WHZ Westsächsische Hochschule Zwickau
Hochschule für Mobilität

ROAD TRAFFIC ENGINEERING
KFT81000 - SUSTAINABLE MOBILITY

PRACTICAL REPORT

RB - 1 (Zwickau Zentrum - Kraslice)

Group - 1

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1. Motivation

Germany's commitment to sustainable transportation underlines the importance of electrifying rail networks and reducing emissions. The Zwickau RB1 route exemplifies cross-border connectivity and represents an opportunity to incorporate sustainable practices in regional rail services. Its operation in both electrified and non-electrified segments provides a testing ground for innovative solutions. The RB1 Vogtlandbahn train service exclusively uses diesel-powered trains, including the RegioSprinter units, for its entire journey from Zwickau Zentrum to Kraslice. The RB1 route, connecting Zwickau Zentrum to Kraslice, presents an opportunity to implement advanced drive systems such as Battery Electric Multiple Units (BEMU) and Hydrogen Electric Multiple Units (HEMU). This report assesses the feasibility, operational efficiency, and environmental benefits of these alternative drive systems. The motivation for analyzing the RB1 route arises from the need to transition from traditional diesel-powered trains to more sustainable alternatives while addressing the limitations of electrification infrastructure. The route, which spans 70.58 km, lacks any electrified track segments, making alternative drive systems, such as Battery Electric Multiple Units (BEMU) and Hydrogen Electric Multiple Units (HEMU), ideal candidates for achieving sustainability goals without the need for track electrification. This report will contribute to understanding how these goals can be operationalized on a practical level and offer insights into scalability across similar routes in Germany and Europe.

2. Task Description and Assessment Methodology

Task Description:

The primary task of the RB1 energy analysis is to evaluate the operational feasibility, energy requirements, and cost implications of replacing conventional diesel trains with sustainable alternative drive systems. This involves a detailed study of Battery Electric Multiple Units (BEMU) and Hydrogen Electric Multiple Units (HEMU) as potential solutions. The tasks include:

- **Route Analysis**:
  - Assessment of the RB1 route characteristics, including track length (70.54 km), station layout, operational schedules, relevant connections.
  - Identification of optimal locations for charging or refueling stations (e.g., Zwickau Zentrum, Falkenstein, and Kraslice).
- **Energy Consumption Evaluation**:
  - Calculation of energy consumed per trip for BEMU and HEMU systems.
  - Assessment of battery or hydrogen fuel requirements based on operational parameters like distance, and waiting times.
- **Operational Feasibility**:
  - Evaluation of train turnaround times at terminal stations.
  - Assessment of the adequacy of charging or refueling durations to meet service demands.

- **Cost Analysis**:
    - Estimation of initial investment costs, including vehicle procurement and infrastructure setup.
    - Comparison of operating costs, such as energy usage, maintenance, and lifecycle costs for BEMU and HEMU systems.

Assessment Methodology

A systematic approach was followed to ensure the accurate and comprehensive assessment of BEMU and HEMU systems for the RB1 route:

- **Data Collection:**
    - Trip characteristics (distance, speed, waiting times, and turnaround durations) were gathered from the route layout and operational schedules.
    - Energy consumption data for BEMU and HEMU systems were calculated based on manufacturer specifications and real-world usage scenarios.
- **Simulation and Modeling**:
    - Simulated energy consumption per kilometer for both drive systems under typical operating conditions, considering route gradients and stopping patterns.
    - Modeled charging and refueling requirements at designated stations to ensure uninterrupted service.
- **Comparative Analysis**:
    - Conducted a comparative assessment of BEMU and HEMU systems in terms of energy efficiency, cost, and infrastructure requirements.
    - Evaluated trade-offs between longer charging durations (BEMU) and hydrogen refueling logistics (HEMU).
- **Cost-Benefit Analysis**:
    - Analyzed investment and operational costs for both systems over the expected lifecycle of the trains.
    - Incorporated economic factors such as potential subsidies for clean energy projects and operational savings due to reduced fuel costs.

3. Alternative Drive Systems

Overview

Alternative drive systems offer sustainable solutions for rail transport by reducing reliance on fossil fuels. Key alternatives include:

- Battery-electric trains
- Hydrogen fuel cell trains
- Hybrid-electric systems

Functionality

• Battery-Electric Trains:
  - Use rechargeable batteries to power electric motors.
  - Operate on non-electrified routes, charging via overhead lines or charging stations.
• Hydrogen Fuel Cell Trains:
  - Convert hydrogen gas into electricity via a fuel cell, emitting only water vapor.
  - Suitable for long non-electrified routes.
• Hybrid Systems:
  - Combine internal combustion engines with electric motors, offering flexibility and reduced emissions.

Characteristics Relevant for the Study

Characteristic	Battery-Electric	Hydrogen Fuel Cell	Hybrid
Emissions	Zero	Zero	Reduced (compared to diesel)
Energy Efficiency	High	Moderate	Moderate
Operational Range	Limited (short-to-medium)	Long	Long
Infrastructure Requirements	Charging stations, partial OHL	Hydrogen refueling stations	Minimal (existing infrastructure)
Costs	Moderate upfront, low operational	High upfront, moderate operational	Moderate upfront and operational
Suitability for RB1 Route	Non-electrified sections	Entire non-electrified route	Entire route with limited upgrades

Analysis and choice of alternative drive systems for further assessment

Given the RB1 route's operational characteristics, BEMUs offer a more practical and cost-effective solution. The analysis shows that:

- BEMUs provide sufficient range (~100-150 km) to cover the RB1 route (70.58 km).
- Charging times at stations fit well within the operational schedule, ensuring minimal service disruptions.
- They offer long-term financial and environmental benefits, making them the optimal choice for sustainable rail transport on the RB1 route.

In conclusion, BEMUs are selected for further assessment due to their superior energy efficiency, lower costs, and compatibility with the RB1 route's operational and infrastructural requirements. This decision aligns with sustainability goals and supports a smooth transition to zero-emission rail transport.

4. Definition of relevant parameter of vehicle and track

Battery Electric Multiple Units (BEMU) and Hydrogen Electric Multiple Units (HEMU) possess distinct characteristics that make them suitable for different operational scenarios. Both systems are heavier than traditional diesel vehicles due to the inclusion of batteries or hydrogen tanks, resulting in an axle load of approximately 18 tons for both BEMU and HEMU trains.

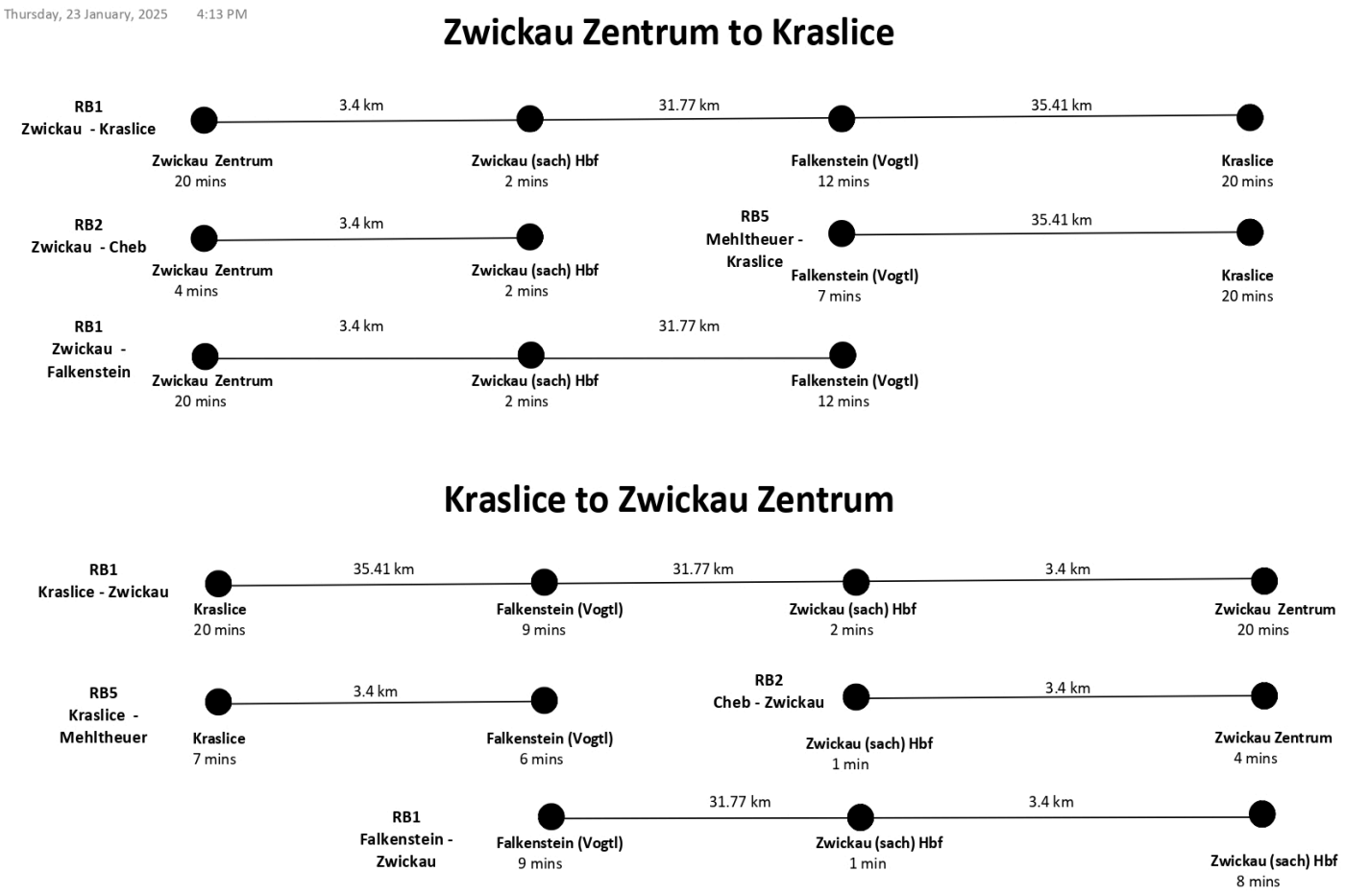
The infrastructure requirements for these systems differ significantly. BEMUs rely on a combination of overhead lines (overhead line islands) and charging stations for energy replenishment, while HEMUs require hydrogen refueling stations, along with a reliable logistical supply chain for hydrogen tanks. In terms of charging concepts, BEMUs can be charged intermittently at stations or during movement via overhead lines, whereas HEMUs are limited to intermittent refueling at designated stations.

Both systems are capable of regenerative braking, allowing energy storage during deceleration, which contributes to improved energy efficiency. However, the range capabilities of the two systems differ notably. BEMUs typically have a range of 40–80 km, making them suitable for shorter regional routes, while HEMUs boast a significantly longer range of up to 600 km, ideal for extended operations.

The physical dimensions and seating capacities also vary between the two technologies. BEMU vehicles come in lengths of 75.2 m, 46 m, and 56.2 m, with seating capacities of 244, 120, and 155 passengers, respectively. On the other hand, HEMU vehicles have lengths of 54.3 m and 47 m, accommodating 150, 120, and 165 passengers, depending on the configuration.

These characteristics highlight the operational flexibility and infrastructure requirements of BEMUs and HEMUs, allowing for tailored deployment based on route-specific demands and logistical constraints.

5. Description of railway network and operational programme



The RB1 route, connecting Zwickau and Kraslice via Vogtlandbahn, spans a total distance of 70.58 km and is serviced by 3 Regio Shuttle trains. For implementing sustainable alternatives, Battery Electric Multiple Units (BEMU) and Hydrogen Electric Multiple Units (HEMU) were evaluated. The BEMU trains are equipped with a battery capacity of 600 kWh, while HEMU trains have a hydrogen storage capacity equivalent to 220 kWh.

Charging infrastructure is proposed at three strategic locations: Zwickau Zentrum, Falkenstein, and Kraslice. BEMU trains can be charged at these stations within 10 minutes at a rate of 20 kWh/min or in motion through overhead lines, where they are charged at 20 kWh/km. In comparison, HEMU trains require 15 minutes to recharge at the stations. The energy requirement per kilometer for BEMU trains is 3.9 kWh/km, making them more energy-efficient than HEMU trains, which require 5.9 kWh/km. This data highlights the operational feasibility and energy efficiency of BEMU trains, supported by adequate charging infrastructure along the RB1 route.

6. Assessment of Railway Network

RB1 - Zwickau Zentrum to Kraslice

Start Trip	Zwickau Zentrum	Turning time (min)	km	Zwickau (Sach) Hbf	km	Falkenstein (Vogtl)	Waiting time (min)	km	Kraslice	Turning time (min)
Energy Consumed (kWh)	0			13.3		123.9			138.099	
Energy Available (kWh)	600			586.7		600	12		461.9	
Energy Charged (kWh)	600			0		240			0	
Return Trip		20	3.40		31.77		CHARGING STATION	35.41		20
Energy Consumed (kWh)	13.3			123.9		138.1			0	
Energy Available (kWh)	463			476.1		600	9		600.0	
Energy Charged (kWh)	400			0		180			400	

Benefit Analysis

Zwickau Zentrum		Remarks
Energy requried (kWh)	137	
Time Required (min)	6.9	
Overhead line required (km)	6.9	
Turning time (min)	20	Okay

RB2 - Zwickau to Cheb

Start Trip	Zwickau Zentrum	Turning time (min)	km	Zwickau (Sach) Hbf
Energy Consumed (kWh)	0			13.3
Energy Available (kWh)	600			586.7
Energy Charged (kWh)	600			0
Return Trip		20	3.40	
Energy Consumed (kWh)				
Energy Available (kWh)				
Energy Charged (kWh)				

RB1 - Zentrum to Falkenstein

Start Trip	Zwickau Zentrum	Turning time (min)	km	Zwickau (Sach) Hbf	km	Falkenstein (Vogtl)	Turning time (min)
Energy Consumed (kWh)	0			13.3		123.9	
Energy Available (kWh)	600			586.7		463	
Energy Charged (kWh)	600			0		0	
Return Trip		6	3.40		31.77		8
Energy Consumed (kWh)	13.3			123.9		0	
Energy Available (kWh)	463			476.1		600	
Energy Charged (kWh)	0			0		160	

RB5 - Meltheuer to Kraslice

Start Trip	Falkenstein (Vogtl)	Waiting time (min)	km	Kraslice	Turning time (min)
Energy Consumed (kWh)	86.4			138.099	
Energy Available (kWh)	600	7		461.9	
Energy Charged (kWh)	140			0	
Return Trip		CHARGING STATION	35.41		20
Energy Consumed (kWh)	138.1			0	
Energy Available (kWh)	581.901	6		600.0	
Energy Charged (kWh)	120			400	

RB1 Kraslice to Zwickau Zentrum

Start Trip	Kraslice	Turning time (min)	km	Falkenstein (Vogtl)	km	Waiting time (min)	Zwickau (Sach) Hbf	km	Zwickau Zentrum	Turning time (min)
Energy Consumed (kWh)	0			138.1			123.9		13.26	
Energy Available (kWh)	600			600.0		9	476		462.8	
Energy Charged (kWh)	600			180			0		0	
Return Trip		20	35.41		31.77	CHARGING STATION		3.40		20
Energy Consumed (kWh)	138.1			123.9			13.3		0	
Energy Available (kWh)	462			600.0		12	586.74		600.0	
Energy Charged (kWh)	400			240			0		400	

Benefit Analysis

Kraslice		Remarks
Energy requried (kWh)	138.1	
Time Required	6.9	
Overhead line required (km)	6.9	
Turning time	20	Okay

RB5 - Kraslice to Meltheuer

Start Trip	Kraslice	Turning time (min)	km	Falkenstein (Vogtl)	Waiting time (min)
Energy Consumed (kWh)	0			138.1	
Energy Available (kWh)	600			600.0	9
Energy Charged (kWh)	600			180	
Return Trip		20	35.41		CHARGING STATION
Energy Consumed (kWh)	138.1			86.4	
Energy Available (kWh)	462			600.0	12
Energy Charged (kWh)	0			240	

RB1 - Falkenstein to Zentrum

Start Trip	Falkenstein (Vogtl)	km	Waiting time (min)	Zwickau (Sach) Hbf	km	Zwickau Zentrum	Turning time (min)
Energy Consumed (kWh)	0			123.9		13.26	
Energy Available (kWh)	600			476		462.8	
Energy Charged (kWh)	600			0		0	
Return Trip		31.77	8		3.40		8
Energy Consumed (kWh)	123.9			13.3		0	
Energy Available (kWh)	600.0			586.74		600.0	
Energy Charged (kWh)	160			0		160	

RB2 - Cheb to Zentrum

Start Trip	Zwickau (Sach) Hbf	km	Zwickau Zentrum	Turning time (min)
Energy Consumed (kWh)			3.9	
Energy Available (kWh)			-3.9	
Energy Charged (kWh)	0		0	
Return Trip		3.40		20
Energy Consumed (kWh)	13.3		0	
Energy Available (kWh)	586.74		600.0	
Energy Charged (kWh)	0		400	

7. Conclusion and outlook

RB1		Unit	BMU	HMU
One Time Investment				
	Number of vehicle	Item	3	3
	Cost of vehicle	Euro	€ 6,100,000.00	€ 6,700,000.00
	Toatl cost of vehicle	**Euro**	**€ 18,300,000.00**	**€ 20,100,000.00**
Infrastructure related cost				
Line electrification				
	Cost/km	Euro	€ 1,000,000.00	-
	Km required	km	0	-
	Total cost	Euro	-	-
Charging Station				
	Number	Item	3	3
	Same for other routes	Item	3	3
	Cost	Euro	€ 2,000,000.00	€ 3,500,000.00
	Total cost	**Euro**	**€ 6,000,000.00**	**€ 10,500,000.00**
Energy Cost Per year				
	Weekly per Vehicle	km/veh	11526.75	11526.75
	Weekly all vehicles	km	34580.25	34580.25
	Number of weeks per year	weeks	52	52
	Total Kilometers in a year	km	1798173	1798173
	Energy comsumption	kWh/km	3.9	5.9
	Energy cost at charging station	Euro/km	€ 0.66	€ 1.26
	Energy cost of overhead line	Euro/km	€ 0.47	-
	% already electricity	%	0	-
	Annual Energy cost (Electrified)	Euro	0	0
	Annual Energy cost of Stations	Euro	€ 4,628,497.30	€ 13,367,618.08
	Total Annual Energy Cost	**Euro**	**€ (4,628,497.30)**	**€ (13,367,618.08)**

Based on the cost analysis, Battery Electric Multiple Units (BEMU) emerge as a more economical solution for the RB1 route compared to Hydrogen Electric Multiple Units (HEMU). The procurement cost of BEMU trains is lower, with an estimated total of €4.6 million for 3 units, compared to €13.7 million for 3 HEMU units. Additionally, the infrastructure required for BEMU operations—charging stations at Zwickau Zentrum, Falkenstein, and Kraslice—is significantly less expensive and easier to implement than the hydrogen refueling stations needed for HEMU, which involve higher costs for hydrogen storage, distribution, and safety systems. Furthermore, BEMU trains incur lower maintenance expenses due to simpler energy systems and fewer moving parts than the complex fuel cell mechanisms of HEMU. These cost advantages make BEMU a more financially viable option for the RB1 route.