wattnet

High-Resolution Carbon and Water Intensity Modelling to Enable Impact-Aware Research Computing

Jaime Iglesias Blanco
iglesias@ifca.es
orcid.org/0009-0007-7761-5600

María Castrillo Melguizo
castrillo@ifca.es
orcid.org/0000-0001-7033-6907

Álvaro López García
aloga@ifca.es
orcid.org/0000-0002-0013-4602

SC4RC 2026 · Sustainability Conference for Responsible Research Computing · May 4–8, 2026 · CERN, Geneva, Switzerland.

PROBLEM & OPEN DATA

Motivation

Modern research computing has a largely invisible environmental cost. The **carbon** and **water** footprint of digital infrastructures depends directly on the **electricity mix** powering them: a mix that varies substantially across time and geography, particularly in highly interconnected systems such as Europe's.

Without visibility into these dynamics, meaningful impact mitigation remains out of reach.

Time Variability · Geography Dependence · Grid Mix Volatility

Coverage & Resolution

Wattnet covers **60 European** grid zones at **15-minute resolution**, spanning national and bidding zone boundaries across the continent's interconnected electricity system.

Data is available historically, in real time, and as 72-hour ahead forecasts.

See the full list of zones at:
`api.wattnet.eu/v1/zones`

Electricity Data Sources & Inputs

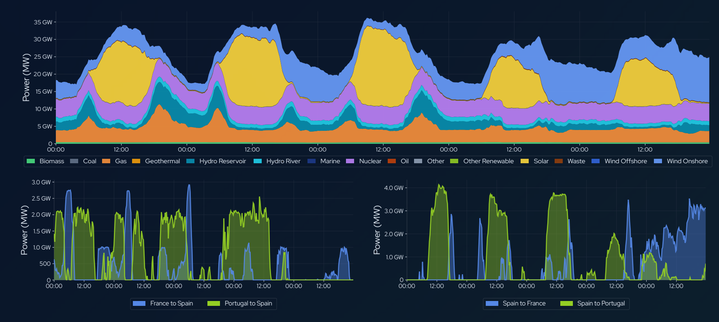
Generation mix by technology, zonal load, and cross-border exchanges are retrieved in MW, representing average power per time interval (15 min, 30 min, or 1 h depending on the zone).

entsoe · ELEXON · EPİAŞ

Data is sourced primarily from **ENTSO-E** (European Network of Transmission System Operators for Electricity), the body coordinating transmission system operators across 36 countries, with national supplements from **NESO/Elexon** (Great Britain) and **EPIAS** (Turkey).

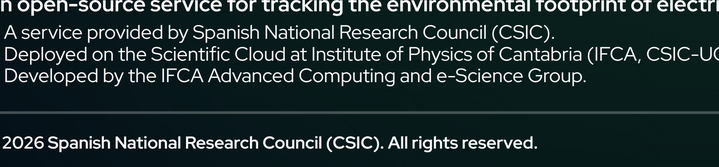
Generation Mix & Exchanges

Spain's (ES) electricity system captured at 15-minute resolution: generation broken down by technology type alongside cross-border power flows with Portugal (PT) and France (FR). All values expressed as average power in MW per time interval.



Environmental Footprint Factors

Wattnet applies both **operational** and **life-cycle** carbon emissions and water consumption factors per generation technology. Operational factors account for direct emissions during generation; Life-Cycle factors incorporate the full chain (manufacturing, construction, fuel supply, and decommissioning).



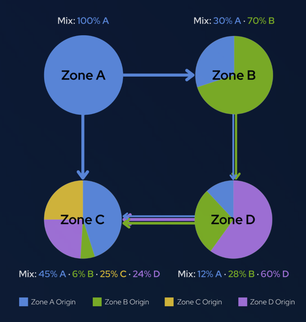
See the environmental footprint factors at: `api.wattnet.eu/v1/factors`

METHODOLOGY

Flow-Tracing Methodology

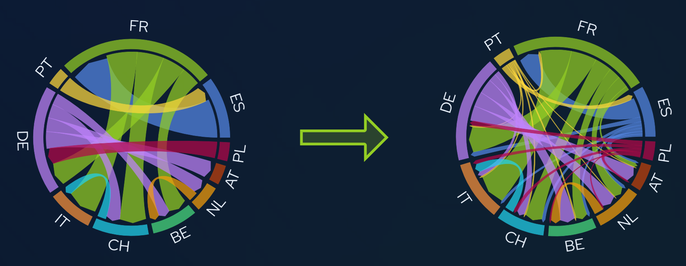
Wattnet implements a **flow-tracing** algorithm based on **proportional mix sharing** over net cross-border flows.

Each zone's consumed electricity is traced back to its generating sources through **successive** interconnections: the imported mix of any zone already carries the blended contributions of its own suppliers, capturing how electricity from distant zones reaches its final consumer across multiple borders.



Declared vs. Traced Cross-border Flows

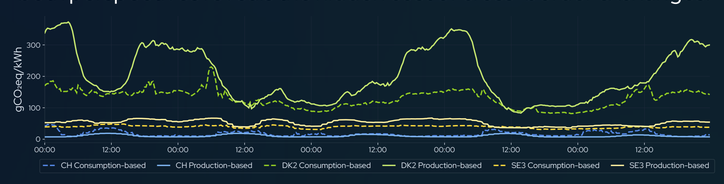
Declared flows capture only direct exchanges between neighbouring zones. Flow-tracing propagates flows through the network chain, resolving the true origin of consumed electricity across multiple borders.



Production vs Consumption-based Intensity

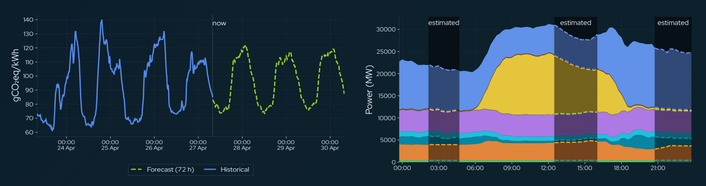
Production-based intensity accounts only for **local generation**, ignoring the origin of imported electricity.

Flow-tracing enables the computation of a **true global footprint**, a **consumption-based** metric that attributes each zone's environmental impact to its actual electricity sources across borders. The gap between both perspectives reveals the hidden cost of cross-border exchanges.



Estimation & Forecasting

Carbon and Water Footprint time series are forecast 72 hours ahead at 15-minute resolution using an **AutoRegressive with eXogenous inputs (*AR-X(p)*)** model, fitted via **Conditional Maximum Likelihood (OLS)**.

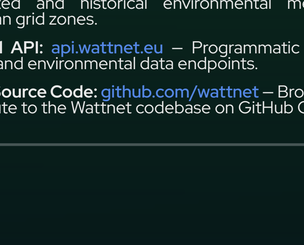


Missing values in input time series are filled using an adaptive framework combining interpolation, autoregressive extrapolation, and linear trend approximation based on data availability and context.

Water Impact & Regional Scarcity

Water impact extends the water footprint by weighting against **regional and seasonal water scarcity**.

The same volume of water consumed has a significantly higher impact in southern Europe during summer than in northern regions, reflecting real-world water stress conditions through **AWARE** characterisation factors.

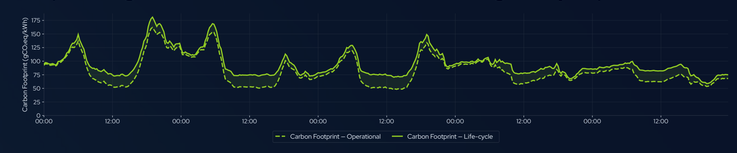


RESULTS & IMPACT

Carbon Footprint

Greenhouse Gas (GHG) emissions are the primary driver of climate change, and electricity generation is one of their largest sources.

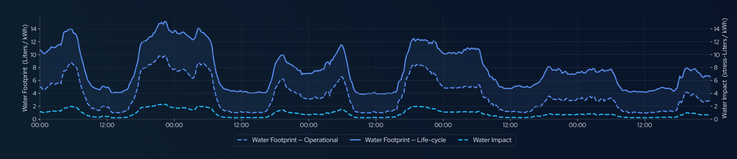
Carbon Footprint measures the CO_2 intensity of consumed electricity in ***gCO_2eq/kWh***. Intensity varies substantially across European zones, driven by differences in generation mix and cross-border exchange patterns. Since carbon emissions have the same climate impact regardless of location, their effects are globally equivalent.



Water Footprint vs. Water Impact

Electricity generation is one of the largest industrial consumers of **freshwater**, through cooling, steam cycles, and reservoir evaporation.

Water Footprint quantifies this consumption as the water intensity of electricity in ***Liters/kWh***, varying substantially across generation technologies and European zones. Unlike carbon, its environmental impact depends on where and when the water is withdrawn, a dependency captured through regional and seasonal scarcity weighting.



Green Score: An Unified Sustainability Metric

Green Score combines carbon footprint and water impact into a single index. Both are first normalised using **Min-Max** scaling across available zones at each time interval, ensuring comparability on a common scale.

The final score is computed as a weighted sum of the scaled impacts, with weights derived from the **JRC environmental footprint assessment**. The result is an interpretable index in the range [0,100], where higher values indicate lower environmental impact.

Explore All Data via RESTful API

Our **API** seamlessly integrates Wattnet metrics into workflows, enabling dashboards, footprint analysis, and easy extensibility. All data in one place.

Energy Metrics

- `GET /generation` — Retrieve zone generation data.
- `GET /load` — Retrieve zone generation data.
- `GET /imports` — Retrieve zone import flows data.
- `GET /exports` — Retrieve zone exports flows data.
- `GET /mix` — Retrieve zone electricity mix data.

Environmental Metrics

- `GET /footprints` — Retrieve environmental footprints.
- `GET /impacts` — Retrieve environmental impacts.
- `GET /green-score` — Retrieve Green Score index.

Shares Metrics

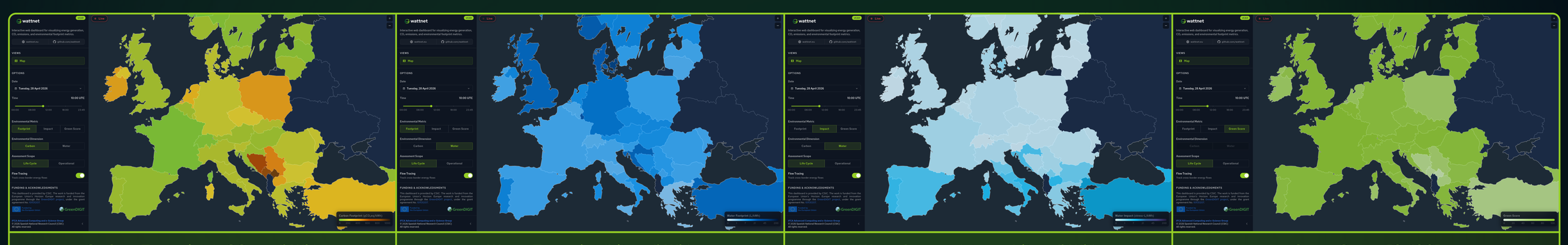
- `GET /flow-share` — Retrieve zone flow share data.
- `GET /mix-share` — Retrieve zone mix share data.
- `GET /footprint-share` — Retrieve footprint share data.
- `GET /impact-share` — Retrieve impact share data.

API Base URL: `https://api.wattnet.eu/v1`

Use Case: GreenScore-Based Workload Scheduling

GreenScore-based workload scheduling optimizes execution by minimizing environmental impact through **temporal** (when to run) and **spatial** (where to run) decisions, enabling efficient operation across federated computing infrastructures.

Wattnet API (GreenScore Endpoint) ⇐ Workload Management System ⇒ Datacenter A / Datacenter B



wattnet · IFCA Instituto de Física de Cantabria · CSIC Consejo Superior de Investigaciones Científicas · UC Universidad de Cantabria

An open-source service for tracking the environmental footprint of electricity across Europe.

- A service provided by Spanish National Research Council (CSIC).
- Deployed on the Scientific Cloud at Institute of Physics of Cantabria (IFCA, CSIC-UC).
- Developed by the IFCA Advanced Computing and e-Science Group.

wattnet.eu

Visit the platform and contribute:

- **Web Dashboard:** dashboard.wattnet.eu — Explore real-time, forecasted and historical environmental metrics across European grid zones.
- **RESTful API:** api.wattnet.eu — Programmatic access to all energy and environmental data endpoints.
- **Open-Source Code:** github.com/wattnet — Browse, fork, and contribute to the Wattnet codebase on GitHub Organization.

Funding and acknowledgments

This work is funded from the European Union's Horizon Europe research and innovation programme through the GreenDIGIT project (greendigit-project.eu), under the grant agreement No.101131207.

Funded by the European Union · GreenDIGIT

advancedcomputing.ifca.es