Estimation of marginal emissions in electricity networks using electricityMap

Olivier Corradi / @corradio
olivier.corradi@tmrow.com

Tomorrow

tmrow.com

/whoami

Olivier Corradi, French/Danish

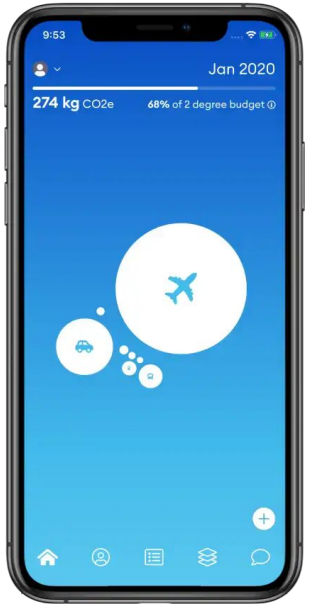
- MSc Mathematical Statistics @ DTU (Copenhagen)
- MSc Engineering @ Centrale Paris
- IBM **Research** (Smart Grids)
- Google (Product Quality, Energy)
- VP Engineering & Datascience @ snips (AI startup, hired first 30+ employees)
- Founded Tomorrow in 2016

The best minds of our generation are thinking about ~~how to make people click on ads~~ climate change.

Our mission: get the world to understand and reduce their carbon footprint

electricityMap

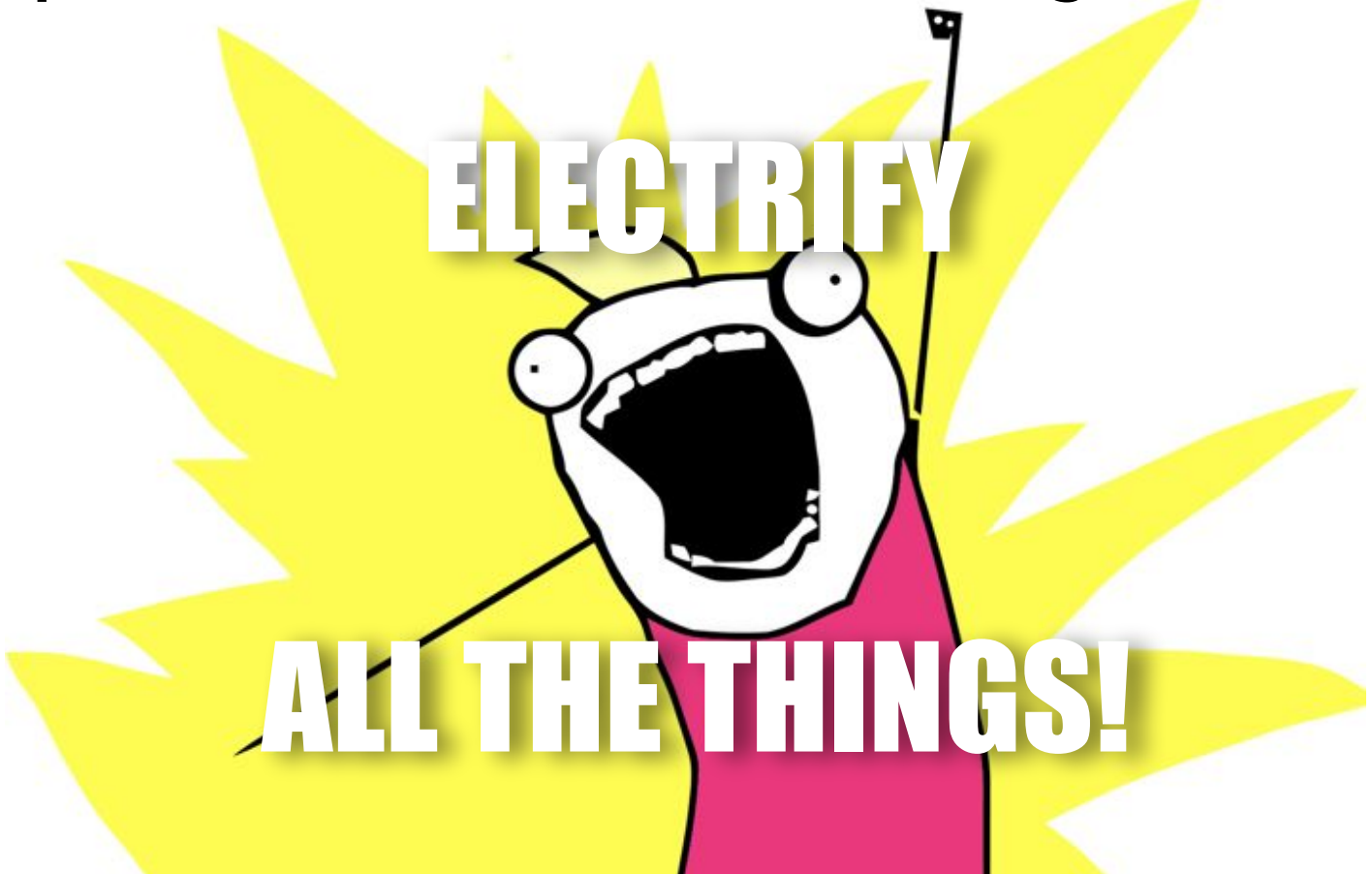
Understand the carbon footprint of electricity usage worldwide

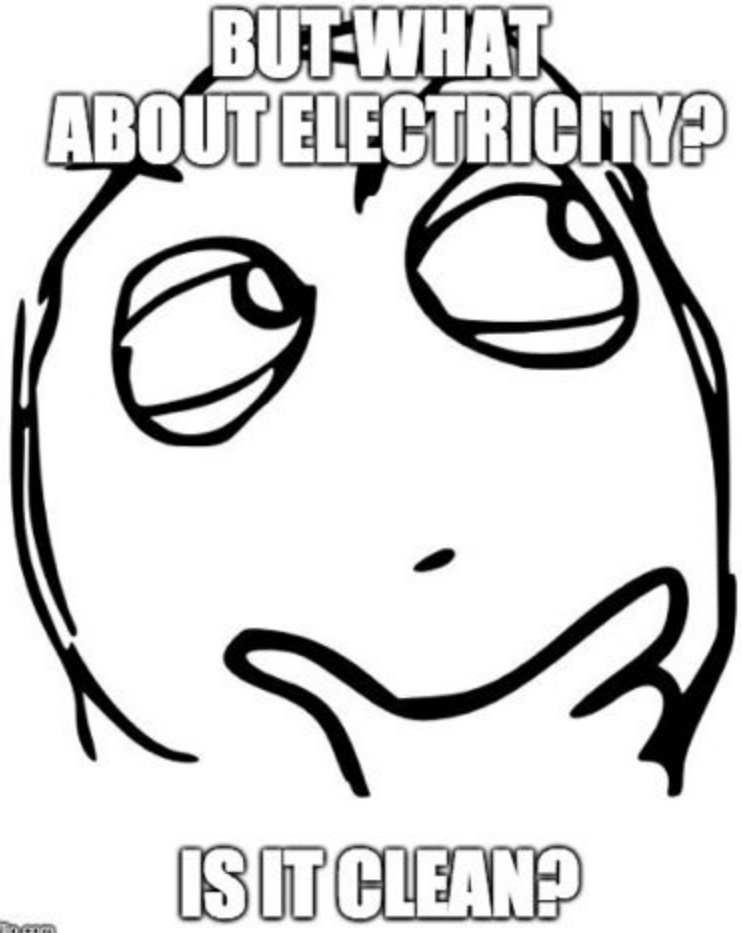


Codename “Tomorrow App”

Automatically calculates the carbon footprint of your daily activities

A proposed solution to climate change

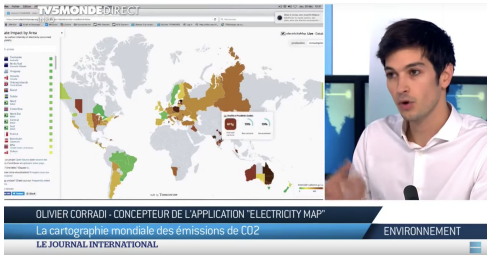



BUT WHAT
ABOUT ELECTRICITY?
IS IT CLEAN?
imgflip.com

In 2016, we built electricitymap.org

to map the world's electricity emissions, **in real-time**

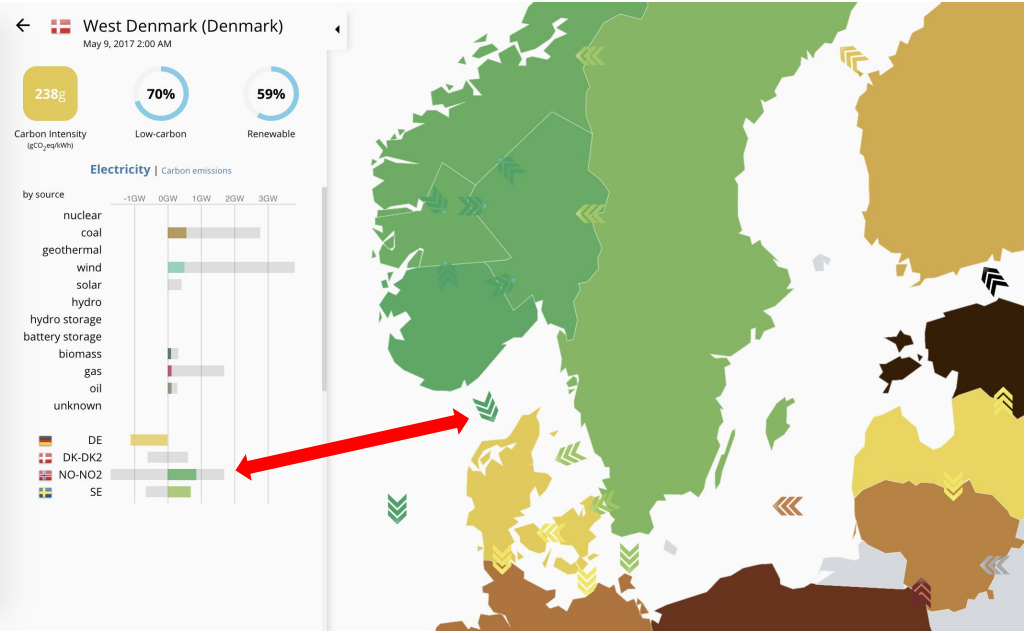
- 3000 daily active users, >1 million yearly visits since 2017
- >1000 github contributions with >90 country integrations
- Used in TV debates, classrooms, universities, by policy makers..



GET IT ON Google Play

Download on the App Store

We use flow-tracing to compute the origin of electricity



Flow tracing rules

1. **Each "zone" is a copper plate**, with electrons perfectly and instantaneously mixed

2. **Imports impact consumption mix** (and thereby carbon intensity) **proportionally to the amount imported**
   For instance, Denmark imports green power from Norway & Sweden, itself potentially importing from Finland etc...

3. **You don't choose what you export/import**.
   Germany imports from Denmark with the carbon intensity of Denmark at that time. It can't "choose" to import only "Norwegian hydro" electrons

Note: Flow-tracing is a well know methodology in scientific literature. We published our own peer reviewed paper using electricityMap data.
Tranberg et al. (2018) "Real-Time Carbon Accounting Method for the European Electricity Markets" https://arxiv.org/abs/1812.06679

Tracing back the origin of electrons

Power and CO2e consumed in a zone must be produced somewhere else **(energy conservation)**

We need to find the **carbon intensity** (gCO2e/kWh) for each zone.

Conversation of energy:

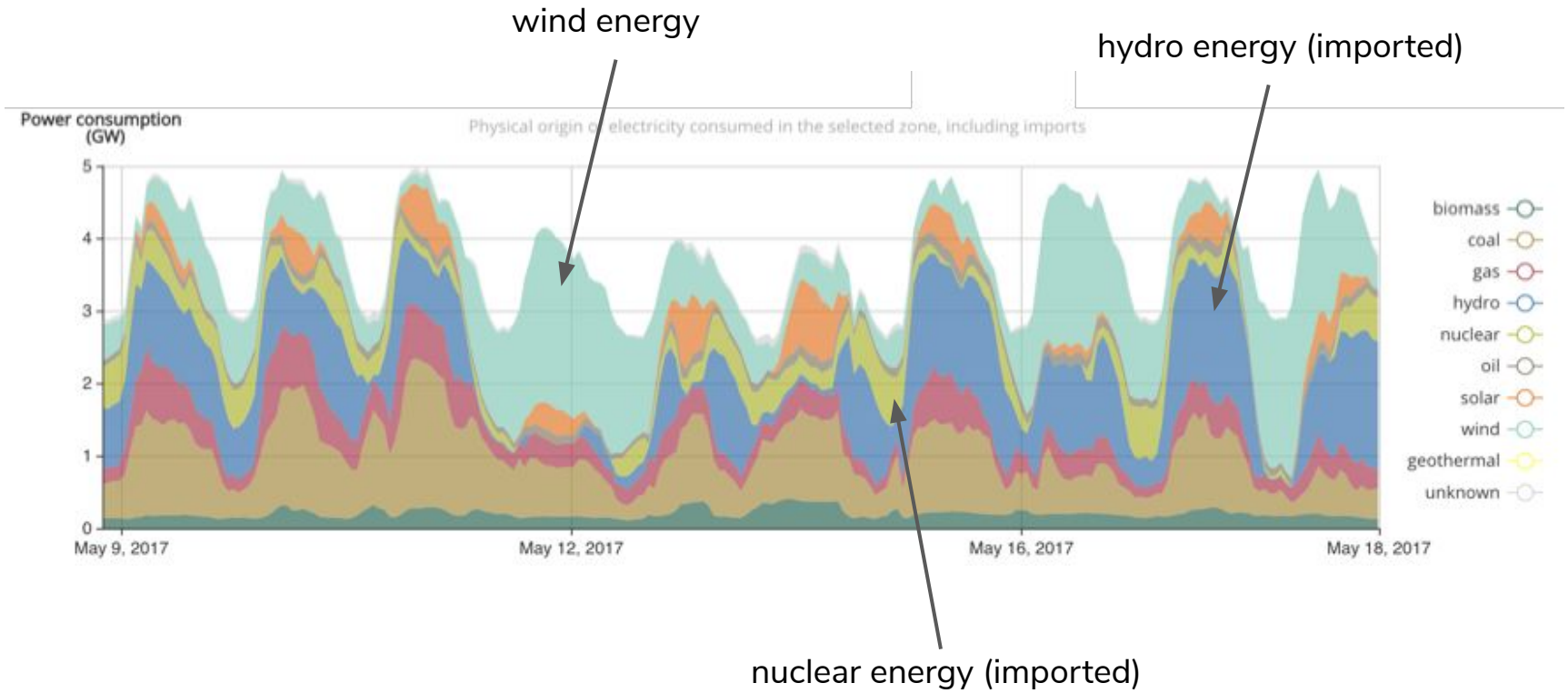
$$\text{power consumed} = \sum \text{production} + \sum \text{imports} - \sum \text{exports}$$

Conversation of CO2:

$$\text{power consumed} * \text{carbon intensity} = \sum \text{production} * \text{carbon intensity of mode} + \sum (\text{imports} * \text{carbon intensity other area}) - \text{carbon intensity} * \sum \text{exports}$$

Last step: solve for x, Ax=b

Physical origin of electricity used in Denmark



What is the marginal origin of electricity

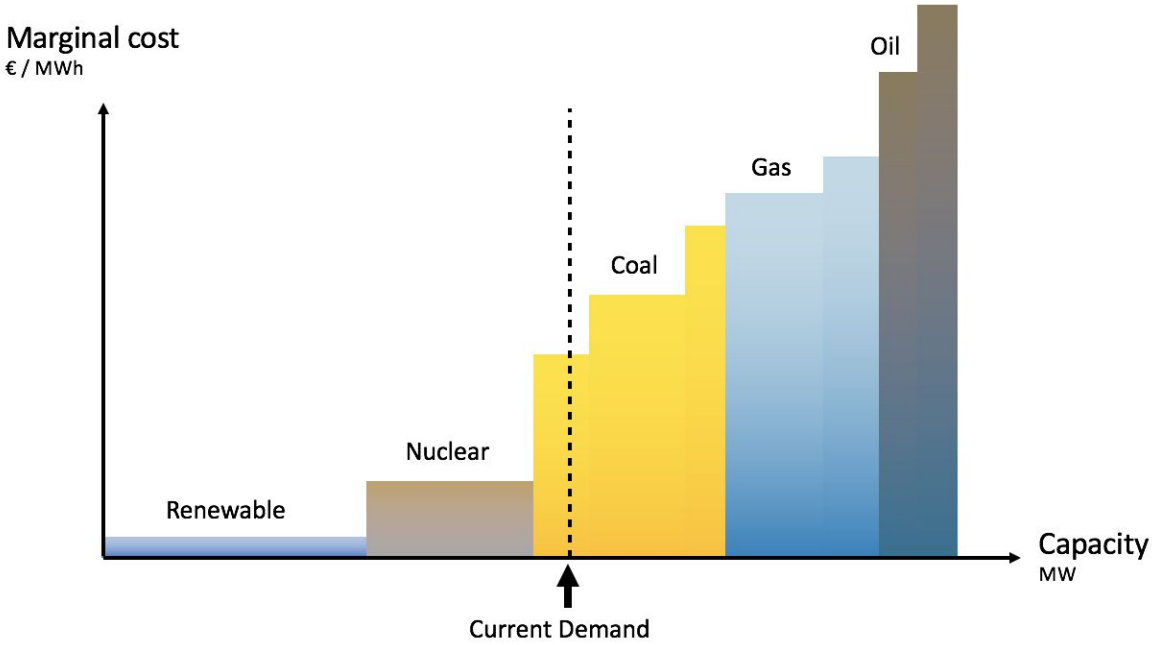
Use case: when I charge my EV, where does that electricity come from?

Power plants are dispatched by increasing cost

When electricity demand is increased, the first power plant to increase its production is cheapest that has spare capacity

We call that power plant the **marginal power plant**.

Problem: the dispatch order is **secret**



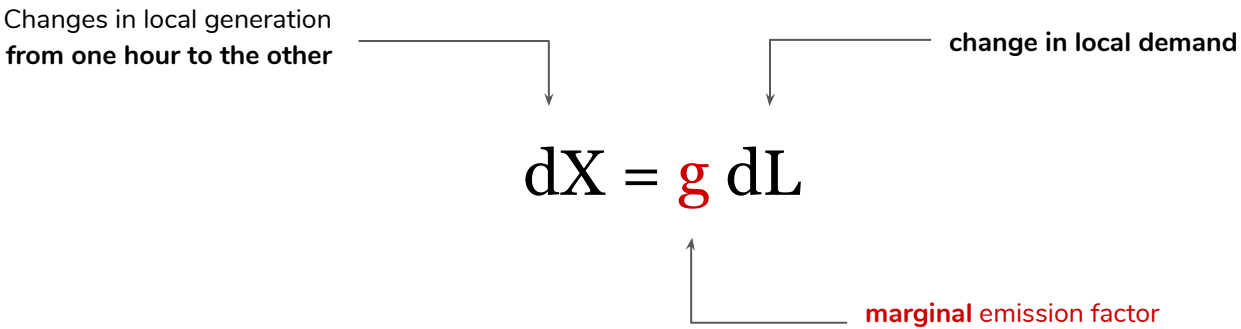
What is the marginal origin of electricity

Color on electricityMap: the footprint of electricity consumed

Marginal: sensitivity analysis (where does the **next** unit of power come from)

Estimating the marginal origin of electricity

What has previously been done:

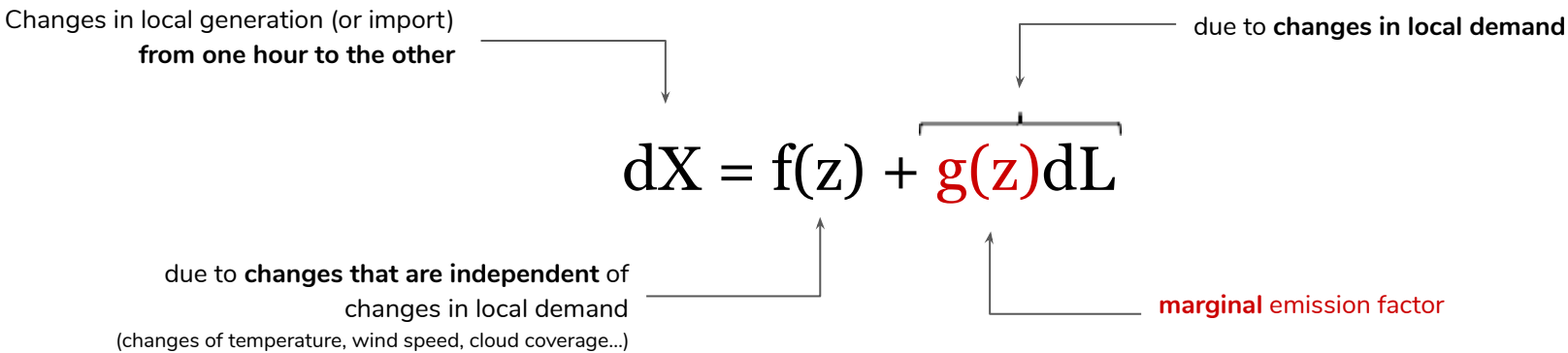


Limitations:

- Doesn't take into account imports/exports
- Doesn't take into account external effects that are independent of changes in local demand
- No hourly granularity

Estimating the marginal origin of electricity

Idea: compare increases in demand in similar situations



Mathematical intuition:

- First order Taylor expansion around a fixed point z (which represents business as usual)
- First response of a Finite Impulse Response (signal processing)

Overall methodology

$$dX = f(z) + g(z)dL$$

1/ Create a **linear** model to reconstruct changes over time dX

Use $\mathbf{Z}$ as a feature vector (wind speed in each area, market prices in each area, etc..).

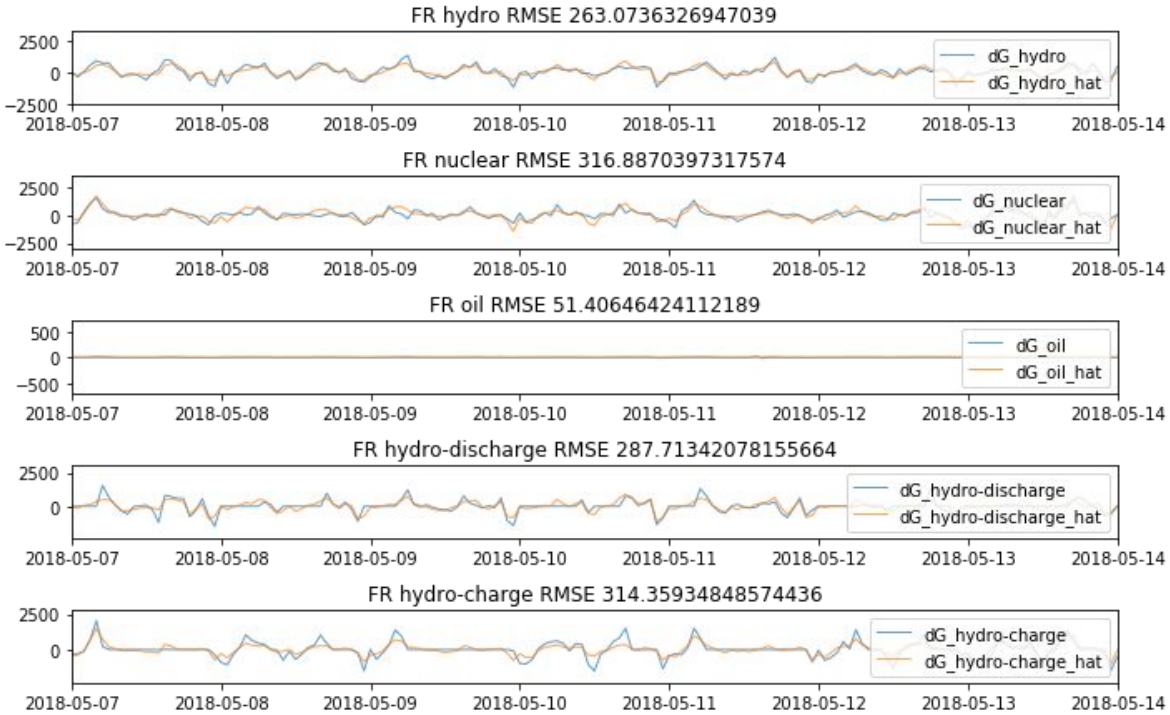
$$dX = z^T c_1 + z^T c_2 \, dL$$

2/ Fit for both changes of local generation and import/exports for each zone

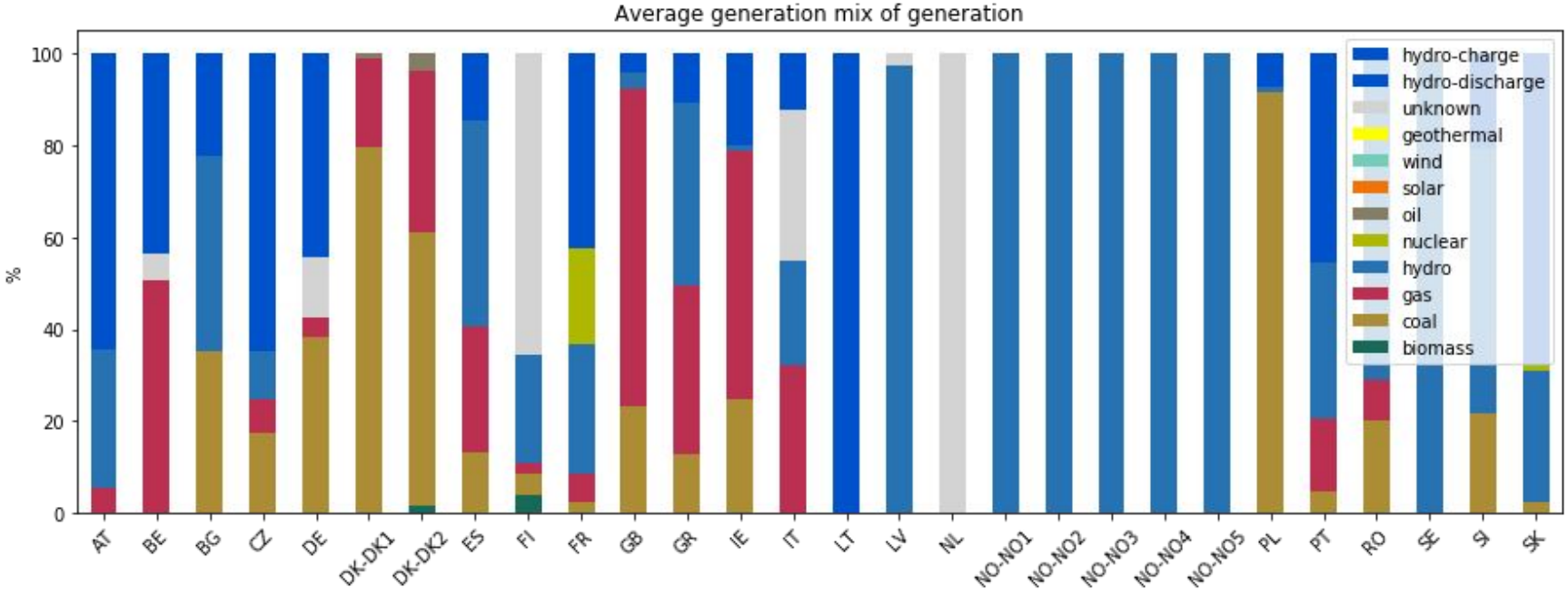
L1 regularization is used to select only the relevant features in $\mathbf{Z}$ (we have >500 features)

3/ Flow-trace and finalize

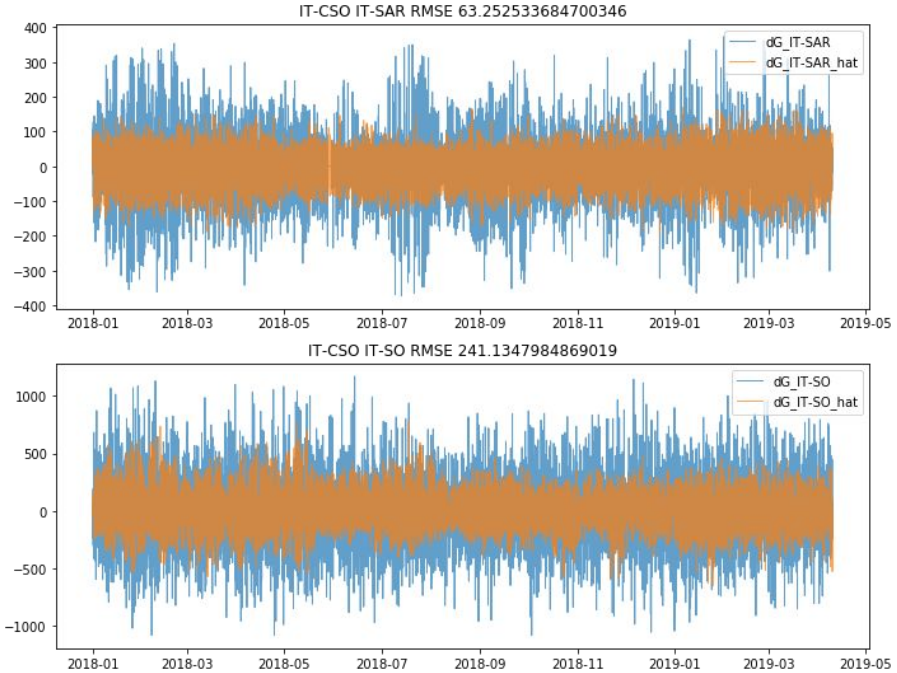
Trying to reconstruct the past (generation mix)



How local generation reacts

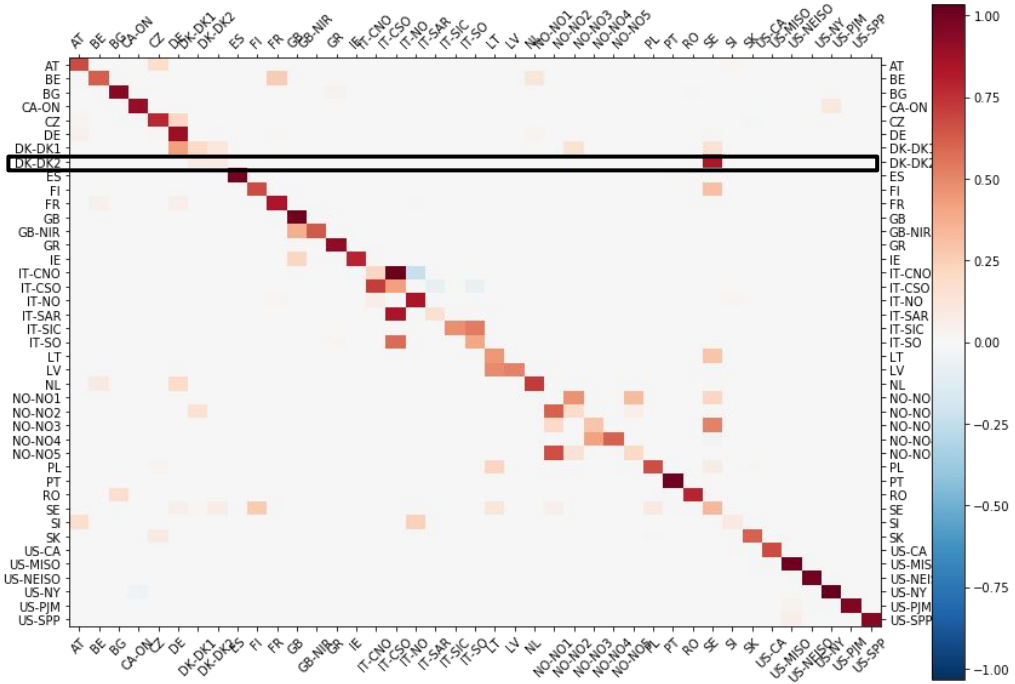


Trying to reconstruct the past (interconnectors)

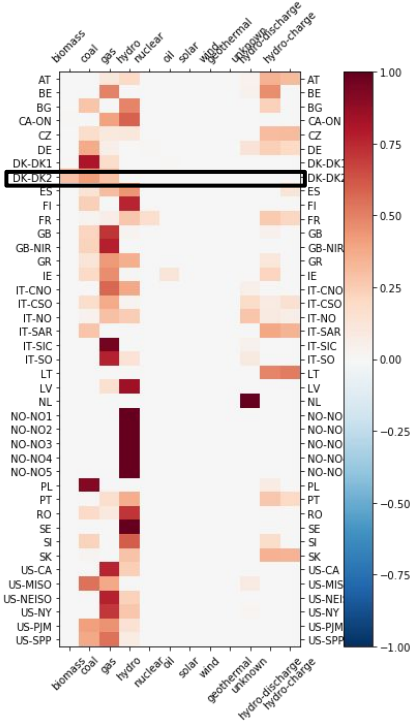


Visualising averages over a year

Do **local generators** or **interconnectors** reacts to a change in demand?



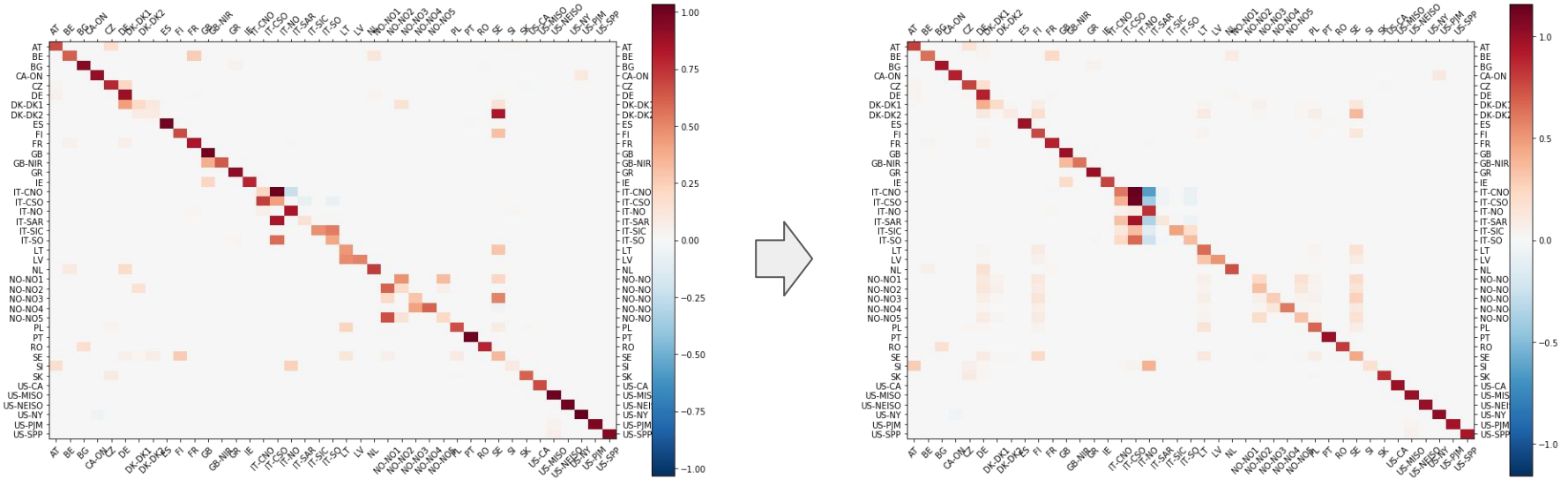
How **local generation** reacts to a change in demand



How interconnectors react to a change in demand

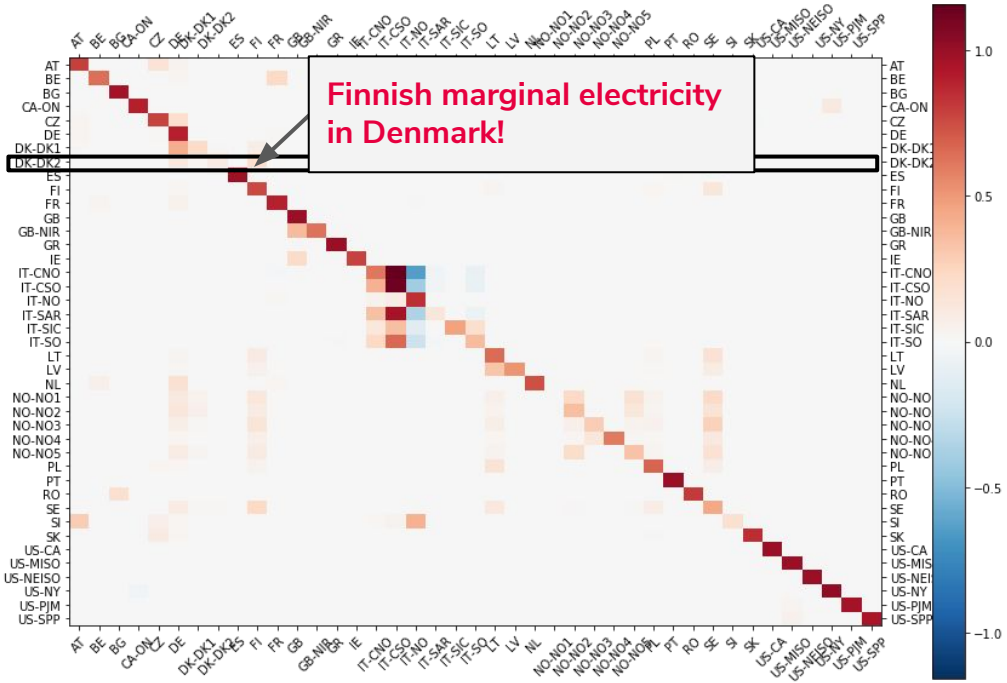
Assumption: an increase in import from zone A is equivalent to an increase in demand in zone A

Using a slightly adjusted **flow-tracing** method (not explained here), one can compute the nth-order matrix.

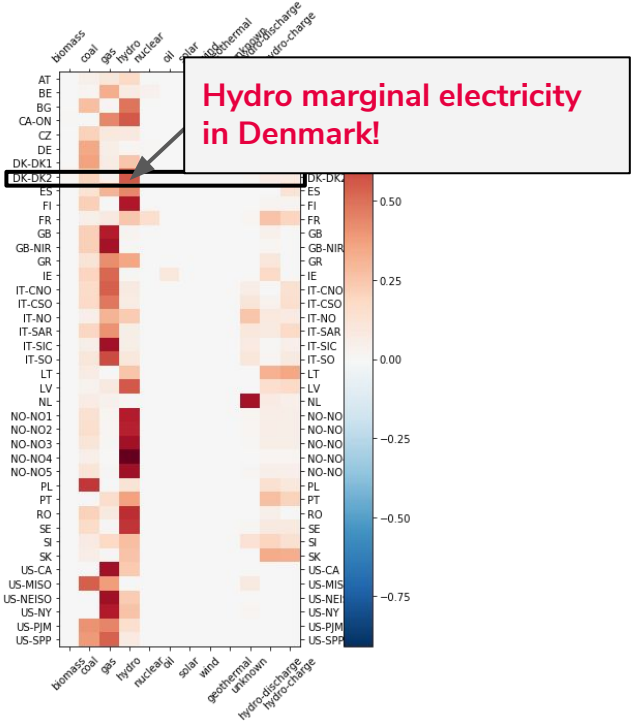


Visualising averages over a year (n-th order)

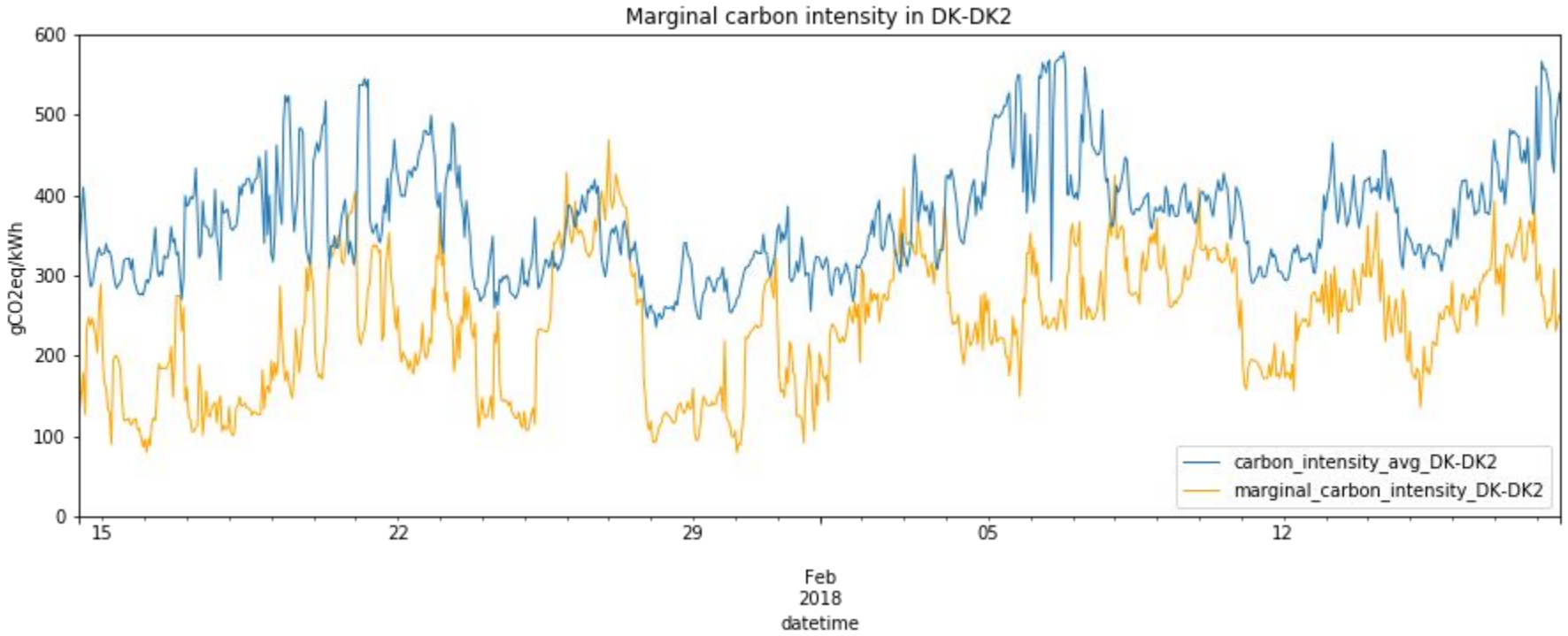
Do **local generators** or **interconnectors** reacts to a change in demand?



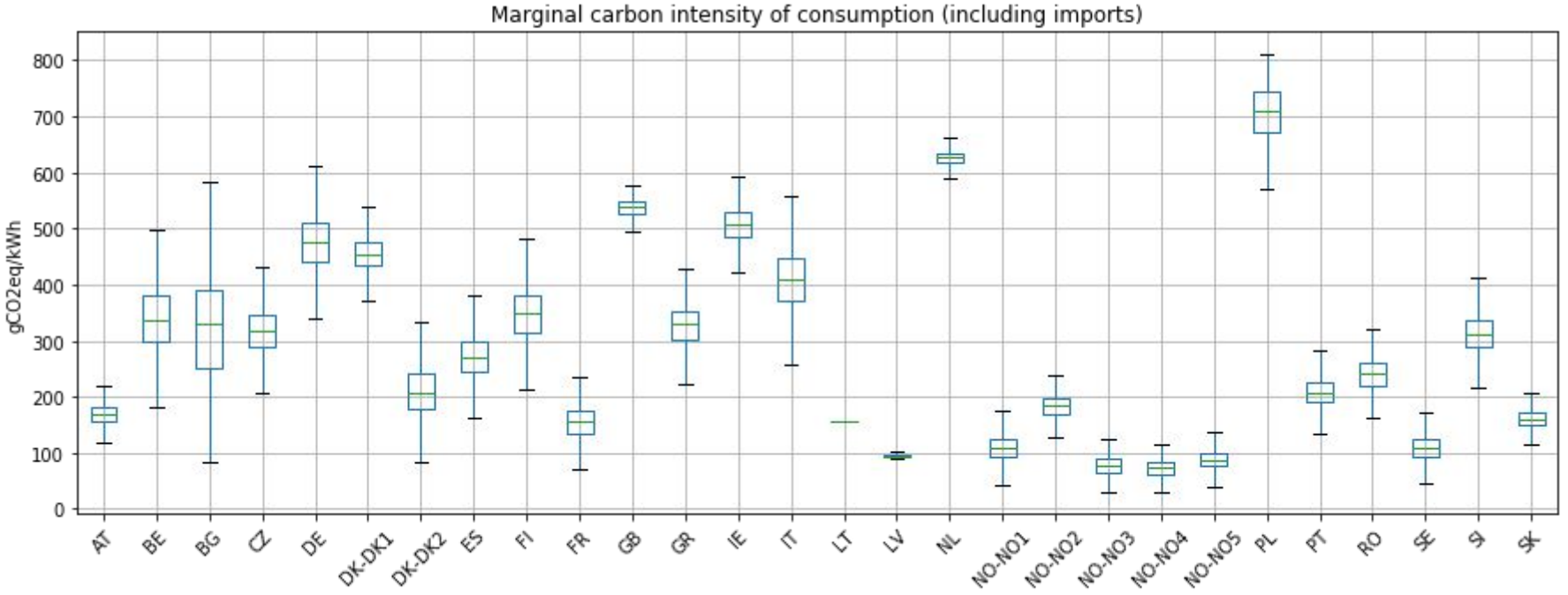
How **local generation** reacts to a change in demand



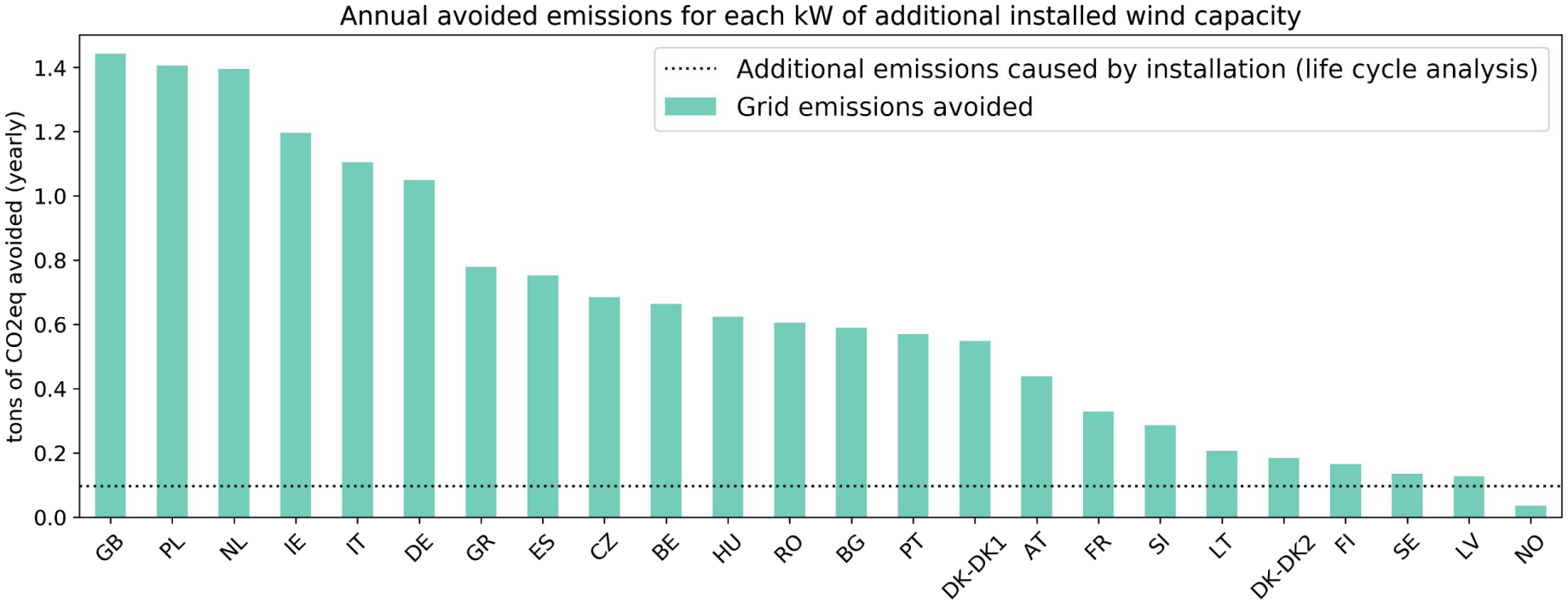
Marginal carbon emissions



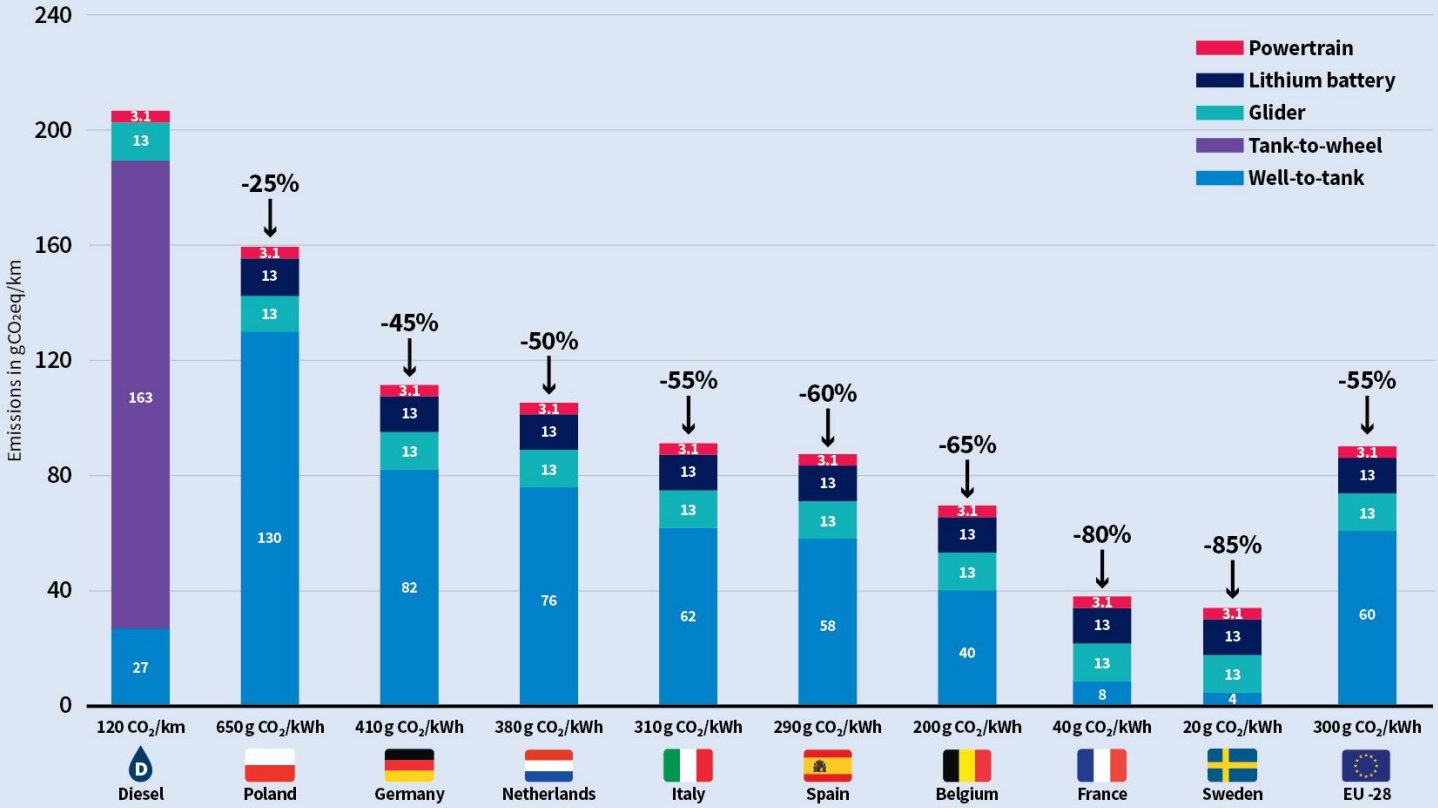
Marginal carbon emissions (average)



Where to install intermittent renewables?



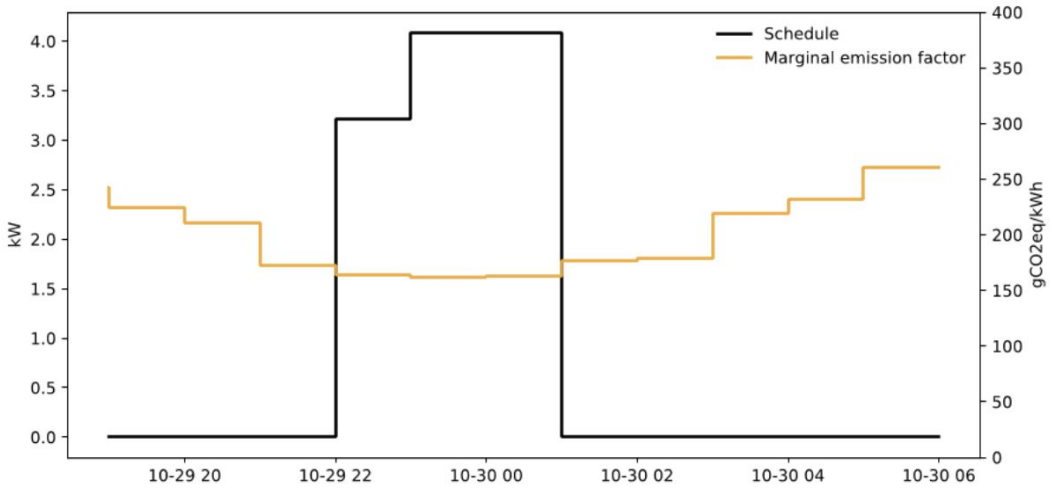
Electric vehicles' climate impact in different energy mixes

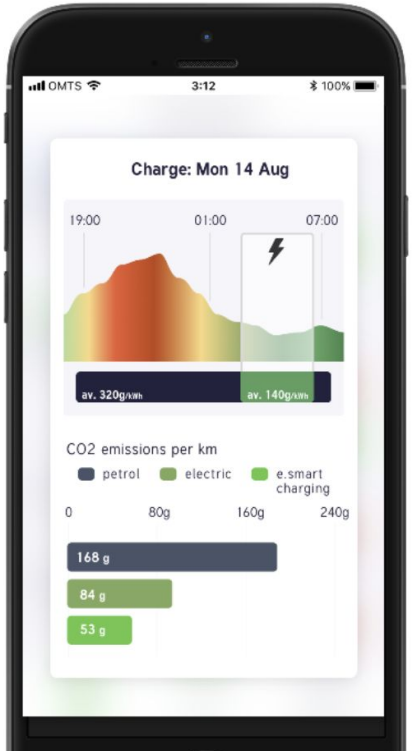


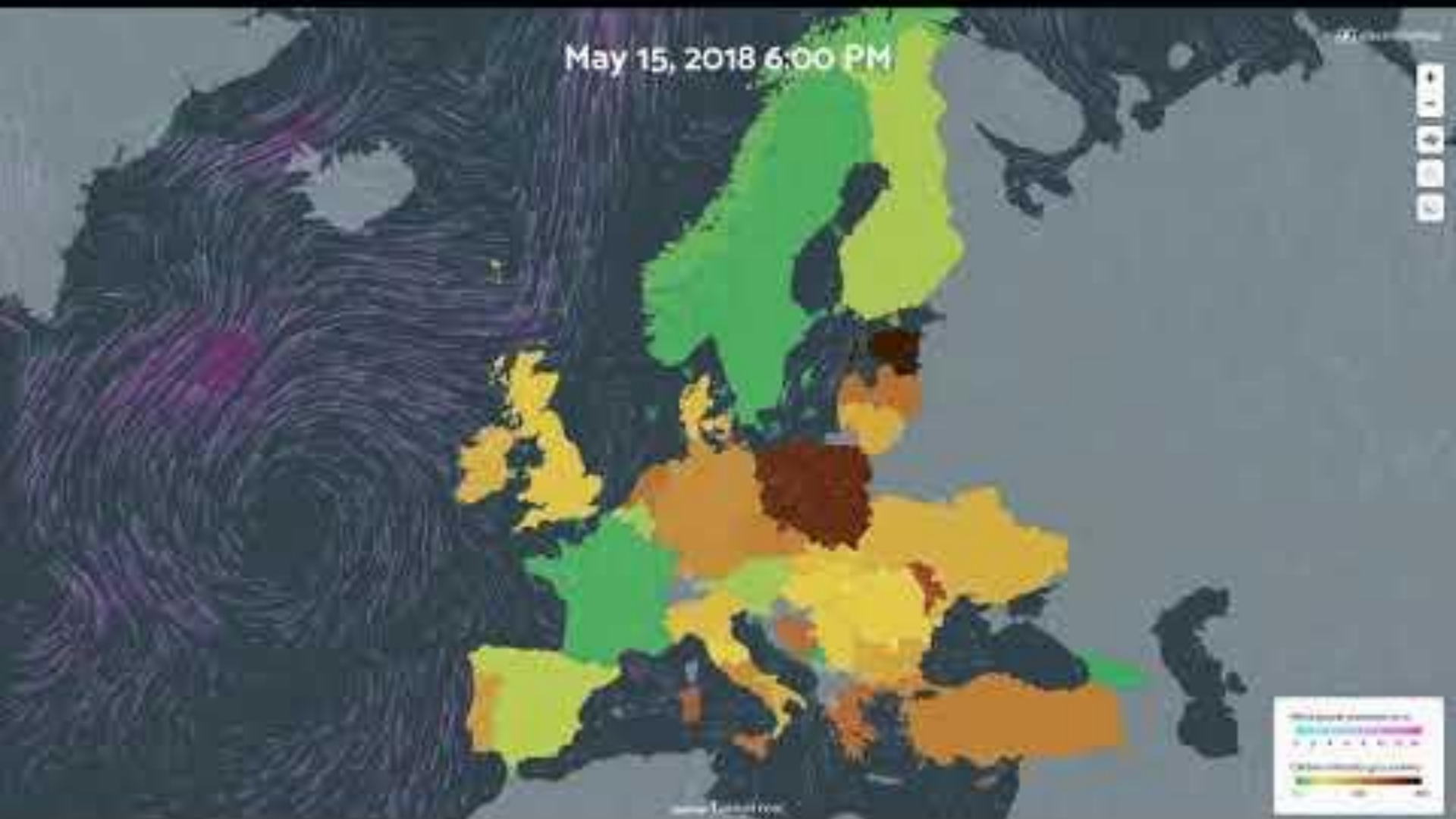
Source: Messagie, M. *Life Cycle Analysis of the Climate Impact of Electric Vehicles*, October 2017. VUB university, Brussels.

Smart charging EVs

Parker project: demonstrated 13% emission avoided with smart charge (compared to “dumb” charge)






May 15, 2018 6:00 PM

api.electricitymap.org

Real-time electricity & carbon API with forecasts

Precisely measure the origin of your electricity and optimize your emissions using data from over 100 geographies worldwide.

Get in Touch | Learn More

Key customers

EDF ENVIRONMENTAL DEFENSE FUND — Finding the ways that work

barry

LANCEY energy storage

ERICSSON

OECD

Key sponsors

eit Climate-KIC

Innovation Fund Denmark

La FRENCH TECH

Horizon 2020
European Union Funding
for Research & Innovation

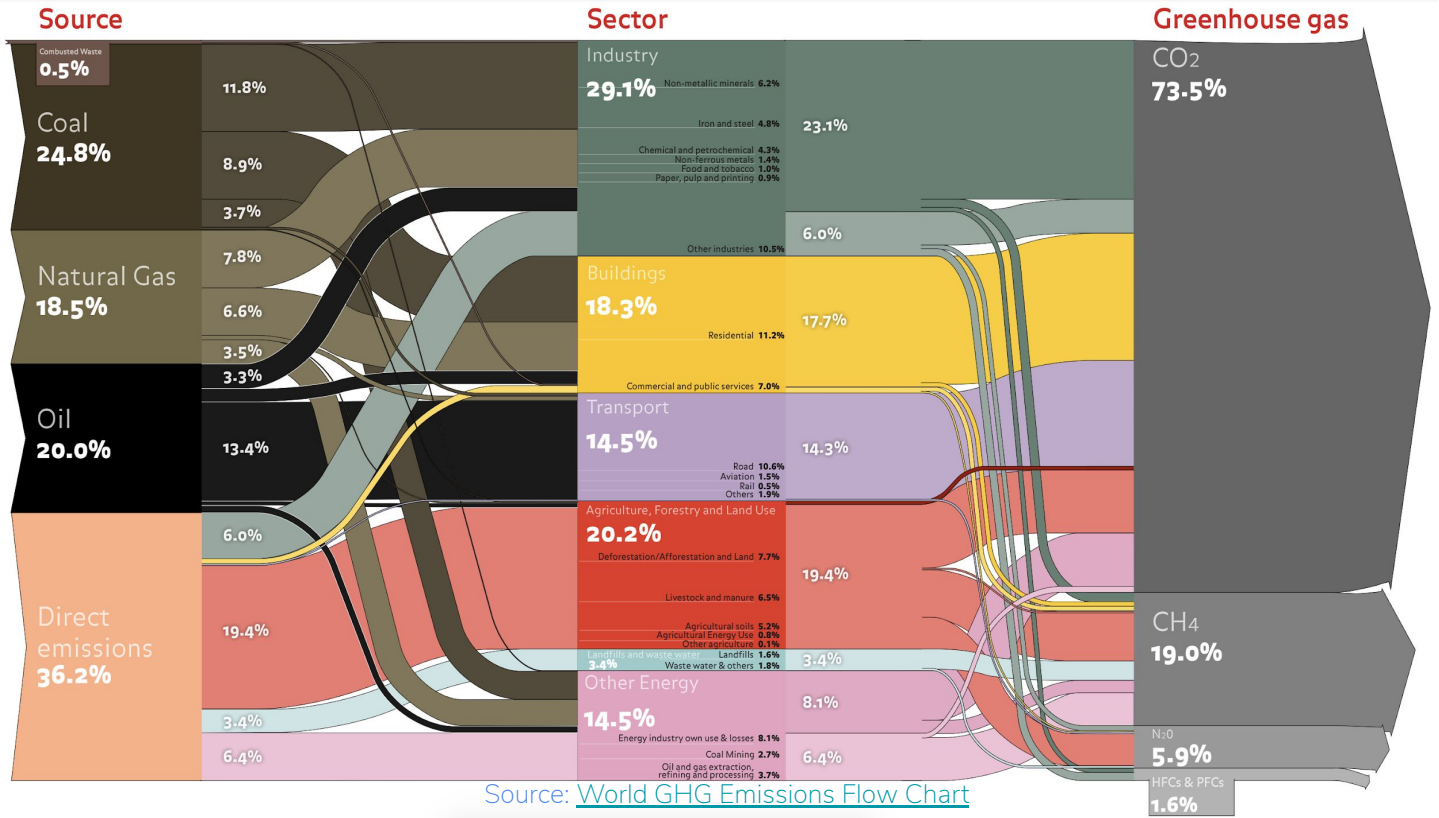
data-driven climate action

Olivier Corradi / **@corradio**
olivier.corradi@tmrow.com

tmrow.com

Zero Emission Vehicles

Do you see a silver bullet?



Source: World GHG Emissions Flow Chart