iDesignRES

Integrated Design of the Components of the Energy System to Plan the Uptake of Renewable Energy Sources: An Open Source Toolbox

Transportation sector: Scenario-dependent final energy demands by fuel at NUTS2 level (EU-27)

WP1/2 – Transport sector final energy demands

Task 1.1 – Data gathering on NUTS-2 level

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1. EXECUTIVE SUMMARY

This data has been prepared for the interlinkage of the different energy system models (GENeSYS-MOD, GeoMEC, and JRC-EU-TIMES-OP).

The data set consists of three main types:

- Downscaled final energy demands by fuel type from NUTS-0 level of GENeSYS-MOD to NUTS-2 level, and adapted to the fuel categories of GeoMEC
- Downscaled final energy demands by transport sector
- Average hourly electricity demand profile indicating the relative distribution of direct electricity demand of the transport sector

This is the first data set of this transport sector data collection but will be improved in the beginning to 2026 to match all requirements for the project. These requirements are continuously discussed with the collaborating teams in the iDesignRES project.

2. Data set structure

2.1 Overview

Table 1 shows an overview of all included files. Some of them serve for a more detailed description of final energy demands by the transport sector, others are for scaling electricity demands to hourly profiles (these are independent of NUTS-2 region and represent one *average* week). Documentation is included for a more detailed technical description of the data preparation.

Table 1: Overview on the content of contained.csv-files

Filename	Description
NUTS2_Transportation_Total_Energy_Demand.csv	Total final energy demands by fuel type by NUTS2
PSNG_Road_NUTS2_Fuel_Consumption.csv	Passenger road final energy demands by NUTS2
FRT_Road_NUTS2_Fuel_Consumption.csv	Freight road final energy demands by NUTS2
PSNG_Rail_NUTS2_Fuel_Consumption.csv	Passenger rail final energy demands by NUTS2
FRT_Rail_NUTS2_Fuel_Consumption.csv	Freight rail final energy demands by NUTS2
PSNG_Air_NUTS2_Fuel_Consumption.csv	Passenger air final energy demands by NUTS2
FRT_Ship_NUTS2_Fuel_Consumption.csv	Freight Shipping (Maritime + IWW) final energy demands by NUTS2 regions
Electricity_hourly_profiles.xlsx	Hourly profiles for electricity demand by different vehicle types, indicating average distribution [Mode Road (car, truck, bus); Mode Rail]
Transportation_Data_Structure_Documentation.md	Documentation on the preprocessing and preparation of the data and data types on

	the fuel consumption and total energy demands (excl. hourly profiles)

2.1.1 Geographic scope

Final energy demands: The final energy demands are scaled using Eurostat data. The most up-to-date data is used, which is typically available for EU-27. Therefore, the geographic scope is limited here to EU-27 and is not currently extended to all European countries.

Hourly demand profiles: The hourly demand profiles are independent of geographic region and time period. They represent an average electricity demand profile for the direct electricity demand by the transportation sector. The temporal scope is one week. The profiles are adaptable to any region (based on the local total electricity demand by the transport sector) and to any modelled year (based on the sequence of days of the week in the respective year).

2.1.2 Temporal scope

The temporal scope for the energy consumption data is given by the GENeSYS-MOD data. This is drawn from https://zenodo.org/records/17249700, which is the quantified output of GENeSYS-MOD. The data used was published on October 2nd, 2025, and has the Version V.1.2.2. The base year of the data set is 2018. The projections in energy demand are given for the years 2025, 2030, 2035, 2040, 2045, 2050, 2055, and 2060.

2.2 Final energy demands

Fuel types given by GENeSYS-MOD:

- Oil
- Power
- H2
- Powerfuel
- Biofuel

The fuel types used in GeoMEC and fuel mapping are:

- Oil → Transportation|Liquids|Fossil
- Power →Transportation|Electricity
- H2 → Transportation|Gases|Hydrogen
- Powerfuel →Transportation|Liquids|E-fuel
- Biofuel → Transportation|Liquids|Biomass

Table 2: Content description of files for final energy demands

Column name	Description	Unit
NUTS2	NUTS 2 level code of region	
Year	Country code (NUTS0)	
Fuel_Category	According to GeoMEC fuel categories	
Fuel_Consumption_PJ	Final energy demands by NUTS2	PJ
Country_Code	Year of annual final energy demand	
Model Version	EU EnVis-2060 scenario	
NUTS2_Region_Name	Region names	

Table 3: Abbreviations for sub-sectors of transport sector (used as in GENeSYS-MOD)

Prefix	Description
FRT_Rail	Freight on rail mode
FRT_Road	Freight on road-based mode
FRT_Ship	Freight transported by ships (Maritime + inland water ways)
PSNG_Air	Passengers transported by aviation mode
PSNG_Rail	Passenger transport with rail
PSNG_Road	Passenger transport on road

2.3 Sector-specific final energy demands

Table 4 gives an overview on the description of the columns.

Table 4: Descriptions of content of "NUTS2_Fuel_Consumption.csv" files

Column name	Description	Unit
Model Version	EU EnVis-2060 scenario	
Country_Code	Country code (NUTS0)	
NUTS2_Code	NUTS 2 level code of region	
NUTS2_Region_Name	Final energy demands by NUTS2	
Year	Year of annual final energy demand	
Technology	Drive-train technology specified with mode and type	
Fuel	Fuel type used (as used in GENeSYS-MOD)	
Country_Total_Fuel_Use_PJ	Aggregated fuel use on country level	PJ
NUTS2_Weight	Downscaling weight used	
NUTS2_Fuel_Use_PJ	Fuel demand at NUTS2 region	PJ

2.4 Hourly profiles

To realistically reflect the variability of traffic volume, a distinction was made between weekdays (Business Days) and weekends (Weekends).

An excerpt of the data (exemplified by January 1, 2022) shows the calculated unweighted percentage charging profiles derived from the kilowatt (kW) specifications:

While these values reflect the temporal distribution of charging demand within the individual sectors, they do not provide information on the absolute contribution of each sector to the overall energy requirement.

Table 5: Descriptions of content of "Electricity_hourly_profiles.csv" files

Column name	Description	Unit
Hour of the day	Enumeration indicating the hour of the day	
Weekly_percentage	Share of weekly total demand indicating the amount of electricity demand at the specific hour of the week	kWh/kWh
Weekday	Day of the week	

3. Details on data preparation

Scripts and data used and produced during the pre-processing procedures can be made available on request.

3.1 Sub-sector final energy demands

3.1.1 PSNG_Road_NUTS2_Fuel_Consumption.csv

Country-level passenger road transport fuel consumption is downscaled to NUTS2 regions using vehicle-kilometers as the distribution indicator. Vehicle-kilometers are derived from Eurostat vehicle stock data (tran_r_vehst, reference year 2023) for three vehicle categories—passenger cars, motorcycles, and buses—multiplied by assumed annual mileage values of 12,540 km/year for cars, 7,000 km/year for motorcycles, and 27,574.6 km/year for buses. The regional weight is calculated as the ratio of a region's total vehicle-kilometers to the country's total vehicle-kilometers, ensuring all weights sum to 1.0 per country. This approach accounts for differences in usage intensity across vehicle types, recognizing that buses contribute significantly to passenger transport activity despite their smaller fleet size.

3.1.2 FRT_Road_NUTS2_Fuel_Consumption.csv

For road freight transport, lorry stock counts as the distribution indicator. The data is sourced from Eurostat's vehicle stock dataset (tran_r_vehst, reference year 2023), filtered for the vehicle type "LOR:Lorries". The regional weight is calculated as the ratio of lorries registered in a NUTS2 region to the total number of lorries registered in the country. This approach assumes that regions with more registered lorries generate proportionally more freight transport demand, using lorry stock as a direct proxy for freight road transport capacity and activity.

3.1.3 FRT_Rail_NUTS2_Fuel_Consumption.csv

Gross Domestic Product (GDP) serves as the distribution indicator for downscaling country-level freight rail fuel consumption to NUTS2 regions. Regional GDP data at current market prices is sourced from Eurostat's economic accounts dataset (nama_10r_2gdp, reference year 2023). The regional weight equals a region's GDP divided by the country's total GDP. Unlike passenger rail, which correlates with population, freight rail demand is driven by economic activity and industrial output. Regions with higher GDP typically have more manufacturing, mining, and commercial activity that generates freight transport demand, making GDP a suitable proxy for freight rail movements.

3.1.4 PSNG_Rail_NUTS2_Fuel_Consumption.csv

For passenger rail transport, population serves as the distribution indicator to downscale country-level fuel consumption to NUTS2 regions. Regional population data is sourced from Eurostat's demographic dataset (demo_r_d2jan, reference year 2024). The regional weight equals the population of a NUTS2 region divided by the total population of the country. This population-based approach reflects the strong correlation between passenger rail demand and residential distribution—regions with larger populations generate more passenger rail trips, both as origins and destinations. In the absence of NUTS2-level rail ridership statistics, population provides a reasonable proxy for passenger rail activity.

3.1.5 PSNG_Air_NUTS2_Fuel_Consumption.csv

Air passenger counts serve as the distribution indicator for downscaling country-level passenger aviation fuel consumption to NUTS2 regions. The data is sourced from Eurostat's air passenger transport dataset (tgs00077, reference year 2023), capturing the number of passengers carried at airports within each region. Regional weights are calculated by dividing a region's air passenger volume by the country total. Since only regions containing airports receive allocations, this method directly links aviation energy demand to locations where air transport activity occurs. Regions without airport infrastructure have zero weight in the distribution.

3.1.1 FRT_Ship_NUTS2_Fuel_Consumption.csv

A hybrid approach is applied to downscale country-level freight shipping fuel consumption to NUTS2 regions, combining maritime freight data with manual allocations for inland waterways. For coastal countries, maritime freight tonnage (goods loaded and unloaded) from Eurostat's maritime transport dataset (tran_r_mago_nm, reference year 2023) serves as the distribution indicator, with regional weights calculated as port tonnage divided by country total. For landlocked countries with inland waterway transport—Austria, Czechia, Hungary, Luxembourg, and Slovakia—manual allocations distribute energy demand to NUTS2 regions containing major river ports along the Danube, Elbe, Vltava, and Moselle waterways. This dual methodology ensures that both seaport activity and inland waterway infrastructure are represented in the regional distribution.

3.2 Hourly profiles

3.2.1 Introduction and Objectives

The average weekly hourly electricity demand profile is created based on sub-sector specific demands. The objective of this data preparation was to create a representative, aggregated load profile for the electrified ground-based transport sector in Europe, focusing on two transport sector that are dominant in the direct electricity demand: road and rail. Since the raw data for the individual transport modes (sectors) are initially available as unweighted, individual demand curves, weighting is necessary. This weighting reflects the varying degrees of electrification and the energetic market share of the respective means of transport within the total traffic volume.

The methodology transforms the isolated weekly demand curves into a realistic overall representation by assigning a specific weighting factor to each sector.

3.2.2 Data Preparation

A central step in the data preparation was the transformation of absolute power values (in kW) into dimensionless percentage shares. This step was taken to ensure the scalability of the profiles at the European level. The procedure can be formalized as follows:

For each time step t (hour), the percentage share $p(t)$ of the total weekly energy demand:

$$p(t) = \frac{P(t)}{E^{week}}$$

Where $P(t)$ corresponds to the share of power at hour t.

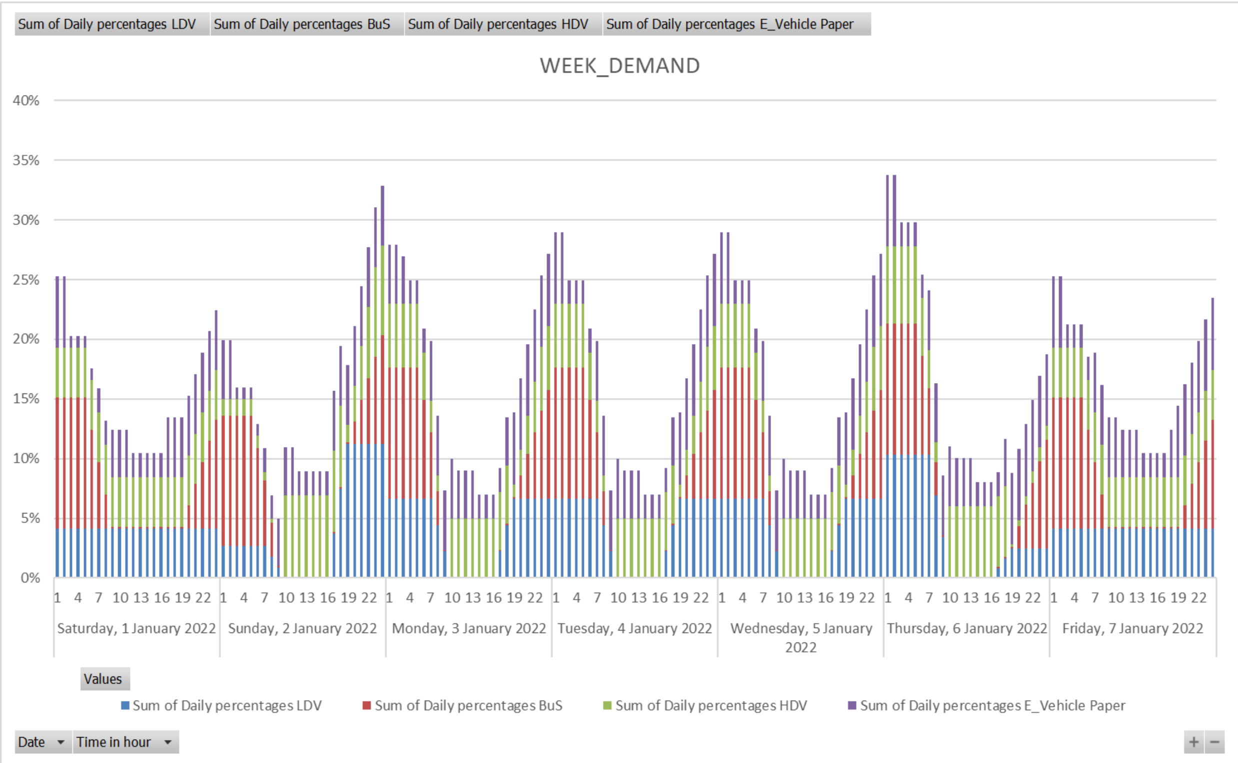

Figure 1: Distribution of % charging profiles within the respective sectors

Figure 1 shows the weekly temporal distribution of charging behavior for the individual sectors: passenger cars (Electric Vehicles – EV), Light Duty Vehicles (LDV), buses (BUS), Heavy Duty Vehicles (HDV), and rail transport (Train). However, this is shown without weighting based on the total share of the transport sector (aviation and maritime transport have been excluded).

3.2.3 Application of Weighting Factors to road subsectors

To reflect the relevance of individual sectors in the European context, weighting factors w_i were established. These factors are based on assumptions regarding the degree of electrification and sales figures (modal split) in Europe, derived from the Eurostat dataset.

The weighting distribution is as follows:

E_Vehicle w_{EV}**: 42 %**

Bus w_{Bus}**: 4 %**

Train w_{Train}**: 47 %**

LDV w_{LDV}**: 1 %**

HDV w_{HDV}**: 6 %**

The sum of all weightings equals 100%, representing the entire electrical transport sector under consideration (excluding aviation and maritime traffic).

The calculation transforms the relative individual profiles into weighted sub-profiles, which are subsequently aggregated into the total load profile.

For each time step t and each Sector i the weighted share in % is calculated. Here, the percentage share from the data table $p_i(t)$ is multiplied by the global weighting factor of the sector w_i.

- The general formula for the adjustment is

$$\text{weighted share in } \% = p_i(t) * w_i$$

Applied to the specific sectors, the following calculation equations result for each time step t:

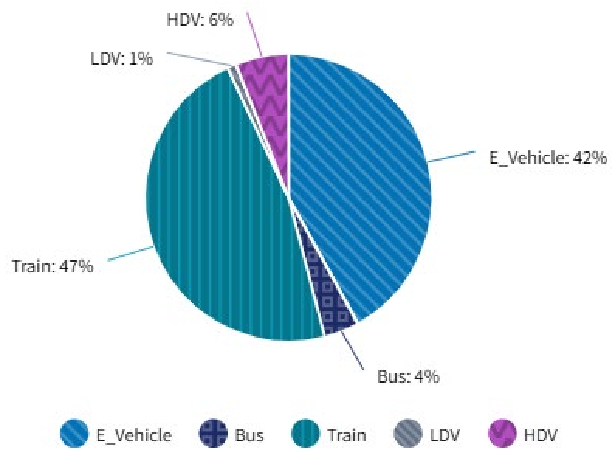

Figure 1: Weighting of individual sectors by total share and degree of electrification

Sample calculation for Hour 1:

For Buses with a utilization of 11% at hour t:

Weighted share in $\%\_Bus = 0.11 * 0.04 = 0.0044\,\%$

For E-Vehicles with a utilization of 6%:

Weighted share in $\%\_EV = 0.06 * 0.42 = 0.0252\,\%$

This approach ensures that sectors with high energy demand or a high degree of electrification (such as trains and private electric vehicles) have a dominant influence on the shape of the overall curve, while smaller sectors (such as LDVs) influence the curve only marginally. The resulting time series—Figure 3: Weighted share in %—therefore no longer represents a simple overlay of usage patterns, but rather an energetically scaled total demand.

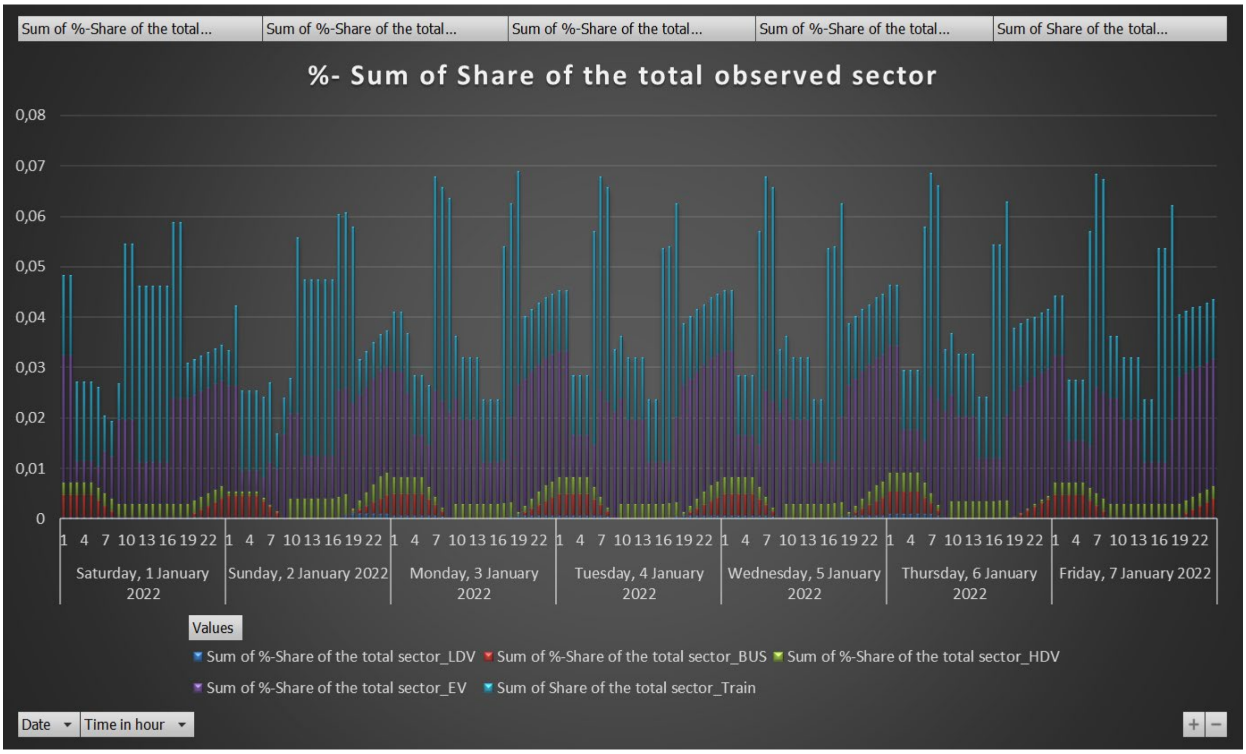

Figure 3: Weighted share by energy demand and electrification within the defined total sector

3.2.4 Data Sources and References

The datasets used originate from various scientific and publicly accessible sources. For comparability, the original power data in kilowatts (kW) were normalized into percentage shares of the respective daily energy demand.
The underlying raw data is available in hourly resolution. The datasets represent the total demand for Austria (*Demand_LNF_BUS_SNF_Train.xlsx*) and, through the percentage representation, can be used as a representative proxy for the EU.

HDV and BUS: Data for heavy-duty vehicles and buses are based on the aggregation and averaging of the Austrian federal states.

LDV: For Light Duty Vehicles, data from the Greater Vienna area were used as a proxy for load behavior and scaled accordingly for the national territory.

For specific vehicle categories, the following primary sources were used to generate separate hourly profiles for weekdays and weekends:

Passenger Cars (E-Vehicle): The normalized daily energy demand for electric vehicles was derived according to Loschan et al. (2023).

Reference: C. Loschan, D. Schwabeneder, G. Lettner, and H. Auer, “Flexibility potential of aggregated electric vehicle fleets to reduce transmission congestions and redispatch needs: A case study in Austria,” *International Journal of Electrical Power & Energy Systems*, vol. 146, p. 108802, 2023. DOI: 10.1016/j.ijepes.2022.108802.
Commercial Traffic (LDV, BUS, HDV): Data for HDV, LDV, and BUS are based on the modeling results of Loschan and Golab (2040).
Reference: Loschan, C. and Golab, A., 2040. *Effects of the Electrification of Commercial Traffic on Redispatch Measures in Austria: Analysis of the Effects for the Year 2040.*

Rail Transport (Train): The load curve for rail transport was derived and modeled from energy consumption data published by ÖBB.
Reference: ÖBB-Infrastruktur AG, (“Facts and Figures” or Sustainability Reports).

4. Next steps - Required improvements and extensions to the data set

This current data set is the first version of transport sector data and projections at NUTS-2. Its primary purpose is the establishing of a data processing pipeline between the outputs of GENeSYS-MOD and GeoMEC, as well as the provision of hourly demand profiles for the operational modeling.

The following summarizes required improvements and extensions for upcoming versions of this data set:

- **Improvements in the maritime sector**: The current maritime downscaling has several limitations. First, port tonnage measures cargo handling at ports rather than where energy is actually consumed during voyages, which may not fully reflect regional shipping energy demand. Second, the manual allocations for landlocked countries are user-specified estimates based on known inland waterway infrastructure, and would benefit from actual NUTS2-level inland waterway freight statistics if such data becomes available from Eurostat. The current hybrid approach needs to be redesigned to achieve this.

- **The geographic scope of the data** set is aimed to ultimately encompass all case study regions. Currently, important regions for this are missing: namely, Great Britain, Bulgaria (FRT_Rail is missing for this region)
- **Adaptation of base year:** To be coherent with the base year used for the modelling of other sectors, the base year of this data set needs to be adapted to **2024**. To do this, we first need to compare results of the final model simulations of GENeSYS-MOD to recent developments in this sector. **This is planned for the beginning of 2026**.
- The current **maritime downscaling** has several limitations. First, port tonnage measures cargo handling at ports rather than where energy is actually consumed during voyages, which may not fully reflect regional shipping energy demand. Second, the manual allocations for landlocked countries are user-specified estimates based on known inland waterway infrastructure, and would benefit from actual NUTS2-level inland waterway freight statistics if such data becomes available from Eurostat. Third, the temporal assumption that 2023 port and waterway patterns remain constant across all model years (2018-2060) does not account for potential shifts in port activity or infrastructure development over time.
- *Validation with partners* that have access to NUTS-2 specific data.
- A required **improvement for hourly profiles** is a smoothing procedure.
- **Optional future extensions** are (if required by project partners)
  - Adaptation of IAMC data format
  - Hourly/Seasonal profiles for hydrogen demand

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Sources:

Loschan, C., Schwabeneder, D., Lettner, G. and Auer, H., 2023. Flexibility potential of aggregated electric vehicle fleets to reduce transmission congestions and redispatch needs: A case study in Austria. International Journal of Electrical Power & Energy Systems, 146, 108802. https://doi.org/10.1016/j.ijepes.2022.108802

Loschan, C. and Golab, A., 2040. Effects of the Electrification of Commercial Traffic on Redispatch Measures in Austria: Analysis of the Effects for the Year 2040.

ÖBB-Infrastruktur AG. "Zahlen Daten Fakten" oder Nachhaltigkeitsberichte. Verfügbar unter: https://static.web.oebb.at/konzern/zdf2023/44/index.html

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