life Cycle Assessment – Dell R740. thinkstep

Increasing the utilization

Fewer servers with higher utilisation reduce the amount of embodied carbon.

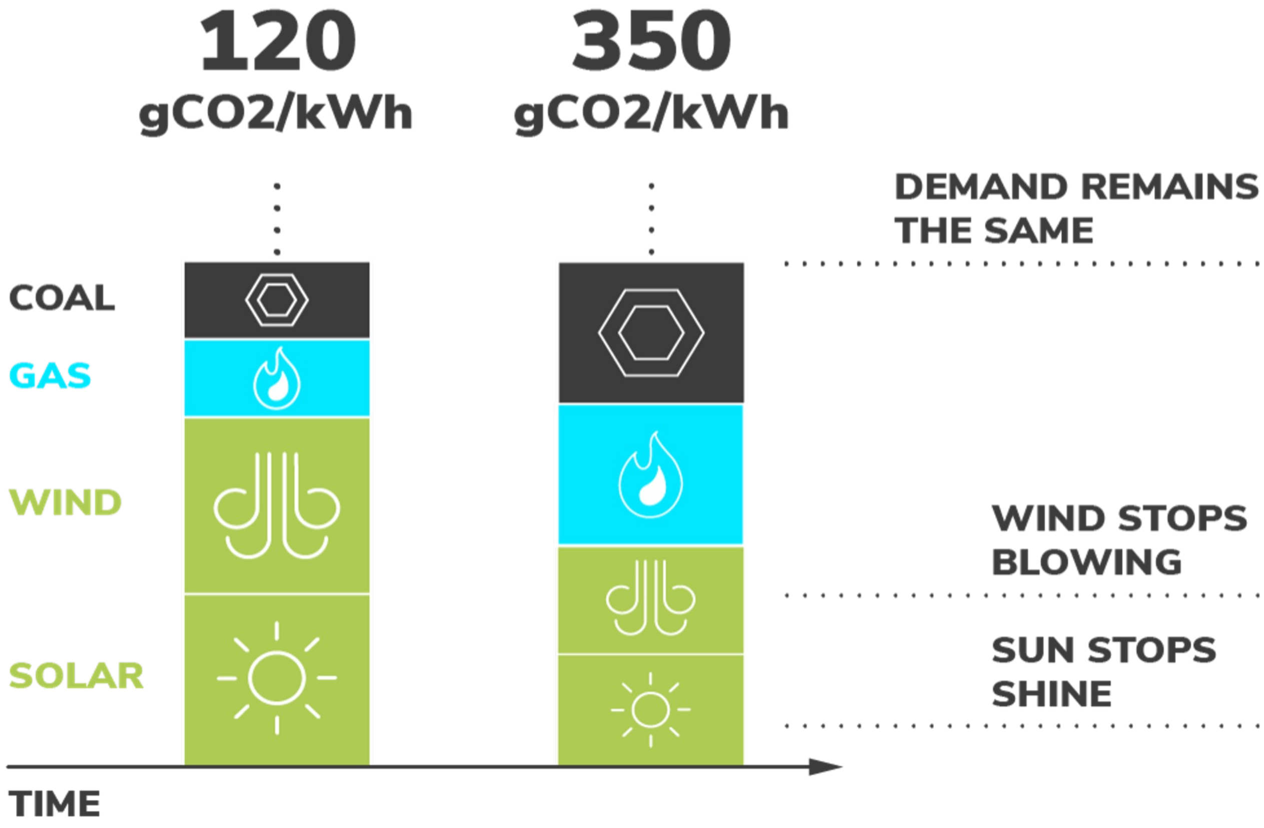
Advantages & Pillars of Green Cloud

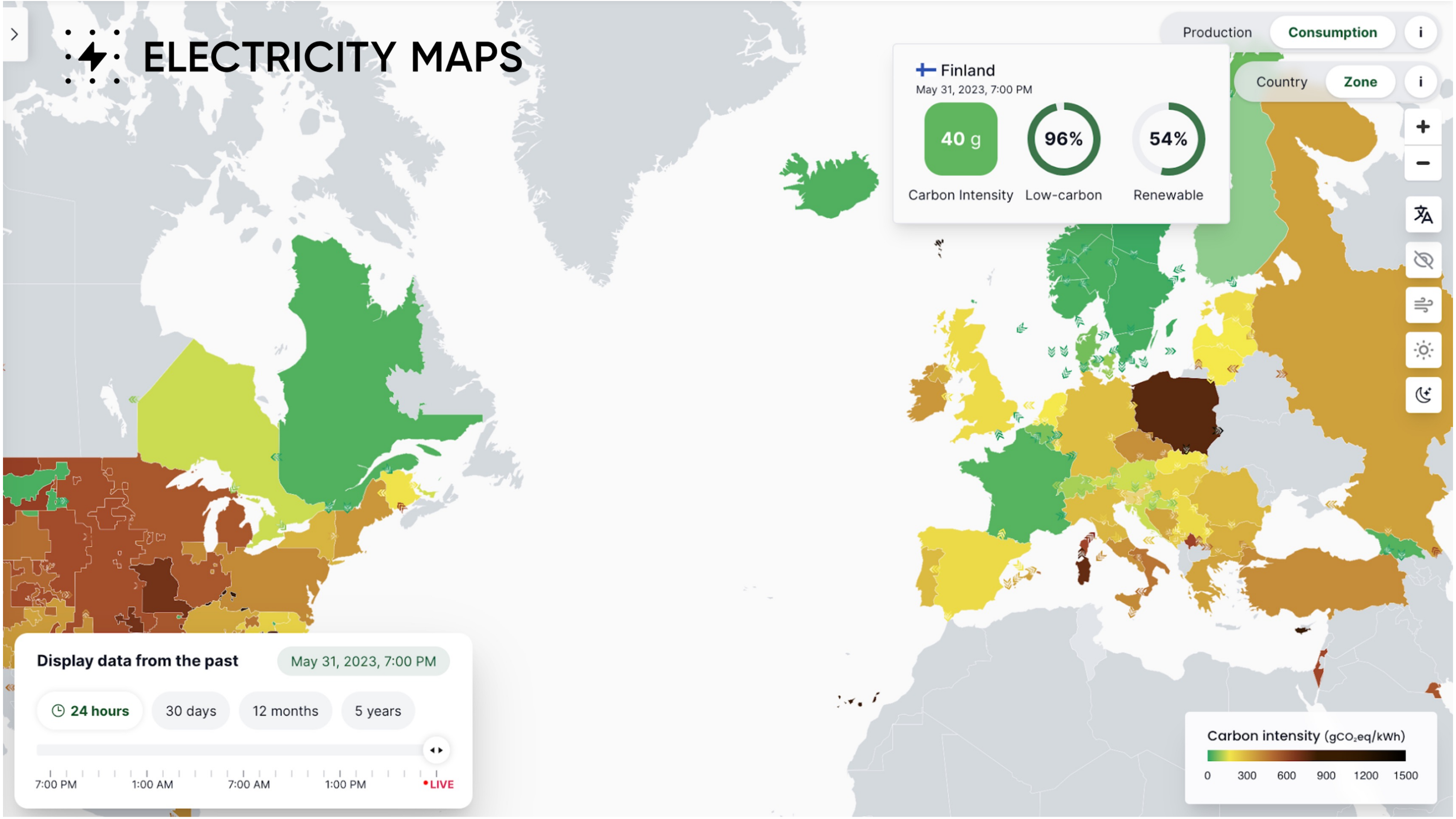
Elastic Usage	Workload Shifting	

Carbon Awareness - How clean or dirty is electricity?

gCO2e/kWh

Varies by time & location



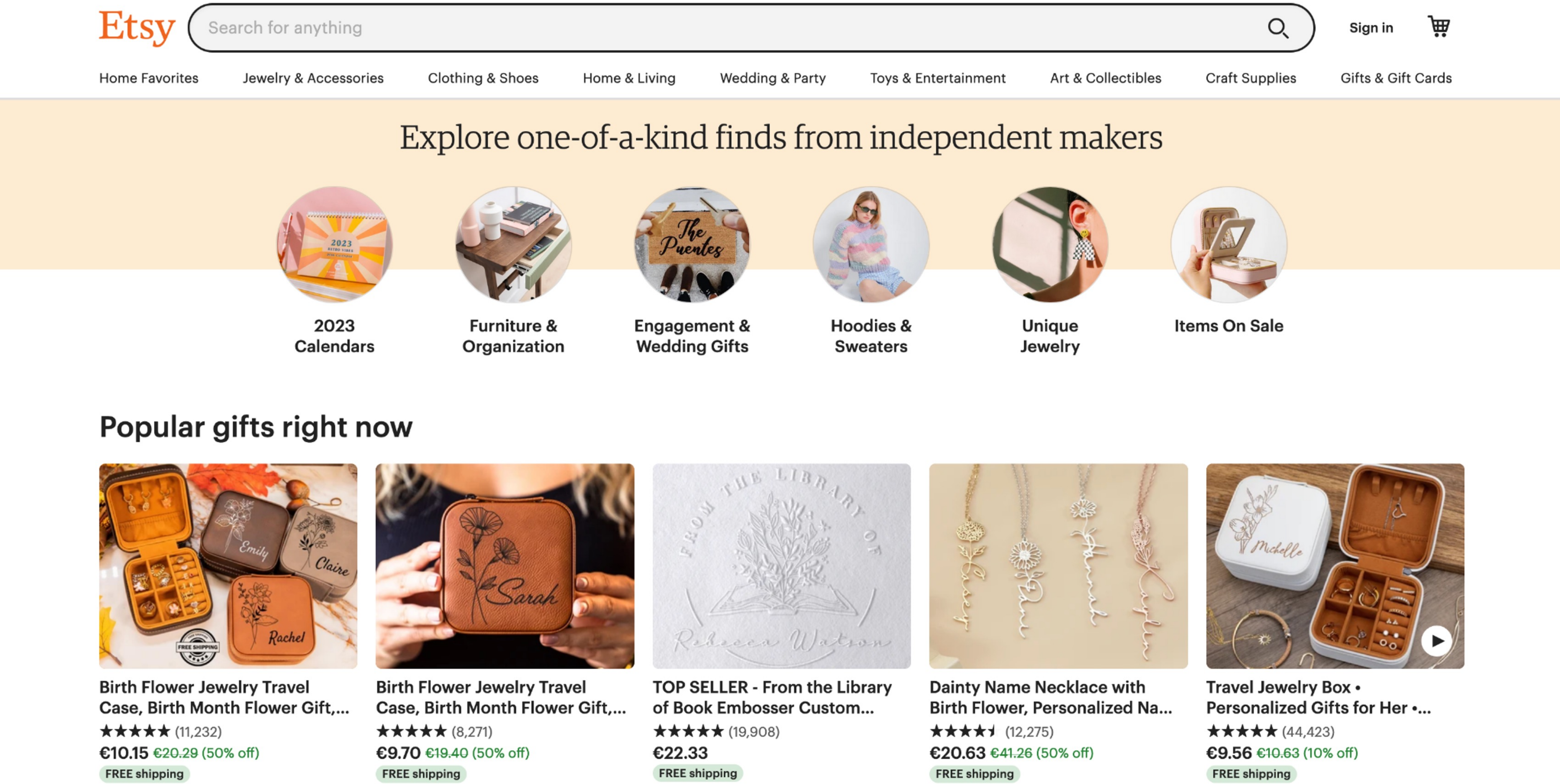

ELECTRICITY MAPS
Production
Consumption
i
Finland
May 31, 2023, 7:00 PM
40 g
Carbon Intensity
96%
Low-carbon
54%
Renewable
Country
Zone
i
Display data from the past
May 31, 2023, 7:00 PM
24 hours
30 days
12 months
5 years
7:00 PM
1:00 AM
7:00 AM
1:00 PM
LIVE
Carbon intensity (gCO₂eq/kWh)
0
300
600
900
1200
1500

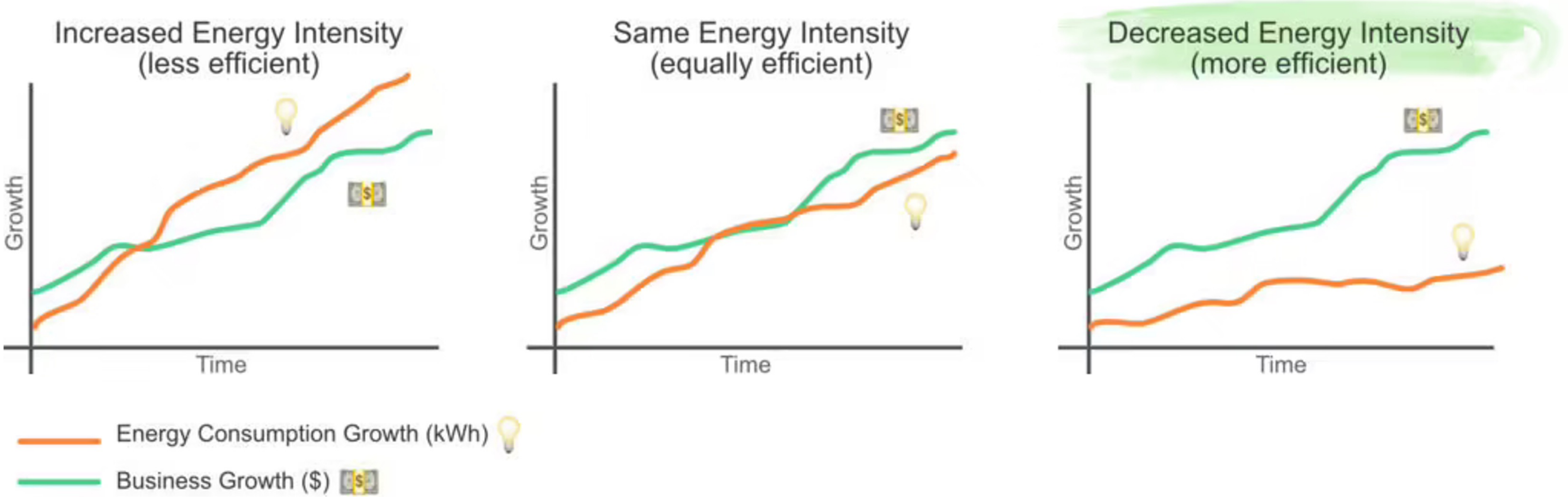
Advantages & Pillars of Green Cloud

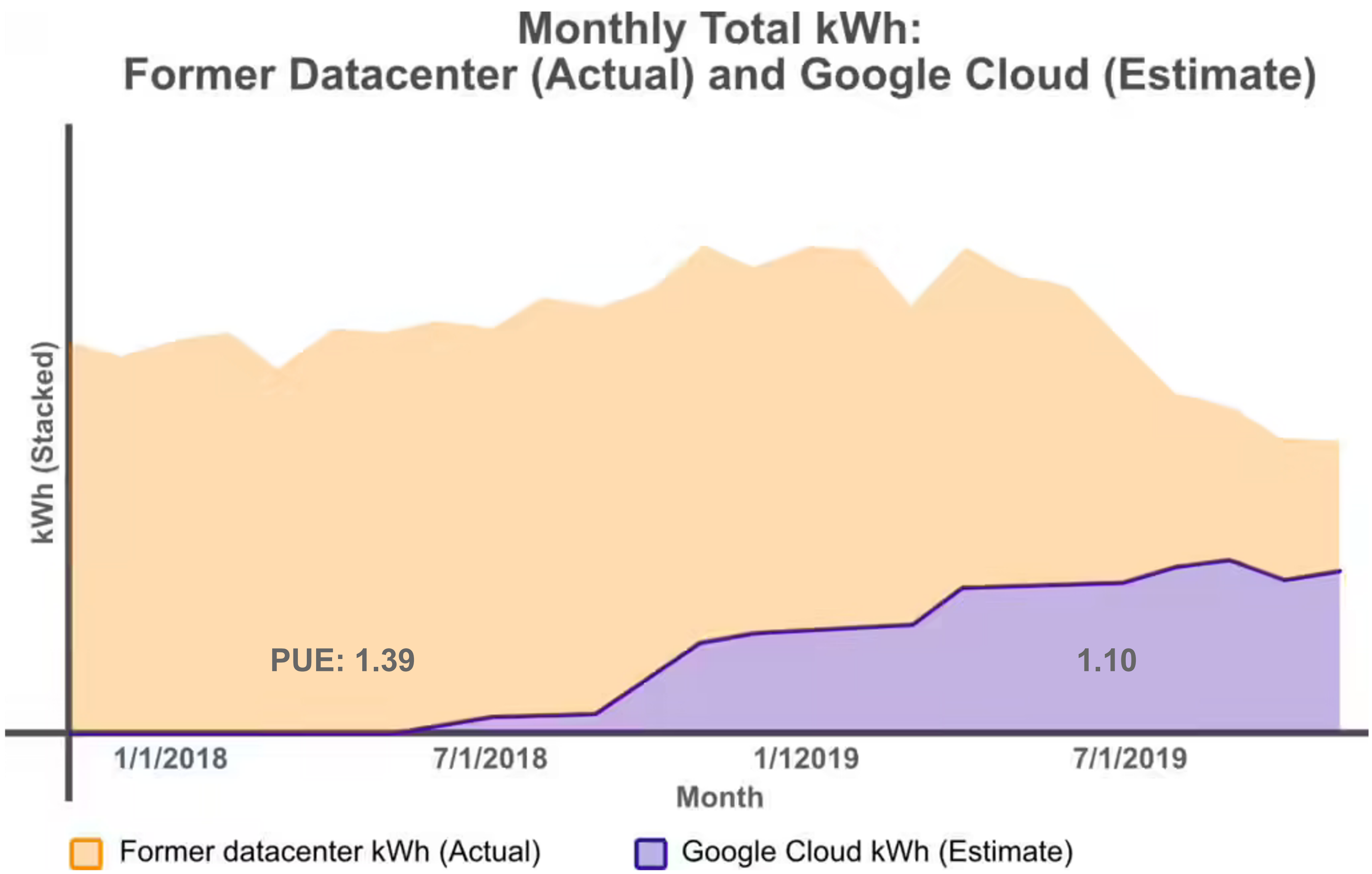
Elastic Usage	Workload Shifting	Efficiency of Data-centres

Power Usage Effectiveness (PUE)

Cloud Carbon Footprint (CCF)


Etsy
Search for anything
Sign in
Home Favorites
Jewelry & Accessories
Clothing & Shoes
Home & Living
Wedding & Party
Toys & Entertainment
Art & Collectibles
Craft Supplies
Gifts & Gift Cards
Explore one-of-a-kind finds from independent makers
2023 Calendars
Furniture & Organization
Engagement & Wedding Gifts
Hoodies & Sweaters
Unique Jewelry
Items On Sale
Popular gifts right now
Birth Flower Jewelry Travel Case, Birth Month Flower Gift,...
★★★★★ (11,232)
€10.15 €20.29 (50% off)
FREE shipping
Birth Flower Jewelry Travel Case, Birth Month Flower Gift,...
★★★★★ (8,271)
€9.70 €19.40 (50% off)
FREE shipping
TOP SELLER - From the Library of Book Embosser Custom...
★★★★★ (19,908)
€22.33
FREE shipping
Dainty Name Necklace with Birth Flower, Personalized Na...
★★★★½ (12,275)
€20.63 €41.26 (50% off)
FREE shipping
Travel Jewelry Box • Personalized Gifts for Her •...
★★★★★ (44,423)
€9.56 €10.63 (10% off)
FREE shipping

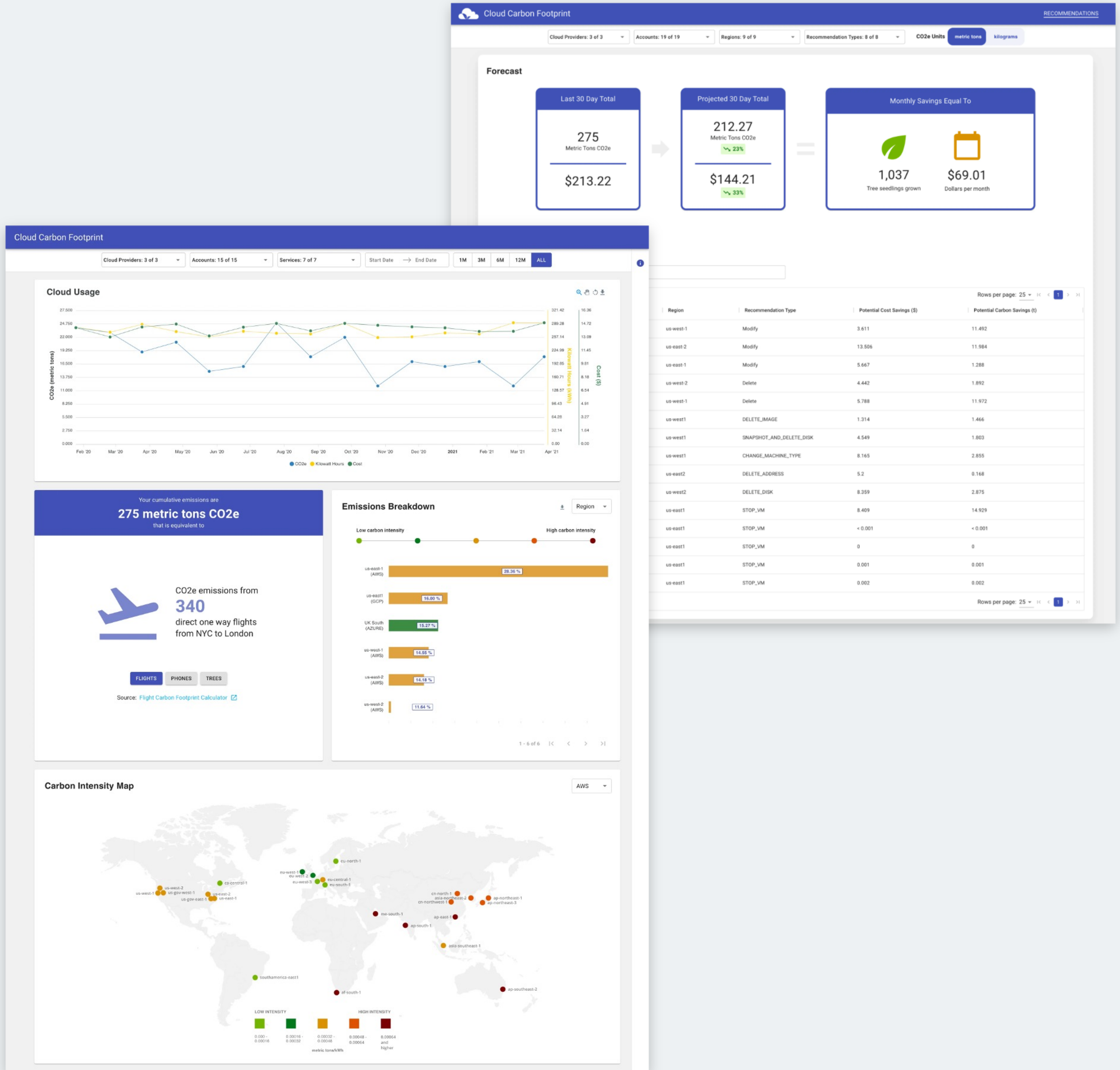

Increased Energy Intensity
(less efficient)
Growth
Time
Same Energy Intensity
(equally efficient)
Growth
Time
Decreased Energy Intensity
(more efficient)
Growth
Time
Energy Consumption Growth (kWh)
Business Growth ($)


Monthly Total kWh:
Former Datacenter (Actual) and Google Cloud (Estimate)
kWh (Stacked)
PUE: 1.39
1.10
1/1/2018
7/1/2018
1/12019
7/1/2019
Month
Former datacenter kWh (Actual)
Google Cloud kWh (Estimate)

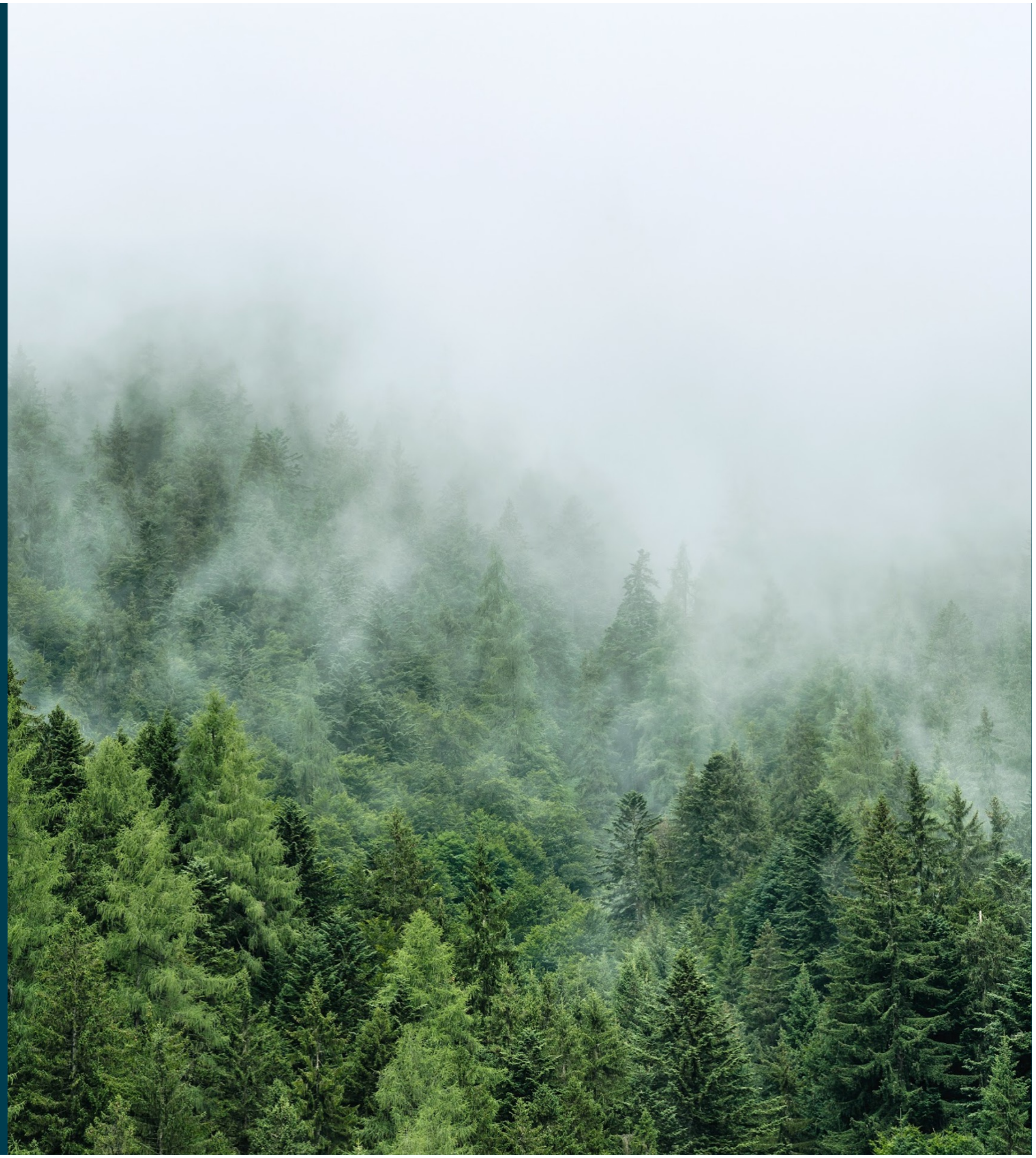
Cloud Carbon Footprint

Estimates for both energy and carbon emissions

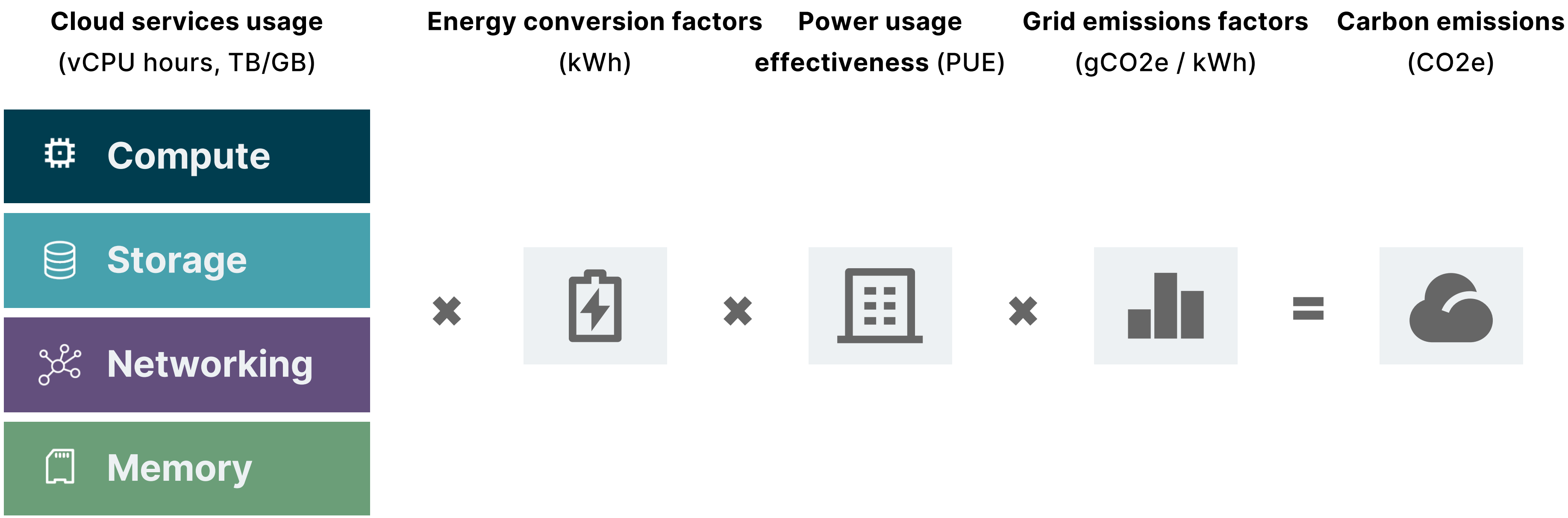
https://demo.cloudcarbonfootprint.org/



But how does it work ??



Cloud Carbon Footprint



cloudcarbonfootprint.org/docs/methodology

CO2e operational emissions calculation

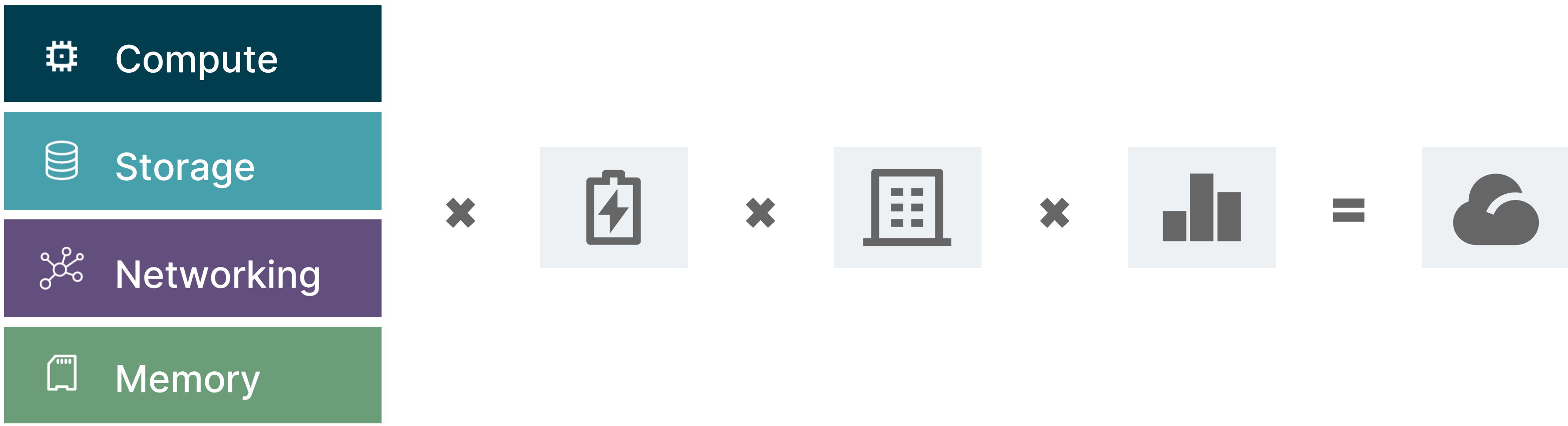
Cloud services usage (vCPU hours, TB/GB)

Energy conversion factors (kWh)

Power usage effectiveness (PUE)

Grid emissions factors (gCO2e / kWh)

Carbon emissions (CO2e)



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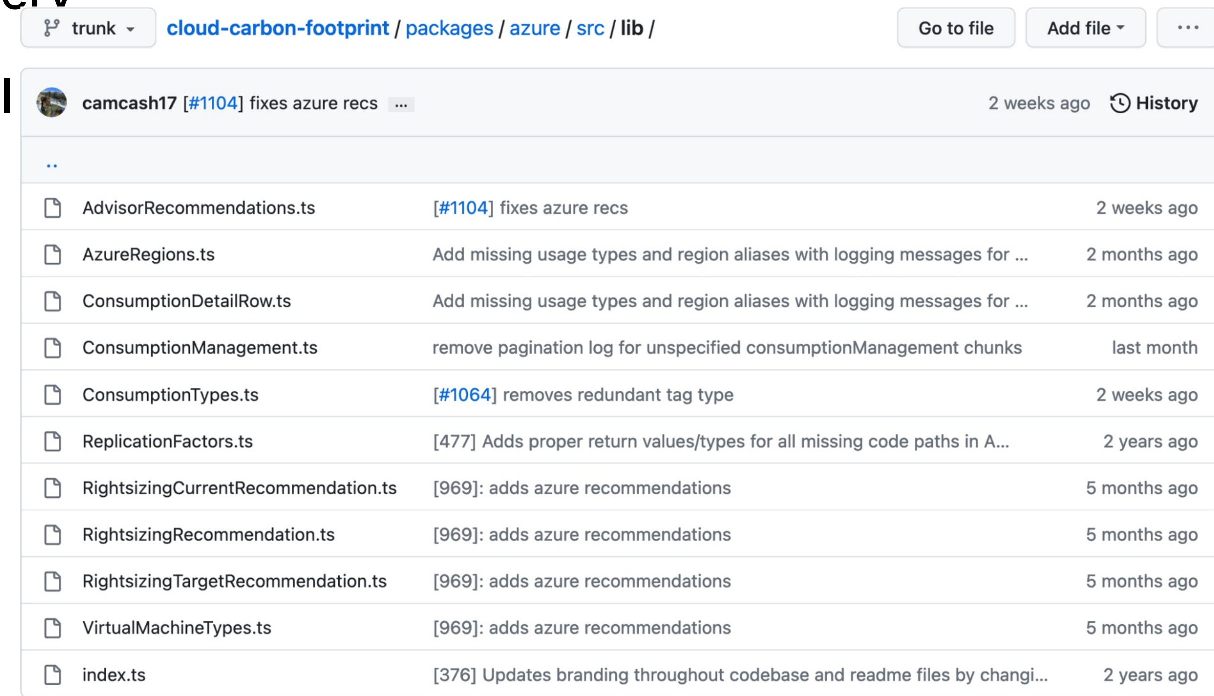
Cloud services usage

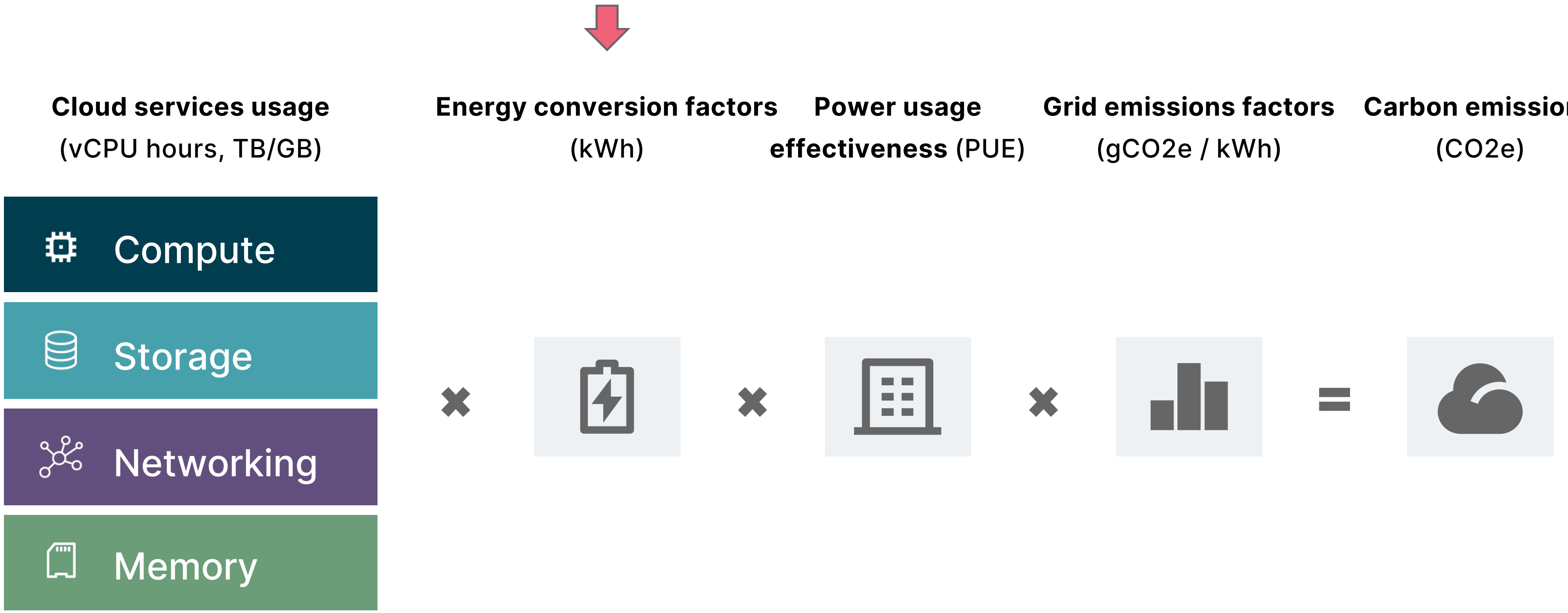
AWS Cost and Usage Reports with Amazon Athena

GCP Billing Export Table using BigQuery

Azure Consumption Management API



CO2e operational emissions calculation



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Energy estimate

Compute

SPECPower database
2016 US Data Center Energy Usage Report
(but AWS has custom processors)

```
Average Watts = Min Watts + Avg vCPU Utilization * (Max Watts - Min Watts)

Compute Watt-Hours = Average Watts * vCPU Hours
```

TEADS dataset for GPUs

Energy estimate

Everything else

Storage (HDD/SSD)

Watts per Terabyte = Watts per disk / Terabytes per disk:

HDD(as per values in 2020): 6.5 W / 10 TB = 0.65 Watt-Hours per Terabyte-Hour * replication factor
SSD(as per values in 2020) : 6 W / 5 TB = 1.2 Watt-Hours per Terabyte-Hour * replication factor

Networking

0.001 kWh/Gb (Assuming hyper-scale cloud providers have a very energy efficient network, smallest coefficient available to date)

Memory (above what's included in SPECPower)

0.000392 Kilowatt Hour / Gigabyte Hour

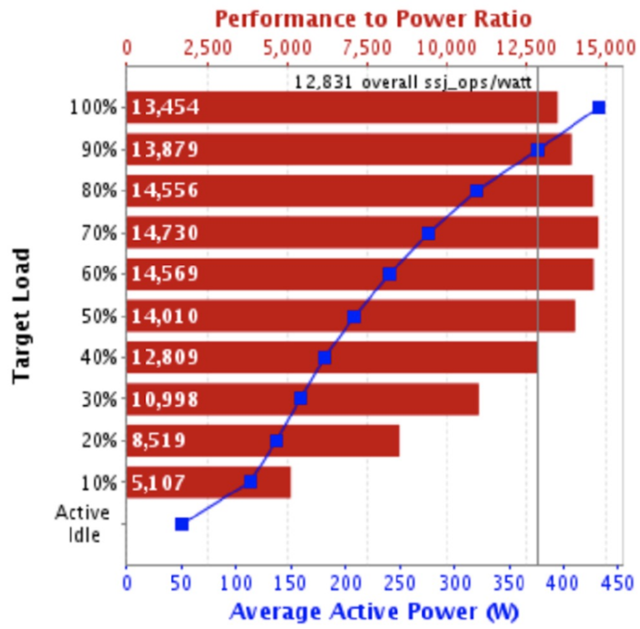
(As per Crucial - ~0.375 W/GB, as per Micron - ~0.4083 W/GB.
Average of both = 0.392Wh/Gh = 0.000392 KWh/Gh)

SPECpower_ssj2008

Dell Inc. PowerEdge R740 (Intel Xeon Platinum 8280, 2.70 GHz)		SPECpower_ssj2008 = 12,831 overall ssj_ops/watt			
Test Sponsor:	Dell Inc.	SPEC License #:	55	Test Method:	Single Node
Tested By:	Dell Inc.	Test Location:	Round Rock, TX, USA	Test Date:	Apr 3, 2019
Hardware Availability:	Apr-2019	Software Availability:	Mar-2019	Publication:	Apr 25, 2019
System Source:	Single Supplier	System Designation:	Server	Power Provisioning:	Line-powered

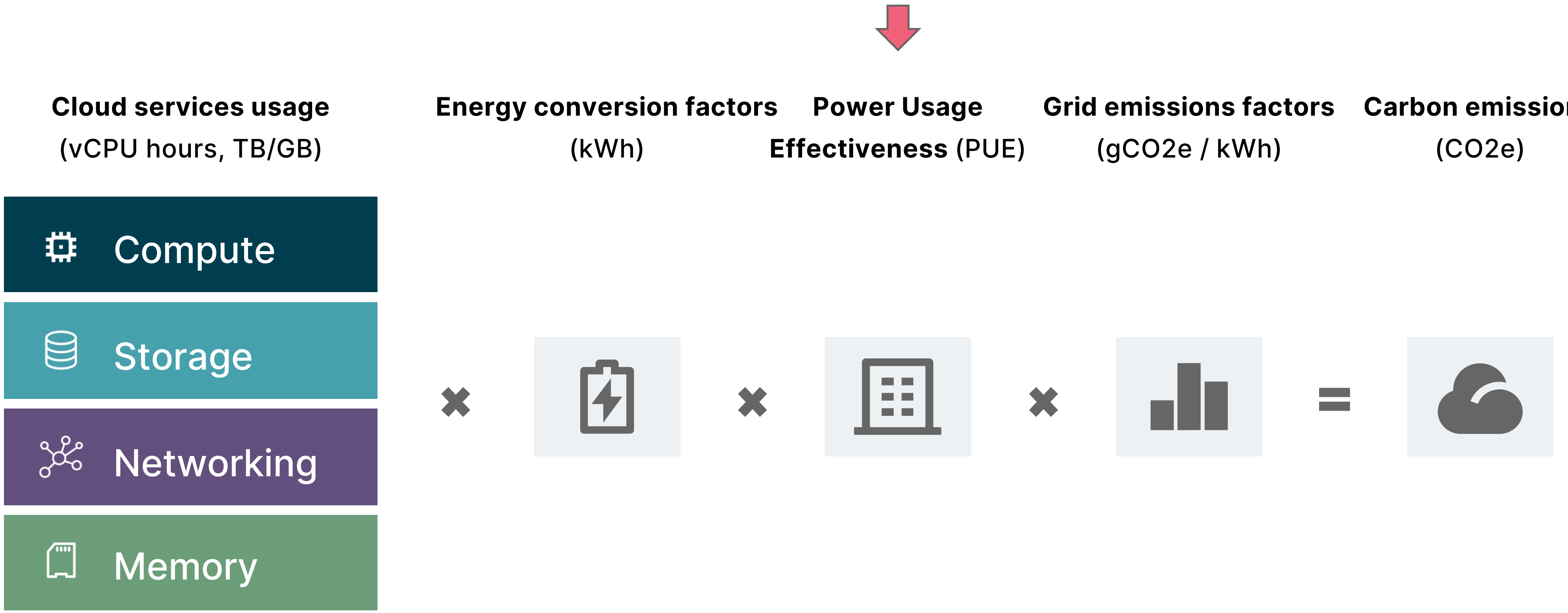
Benchmark Results Summary

Performance			Power	Performance to Power Ratio
Target Load	Actual Load	ssj_ops	Average Active Power (W)	
100%	99.9%	5,811,114	432	13,454
90%	89.7%	5,217,814	376	13,879
80%	79.9%	4,648,443	319	14,556
70%	70.1%	4,077,942	277	14,730
60%	60.0%	3,491,467	240	14,569
50%	50.0%	2,909,373	208	14,010
40%	40.0%	2,325,614	182	12,809
30%	30.0%	1,745,535	159	10,998
20%	20.0%	1,165,221	137	8,519
10%	10.0%	580,574	114	5,107
	Active Idle	0	49.8	0
			∑ssj_ops / ∑power =	12,831



System Under Test

CO2e operational emissions calculation



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Power usage effectiveness

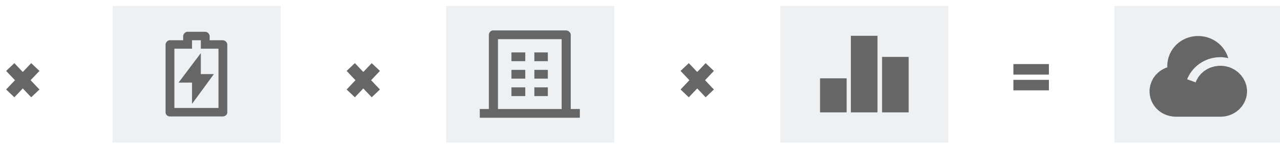
Cloud provider PUEs being used:

- AWS: 1.135
- GCP: 1.1
- Azure: 1.185

CO2e operational emissions calculation

Cloud services usage (vCPU hours, TB/GB) | **Energy conversion factors** (kWh) | **Power Usage Effectiveness** (PUE) | **Grid emissions factors** (gCO2e / kWh) | **Carbon emissions** (CO2e)

- Compute
- Storage
- Networking
- Memory



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Emissions factors

Google

Convert estimated KWh of usage into estimated CO2e using publicly available data on emission factors for a given electricity grid based on the mix of local energy sources. We do this based on the cloud provider datacenter region that each service is running in. e.g. for Google, values are as shown on right.

Carbon data across GCP regions

Google Cloud Region	Location	Google CFE%	Grid carbon intensity (gCO_2eq/kWh)	Google Cloud net operational GHG emissions	
asia-east1	Taiwan	17%	456	0	
asia-east2	Hong Kong	28%	360	0	
asia-northeast1	Tokyo	16%	464	0	
asia-northeast2	Osaka	31%	384	0	
asia-northeast3	Seoul	31%	425	0	
asia-south1	Mumbai	10%	670	0	
asia-south2	Delhi	8%	671	0	
asia-southeast1	Singapore	4%	372	0	
asia-southeast2	Jakarta	13%	580	0	
australia-southeast1	Sydney	21%	598	0	
australia-southeast2	Melbourne	31%	521	0	
europe-central2	Warsaw	20%	576	0	
europe-north1	Finland	91%	127	0	Low CO_2
europe-southwest1	Madrid	*	121	0	Low CO_2
europe-west1	Belgium	82%	110	0	Low CO_2
europe-west2	London	57%	172	0	
europe-west3	Frankfurt	60%	269	0	
europe-west4	Netherlands	53%	283	0	
europe-west6	Zurich	85%	86	0	Low CO_2
europe-west8	Milan	*	298	0	
europe-west9	Paris	*	59	0	Low CO_2
northamerica-northeast1	Montréal	100%	0	0	Low CO_2

CO2e operational emissions calculation (Scope 2)

Cloud services usage (vCPU hours, TB/GB)		Energy conversion factors (kWh)		Power Usage Effectiveness (PUE)		Grid emissions factors (gCO2e / kWh)		Carbon emissions (CO2e)

- Compute
- Storage
- Networking
- Memory

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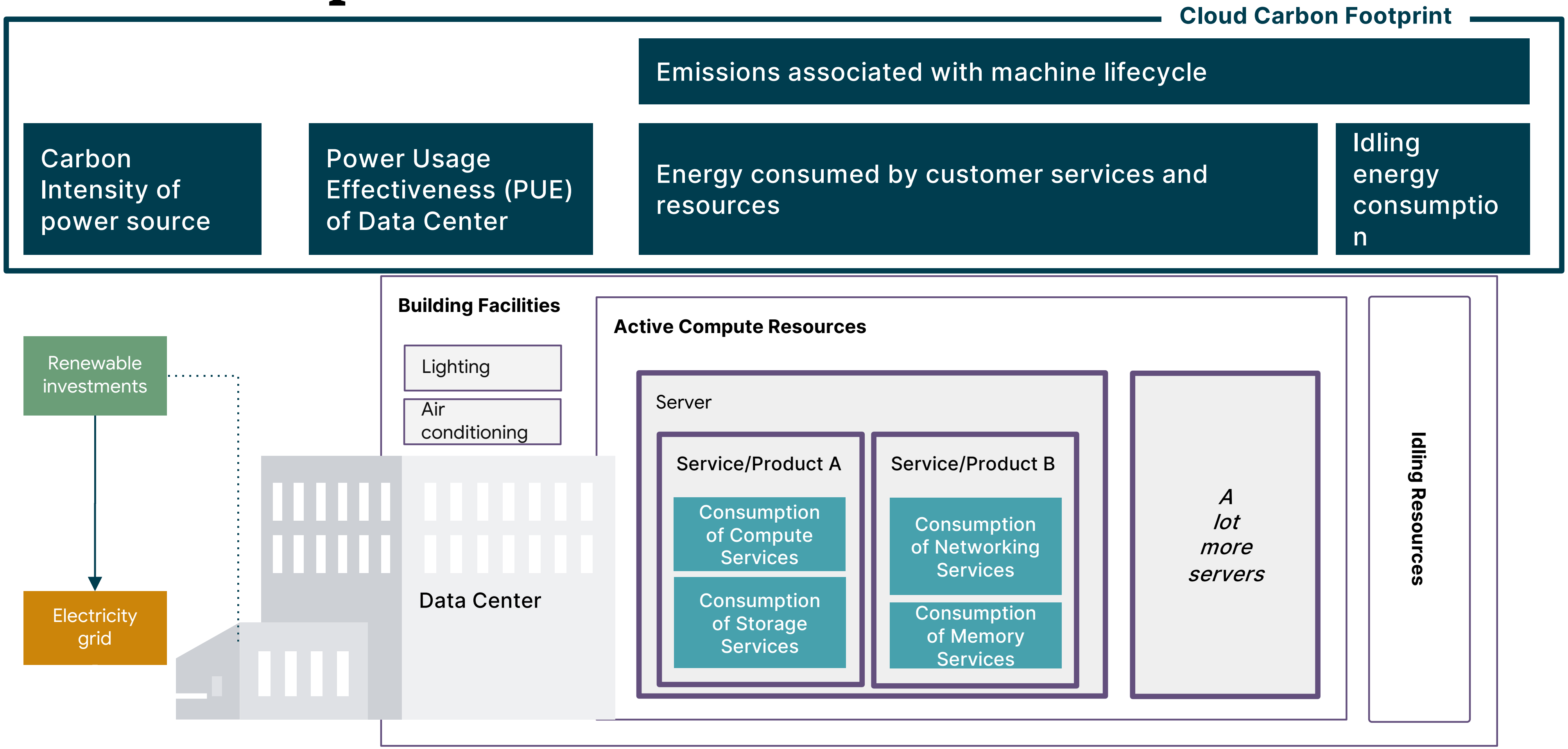
Embodied emissions (Scope 3)

Embedded Emissions is the amount of carbon emitted during the creation and disposal of a hardware device. These need to be considered while calculating Scope 3 emissions in a datacenter.

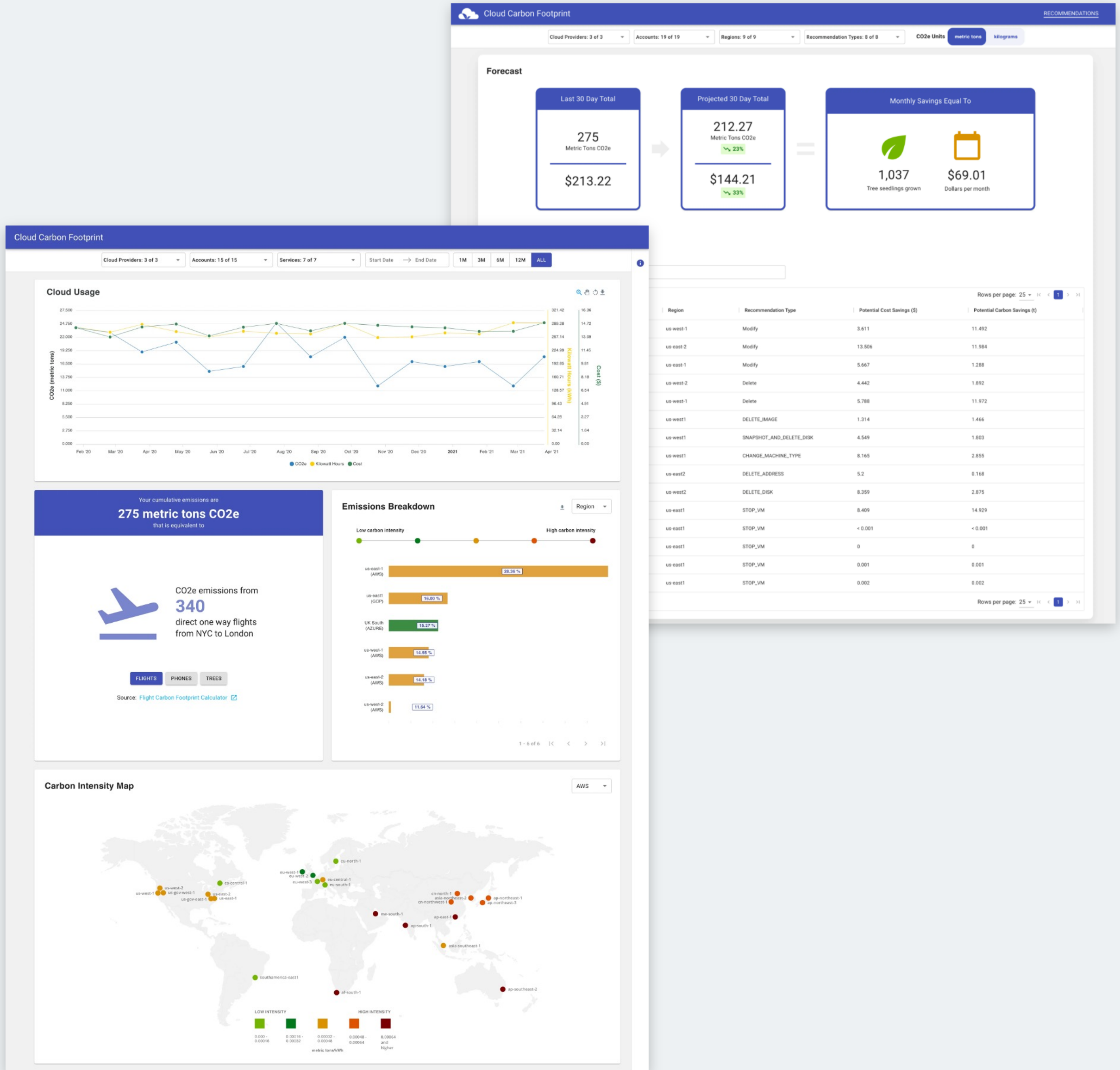
```

export const VIRTUAL_MACHINE_TYPE_SERIES_MAPPING: {
  [series: string]: { [instanceType: string]: number[] } // [vcpus, memory, embodied emissions]
} = {
  'As-series': {
    A0: [1, 0.75],
    A1: [1, 1.75],
    A2: [2, 3.5],
    A3: [4, 7],
    A4: [8, 14],
  },
  'Bs-series': {
    B1Ls: [1, 0.5, 1.2388],
    B1s: [1, 1, 1.2388],
    B1Ms: [1, 2, 1.2388],
    B2s: [2, 4, 1.2388],
    B2ms: [2, 8, 1.2388],
    B4ms: [4, 16, 1.2388],
    B8ms: [8, 32, 1.2388],
    B12ms: [12, 48, 1.2388],
    B16ms: [16, 64, 1.2388],
    B20ms: [20, 80, 1.2388],
  },
  'Av2 Standard': {
    'A1 v2': [1, 2, 1.2166],
    'A2 v2': [2, 4, 1.2166],
    'A2m v2': [2, 16, 1.2166],
    'A4 v2': [4, 8, 1.2166],
    'A4m v2': [4, 32, 1.2166],
    'A8 v2': [8, 16, 1.2166],
    'A8m v2': [8, 64, 1.2166],
```

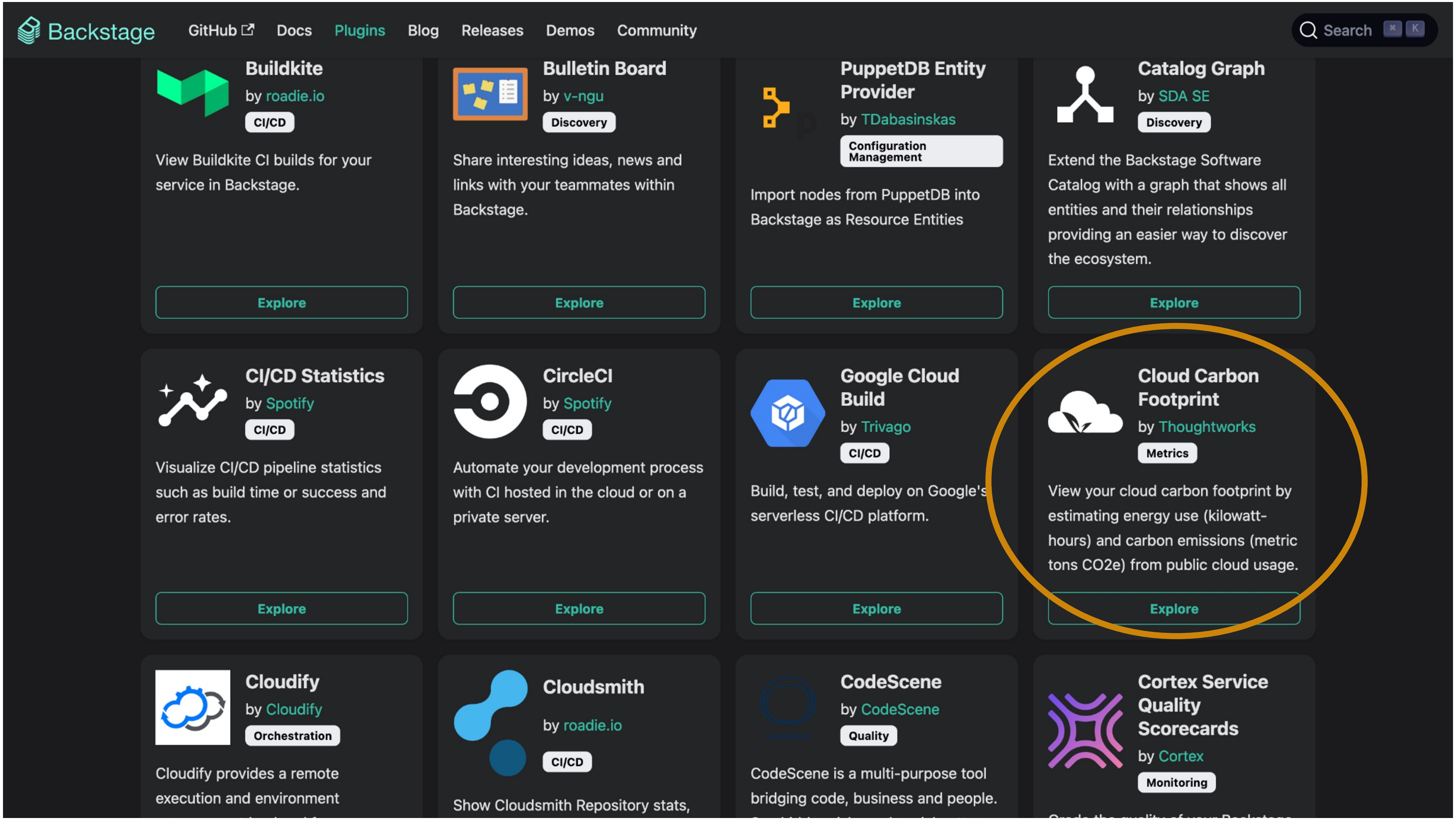
Carbon Footprint of Cloud Data Centers



Benefits of CCF:

- Estimates for both energy and carbon emissions
- Multiple cloud providers
- Actionable recommendations
- Visualises energy usage and carbon footprint
- Multiple ways to integrate energy and carbon metrics
- Open source and extensible
  github.com/cloud-carbon-footprint




Backstage
GitHub
Docs
Plugins
Blog
Releases
Demos
Community
Search
Buildkite
by roadie.io
CI/CD
View Buildkite CI builds for your service in Backstage.
Explore
Bulletin Board
by v-ngu
Discovery
Share interesting ideas, news and links with your teammates within Backstage.
Explore
PuppetDB Entity Provider
by TDabasinskas
Configuration Management
Import nodes from PuppetDB into Backstage as Resource Entities
Explore
Catalog Graph
by SDA SE
Discovery
Extend the Backstage Software Catalog with a graph that shows all entities and their relationships providing an easier way to discover the ecosystem.
Explore
CI/CD Statistics
by Spotify
CI/CD
Visualize CI/CD pipeline statistics such as build time or success and error rates.
Explore
CircleCI
by Spotify
CI/CD
Automate your development process with CI hosted in the cloud or on a private server.
Explore
Google Cloud Build
by Trivago
CI/CD
Build, test, and deploy on Google's serverless CI/CD platform.
Explore
Cloud Carbon Footprint
by Thoughtworks
Metrics
View your cloud carbon footprint by estimating energy use (kilowatt-hours) and carbon emissions (metric tons CO2e) from public cloud usage.
Explore
Cloudify
by Cloudify
Orchestration
Cloudify provides a remote execution and environment
Cloudsmith
by roadie.io
CI/CD
Show Cloudsmith Repository stats,
CodeScene
by CodeScene
Quality
CodeScene is a multi-purpose tool bridging code, business and people.
Cortex Service Quality Scorecards
by Cortex
Monitoring

3Degrees™ San Francisco, CA • Portland, OR • Portland, ME • Oslo, Norway

June 3, 2022

To Stakeholders of Google Cloud Services:

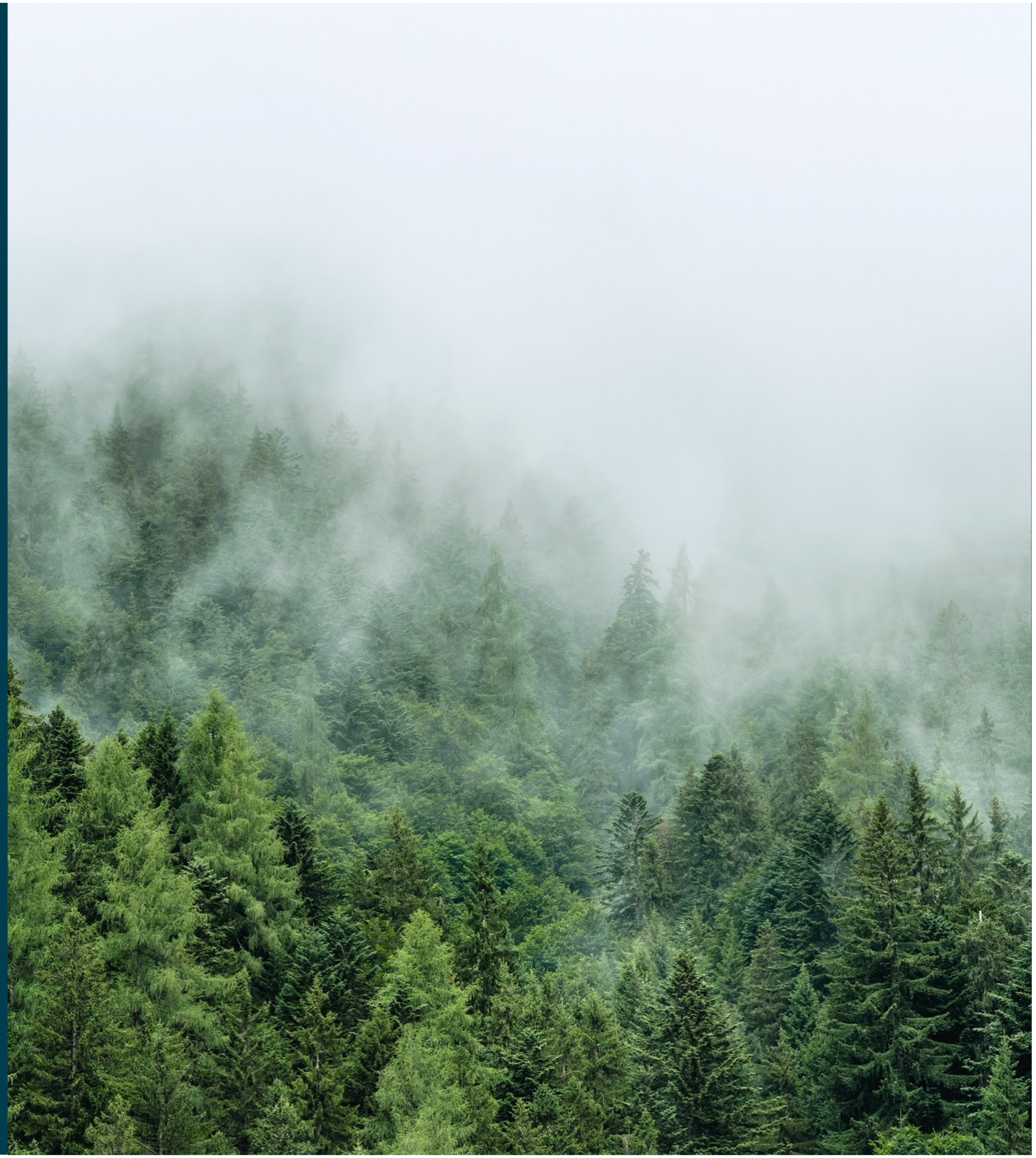
3Degrees was engaged by Google to perform a review as described here, of the company's method for determining customer-specific greenhouse gas emissions associated with the usage of Google Cloud products. We conducted an initial review in October 2021 and a second review in April 2022 as Google updated and expanded its calculations. This letter applies to the product

CONCLUSIONS

Based on our review, we conclude that the method as described to us is a reasonable and appropriate means of calculating and allocating greenhouse gas emissions arising from Google Cloud products to individual customers per the GHG Protocol and typical customer expectations. In addition, we found that the user documentation is sufficiently clear and

Optimize

Implement sustainable defaults and best practices into your cloud infrastructure



Apply Sensible / Sustainable Defaults

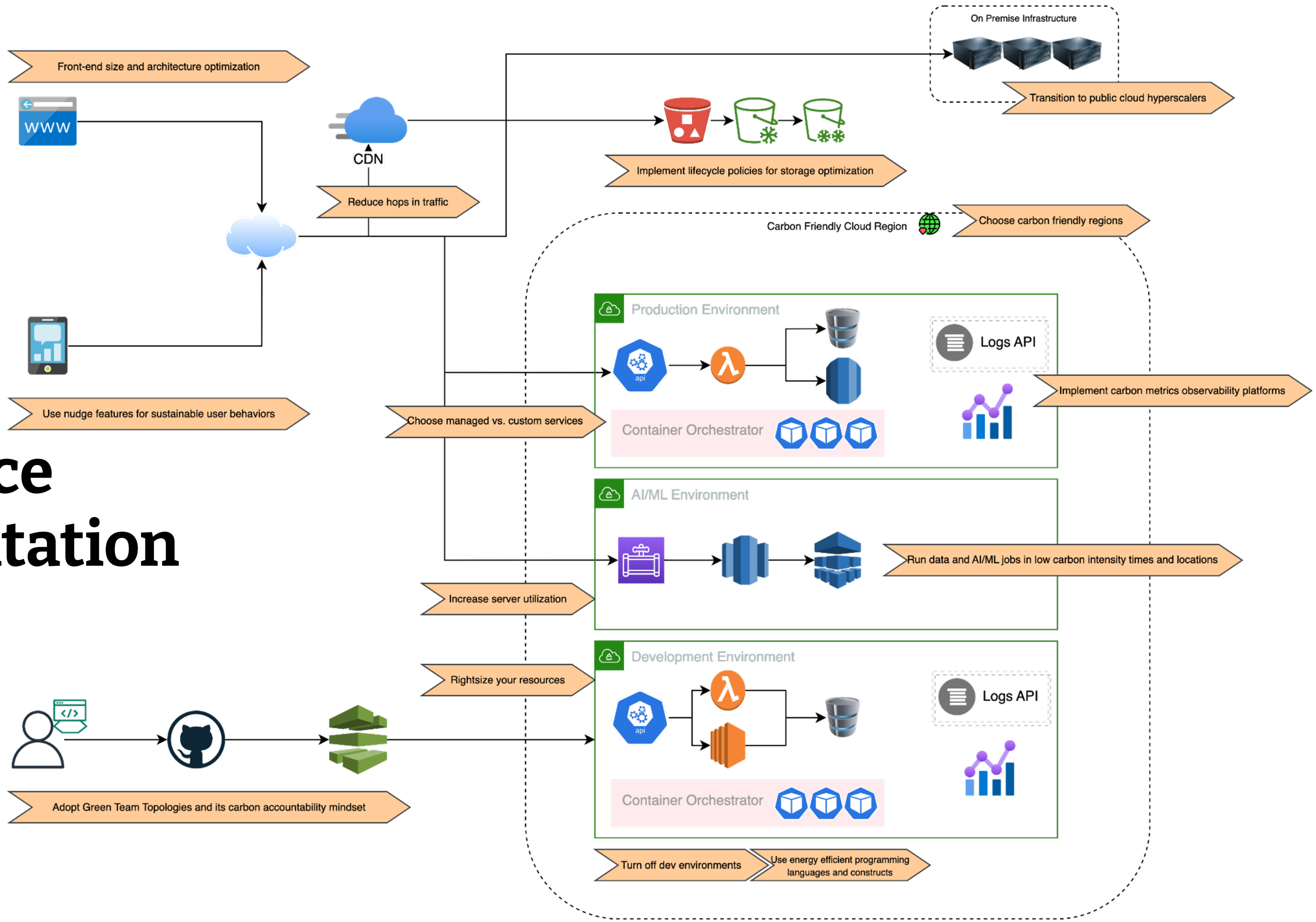
Provisioning infrastructure with sustainable defaults will lower carbon growth, hence Greener cloud

Use cleanest and closest region	Reduce storage usage	Improve caching	Leverage event driven architecture
Containerize applications	Consider serverless	Run workloads at an optimal time	Turn off non-prod environment , when not in use

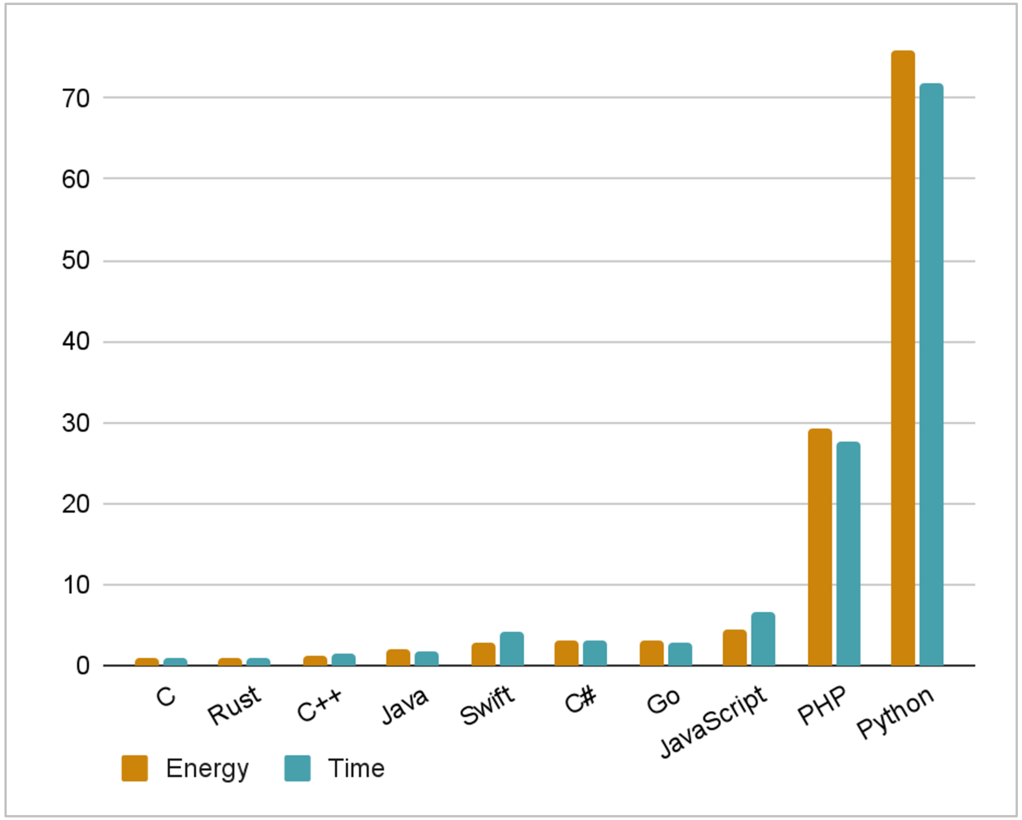
Optimization Strategies For a Greener Cloud

Resource Management	Rightsizing	Data deduplication	Removing idle resources	Auto-archiving and cold data storage	Increasing utilisation		
Cloud Native Patterns	Locality of reference	Autoscale horizontally	Lazy processing	Decouple Storage & Compute			
Architecture Style	Containerize & Microservices	Fine grained horizontal scalability	Energy efficient interaction methods	Energy efficient protocols and messaging	Storage formats		
Data management and Content delivery	Effective caching	CDNs for static content	Optimized ML				
Provisioning and delivery automation	Immutable environments	4-key metrics optimised	Optimised testing throughput	Less but reliable end-to-end testing	Ephemeral dev and test environments		
Infrastructure strategy	Schedule resources & shutdown	Follow sun and wind	Serverless	Region Optimization	Batch Redesign & Reordering	Maximise use of allocated resources	Use managed services

A Reference Implementation



Efficiency “in” the Cloud



Language	Energy	Time
C	**1.00**	**1.00**
Rust	1.03	1.04
C++	1.34	1.56
Java	**1.98**	**1.89**
Swift	2.79	4.20
C#	3.14	3.14
Go	3.23	2.83
JavaScript	**4.45**	**6.52**
PHP	29.30	27.64
Python	75.88	71.90

Rui Pereira, et al.. 2017. Energy Efficiency across Programming Languages. In Proceedings of SLE’17, Vancouver, BC, Canada, October

Green Cloud :
A step towards a Sustainable Future

Sudhanshu Garg
sudhanshu.garg@thoughtworks.com
www.linkedin.com/in/sudhanshu-garg

/thoughtworks