Cloud Provider Sustainability Current Status and Future Directions

DevSusOps: Adding sustainability concerns to development and operations

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Agenda

Why does sustainability matter?
Why is this hard?

Terminology and mental models
Cloud provider similarities and differences
Cloud carbon measurements
Things developers need to build

Apology

There is a lot of dense content in this talk

also I don’t have a graphic design budget
to make it look nicer nowadays…

Leave the world habitable for future generations

Market transition risks

Regulatory compliance

Physical risks to business assets

Why does sustainability matter?

“Green” market positioning

Employee enthusiasm

Reduced costs now or in the future

Social license to operate

Things we can do now…

Development

Optimize code

Choose faster languages and runtimes

Efficient algorithms

Faster implementations

Reduce logging

Reduce retries and work amplification

Operations

Higher utilization

Automation

Relax over-specified requirements

Archive and delete data sooner

Deduplicate data

Choose times and locations carefully

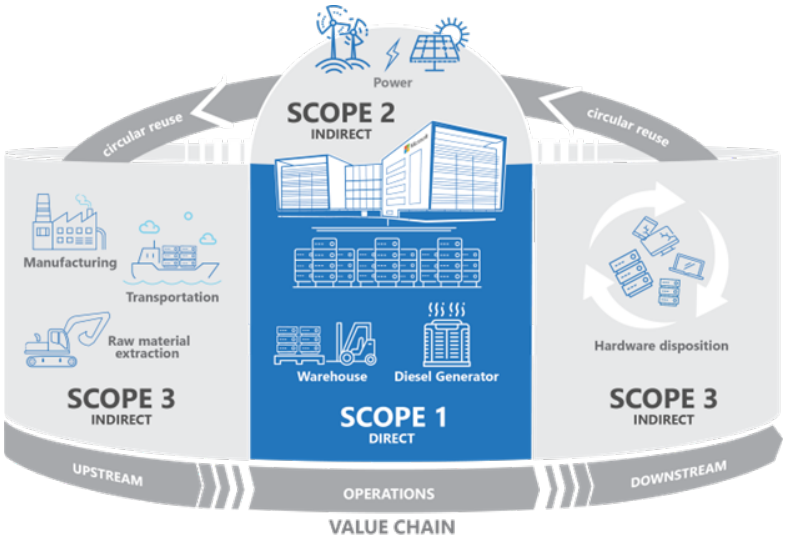
Measuring Carbon

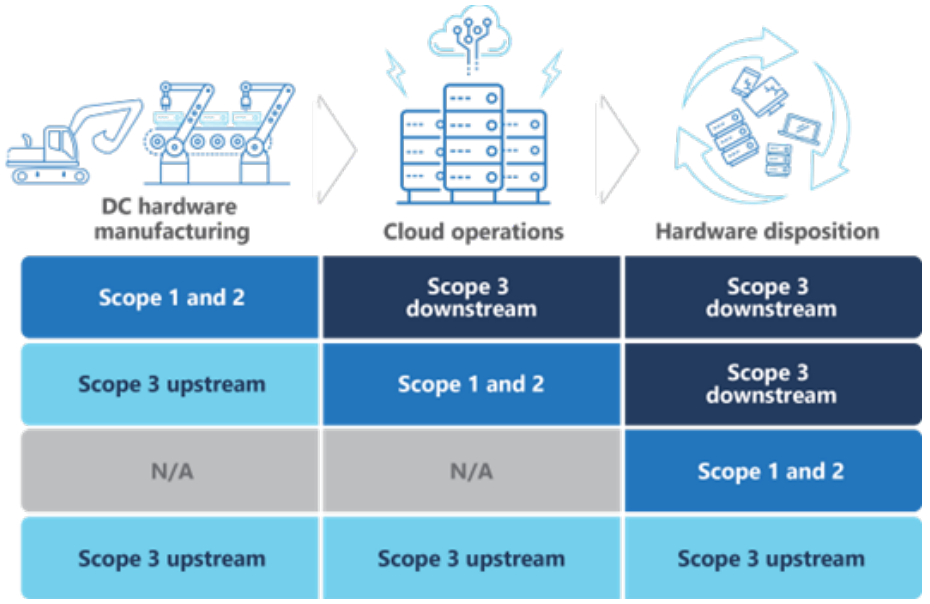
Why is this hard?

We just have to multiply two numbers, right?

Energy * Carbon Content

Need to account for the whole lifecycle…





https://learn.microsoft.com/en-us/industry/sustainability/api-calculation-method

As the carbon content of energy tends to zero scope 3 dominates carbon footprints

Energy * Carbon Content + Scope 3

In the EU and US this happened a few years ago

API for supply chain carbon data
WBCSD Pathfinder is an emerging interchange protocol standard

https://www.wbcsd.org/Programs/Climate-and-Energy/Climate/SOS-1.5/Resources/Pathfinder-Framework-Version-2.0

Cloud Provider Scope 3 Differences

Amazon Web Services (AWS) - No public scope 3 reports yet

- Latest discussion of why not on Adrian's Medium Blog LinkedIn page and a Computer Weekly story
- https://www.computerweekly.com/news/365531874/Amazon-denies-claims-hiring-freeze-is-slowing-AWS-sustainability-work
- Summary: work continues, slowly, don't hold your breath… escalate to get estimates under NDA if needed

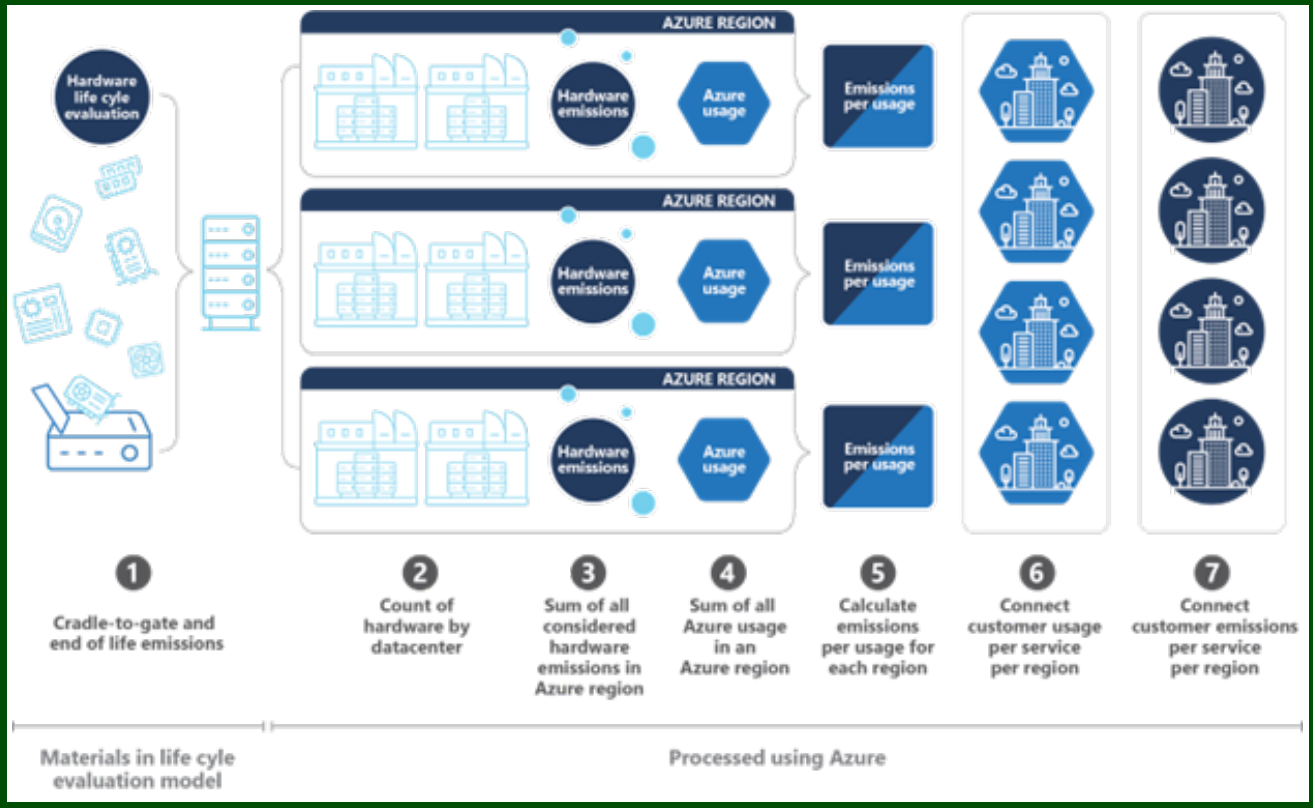
Microsoft Azure - Detailed scope 3 data and API

- Lauched in 2021 - excellent methodology white paper
- Includes recycling, doesn't include transport and buildings yet
- Numbers will increase a bit when these are added…

Google Cloud Platform (GCP) - Detailed scope 3

- Includes transport and buildings
- Doesn't include end of life recycling (estimated to be immaterial)

Scope 3 Methodology



https://learn.microsoft.com/en-us/industry/sustainability/api-calculation-method

Data Centers Impact distribution by country

Region	gCO2e/KWh	Scope 1	Scope 2	Scope 3	Scope 1	Scope 2	Scope 3	TOTAL	var Vs EU-28
EU-28	265	0.7%	68.2%	31.1%	0.7	68.2	31.1	100.0	
Sweden	27	1.8%	19.7%	80.3%	0.7	6.9	31.1	38.7	**-61%**
Finland	148	1.0%	55.5%	44.5%	0.7	38.1	31.1	69.9	**-30%**
Norway	37	1.7%	24.7%	75.3%	0.7	9.5	31.1	41.3	**-59%**
France	85	1.3%	42.1%	57.9%	0.7	21.9	31.1	53.7	**-46%**
Poland	780	0.3%	86.6%	13.4%	0.7	200.7	31.1	232.5	**133%**
Ireland	342	0.6%	74.0%	26.0%	0.7	88.0	31.1	119.8	**20%**

gCO2e/KWh: source electricitymaps.org and European Environment Agency for EU-28 data
Scope 1, 2 & 3 of EU-28 from "Digital technologies in Europe: an environmental life cycle approach" Dec. 2021

Thanks to Cyril Deblois - AWS Sustainability Lead - Cloud Economic for this chart.

OK, but scope 3 is about hardware, so it's an "Ops problem",
we developers just have to multiply two numbers, right?

Energy * Carbon Content

Energy

How much energy does a specific line of code use?
How much energy does a transaction use? (SCI)
How much energy does a specific workload use?
How much energy does a container use?
How much energy does a specific cloud instance use?

Cloud providers don’t tell you any of these things…

See https://www.noureddine.org/research/joular/joularjx for real-time JVM energy monitoring
See https://github.com/sustainable-computing-io/kepler for Kubernetes energy analysis

DIY Energy Usage Measurement

Repeatability and Reproducibility challenges

Lookup how to do Gage R&R statistical analysis!

Huge variance from one run to the next

Huge variance from one system/user to the next

Lots of confounding effects

Possibly a fun project to try at home…?

https://dev.to/adrianco/measuring-energy-usage-5ip

OK, Energy is a pain, so we'll use an average hourly rate.
Where do we get the Carbon Content from?

Energy * Carbon Content

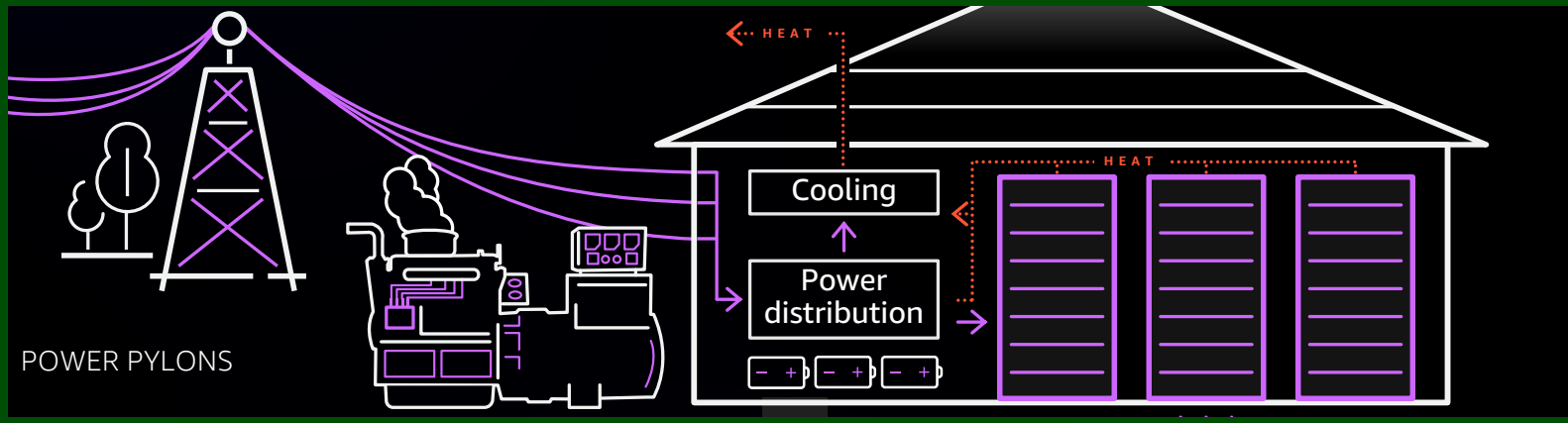
Carbon Content - It depends…

What is the grid mix for energy generation in that location?
When did you get measures of the grid mix? (months later)
Do you have hourly grid mix? (GCP does but doesn't share it)
Did the grid mix numbers change after you used them? (yes)
How much private cloud provider energy was used? (they don't say)
How much "Bundled REC" energy was used? (they don't say)
How much "Unbundled REC" energy was used? (they don't say)

Power Usage Efficiency (PUE) accounts for losses and cooling overhead but value depends on where it is measured

Power distribution and UPS batteries may be centralized or distributed in different datacenter architectures

Grid Mix is obtained from the local utility bill, usually a month or so in arrears, combined with any power purchase agreements (PPAs) or renewable energy credit (REC) purchases

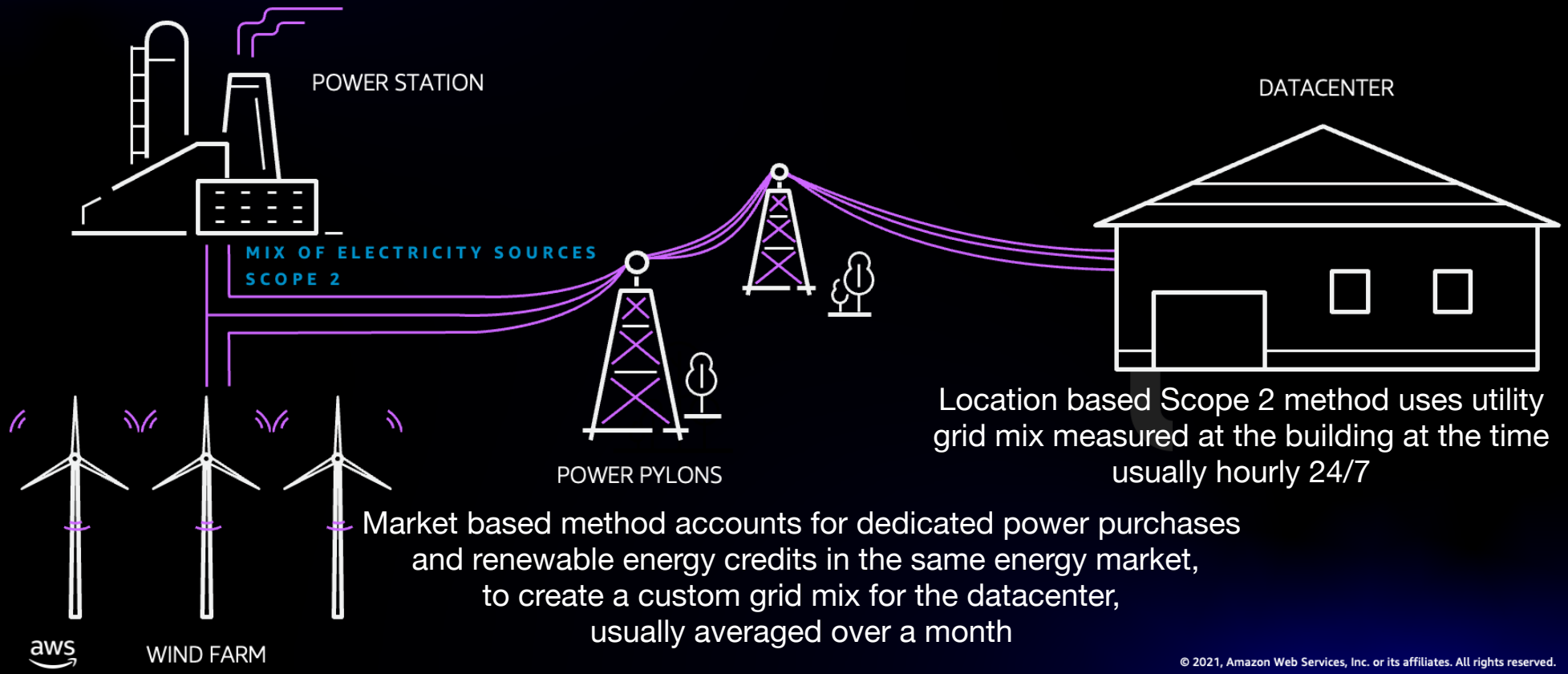


Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Two methodologies for reporting carbon

Location based vs. Market based

Market vs. Location Reporting for Scope 2



Location based Scope 2 method uses utility grid mix measured at the building at the time usually hourly 24/7

Market based method accounts for dedicated power purchases and renewable energy credits in the same energy market, to create a custom grid mix for the datacenter, usually averaged over a month

Why does it matter?

AWS and Azure carbon data is Regional Market based
e.g. PPA generation is connected to the same grid 😊

Google's 100% renewable since 2017 claim is Global Market based
e.g. Generation in USA and EU was counted against Singapore 😒

Google's current data, API and 24/7 work is Location Based 🥳
Numbers can't be compared, but more useful for tuning work

As the utility grid decarbonizes over time, it matters less…

Problems…

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Utility bills delayed by a month or more, depending where in the world they are…

PPA - Power Purchase Agreements are contracts to build and consume power generation capacity e.g. Amazon has over 20GW of PPAs (Solar, Wind, Battery)

REC - Renewable Energy Credits are purchases of renewable generation capacity on the open market, from existing generators, the energy can only be claimed once, but can be claimed later

RECs may be used to “top up” on top of PPAs, helps fund existing renewable capacity, but don’t create additional capacity, like PPAs do

Good RECs and Bad RECs

Guarantee of Origin (in EU) and Renewable Energy Credit (in USA)

- Similar but have some detailed differences in how they are calculated, regulated and traded

Local Market REC

- Reserve the renewable energy from a supplier on the same grid - GOOD!

Cross-border/non-local market REC

- Renewable energy that can't flow to you
- Extra funding helps to subsidize existing renewable generation - GOOD
- Argument that carbon reduced in one part of the world offsets other parts of the world…
- Often used as a cheap carbon offset - greenwashing - BAD

https://www.ecocostsvalue.com/lca/gos-and-recs-in-lca/
https://sustainability.google/progress/projects/ppa/
https://www.blog.google/outreach-initiatives/environment/meeting-our-match-buying-100-percent-renewable-energy/

Problems…

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Grid mix changes every month but is mostly getting better over time

Hourly data for 24/7 grid mix starting to appear for some suppliers in some parts of the world

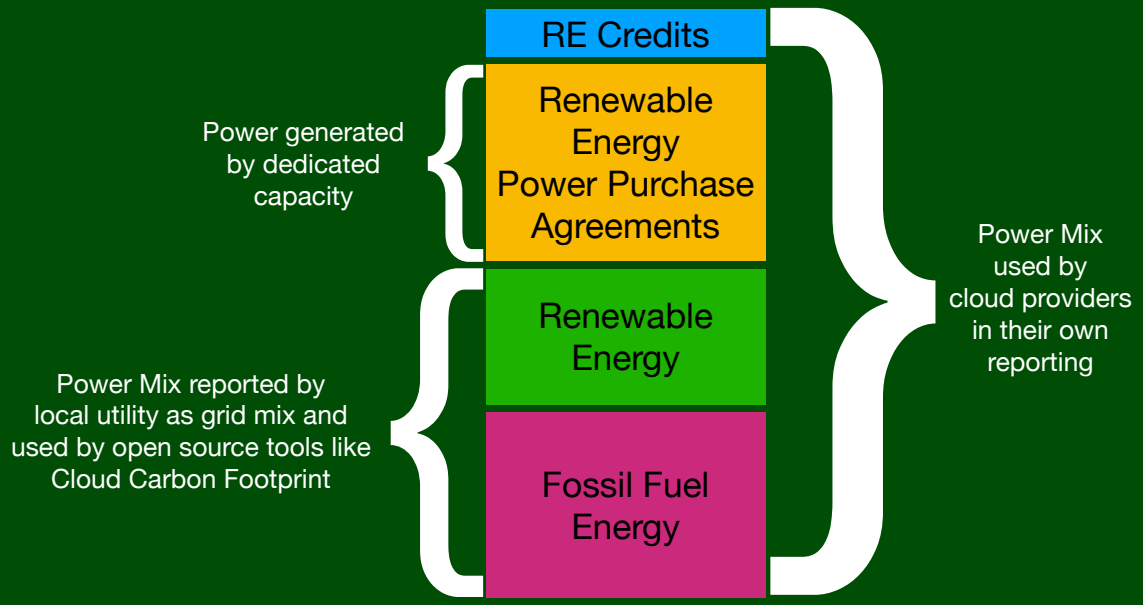
GCP and Azure publicly working towards 24/7

cloudcarbonfootprint.org open source tool estimates don’t include PPAs or RECs

Also see FlexiDAO.com startup working on 24/7 energy trading

Power Mix Problems and Misconceptions

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity



Typical Proportions in Emerging Markets

Misconceptions - most people don't understand that RECs and PPAs are excluded from the grid mix

PPAs are private and don't affect the grid mix for everyone else

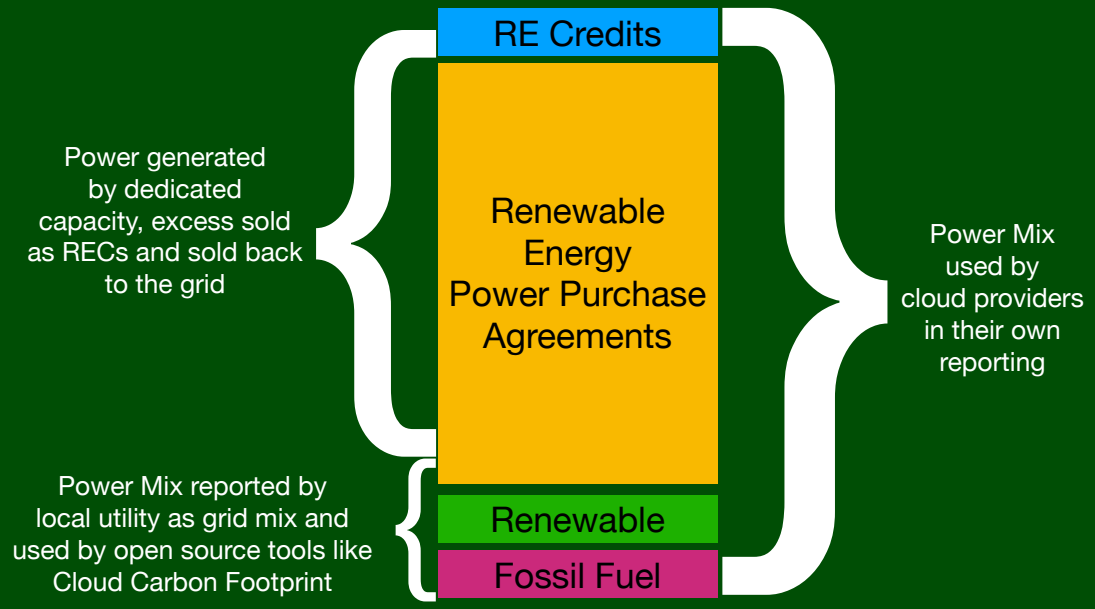
Use of local market RECs is good, but makes the grid mix worse for everyone

RECs can be traded for up to a year, so you can pay to offset past emissions, and that changes the grid mix for the month, for up to a year later…

https://www.ecocostsvalue.com/lca/gos-and-recs-in-lca/

Power Mix Problems and Misconceptions

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity



Typical Proportions in Mature Markets that are dominated by PPA

Misconceptions - most people don't understand that RECs and PPAs are excluded from the grid mix

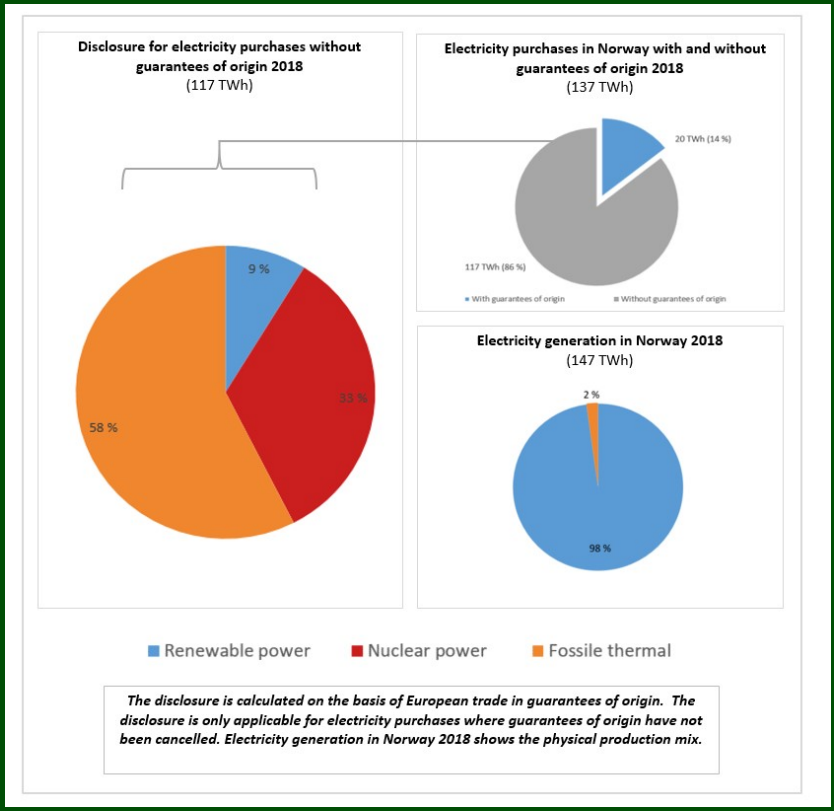
PPAs are private and don't affect the grid mix for everyone else

Use of local market RECs is good, but makes the grid mix worse for everyone

RECs can be traded for up to a year, so you can pay to offset past emissions, and that changes the grid mix for the month, for up to a year later…

https://www.ecocostsvalue.com/lca/gos-and-recs-in-lca/

The “Norway Problem”



(a) The country produced in 2018, physically, 2% fossil electricity, (b) the country used 14% unbundled GOs (the rest can be sold abroad to get extra revenues), leading to a Residual Mix of 86%, (c) that Residual Mix is assumed to be the European Electricity Mix, so the own population has 58% of 86%, is 50%, administrative fossil electricity.

For a Norwegian based company that just buys energy from the grid, it will have to report about 50% fossil grid mix, unless it pays extra to buy the GOs to claim the benefit of the local renewable power.

This is because selling GOs/RECs across borders is allowed, but is generally considered a bad practice nowadays.

https://www.ecocostsvalue.com/lca/gos-and-recs-in-lca/

https://www.nve.no/norwegian-energy-regulatory-authority/retail-market/electricity-disclosure-2018/

Problems…

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Power Usage Efficiency is not well standardized. Values can be compared for similar datacenter designs, but some good efficiency improvements may move components from the infrastructure to the equipment, and make PUE worse.

AWS doesn't publish PUE and points to this blog
https://perspectives.mvdirona.com/2009/06/pue-and-total-power-usage-efficiency-tpue/

Azure published PUE
https://azure.microsoft.com/en-us/blog/how-microsoft-measures-datacenter-water-and-energy-use-to-improve-azure-cloud-sustainability/

Google published PUE
https://www.google.com/about/datacenters/efficiency/

Problems…

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Dedicated compute and storage capacity is relatively easy to account for, but sliced instances, shared services, network equipment etc. Is a challenge to allocate

If you are operating a multi-tenant service and want to report carbon, then you have a problem figuring out how much capacity to allocate to each customer, and how much is overhead that you should own yourself…

Problems…

Scope 2 Carbon = Power Mix * PUE * Capacity Used * Emissions factor per capacity

Need to know how much power each instance type, storage class or service uses
This depends on utilization and other overheads confuse measurements

Mostly unavailable data at present…

Takeaways

What can you do today?

Use Less Stuff

This will make the biggest difference

AWS "Better than 95% Renewable" Regions

To achieve our goal of powering our operations with 100% renewable energy by 2025—five years ahead of our original 2030 target—Amazon contracts for renewable power from utility scale wind and solar projects that add clean energy to the grid. These new renewable projects support hundreds of jobs while providing hundreds of millions of dollars of investment in local communities. We also may choose to support these grids through the purchase of environmental attributes, like Renewable Energy Certificates and Guarantees of Origin, in line with our Renewable Energy Methodology.

As a result, in 2021, the following AWS Regions were powered by over 95% renewable energy:

- US East (Northern Virginia)
- GovCloud (US-East)
- US East (Ohio)
- US West (Oregon)
- GovCloud (US-West)
- US West (Northern California)
- Canada (Central)
- Europe (Ireland)
- Europe (Frankfurt)
- Europe (London)
- Europe (Milan)
- Europe (Paris)
- Europe (Stockholm)

Mostly located in the USA and Europe but more projects in Asia than Azure and GCP

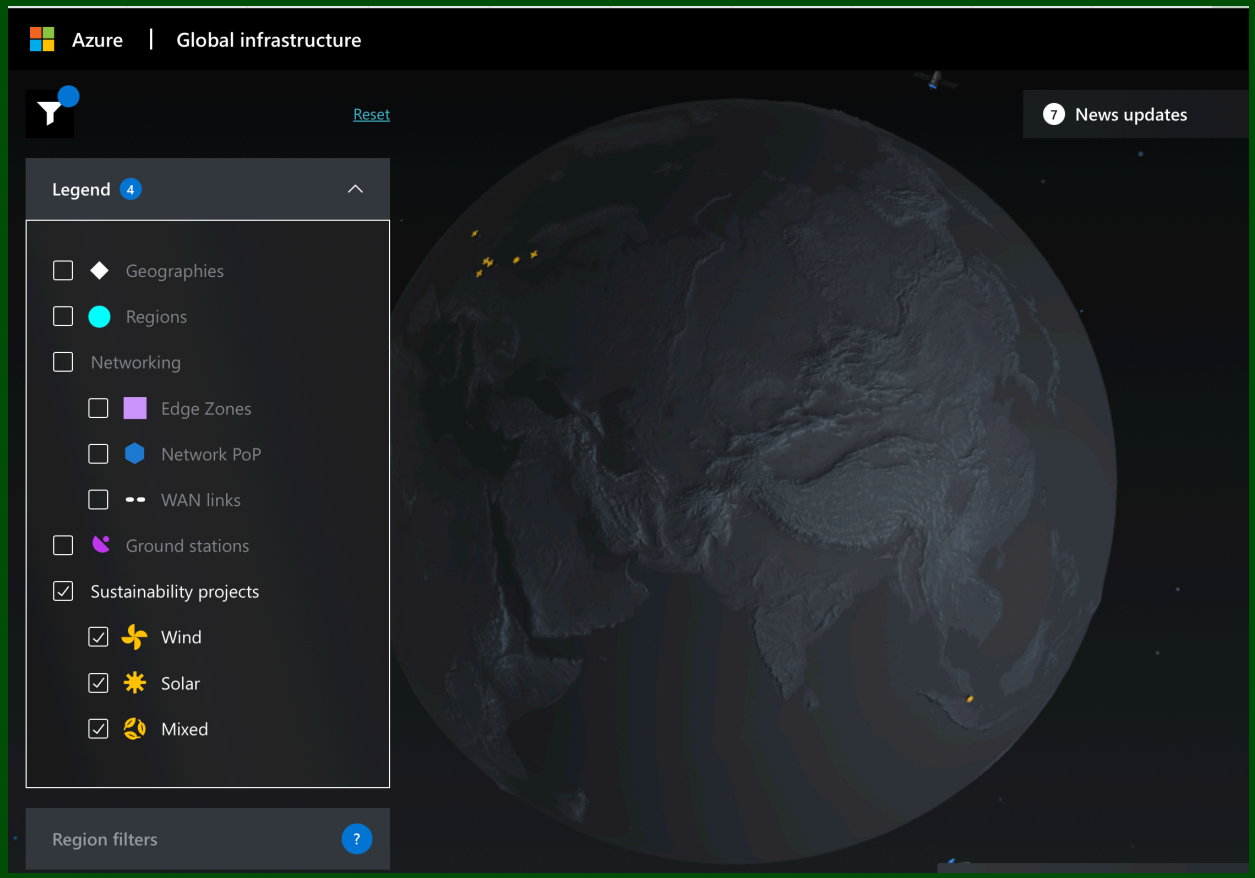
100% Renewable by 2025 commitment

https://sustainability.aboutamazon.com/environment/the-cloud?energyType=true

Azure Global Renewable Projects

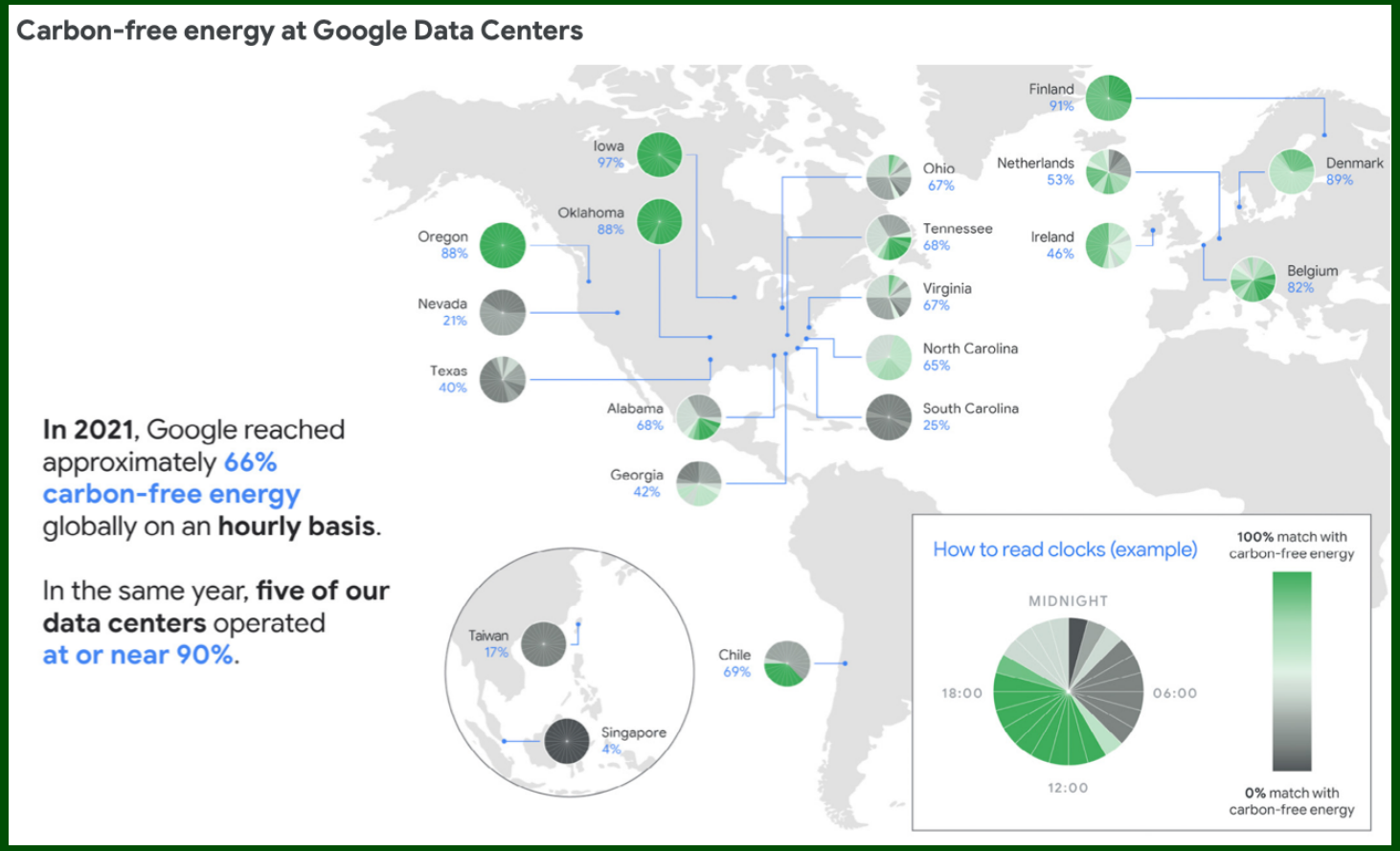
Mostly located in the USA and Europe today

100% Renewable by 2025 commitment



https://infrastructuremap.microsoft.com/explore

GCP 24x7 Hourly Differences Worldwide



https://sustainability.google/progress/energy/

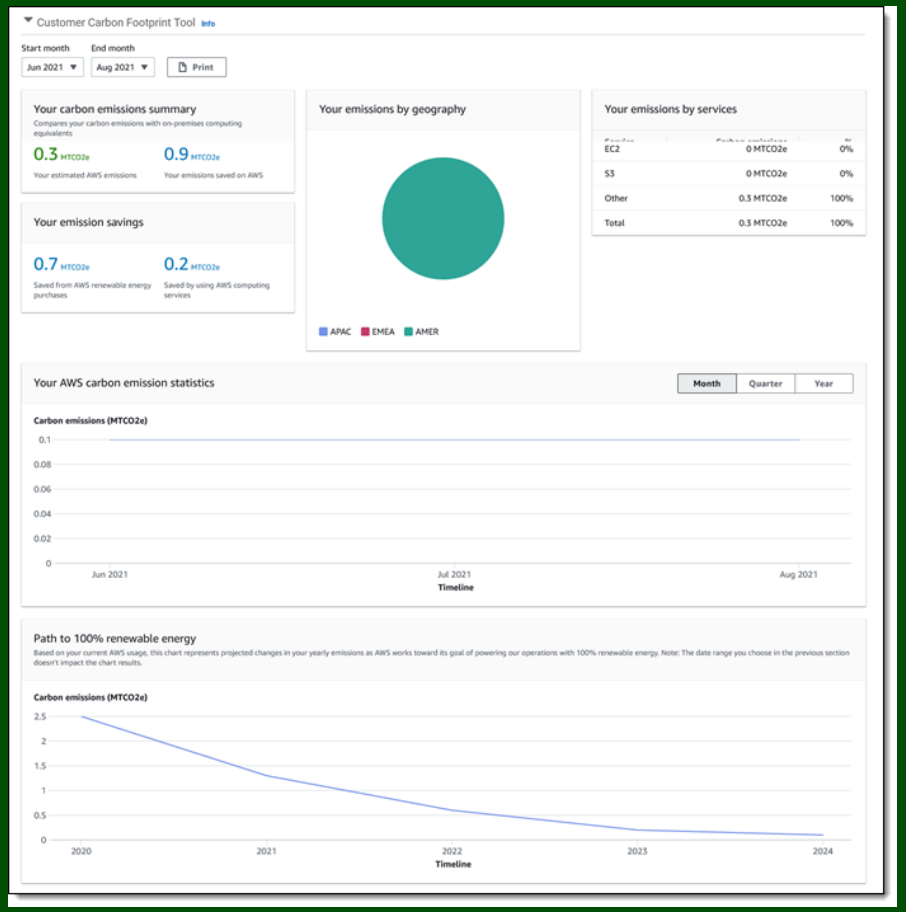
Use any cloud provider but try to minimize use of Asia regions for the next few years

There really isn't that much difference in carbon footprint between the cloud providers
They are all buying gigawatts of renewables
All have the same grid challenges in Asia
Scope 3 is dominated by the same Asian chip suppliers

They are all much better than a typical enterprise datacenter

Measuring Carbon…

Compare APIs and Schemas across AWS, Azure and GCP - and propose what we really want



AWS Customer Carbon Footprint Tool (no API)

Time: Monthly summary
Place: Continent level
Specificity: Account, EC2, S3, Other
Resolution: 0.1 Metric Tons of CO2e
Models: Scope 1, market based scope 2

https://aws.amazon.com/aws-cost-management/aws-customer-carbon-footprint-tool/
https://aws.amazon.com/blogs/aws/new-customer-carbon-footprint-tool/

Sample queries for the EnrollmentEmission entity

Query type	Example
Emissions by enrollment	{serviceRoot}/emissions
Select certain fields	{serviceRoot}/emissions?$select=enrollmentId,totalEmissions,scopeId
Include count	{serviceRoot}/emissions?$count=true
Limit result count	{serviceRoot}/emissions?$top=100
Paging	{serviceRoot}/emissions?$skip=100&$top=50
Filter by scope	{serviceRoot}/emissions?$filter=ScopeId eq 1
Filter and aggregate	{serviceRoot}/emissions?$apply=filter(ScopeId eq 1)/aggregate($count as Count, totalEmissions with average as Average, totalEmissions with sum as Sum)
Filter and group	{serviceRoot}/emissions?$apply=filter(totalEmissions gt 0.05)/groupby((ScopeId), aggregate($count as Count))`

EnrollmentUsage entity

Represents a calculated usage factor of Microsoft cloud resources.

Property	Type	Notes
dateKey	int32	Date in yyyymmdd format; dd is always 01.
enrollmentId	string	Also known as billing account ID.
orgName	string	
subscriptionId	string	
subscriptionName	string	
subService	string	For example, Azure Storage or Azure Compute.
azureRegionName	string	
usage	double	For more information about Microsoft's calculation methodology, go to Microsoft Cloud for Sustainability API calculation methodology.

Azure Carbon Footprint API Schema (OData Preview)

Time: Monthly summary
Place: Country and region specific
Specificity: Account, service
Resolution: 0.001 Metric Tons of CO_2e
Models: Scope 1, market based scope 2, scope 3

https://learn.microsoft.com/en-us/industry/sustainability/api-overview

Carbon Footprint export data schema

Send feedback

After configuring an export, a BigQuery table with the following schema is created:

Field	Type	Description	Example
usage_month	Date	Month during which this usage occurred	2021-10-01
billing_account_id	String	The Cloud Billing account ID used for the carbon footprint export	007GD7-15C0E6-BDE6B3
project.id	String	Identifier of the Google Cloud project the carbon footprint is from	my-project
project.number	String	Number of the Google Cloud project the carbon footprint is from	802583874831
service.description	String	Readable name for the Google Cloud service the carbon footprint is from	Cloud Run
service.id	String	Identifier of the Google Cloud service the carbon footprint is from	F17B-412E-CB64
location.location	String	Location of the carbon footprint at the level of a country, region, or zone	us-central1-a
location.region	String	Cloud region for the carbon footprint. NULL if usage is multi-region or global	us-central1
carbon_model_version	Integer	Version of carbon model that produced this output. This value is updated whenever the model is changed	1
carbon_footprint_total_kgCO2e.after_offsets	Float	Total carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent. Equivalent to scope 1 + scope 2 market-based + scope 3 + carbon offsets. **Currently set to NULL**	NULL
carbon_footprint_total_kgCO2e.market_based	Float	Total carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent. Equivalent to scope 1 + scope 2 market-based + scope 3. **Currently set to NULL**	NULL
carbon_footprint_total_kgCO2e.location_based	Float	Total carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent. Equivalent to scope 1 + scope 2 location-based + scope 3	1587.3
carbon_footprint_kgCO2e.scope1	Float	Total scope 1 carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent	10
carbon_footprint_kgCO2e.scope2.location_based	Float	Total scope 2 location-based carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent	400
carbon_footprint_kgCO2e.scope2.market_based	Float	Total scope 2 market-based carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent. **Currently set to NULL**	NULL
carbon_footprint_kgCO2e.scope3	Float	Total scope 3 carbon footprint for the account, project, service, location, and month in kg of CO_2 equivalent	986.8
carbon_offsets_kgCO2e	Float	Total carbon offsets for the account, project, service, location, and month in kg of CO_2 equivalent. **Currently set to NULL**	NULL

Google Carbon Footprint BigQuery Export Schema

Time: Monthly summary
Place: Country, region and zone specific
Specificity: Account, project, service
Resolution: 0.1 Kilograms of CO2e
Models: Scope 1, location based scope 2 with placeholders for market based, scope 3

https://cloud.google.com/carbon-footprint/docs/data-schema

Measuring Carbon

What do we want?

Real time carbon metrics for optimization
Just another metric like CPU Utilization

Reported via the same tools we already use
(e.g. from CloudWatch or Azure Monitor via Prometheus)

Real-Time Carbon Footprint Standard

A proposal - what @adrianco thinks would be useful…

Support: Same data for all cloud providers and datacenter automation tools
Time: Same resolution as existing monitoring tools, typically minutes
Place: Country, region and zone specific
Specificity: Account, project, service, instance, container, filesystem, etc…
Resolution: Grams of CO2e, energy in 0.001 joules (milliwatt-seconds)
Models: Scope 1, location *and* market based scope 2, scope 3

Energy data would be final, CO2e would be reported as mean and 95-percentile upper and lower confidence intervals, based on hourly updates to 24/7 renewable mix estimates including RECs and PPAs. CO2e could be re-processed to narrow the confidence interval to audit report quality after 1-2 months, and to finalize after REC settlement grid mix adjustments and supply chain scope 3 updates at 12 months.

https://github.com/Green-Software-Foundation/sci/discussions/354

Real-Time Carbon Footprint Standard

Instance Energy - updates every minute (Cloud Provider)
Carbon Intensity - updates every hour (Cloud Provider)
CPU/RAM/Process Utilization/Energy - updates every minute (Kepler)

Kepler Allocation algorithm already estimates and allocates energy


```
Metric: carbon.footprint.energy
Value: 123.4
Timestamp: Tue, 21 Mar 2023 17:47:26 -0700
Tags:
unit=joules
model=measured.v1 (or sampled, or estimated, or simulated)
pod=
node=
namespace=
instance=
project=
account=
region=us-east-1a
```

Real-Time Carbon Footprint Standard (interim)

Instance Energy - estimation model (table driven)
Carbon Intensity - updates every hour (e.g. electricitymaps.com)
Pod CPU utilization - crude allocation - updates every minute

Allocation algorithm measures active pods and exports for the cluster


```
Metric: carbon.footprint.scope2upper
Value: 234.5
Timestamp: Tue, 21 Mar 2023 17:47:26 -0700
Tags:
unit=grams
model=local (or marketplace)
pod=
node=
namespace=
instance=
project=
account=
region=us-east-1a
```

Same metric schema, but with wider confidence interval, allows portable development of tooling without waiting for everyone to provide high quality data

Comparison	Real-Time Carbon Footprint Standard	AWS Customer Carbon Footprint Tool	Azure Emissons Impact Dashboard	GCP Carbon Footprint
API Format	Prometheus/ OpenTSDB	None	OData	BigQuery
Support	All Providers	AWS	Azure	GCP
Time	Minutes	Month	Month	Month
Place	Country, Region, Zone	Continent	Country, Region	Country, Region, Zone
Specificity	Accounts, services down to containers	Accounts, EC2, S3, Other	Account, Service	Account, Project, Service
Resolution	Grams CO2e +/- 0.001 Joules energy	0.1 Metric Tons CO2e	0.001 Metric Tons CO2e	0.1 Kg CO2e
Models	Scopes 1, 2L, 2M, 3	Scopes 1, 2M	Scopes 1, 2M, 3	Scopes 1, 2L, 3
Data Availability	Immediate, 2 month, 12 month final	3 month	2 month	2 month

Measuring Carbon

What tools could we build?

Re-use cost and performance optimization tooling for CO2e optimization

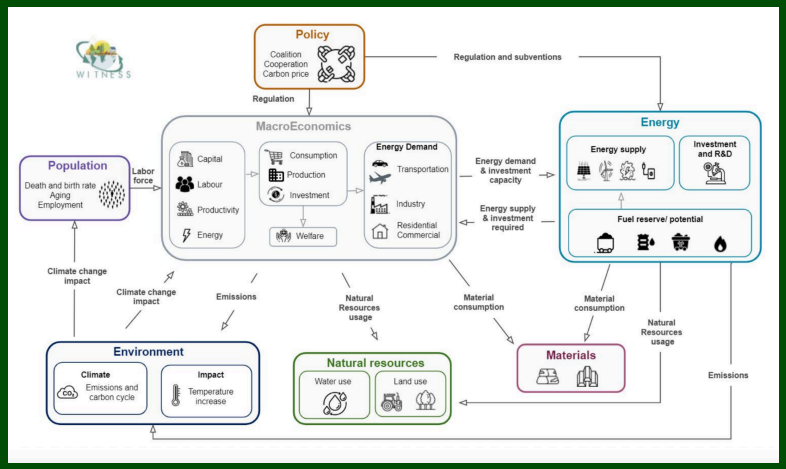
SaaS provider attribution and allocation tools for per-customer carbon reports

Architecture planning tools - e.g. what's the carbon footprint difference between running your own Kafka on EC2 vs. AWS MSK vs. Confluent vs. RedPanda vs. AWS Kinesis?

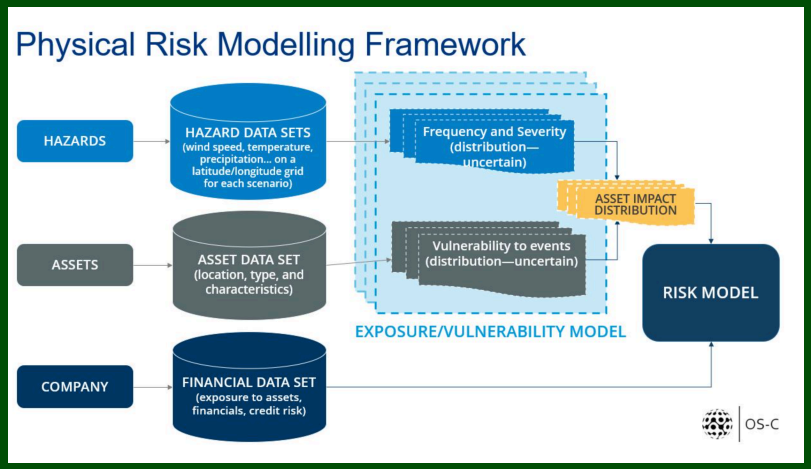
Your ideas?

One more thing...
Measuring Climate Impact Risk - On You!

OS-Climate.org - Open source - contributions welcome…



https://os-climate.org/transition-analysis/



https://os-climate.org/physical-risk-resilience/

https://github.com/os-climate/OS-Climate-Community-Hub

Things developers need to build

Add energy usage instrumentation to applications

Data lakes to collect energy and carbon measurements

Attribution and allocation algorithms

IoT/Mobile instrumentation and optimization at the edge

Supply chain carbon interchange protocols

Energy usage dashboards and reports

Energy to carbon models

Climate change impact and risk models

Questions?

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Cloud Provider Sustainability Current Status and Future Directions

DevSusOps: Adding sustainability concerns to development and operations

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March 2023