TECHNOLOGICAL, ECONOMIC AND ECOLOGICAL ASSESSMENT OF POWERTRAIN TECHNOLOGIES IN THE RAILWAY SECTOR

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Introduction

Today only 56 % of the more than 200,000 km rail roads within the European Union are electrified using catenary lines [1]. The remaining routes are still mostly operated with diesel-based rail vehicles. In light of aggravating climate conditions due to the climate change and massive cost increases due to the aging fleet with internal combustion engine technology, the necessity to transition into sustainable propulsion systems becomes evident. However, the electrification of railway lines requires considerable resources and investment. Battery or fuel cell-powered trains are therefore promising alternatives especially for branch lines or less frequented routes.

Objective

As far as the utilization of the different propulsion systems is considered, all have their advantages and disadvantages. The question which alternate option is the best and should be used for regional rail traffic actually depends on the case-by-case boundary conditions such as geographic location, daily driving distance, political landscape, costs, environmental footprint and other aspects.

On a technology-neutral basis, this paper addresses a scientific comparison of different powertrain variants to replace the classic DMU (diesel multiple unit). To present a comprehensive and holistic analysis this includes the rolling stock as well as the infrastructure required to provide the corresponding energy source. The considered variants are the EMU (electric multiple unit), the BEMU (battery electric multiple unit) and the HEMU (hydrogen electric multiple unit). The EMU mainly consists of pantographs, transformers and electric machines. Its infrastructure includes the catenary line and transformer stations. The BEMU uses batteries to supply the electric machines via inverters with traction power. Its infrastructure comprises a charging station and a transformer station. The HEMU operates via a combination of fuel cells and batteries. Its infrastructure is built on an electrolysis system for renewable hydrogen production on site and a fueling station.

The evaluation of the different propulsion systems is performed on a multiple-criteria decision analysis taking the respective energy consumption, environmental footprint, total costs and further aspects, e.g. powertrain mass / volume, recharging / refueling times, resilience / safety or maturity / experience, into account. A crucial part of the comparison is the quantification of the resource use and greenhouse gas emissions as well as the calculation of the total costs. Regarding the environmental footprint a simplified life cycle assessment according to ÖNROM EN ISO 14040 [2] and ÖNORM EN ISO 14044 [3] is applied. This considers the resources and emissions in pre-use phase, i.e. extraction, manufacturing and transport, and use phase. With respect to the costs, the calculation is based on ÖNORM M 7140 [4] and distinguishes between CAPEX (capital expenditures) and OPEX (operational expenditures). The first includes all costs for investments and reinvestments, the latter all costs for maintenance and energy.

The basis for the evaluation is a longitudinal dynamics simulation of the vehicles. The models include all relevant components like propulsion system, HVAC (heating, ventilation and air conditioning) or thermal management as well as all general vehicle parameters and track information. Beyond the simulation model, a comprehensive database concerning profound external industry and vehicle data, latest academic publications, newest manufacturer information and in-house expertise is used. As these values are subject to variations, a baseline scenario is specified as a representation of the state of the art as well as an optimistic and a pessimistic scenario to cover those ranges of uncertainty.

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Results

In this paper, the comparison is discussed using the example of a regional railway line with a relatively long and steep track. The railway route considered is a standard-gauge (1,435 mm), single-track line with a total distance of around 60 km. The height difference between the lowest and highest point is more than 350 m, which results in a maximum inclination of 50 ‰. Daily 18 cycles and 1,080 km are covered.

The resulting carbon footprint and total costs for each technology are given in Figure 1. The bars show the baseline scenario and both ends of the whiskers indicate the optimistic or pessimistic scenario. The DMU is driven with fossil diesel, the EMU and BEMU with electricity from renewable energies and the HEMU with renewable hydrogen produced decentralized by means of renewable electricity. As can be seen in (a), by far the largest carbon footprint is observed by the DMU. Although it is locally emission-free, the EMU is assigned to a significant number of CO_2-emissions which is primarily due to the construction of the catenary line and its demand for enormous amounts of resources. The BEMU and HEMU are responsible for considerably less CO_2-emisisons. From (b) it can be seen that DMU is still the most cost-effective technology, since it is highly sophisticated and is used for decades. The BEMU and HEMU result in additional costs of approximately 30-40 million € within a period of consideration of 30 years. By far the highest costs are credited to the EMU which is again due to the large extent of the electrification of the rail road.

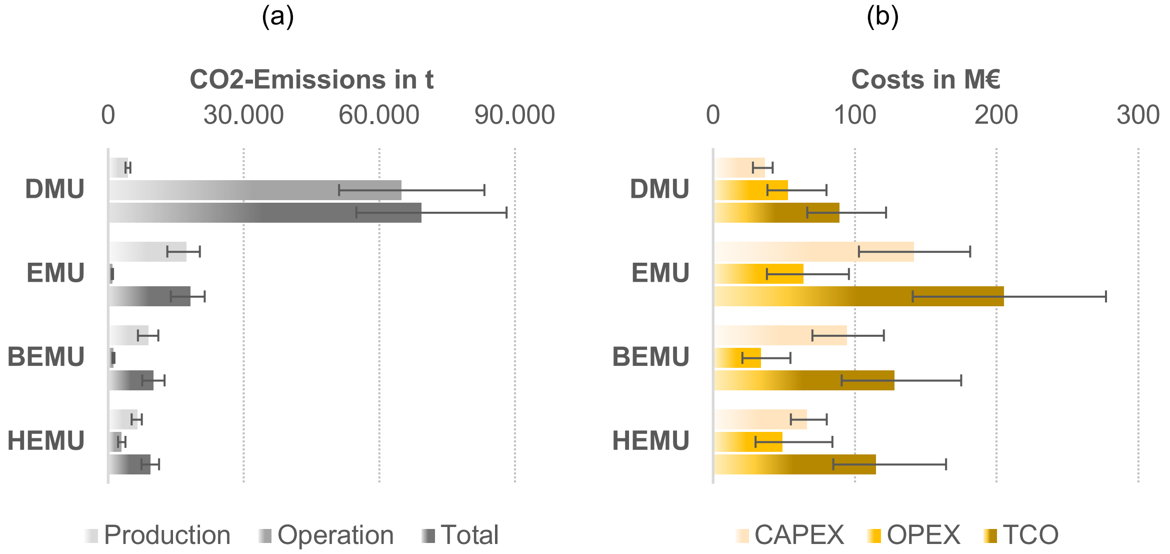

Figure 1: Comparison of CO_2-emissions and costs for different propulsion systems.

Conclusion

The choice of the optimum powertrain technology in terms of technological, economic and ecological targets depends largely on the routes, operating mode and operating conditions as well as the availability of renewable energy. The methodology and results presented offer a technology-open and technology-neutral assessment on a scientifically founded and validated basis and is therefore suitable for supporting decisions regarding the use of the optimum train technology.

Literature

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