Interreg Hungary – Croatia

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RenewMap

Renewable Energy Potential

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The Core Problem: Understanding "Potential"

- Not all energy in nature is usable.
- Potential definitions provide a roadmap for investors and policymakers.
- Transitioning from "What is possible" to "What is profitable."

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The Hierarchy of (Renewable) Energy Potentials

1. **Theoretical** – Total physical energy available in nature.
2. **Geographic** – Theoretical potential limited by spatial and land-use constraints.
3. **Technical** – Geographical potential narrowed by the efficiency of current technology.
4. **Economic** – The portion of technical potential that is cost-competitive.
5. **Market** – Realized energy production considering subsidies and barriers.

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Overview of Renewable Energy Sources (RES)

- **Solar Energy** – Photovoltaics (PV) and solar thermal.
- **Wind Energy** – Onshore and offshore wind farms.
- **Hydropower** – Large-scale plants, small hydro, and marine energy.
- **Biomass** – Biofuels, biogas, and solid biomass.
- **Geothermal** – Deep heat for electricity and shallow heat for pumps.

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Solar Energy Potential

- The Sun acts as a massive fusion reactor, emitting vast amounts of electromagnetic radiation.
- Atmospheric Losses: absorption, scattering, and reflection.
- Sun energy is distributed due to Earth spinning (rotation) over the Earth's surface (day/night), so Sun irradiation to Earth is on average daily 5,52 kWh/m^2 (depending on latitude).
- The annual solar energy reaching Earth exceeds global energy demand by more than 10,000 times.

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Solar Energy Potential Measurement

- Sun radiation potentials could be assessed by both **measurement** or **analytical**.
- Measurements could be local or by satellite.
- Pyranometer (thermic or semiconductor) is used for measurement of global (total), direct, and diffuse (scattered) irradiation on a horizontal plate:
  - Sun radiation energy density ***H*** **in [Wh/m²]** over time (irradiation)
  - Sun radiation intensity ***G*** **[W/m²]** (irradiance).

Pyranometers measuring different components of Solar radiation

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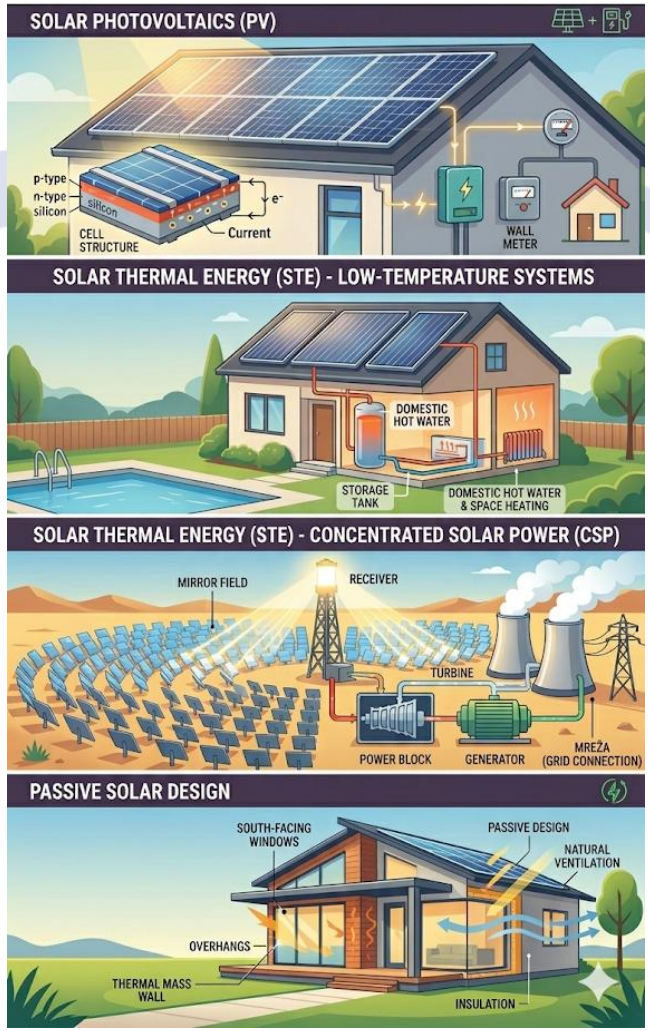
Solar Energy Technologies

- **Solar Photovoltaics (PV)** – Convert sunlight directly into electricity using semiconductor materials (solar cells)
- **Solar Thermal Energy (STE)** – Technologies capture solar radiation in the form of heat. They are classified by their operating temperature:
  - **Low-Temperature Systems** – Used primarily for domestic hot water, swimming pool heating, and space heating.
  - **Concentrated Solar Power (CSP)** – Large-scale systems that use mirrors or lenses to focus sunlight to reach high temperatures. This heat drives steam turbines to produce utility-scale electricity.
- **Passive Solar Design** – An architectural approach that utilizes a building's orientation, materials, and window placement to naturally heat, cool, and light interior spaces without active mechanical systems.



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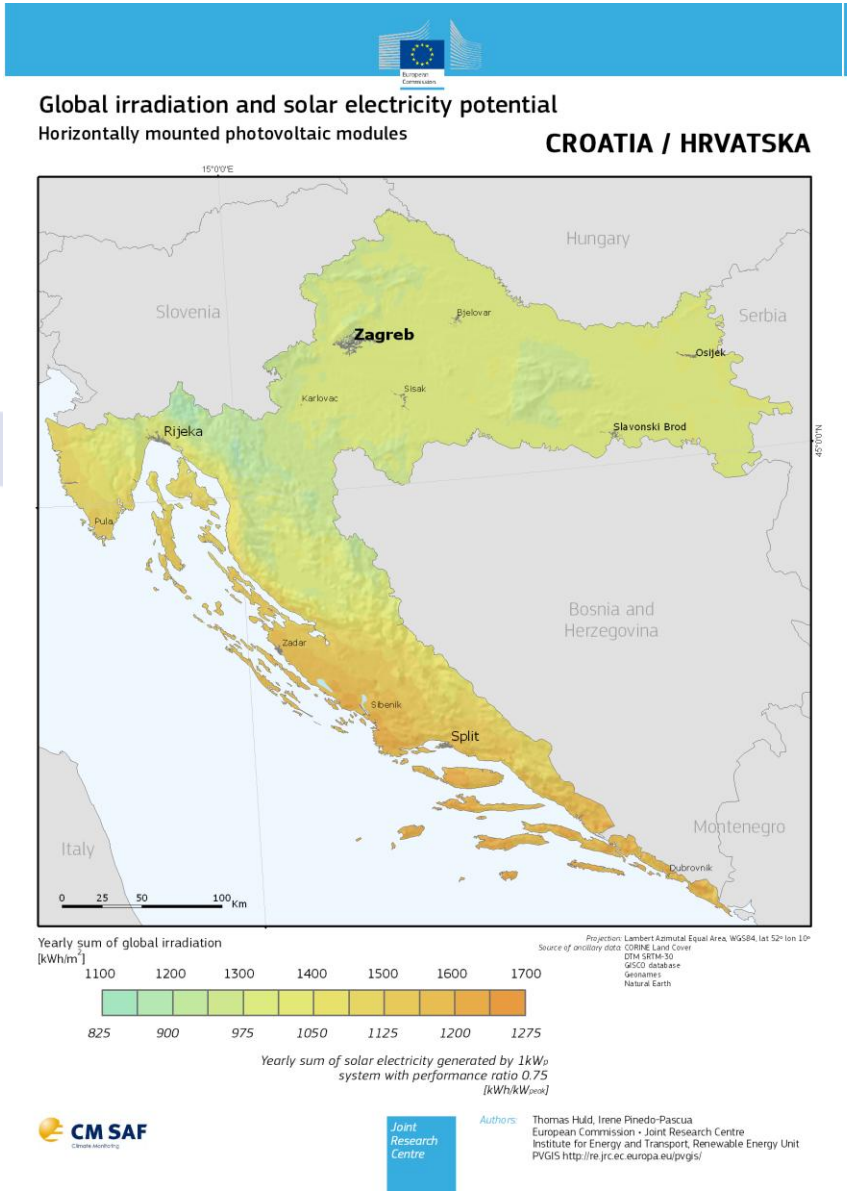

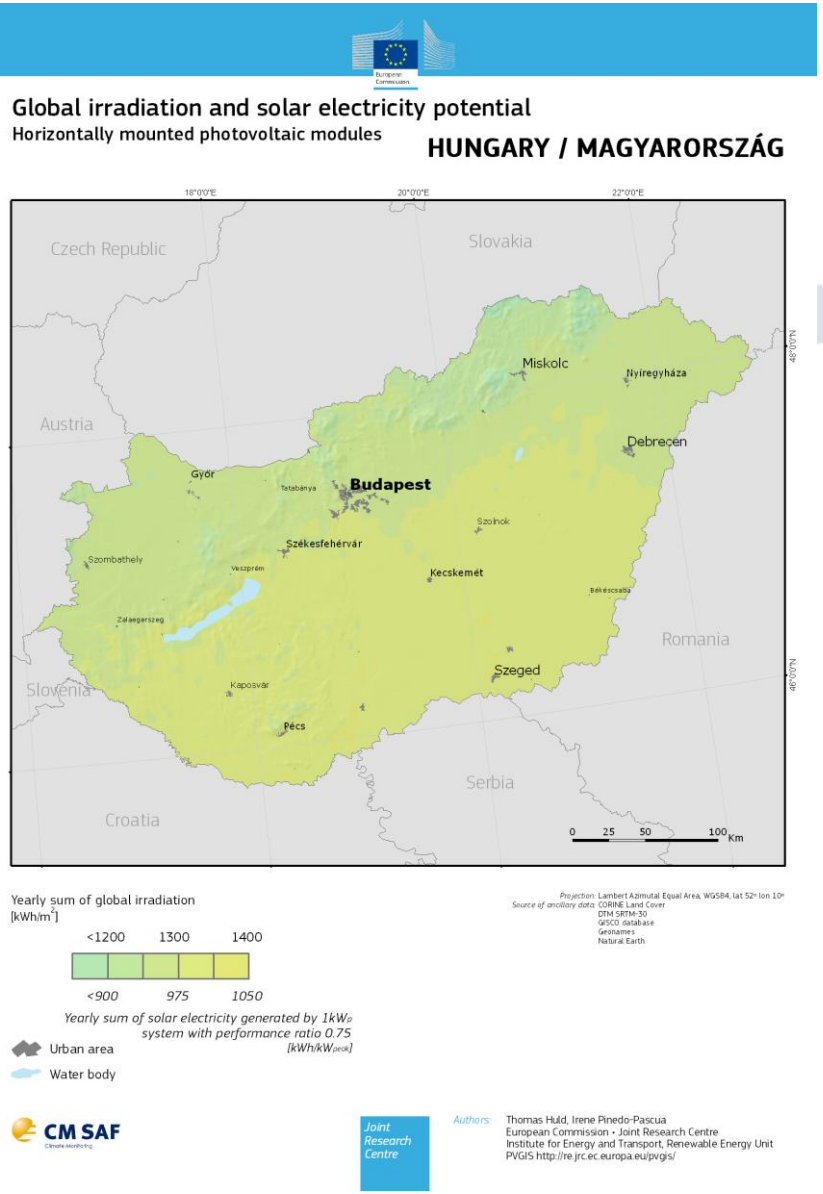

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Wind Energy Potential

- **Wind** is a form of solar energy caused by the uneven heating of the Earth's atmosphere.
- **Kinetic Energy –** The conversion of moving air into mechanical torque and then electricity via a **wind turbine and generator**.
- **Global Distribution –** Wind resources are abundant but highly dependent on geography and altitude.

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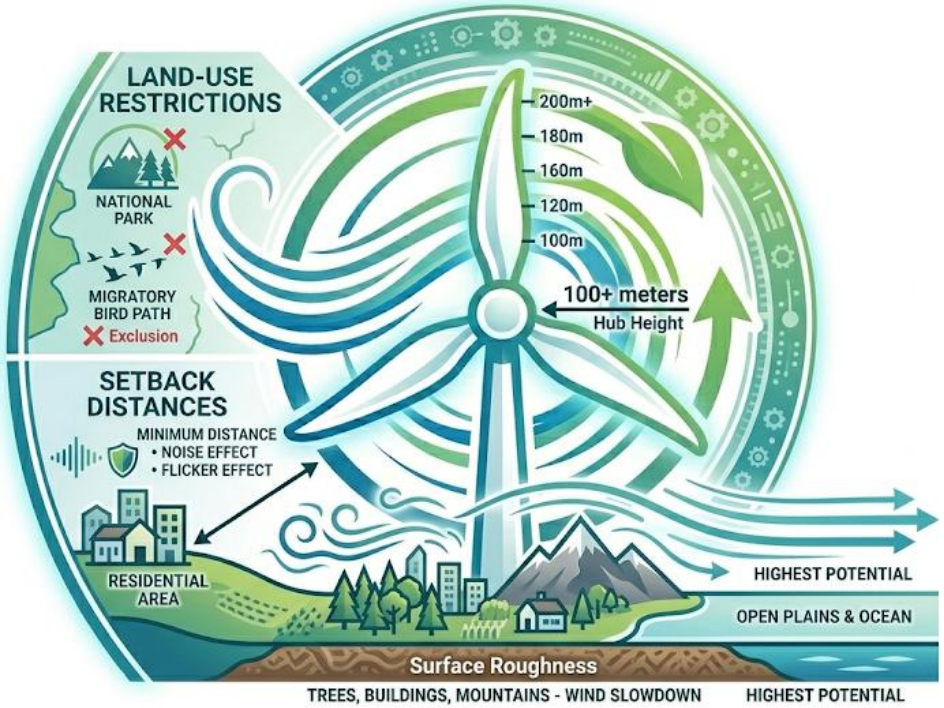
Geographic and Spatial Constraints of Wind Energy

- **Surface Roughness** – Trees, buildings, and mountains slow down wind. Open plains and oceans have the highest potential.
- **Land-Use Restrictions** – Exclusion of national parks and migratory bird paths.
  - **Setback Distances** – Minimum distance from residential areas due to noise and flicker effects.
  - **Hub Height** – Wind speeds are significantly higher at 100+ meters above ground level.



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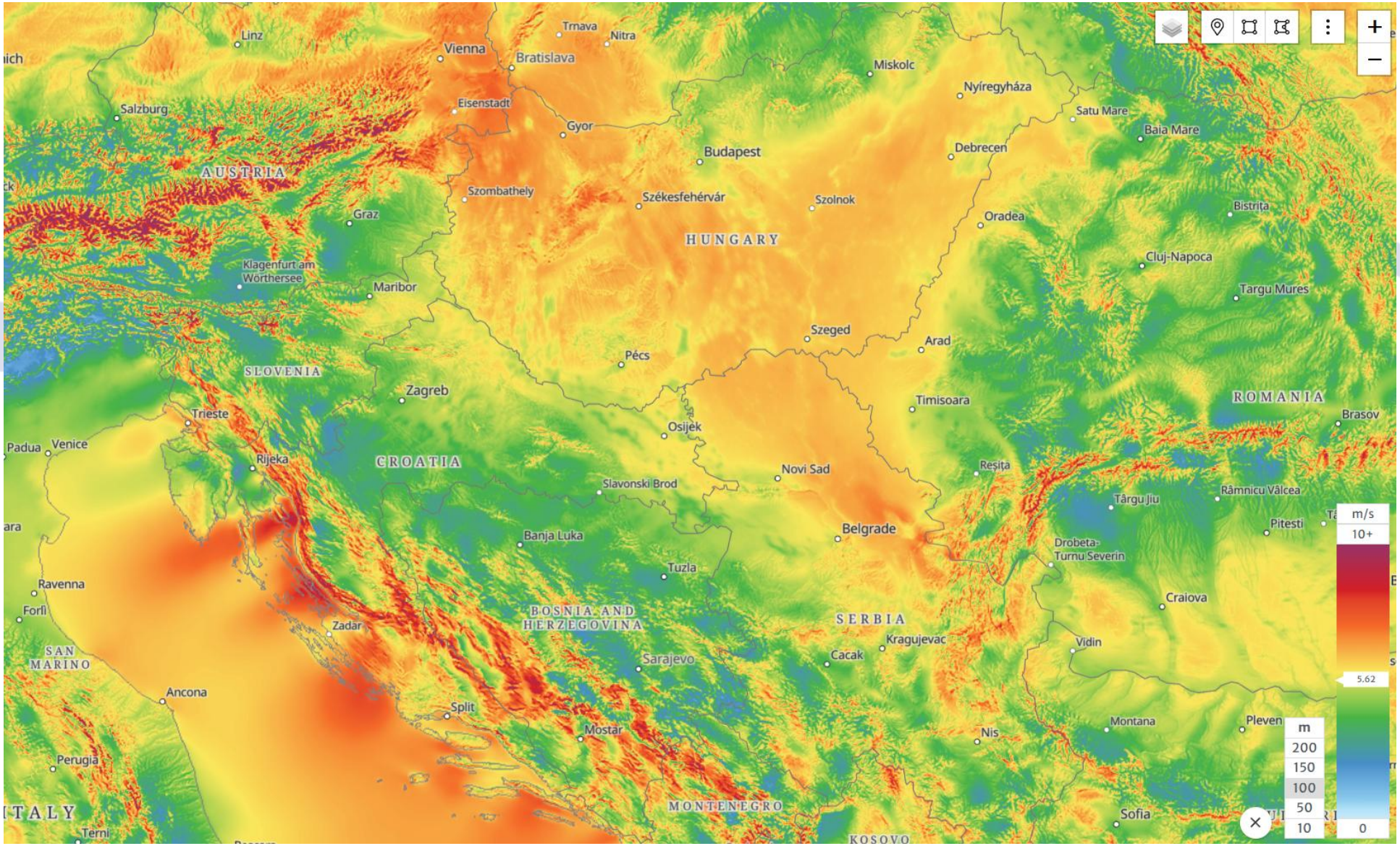
Mean wind speed in m/s (source: Global Wind Atlas)



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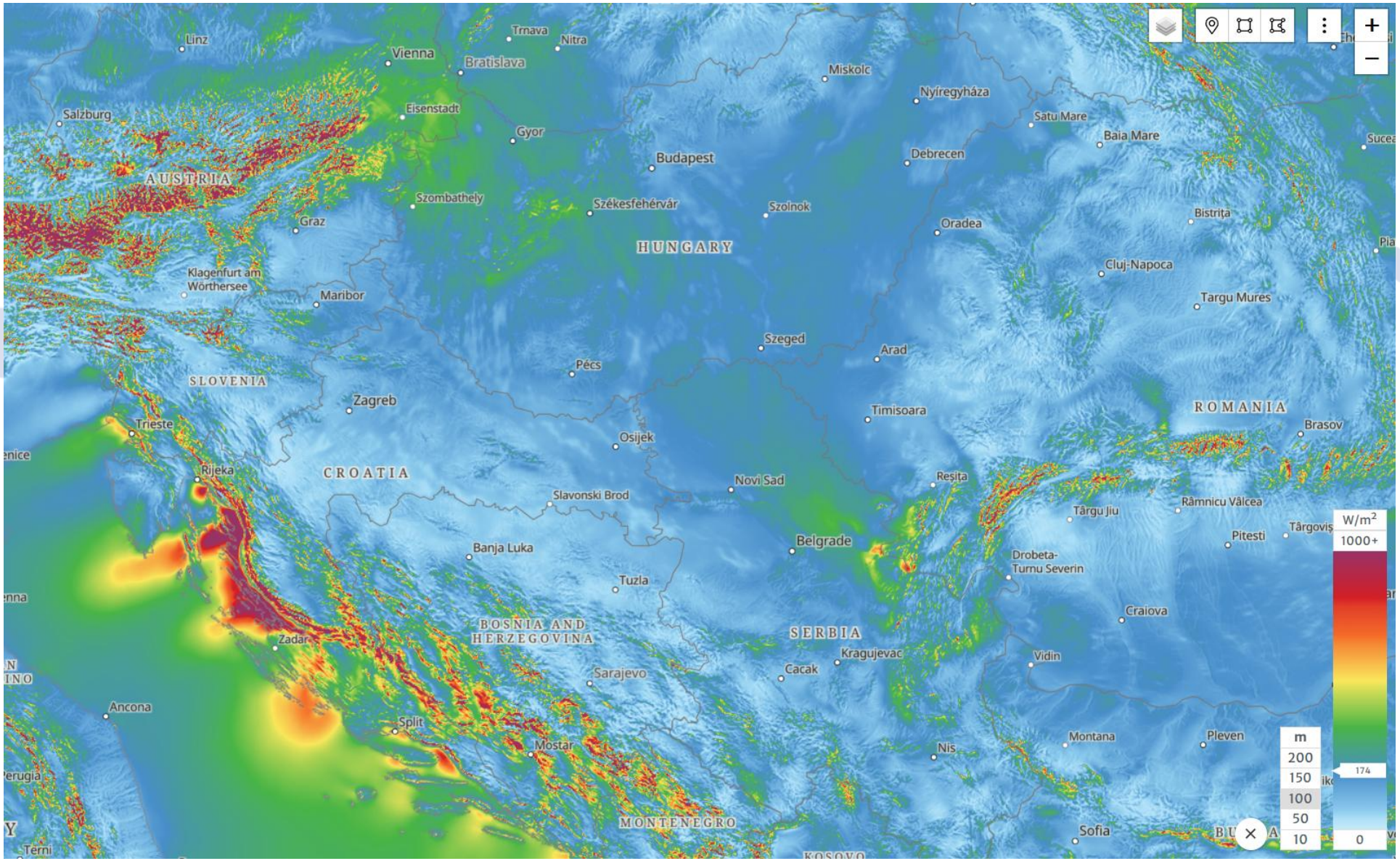
Mean Power Density in W/m^2 (source: Global Wind Atlas)



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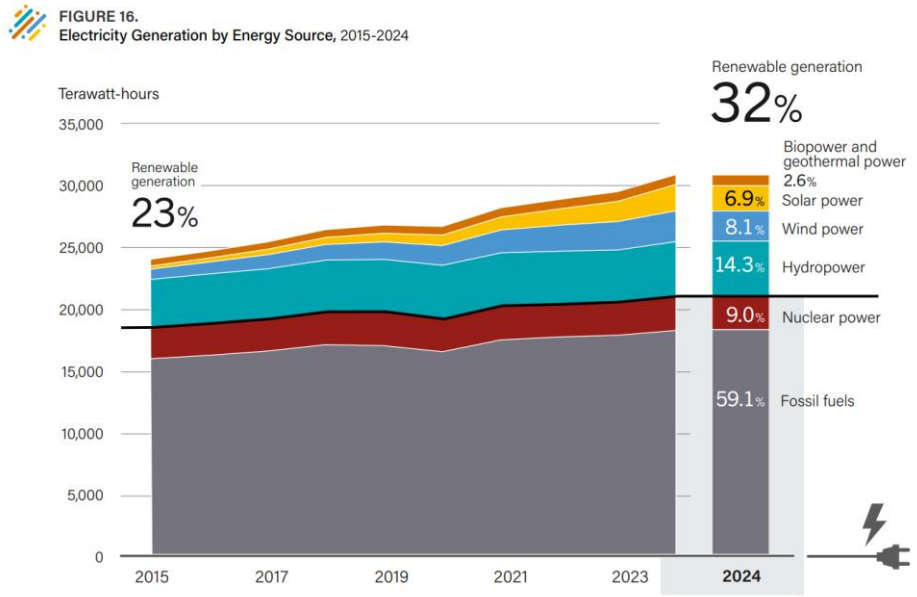
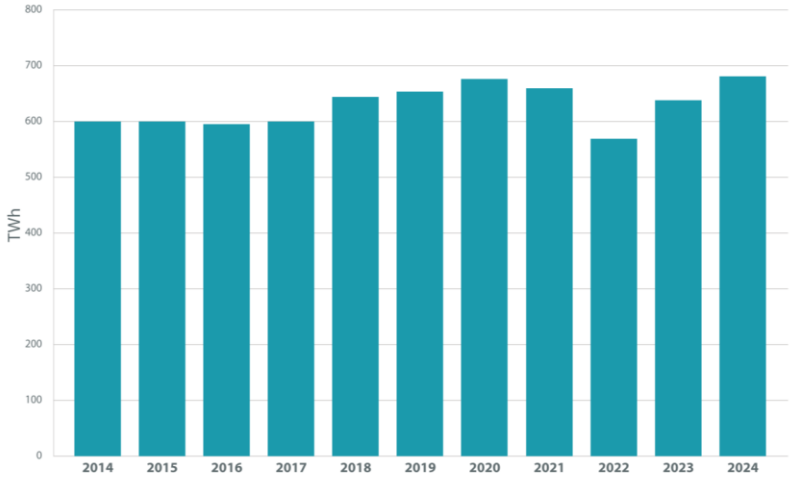
Hydropower Potential

- Most mature, reliable, and largest source of renewable electricity globally.
- It relies on the **potential energy** of water at height or the **kinetic energy** of flowing water.
- Unlike solar and wind, it is often dispatchable, meaning it can provide power on demand.
- In Europe, about 75% of the technical potential is already utilized, leaving little room for new large-scale projects compared to Africa or Asia.





Europe hydropower generation 2014 to 2024 (TWh)

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Defining Technical and Geographic Limits of Hydropower Potential

- **Theoretical Potential** – Total runoff of all rivers from their source to the sea.
- **Geographic Potential** – Limited by suitable terrain for dam construction and reservoir flooding.
- **Technical Potential** – Further limited by modern turbine capabilities and the need to maintain environmental flow (the minimum water needed for the river ecosystem to survive).

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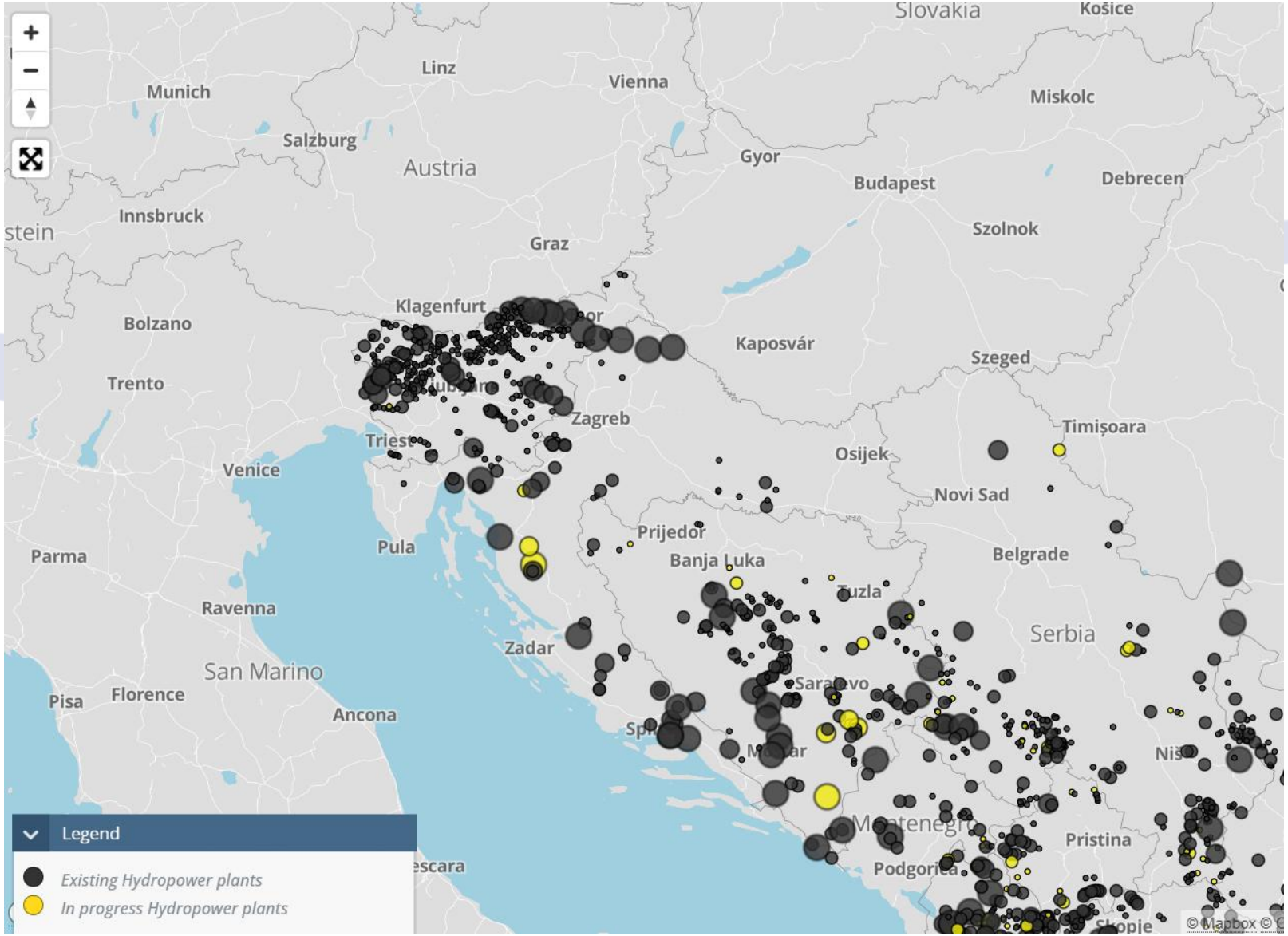

Hydropower plants in Croatia and Hungary (source: Save the Blue Heart of Europe)

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Biomass Energy Potential

- **Biomass** – Organic material derived from plants and animals (wood, agricultural residues, organic waste).
- **Biogas** – A mixture of methane (CH_4) and carbon dioxide (CO_2) produced by the anaerobic digestion of organic matter.
- **Carbon Neutrality** – The CO_2 released during combustion is approximately equal to the CO_2 absorbed during the plant's growth.

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Technical and Economic Realities of Biomass

- **Theoretical Potential -** Immense energy stored in forestry, agriculture, and municipal waste streams.
- **Logistics (The "Economic Radius")** – Transporting low-density biomass beyond 50–100 km often becomes unprofitable.
- **The "Food vs. Fuel" Debate** – Geographic potential is limited by land competition with food production.
- **Strategic Advantage** – Unlike solar/wind, biomass is a dispatchable source, thus providing stable output power.

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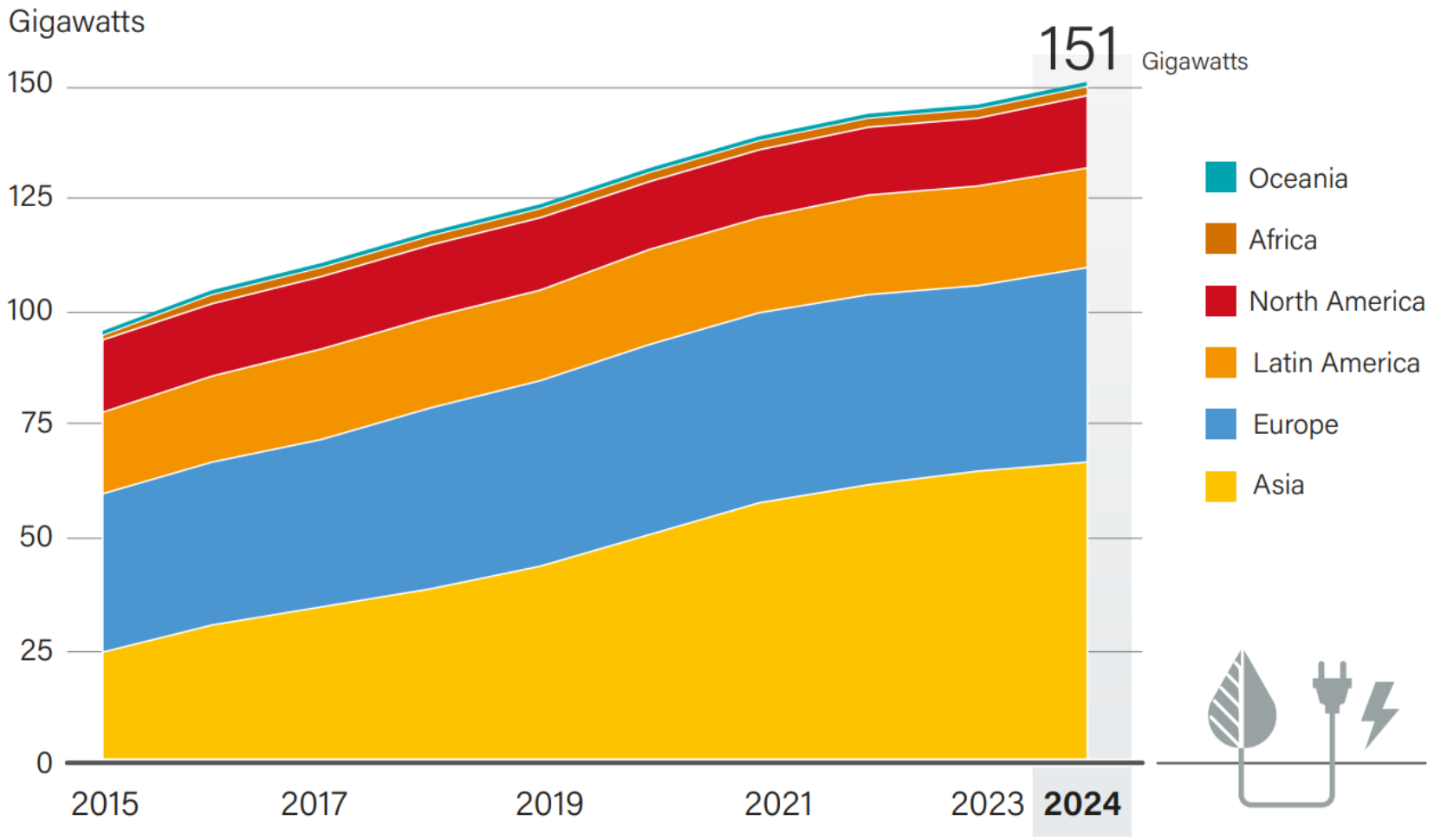
FIGURE BIO-3
Global Bioelectricity Installed Capacity, by Region, 2015-2024



Source: REN21, Global Status Report 2025

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Geothermal Energy Potential

- **Source** – Thermal energy generated and stored in the Earth's core from radioactive decay and primordial heat.
- **Theoretical Potential** – Virtually inexhaustible; the heat within the first 10 km of the Earth's crust is thousands of times greater than global fossil fuel reserves.
- **Geographic Potential** – Traditionally concentrated near tectonic plate boundaries (e.g., Iceland, Italy, New Zealand), but expanding through Enhanced Geothermal Systems (EGS).

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Technical Maturity and Market Barriers of Geothermal Energy

- **Dispatchability** – Unlike solar and wind, geothermal it offers stable generation (like biomass power plants).
- **Technical Constraints**:
  - **Exploration Risk** – High uncertainty in drilling success for new reservoirs.
  - **Fluid Chemistry** – Corrosive and scaling fluids require specialized materials and maintenance.
- **Economic Potential** – High initial CAPEX (drilling costs) compared to other renewables, though OPEX is exceptionally low.
- **Market Potential** – Driven by district heating systems and industrial heat applications.

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Geothermal Energy Conversion Technologies

- **Dry Steam Plants –** The oldest and simplest design; uses steam directly from the geothermal reservoir to turn the turbine and generator.
- **Flash Steam Plants –** Most common type; takes high-pressure hot water from deep underground and "flashes" it into steam by reducing pressure.
- **Binary Cycle Power Plants –** Used for lower-temperature resources; geothermal water heats a secondary "working fluid" with a lower boiling point, which then evaporates and drives the turbine and generator.
- **Ground Source Heat Pumps (GSHP) –** Utilize the constant temperature of the shallow earth (10-15°C) for highly efficient space heating and cooling.
- **Direct Use –** Utilization of geothermal heat without conversion to electricity for district heating, greenhouses, and industrial processes.

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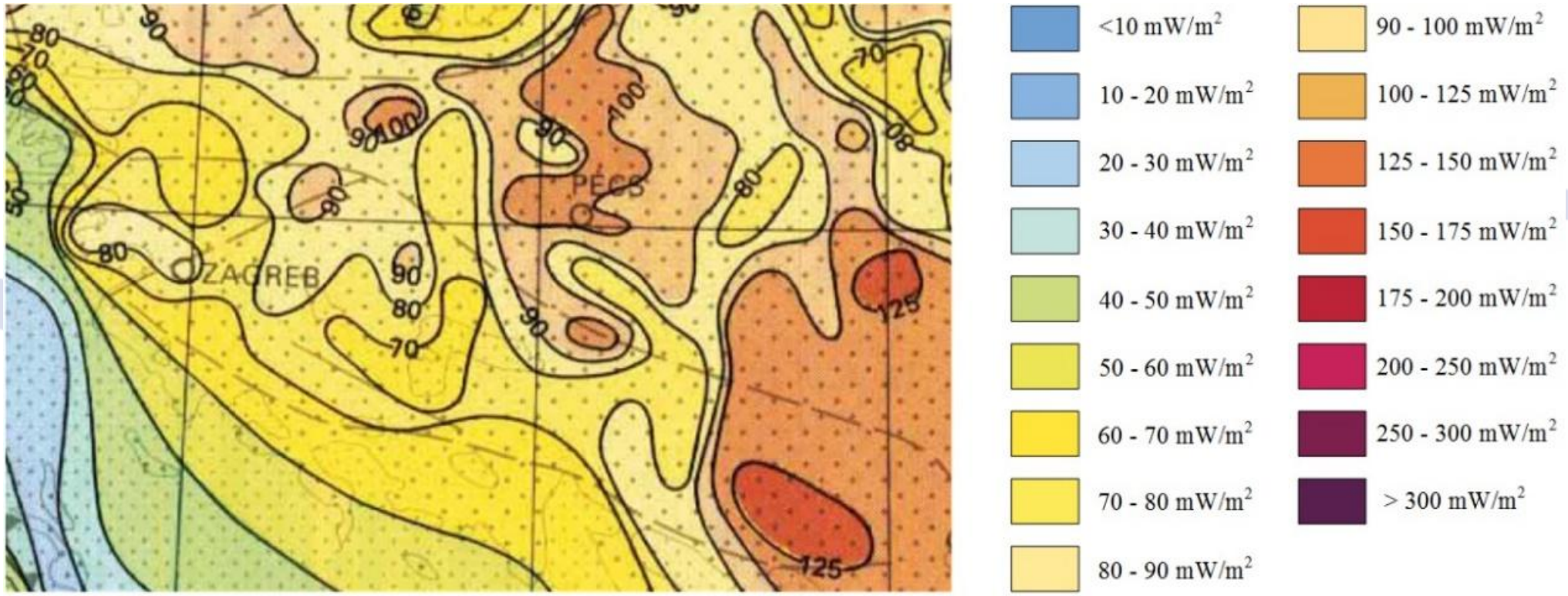

Thermal flux density in the area of the former Pannonian sea (source: Energetski institut Hrvoje Požar)

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Conclusions

- **Croatia's Strength –** High Hydropower and Wind potential. The Dinaric Alps and Adriatic coast provide excellent height differences for hydro and high-velocity wind corridors (Bura/Jugo).
- **Hungary's Strength –** Exceptional Geothermal and Solar potential. The Pannonian Basin has one of the highest geothermal gradients in Europe, coupled with favorable horizontal solar irradiation.
- **Shared Challenges:**
  - **Grid Integration –** Both countries face the Technical Limit of aging infrastructure that must be upgraded to handle variable renewable energy
  - **Biomass Role –** Both nations possess significant agricultural residues, making biogas a key bridge for dispatchable power and heating.

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