UNIVERSITY OF ZAGREB

Faculty of Electrical Engineering and Computing

Dr. sc. Sara Raos

Dr. sc. Bojan Franc

ERRES Forum 2025.

/Department of Energy and Power Systems

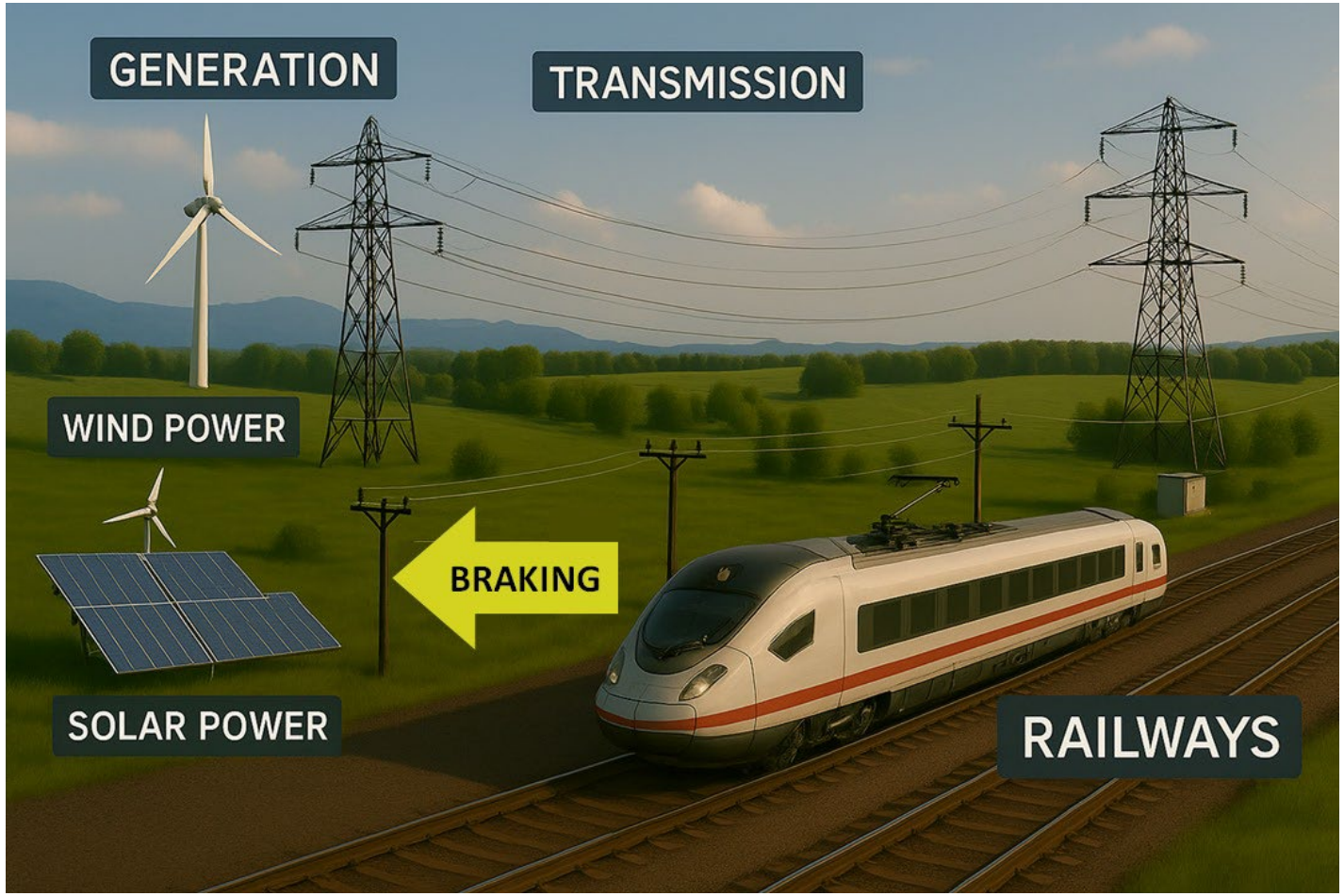
Cooperation HŽi – FER – electrical energy billing

- Cooperation between the University of Zagreb Faculty of Electrical Engineering and Computing and HŽ Infrastruktura LLC
  - Long-term cooperation
  - Our field of interest (Department within FER) – Energy and Power Systems

- Project - *Billing for electricity according to actual consumption with the possibility of regenerative braking and billing according to specific consumption*
  - Evaluation and software implementation of the billing model
  - Monthly billing to Railway Undertaking (RU)
  - Archiving data on train el. en. measurements, specific consumption on railway sections and train run data

Electrical Railways and regenerative braking

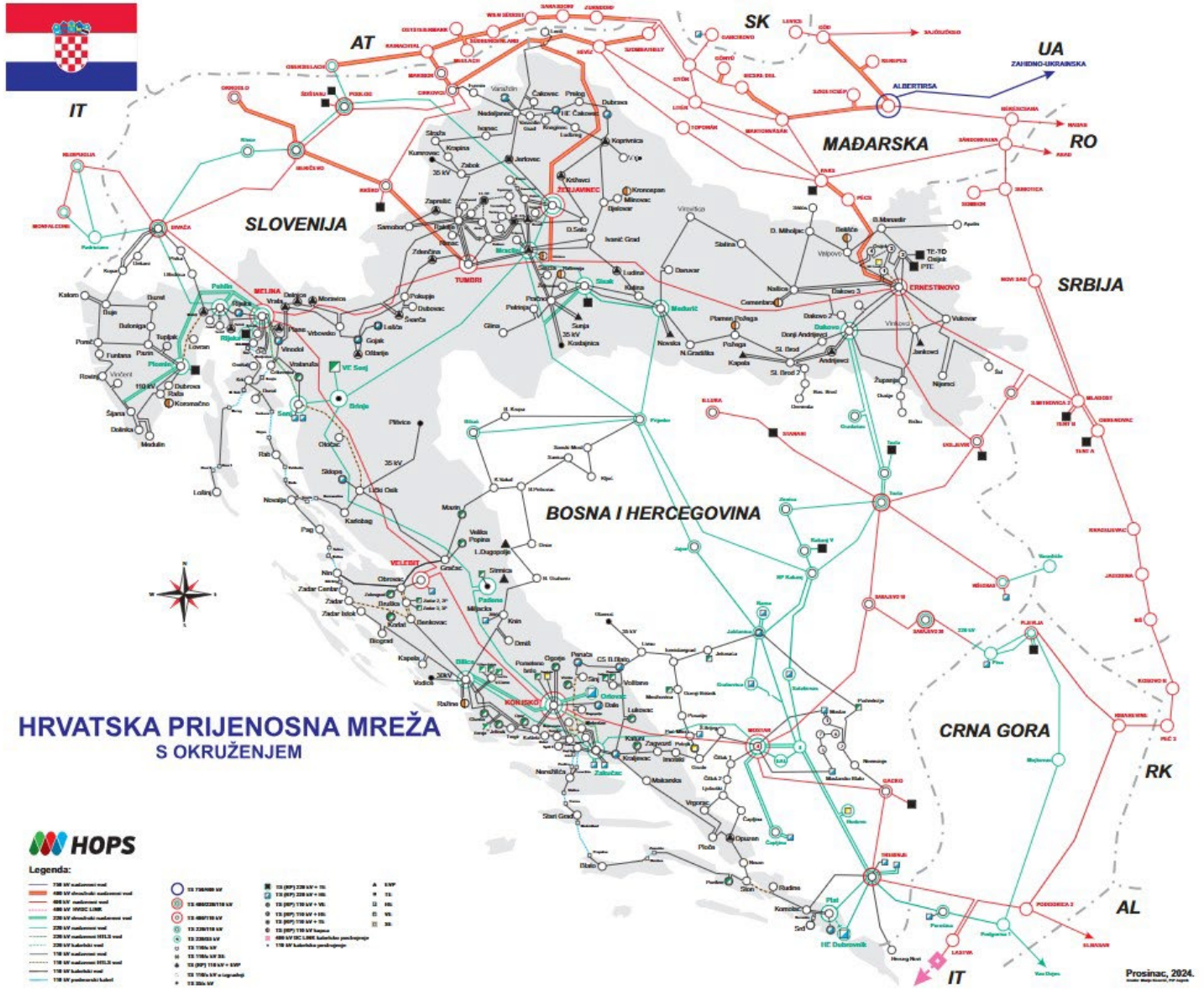
- Regenerative braking
  - Produces el. en. by running the motor in the generating regime
    - Can be stored/used by the train itself
    - Can be passed to the catenary network – used by nearby trains (no outside/market impact)
    - Can be passed to the transmission network – influences other actors in the energy market



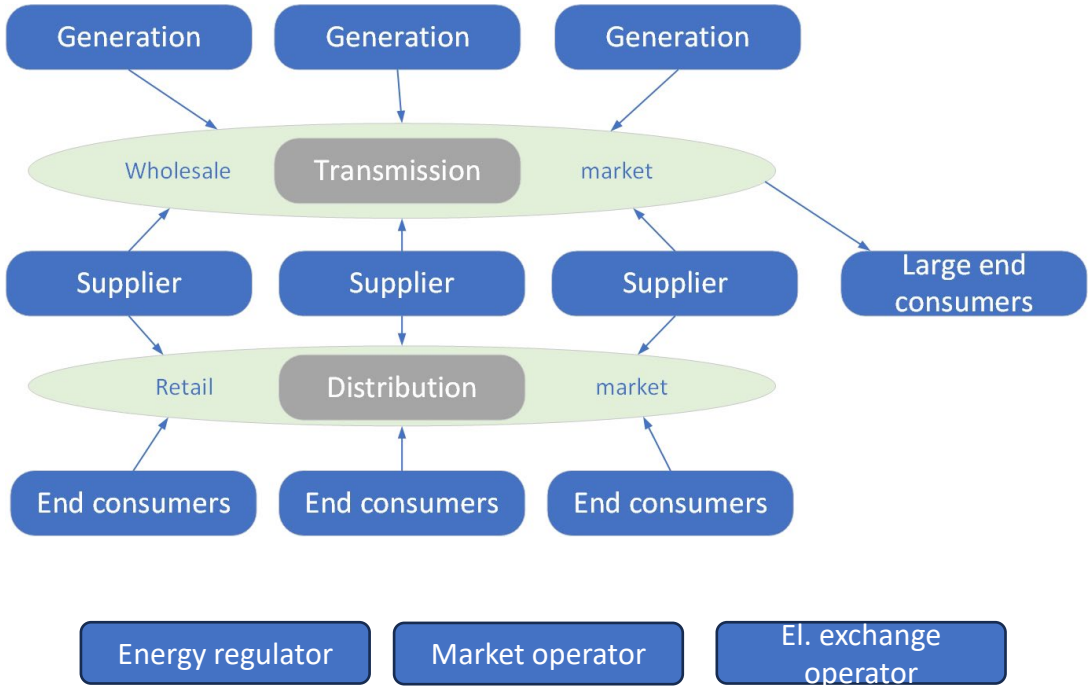
Croatian Transmission Network System

- **400 kV** - 1246,28 km (red)
- **220 kV** - 1268,02 km (green)
- **110 kV** - 5249,23 km (black)

- 21 EVP – substations for powering the railway contact grid



Liberalized electricity market and key participants



- **Unbundling:**
  - **Generating company** (GENCO) owns and/or manages the generation assets and sells electricity on the wholesale market
  - **Transmission company** (TRANSCO) owns and/or manages the transmission network, more commonly known as the transmission system operator (**TSO**)
  - **Distribution company** (DISCO) owns and/or manages the distribution network, more commonly known as the distribution system operator (**DSO**)
  - **Supplier** is a company that buys electricity on the wholesale TEE and sells it to customers on the retail market
  - **Consumers** are the end users of electricity, and they buy it on the wholesale market directly (large) or via suppliers (small)

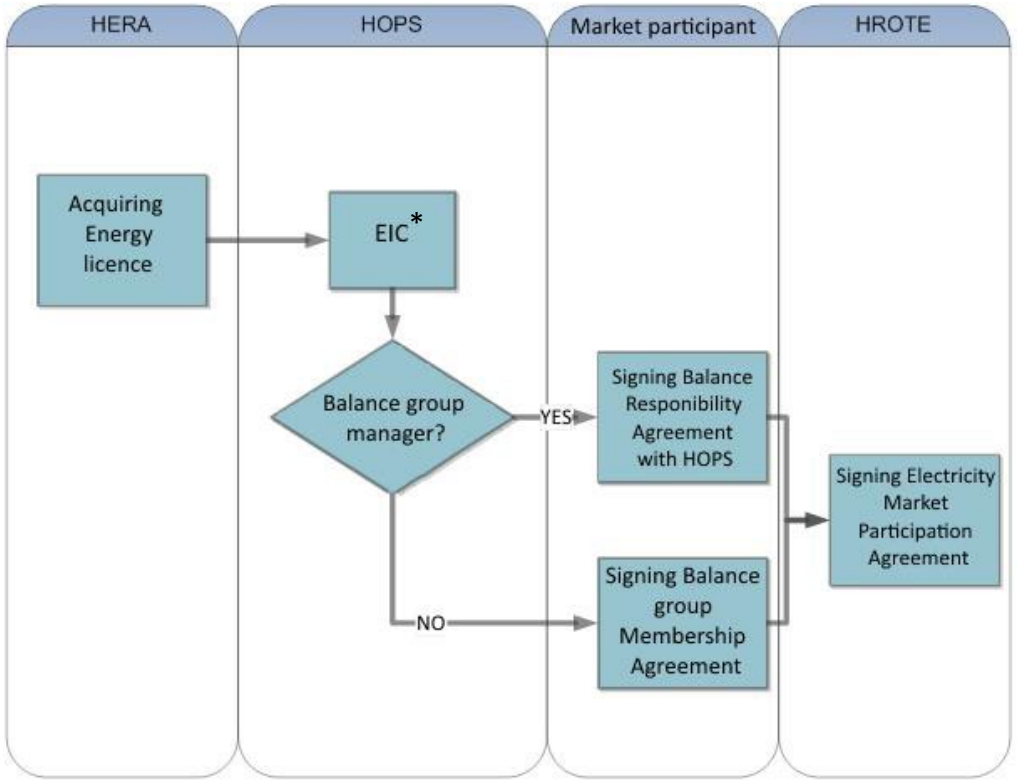
5

Bodies and Operators connected to the electricity market:

- The **energy regulator** oversees all energy activities within a given system.
- The **market operator** carries out the activity of organizing the electricity market as a public service, under the supervision of the energy regulator.
- The **electricity exchange operator** manages the organized electricity market according to the conditions set by the market operator and under the supervision of the energy regulator.

Participants in Croatian power system

- A producer, supplier and trader must have a license for performing energy activity, issued by the **Croatian Energy Regulatory Agency** (HERA).
- The organization of the electricity market, electricity transmission and distribution are regulated activities performed as public services:
  - **HROTE** is responsible for the organization of the electricity market,
  - **HOPS** (Croatian TSO) is responsible for electricity transmission, maintenance, development and construction of transmission system, and power system control,
  - **HEP-DSO** is responsible for electricity distribution, maintenance, development and construction of distribution system



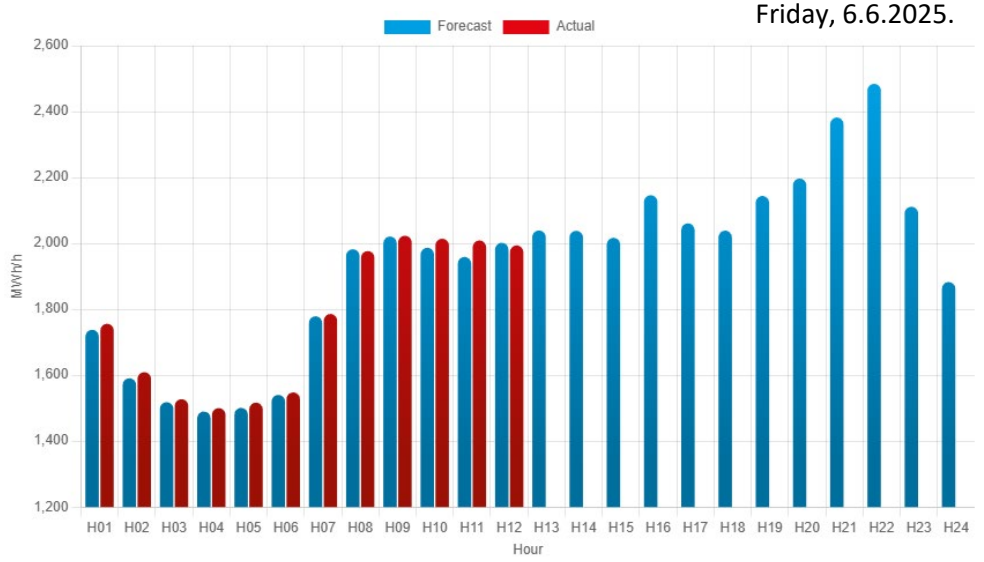
* Energy Identification Code

Electricity markets

CROATIA

- There are **two electricity markets:**
  - In the initial phase of its opening, a bilateral market model was chosen, which was upgraded by the Rules for the organization of the electricity market with a **model of balance groups** in which electricity trading is carried out by bilateral contracts.
  - Another electricity market is the **organized electricity market (CROPEX).**

Friday, 6.6.2025.

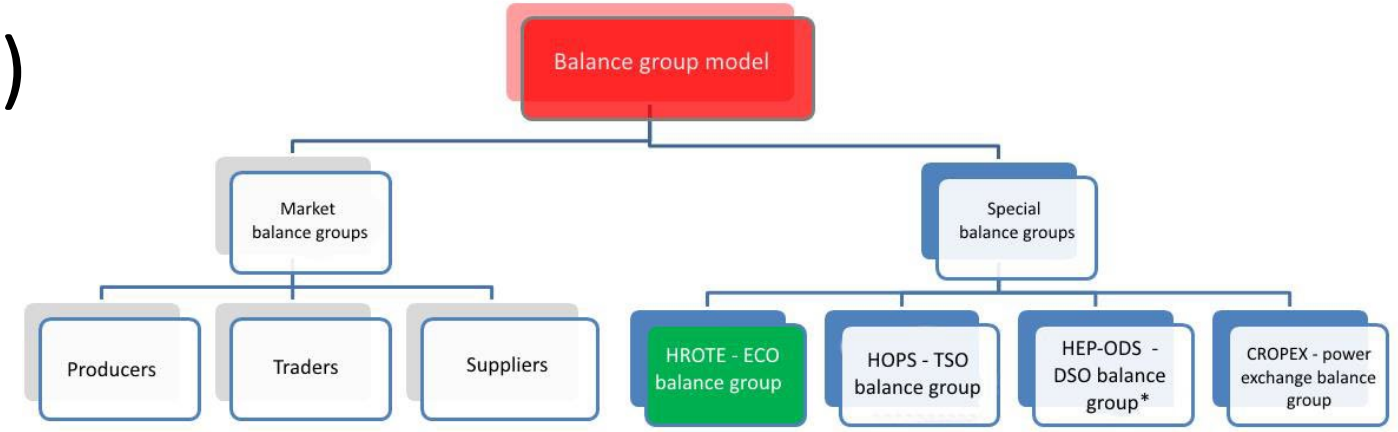


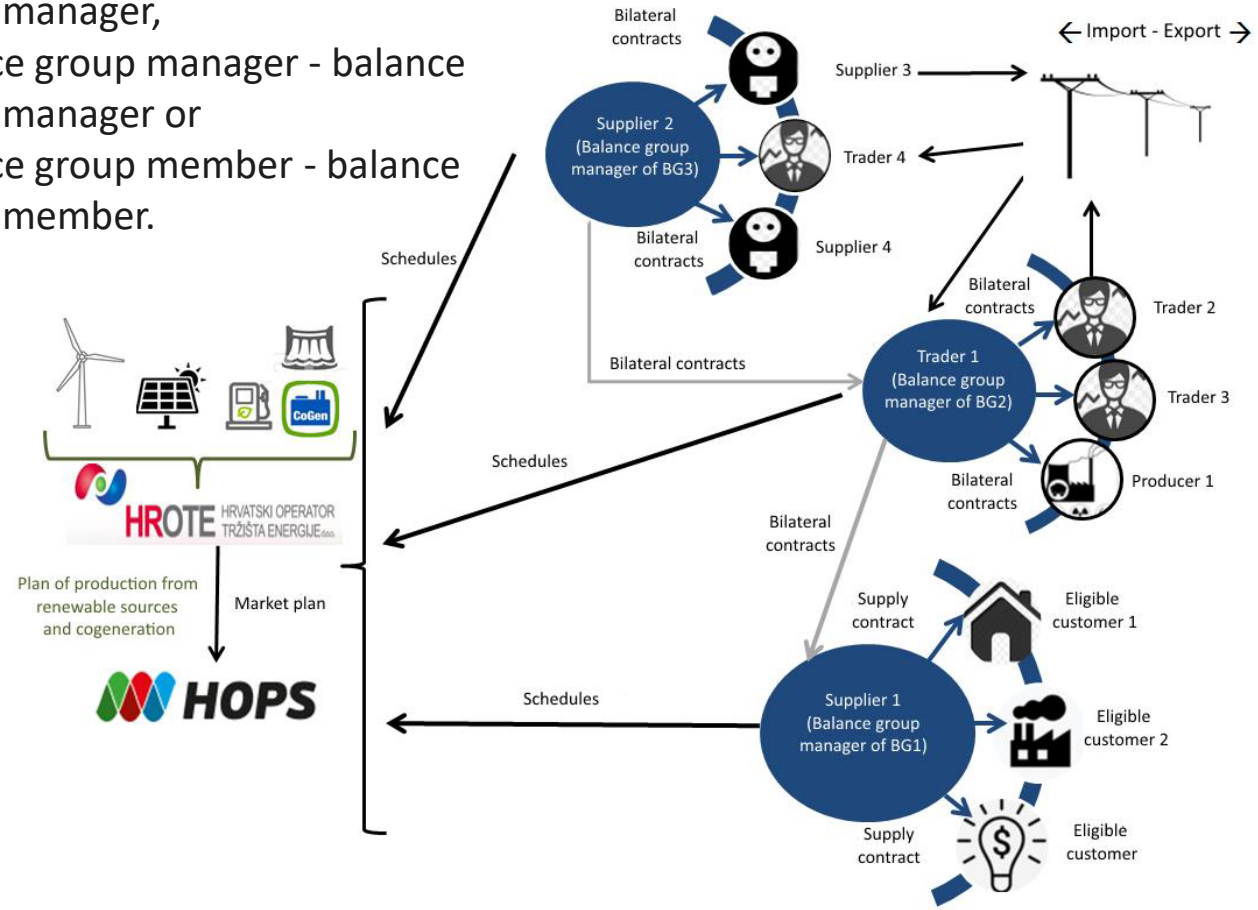
Hour	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12
Forecast	1,738	1,591	1,518	1,490	1,501	1,540	1,779	1,982	2,021	1,987	1,959	2,002
Actual	1,756	1,609	1,527	1,500	1,517	1,548	1,786	1,977	2,023	2,014	2,009	1,994

Source: https://www.hops.hr/en/daily-load

Balance group model (Croatia)

- Bilateral contracts concerning electricity trade (purchase or sale, internal or external) are concluded between the **supplier**, the **trader** or the **producer**. The contracting parties in a bilateral contract are:
  - balance group member - balance group manager,
  - balance group manager - balance group manager or
  - balance group member - balance group member.

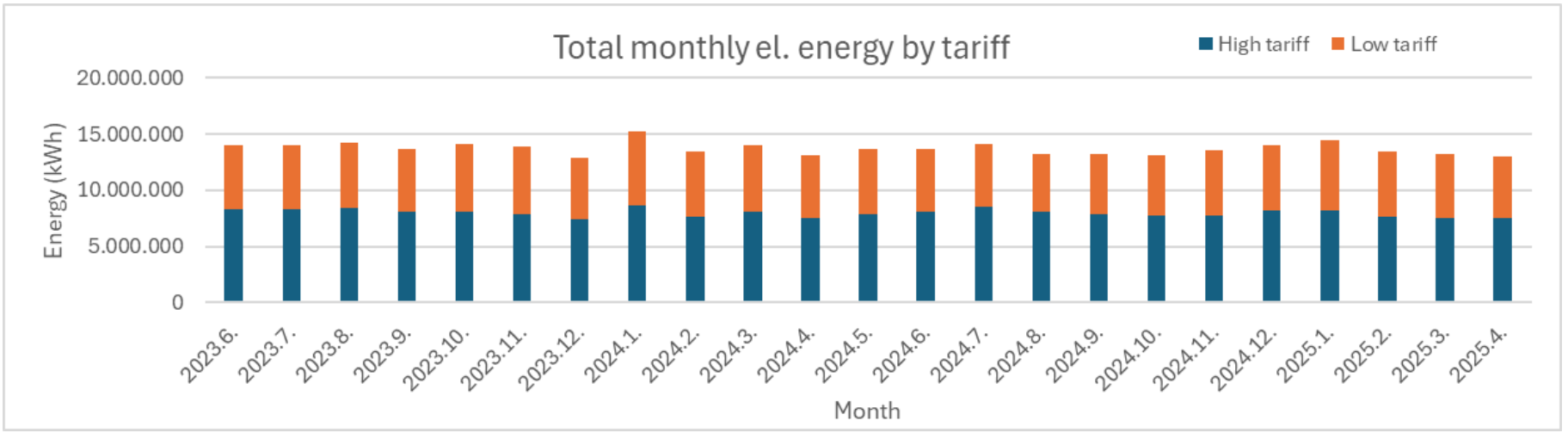


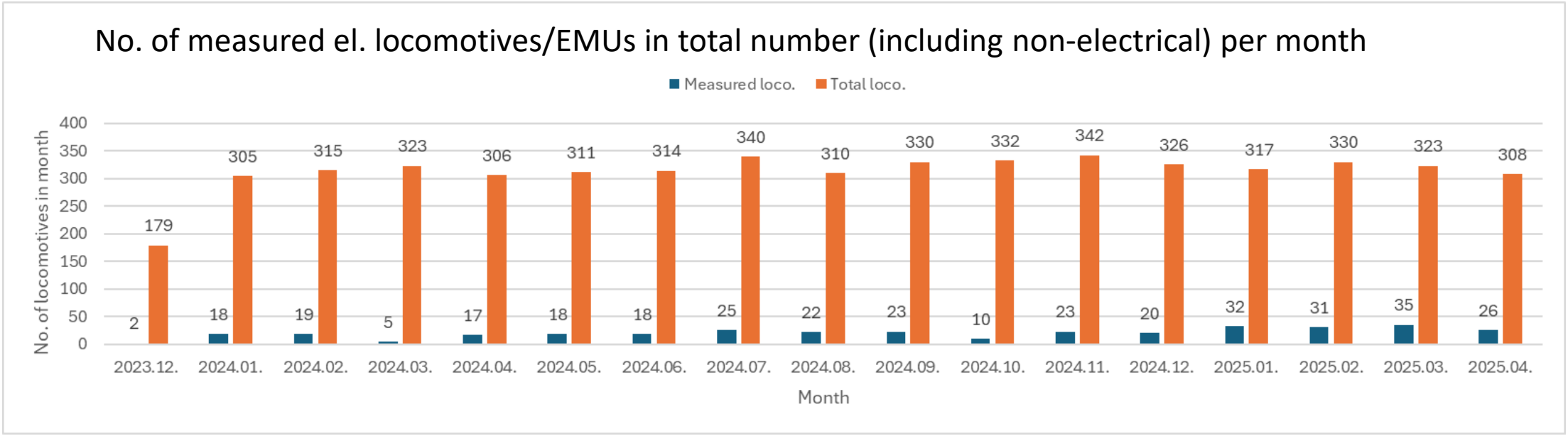


- Contractual parties in the electricity supply contract are the eligible customer and the supplier. Besides the supply contract or the electricity trade contract, **the eligible customer** and producer shall conclude a contract for using the network with Croatian Transmission System Operator (**HOPS**) or with HEP-Operator distribucijskog sustava (**HEP-DSO**).

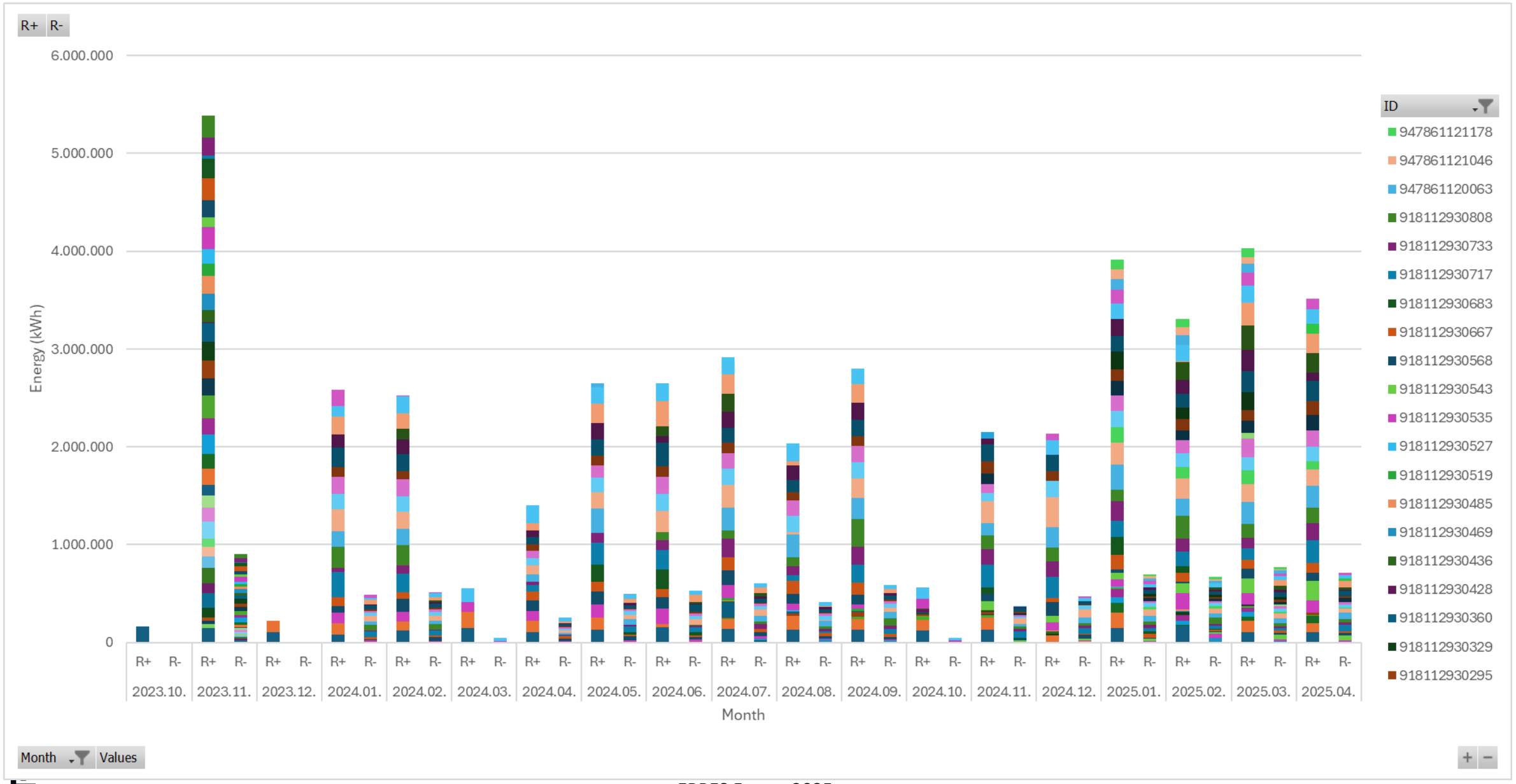
- Example: **ECO balance group (HROTE)**
  - **WPP**
  - **SPP**
  - **HPP**
  - **PP with installed capacity less than 30 kW**

Electrical energy data



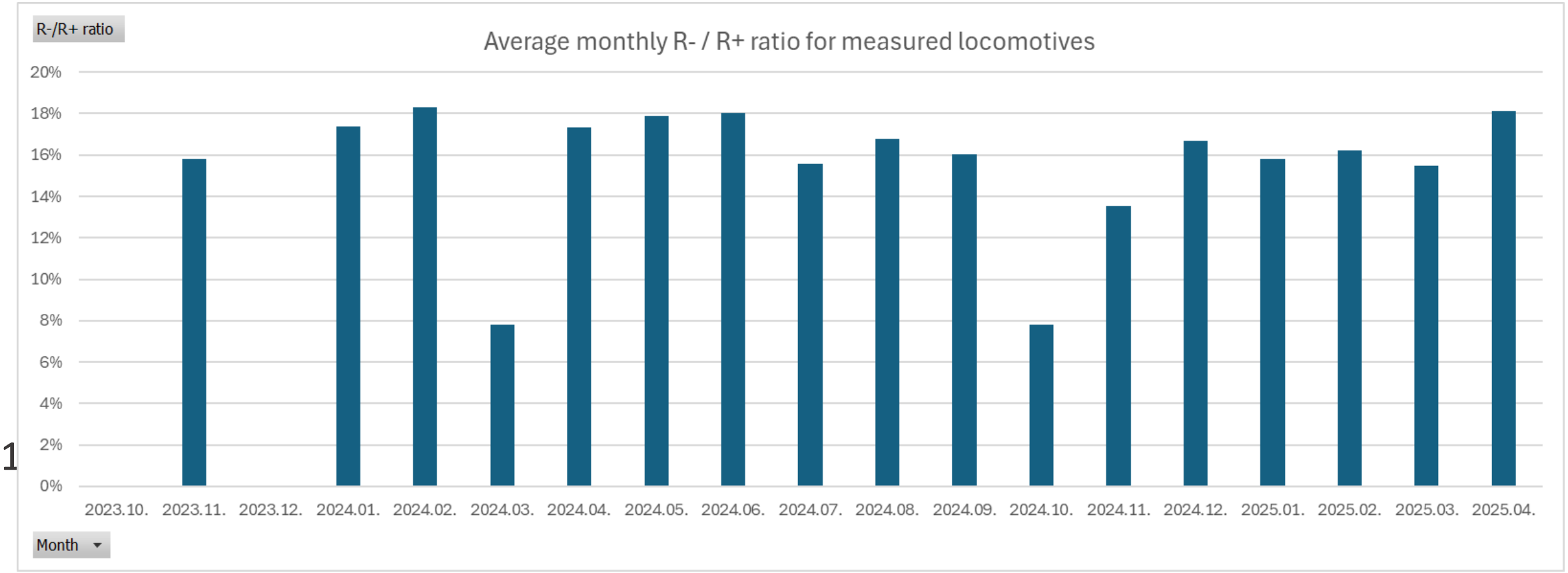


Monthly consumed and produced energy



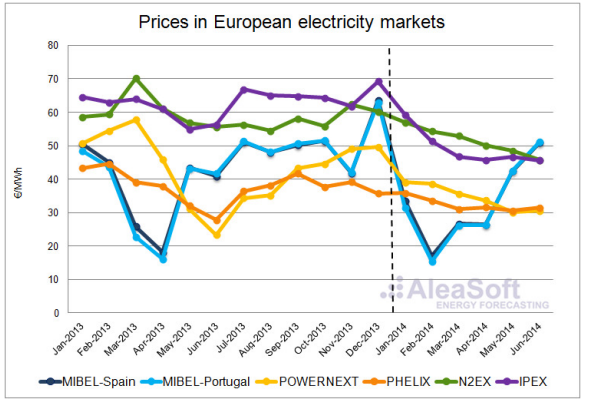
/Department of Energy and Power Systems

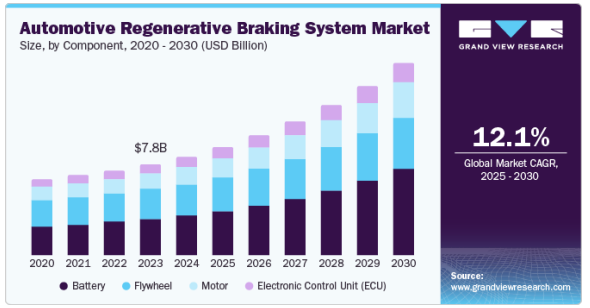
Monthly ratio of consumed and produced energy

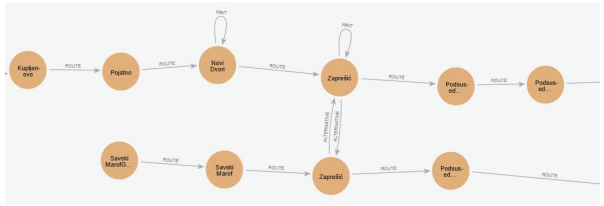


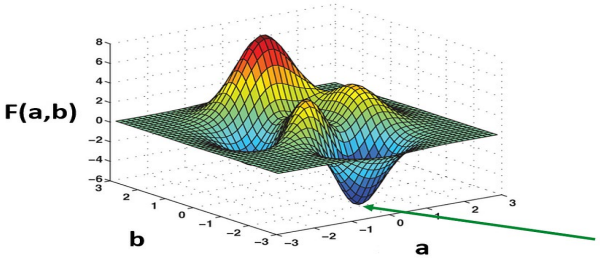
Current & Future Work – AI in Railways

- Price forecasting for electricity market(s) – Done/Doing/To-Do
  - Forecasted markets
    - Day-Ahead / Intra-Day / Balancing / etc.
  - Used by TSO's, DSO's, produces, traders, suppliers, customers
  - Can be used by railway operators (in the electricity market)
- Power production by regenerative braking forecasting – To-Do
  - Timetables, train run data, el. en. train measurements
- Resolving rail congestion – Doing/To-Do (master thesis 2024/2025)
  - Adaptive Multi-step Conditional Check (AMCC)
  - Timetables, train run data
- Optimization of train specific consumption using machine learning methods
  - Doing/To-Do : Student seminar 2024/2025 / master thesis 2025/2026
  - Based on el. en. train measurements









UNIVERSITY OF ZAGREB

Faculty of Electrical Engineering and Computing

AI in Railways

ERRES Forum 2025.

Split, 12.6.2025.

Dr. sc. Sara Raos
sara.raos@fer.hr

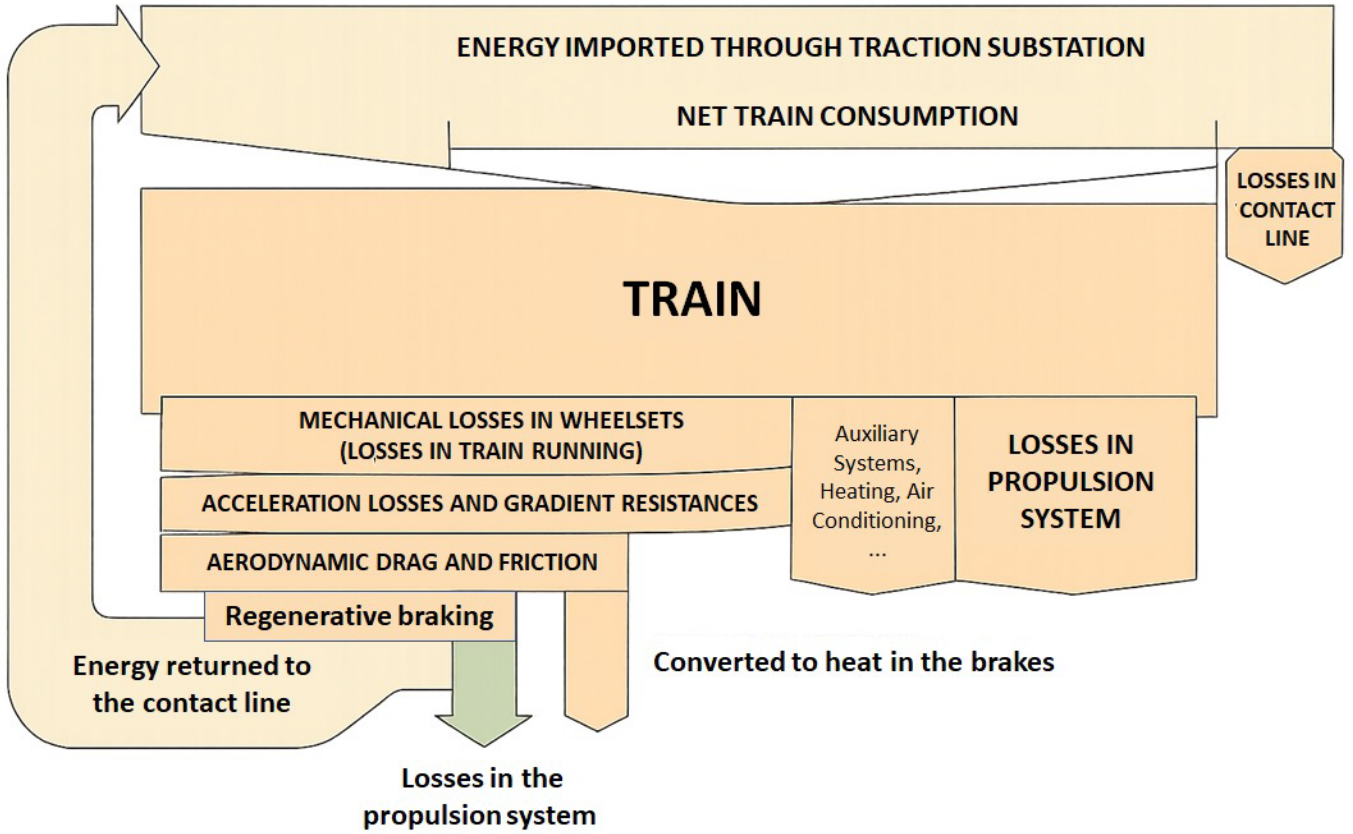
Dr. sc. Bojan Franc
bojan.franc@fer.hr

Additional slides

More information and details after this slide

Electrical Railways and regenerative braking

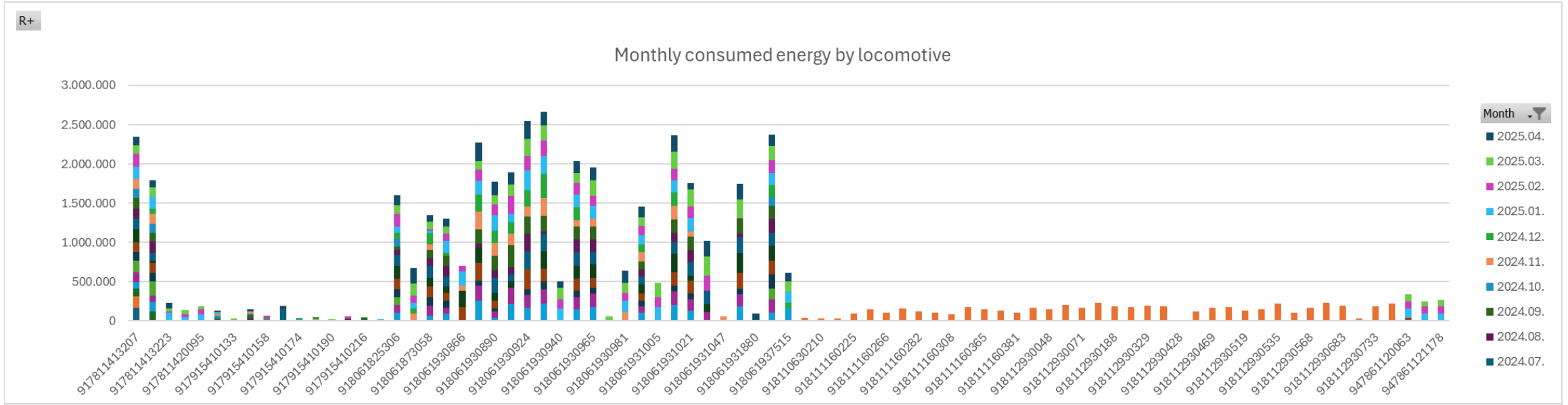
- Regenerative braking
  - Braking power (single locomotive) - 6 MW
    - Multiple locomotives on a section – significate amount of power
    - Maximum measured power sent from the catenary network to the TSO substation in 2021-2023:
      - EVP Plase – 4,4 MW (15 min average)
      - Peak power up to 8 MW (measured during testing)

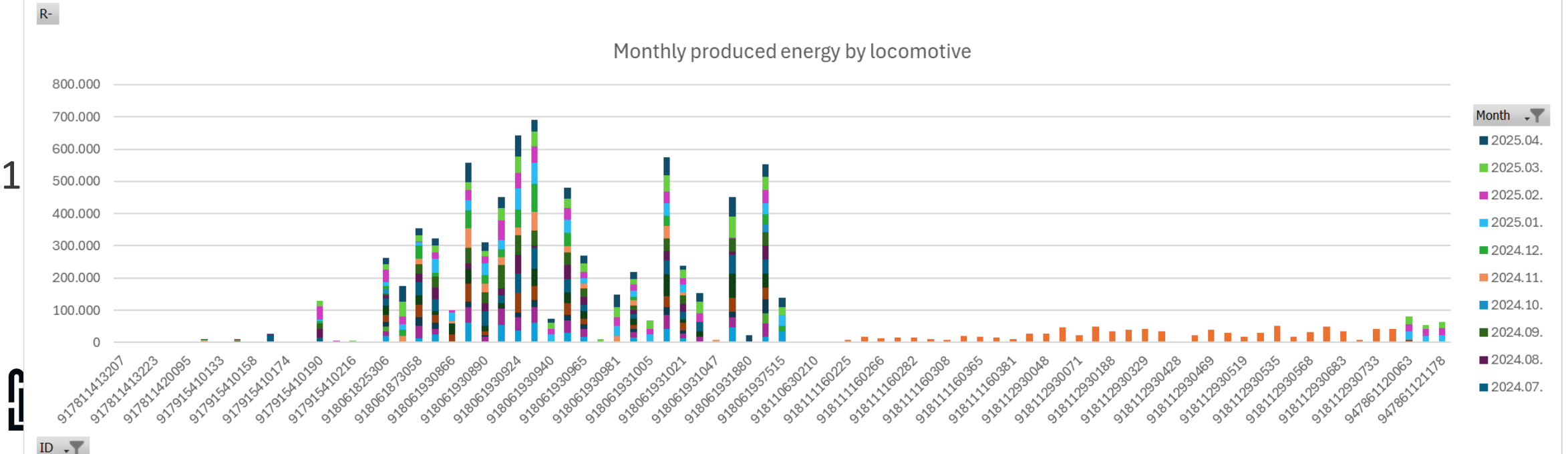


15

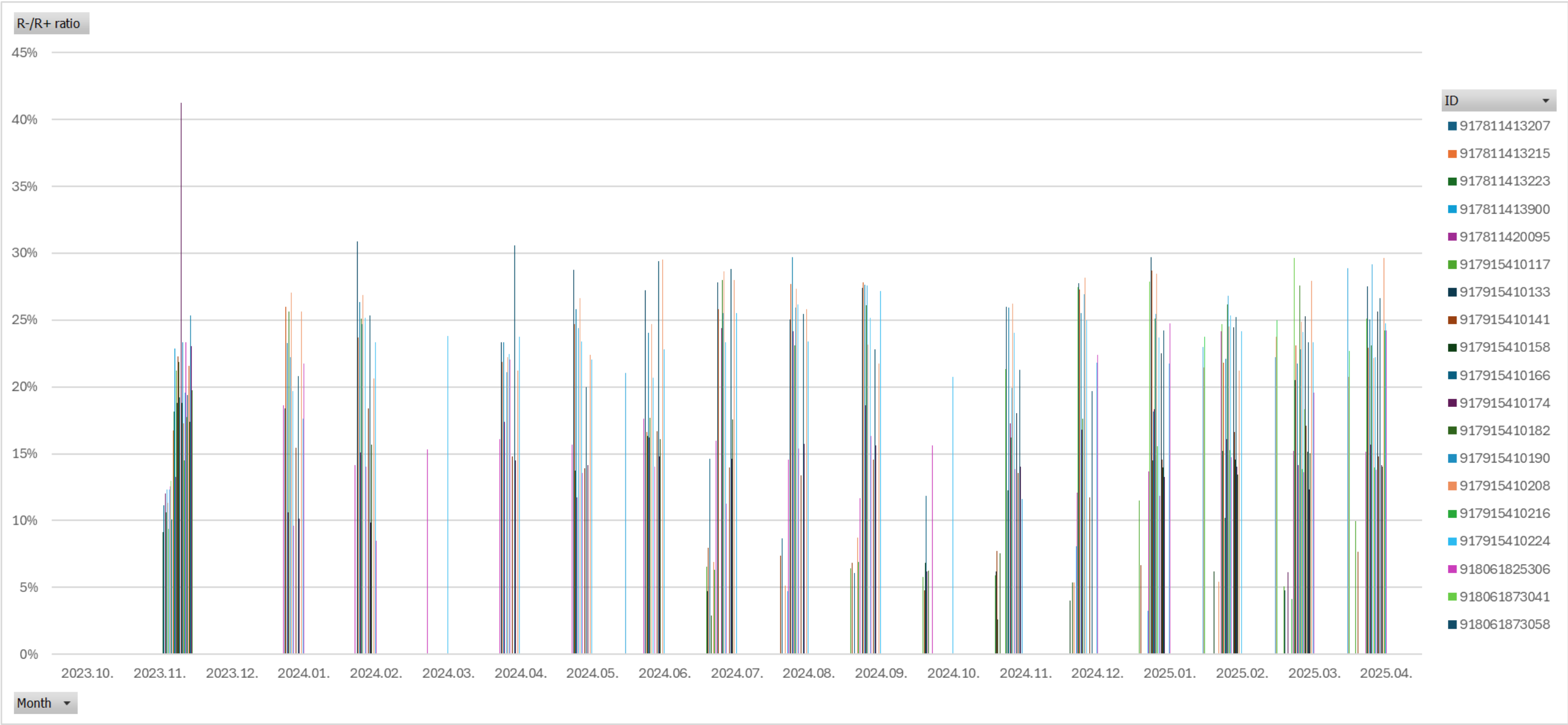
- Excess energy is passed to the transmission network -> market

Monthly consumed and produced energy by locomotives / EMU

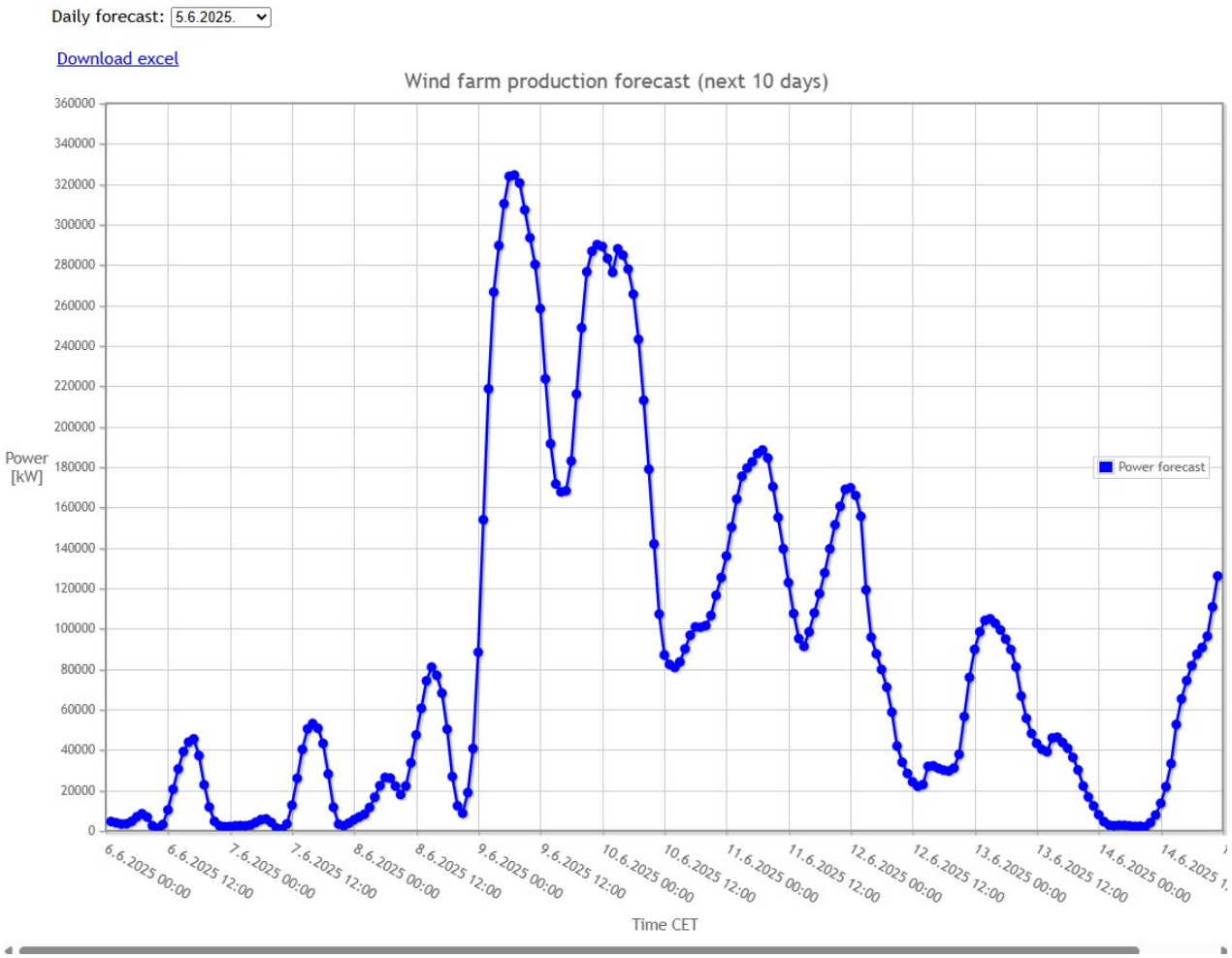




Monthly ratio of consumed and produced energy by locomotive / EMU

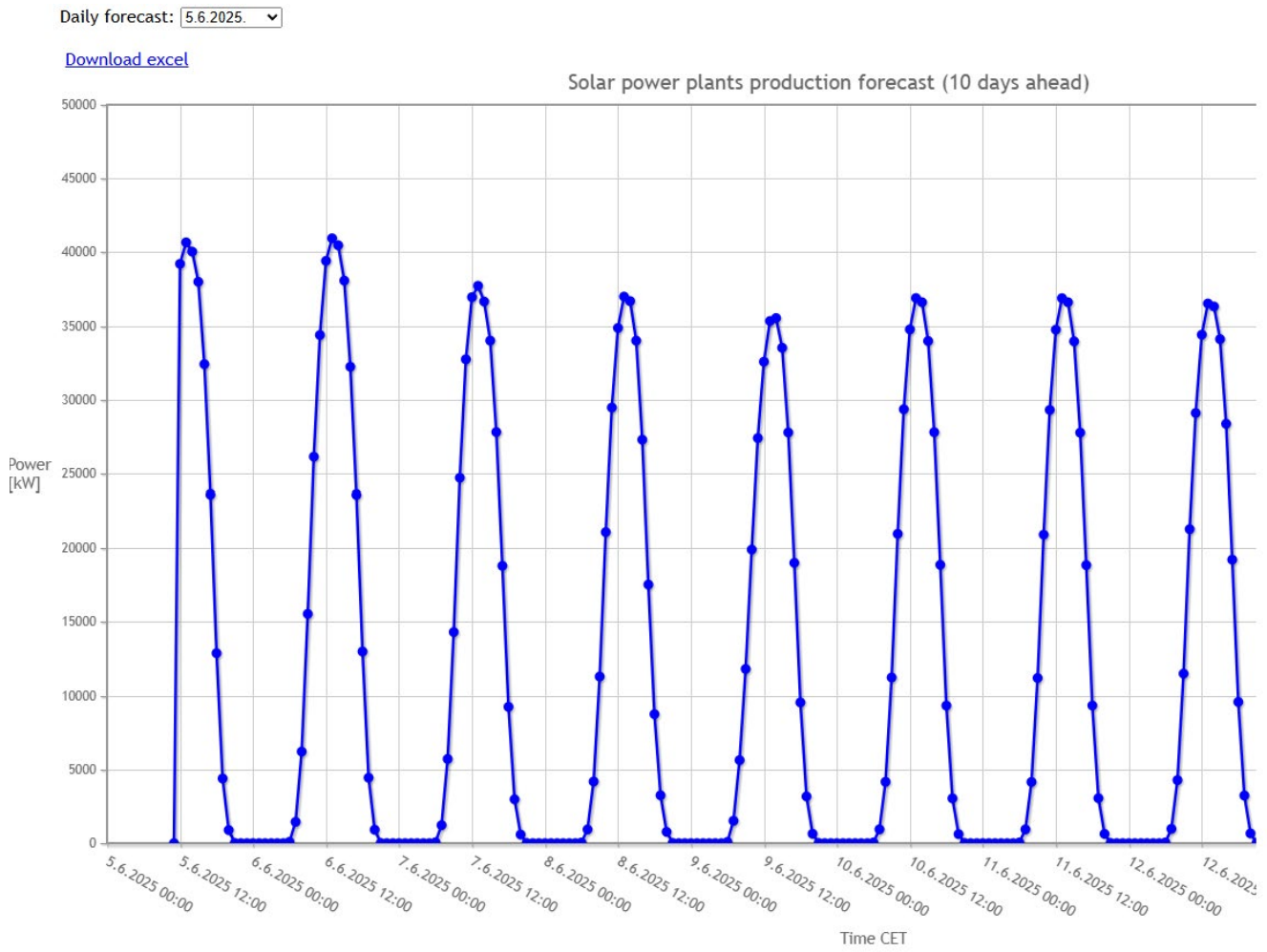


Wind power plants forecast (ECO balance group)



Source: https://www.hrote.hr/planning-electricity-production-for-the-eco-balance-group

Solar power plants forecast (ECO balance group)



Source: https://www.hrote.hr/planning-electricity-production-for-the-eco-balance-group