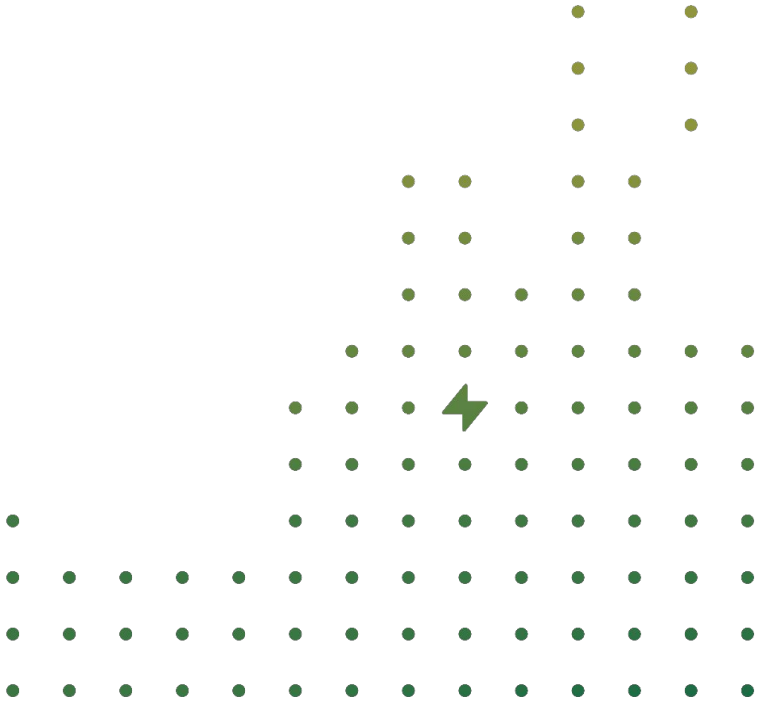
ELECTRICITY
MAPS

Data-driven grid decarbonisation

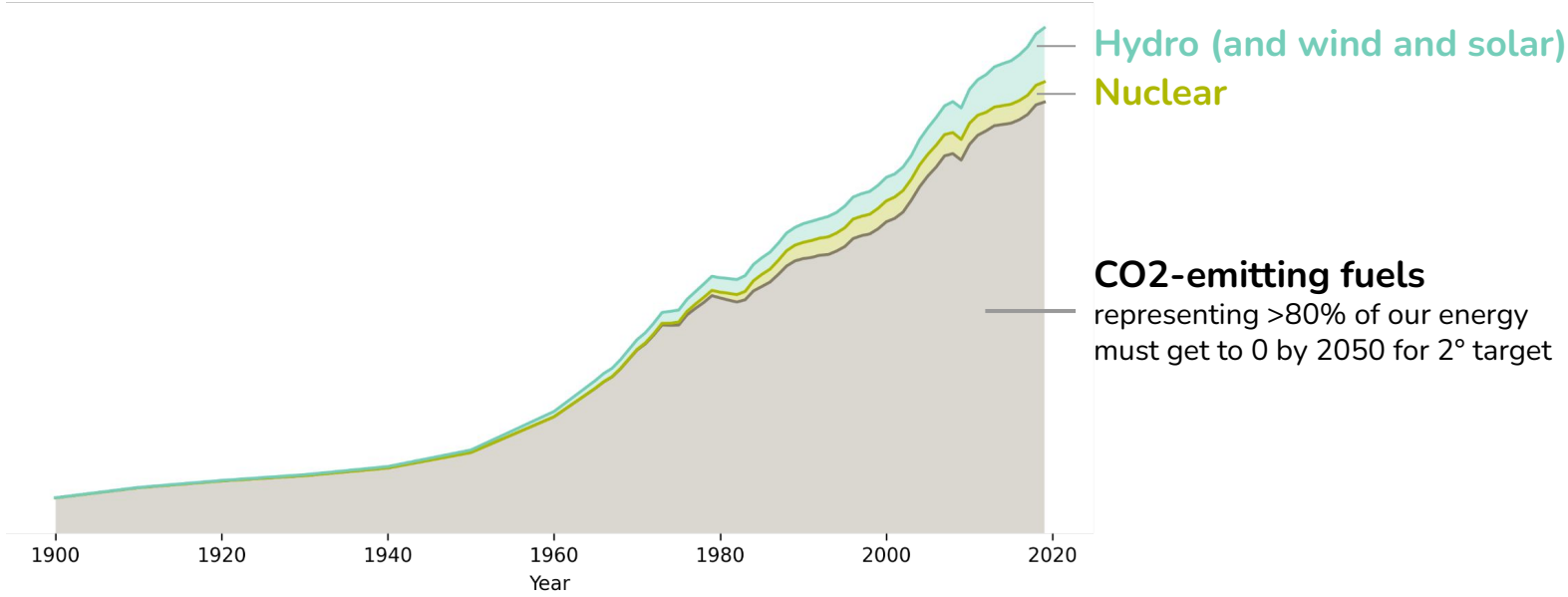


Olivier Corradi / @corradio

electricitymaps.com

Climate change is caused by fossil fuels

and our world is powered by them



Goal: electrify with clean energy

The largest decarbonisation opportunity is at stake.

Accounting for the footprint of electricity is critical.

Opportunity: availability of granular grid data

Free, popular and used across the globe
25k daily active users on our real-time map (organic traffic only). Used in universities as part of curriculum, heavily discussed on social media.

Open source
1300 contributions led to 100+ countries on the map.
Most popular #climate-change project on github.
+6000 Home Assistant integrations

Shaping emerging regulation
Used by ministers and head of states, enabling us to engage at policy level and to raise awareness about the need for granular and real-time electricity data

Electricity Maps App
+1M unique visitors in 2021

Challenges appear when attempting to *define* the carbon footprint of X

Q: What is the footprint of travelling by plane?

What is the footprint of travelling by plane?

Answer 1: I get attributed a share of the plane's engine emissions.
Footprint = engine emissions / number of passengers.

Question answered:
What is my share of emissions?

Answer 2: The plane probably takes off irrespectively of my decision (with an empty seat, or with my seat occupied by someone else).
Footprint ~ 0

Question answered:
What is the *immediate* impact of my decision?

Answer 3: If enough people decide to avoid flying (critical mass), one plane will stay on the ground, meaning my decision is only a small contribution.
Footprint = engine emissions / critical mass

Question answered:
What is the *expected long-term* impact of my decision?

What is the footprint of travelling by plane?

Answer 1: I get attributed a share of the plane's engine emissions.
Footprint = engine emissions / number of passengers.

Attributional accounting (average emissions)

Answer 2: The plane probably takes off irrespectively of my decision (with an empty seat, or with my seat occupied by someone else).
Footprint ~ 0

Consequential accounting (marginal)

Answer 3: If enough people decide to avoid flying (critical mass), one plane will stay on the ground, meaning my decision is only a small contribution.
Footprint = engine emissions / critical mass

Consequential accounting (long-run marginal)

Behavioral incentives

Answer 1: I get attributed a share of the plane's engine emissions.
Footprint = engine emissions / number of passengers.

Proper incentive ✓

Answer 2: The plane probably takes off irrespectively of my decision (with an empty seat, or with my seat occupied by someone else).
Footprint ~ 0

Wrong incentive ✗ (although physically correct)

Answer 3: If enough people decide to avoid flying (critical mass), one plane will stay on the ground, meaning my decision is only a small contribution.
Footprint = engine emissions / critical mass

Proper incentive ✓

Calculation complexity

Answer 1: I get attributed a share of the plane's engine emissions.
Footprint = engine emissions / number of passengers.

Easy to calculate ✓

Answer 2: The plane probably takes off irrespectively of my decision (with an empty seat, or with my seat occupied by someone else).
Footprint ~ 0

Exceptions are difficult to detect ×

Answer 3: If enough people decide to avoid flying (critical mass), one plane will stay on the ground, meaning my decision is only a small contribution.
Footprint = engine emissions / critical mass

Critical mass is difficult to evaluate ×

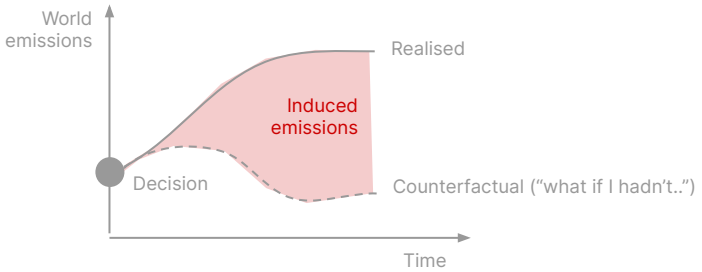
Two accounting paradigms

Attributional accounting:
Makes each party responsible for a share of emissions, and incentivises each to reduce their share to zero.

p1	p2	..	..	..	pn

- Several attribution rules possible (by passenger, by ticket price, by passenger weight..)

Consequential accounting:
Compares decision (taking the plane) with a counterfactual (not taking the plane), and makes assigns the difference as footprint



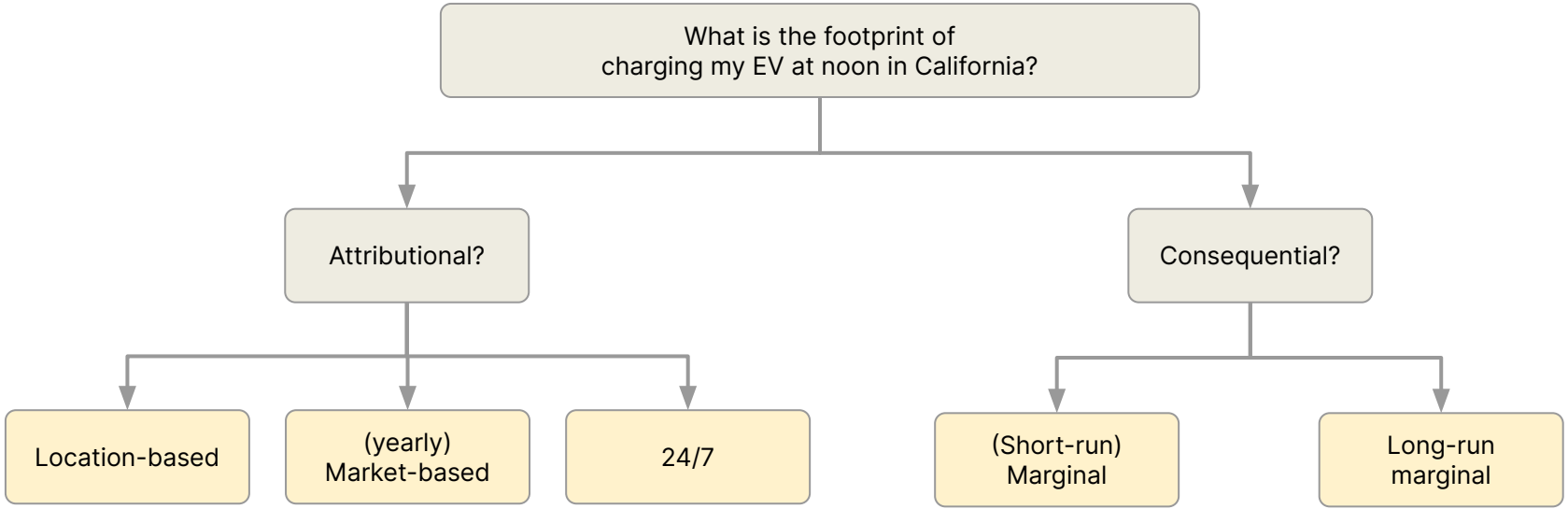
- Sensitive to time-scale considered (short-term, long-term..)
- Requires simulation of alternative future (counterfactual)

Summary

Methodology	Sends the right incentive?	Simple to calculate?	Metric
Attributional	✓	✓	Average emissions
Consequential (short-term)	✗ It overlooks long-term consequences	✗ it requires simulating of alternative world (counterfactual)	Marginal
Consequential (long-term)	✓	✗ it requires simulating of alternative world (counterfactual)	Long-term marginal

What is the footprint of charging my EV at noon in California?

It’s complicated!



Different ways to *attribute* emissions

There are **multiple ways to attribute emissions from generators to consumers**

	location-based	(yearly) market-based	24/7
What	Consumers can't chose the origin of their electricity, as it irreversibly mixes as it gets injected into the grid	Consumers can buy GOs/RECs to cover their annual consumption and thus become 100% renewable	Same as market-based but GOs/RECs need to be physical deliverable (temporal and spatial matching)
Impact	✓ Incentivises flexibility ✓ Incentivises optimal sitting × No way to fund capacity investments × No way to fund storage investments ✓ Credible traceability instrument	× Incentivises flexibility × Incentivises optimal sitting ✓ Funds capacity projects[1] × No way to fund storage investments × Credible traceability instrument	✓ Incentivises flexibility ✓ Incentivises optimal sitting ✓ Funds capacity projects[1] ✓ Funds storage and other grid projects ✓ Credible traceability instrument

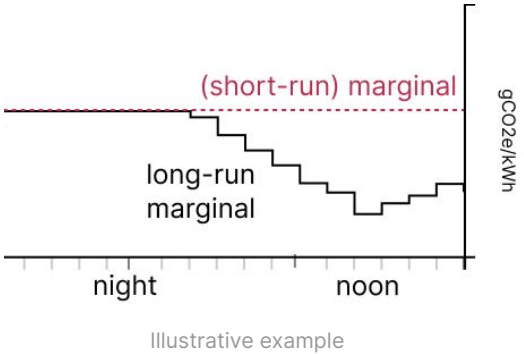
[1] if the purchase is additional

Different time scales of *consequences*

	‹seconds	minutes, hours	›years
Metric	NA	(short-run) marginal	Long-run marginal
What	The inertia of the system causes slight changes of its frequency, but doesn't cause power plants to ramp up / down	The marginal power plant might be caused to ramp up / down	Might change offer/demand patterns, which alters the business case of generation assets, causes new plants to be installed, and existing plants to be decommissioned
Impact	× Imperceptible carbon impact × No meaningful incentive	✓ Reduces immediate emissions × Hinders long-term reductions[1] × Hinders optimal sitting[2]	× Reduces immediate emissions ✓ Incentivises long-term reductions ✓ Incentivises optimal sitting

[1] short-run marginal rarey incentivizes installation of new renewable capacity, read more here.

Why (short-run) marginal doesn't always incentivize long-term reductions



Illustrative example

Short-run marginal is typically gas (at all hours)

Long-run marginal is typically solar/wind during sunny/windy hours

(Short-run) marginal *rarely* incentivises consuming during most sunny hours
Because more consumption can't cause the sun to shine more intensely.
Exception: curtailment, which is difficult to capture/predict

Long-run marginal *incentivises* consuming during sunny/windy hours
Because persistent additional demand during these sunny hours creates incentives to install new renewables, and to decommission fossil assets

Consuming outside of sunny hours prevents the incentivisation of new solar capacity, and prevents decommissioning of fossil assets used for non-sunny hours.

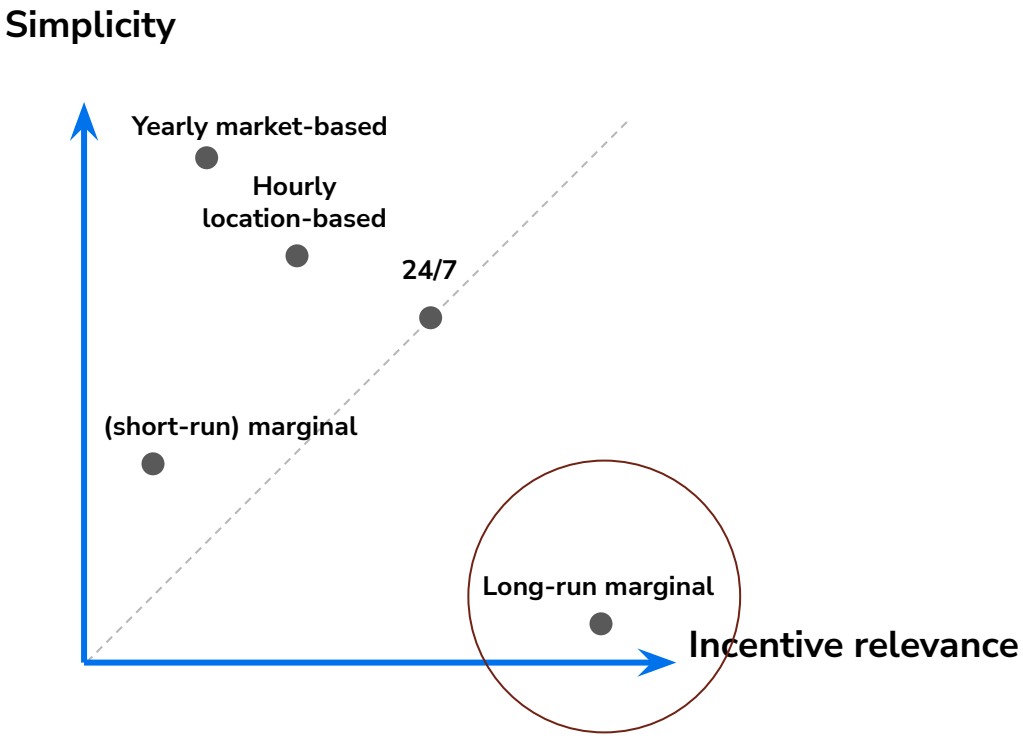
More at https://www.electricitymaps.com/blog/marginal-vs-average-real-time-decision-making

Summary

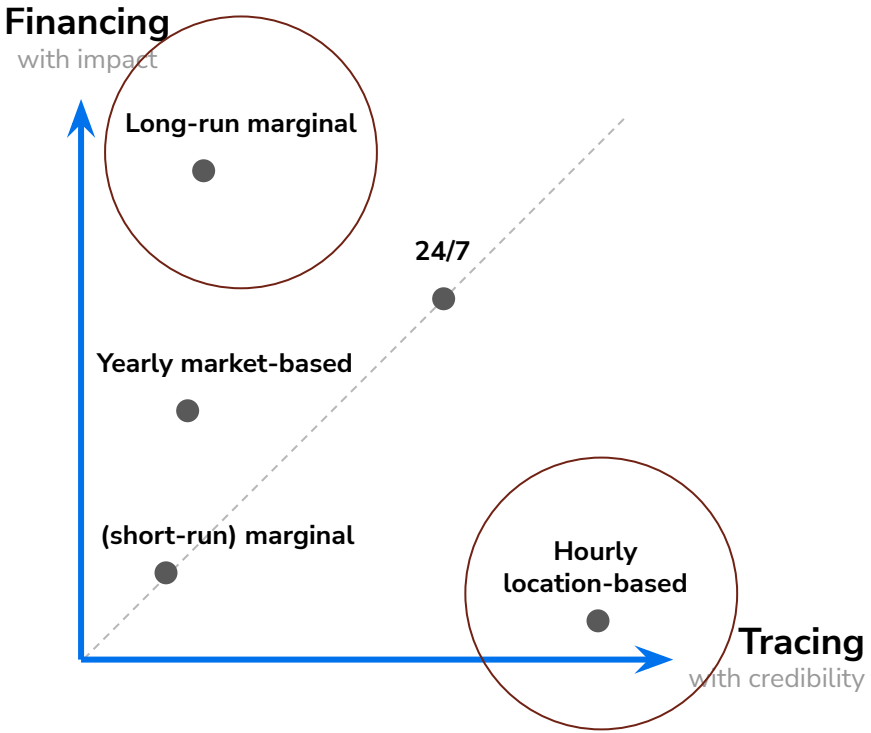
Methodology	Sends the right incentive?	Simple to calculate?	Metric
Attributional (hourly location-based)	– Incentivises flexibility but not financing new capacity	✓	Average emissions
Attributional (yearly market-based)	– Incentivises new capacity but not flexibility nor optimal sitting	✓	
Attributional (24/7)	✓	– (residual mix increases complexity)	
Consequential (short-term)	✗ it overlooks long-term consequences by only decarbonising the margin	✗ it requires simulating an alternative world (counterfactual)	(Short-run) marginal
Consequential (long-term)	✓	✗ it requires simulating an alternative world (counterfactual)	Long-term marginal


COMPROMISES
LIGHTYEAR
COMPROMISES EVERYWHERE
imgflip.com

Incentive relevance vs computational simplicity



Traceability or financing?



Practical examples

What is the footprint of charging my EV at noon in California?

What is the footprint of charging my EV at noon in California?

Answer 1a (location-based): low (it's solar!)

Answer 1b (market-based): low if a certificate was bought, high if everyone else bought the solar

Answer 1c (24/7): low if a purchased certificate generated electricity locally and during that hour, high if everyone else bought the local solar certificates of that hour.

Answer 2 (marginal): high (due to fossils being on the margin)

Answer 3 (long-term marginal): negative (due to induced negative emissions of incentivising fossil replacement with solar)

Where should I install my next data center?

Where should I install my next data center?

Answer 1a (location-based): in places that will deliver low-carbon electricity when I expect to use it

Answer 1b (market-based): anywhere?

Answer 1c (24/7): in places that will deliver low-carbon electricity when I expect to use it

Answer 2 (marginal): in places where the margin is the least emitting

Answer 3 (long-term marginal): in places where the additional demand will be met with new low-carbon investments

In conclusion

Summary:

- Attributional = chunk emissions, attribute responsibility to each consumer
- Consequential = compare worlds
- Several attribution rules for attributional (location-based, yearly market-based, 24/7)
- Several time-scales for consequential
- No silver bullet: compromises must be made

Recommendations:

- Want traceability (i.e. use in an app)? Use location-based or 24/7
- Want to assess the impact of bigger strategic decisions (installing a datacenter, making a policy recommendation…)? Use long-term marginal if available, fallback to projected location-based or 24/7

More at https://www.electricitymaps.com/blog/marginal-vs-average-real-time-decision-making and https://www.electricitymaps.com/guides/accounting-guide

Thanks for listening

Olivier Corradi
olivier.corradi@electricitymaps.com

electricitymaps.com