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On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers

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ABSTRACT

Electrification is widely considered as a viable strategy for reducing the oil dependency and environmental impacts of road transportation. In pursuit of this strategy, most attention has been paid to electric cars. However, substantial, yet untapped, potentials could be realized in urban areas through the large-scale introduction of electric two-wheelers. Here, we review the environmental, economic, and social performance of electric two-wheelers, demonstrating that these are generally more energy efficient and less polluting than conventionally-powered motor vehicles. Electric two-wheelers tend to decrease exposure to pollution as their environmental impacts largely result from vehicle production and electricity generation outside of urban areas. Our analysis suggests that the price of e-bikes has been decreasing at a learning rate of 8%. Despite price differentials of 5000 ± 1800 EUR_{2012} $kW\,h^{-1}$ in Europe, e-bikes are penetrating the market because they appear to offer an apparent additional use value relative to bicycles. Mid-size and large electric two-wheelers do not offer such an additional use value compared to their conventional counterparts and constitute niche products at price differentials of 700 ± 360 EUR_{2012} kW^{-1} and 160 ± 90 EUR_{2012} kW^{-1}, respectively. The large-scale adoption of electric two-wheelers can reduce traffic noise and road congestion but may necessitate adaptations of urban infrastructure and safety regulations. A case-specific assessment as part of an integrated urban mobility planning that accounts, e.g., for the local electricity mix, infrastructure characteristics, and mode-shift behavior, should be conducted before drawing conclusions about the sustainability impacts of electric two-wheelers.

Introduction

Scientists, policy makers, and industry experts support the gradual electrification of road transportation as a strategy to reduce transport-related oil dependency, carbon dioxide (CO_2) emissions, and urban air pollution (e.g., IEA, 2009; EGCI, 2010; EU, 2012; Weeda et al., 2012). In pursuit of these objectives, mass-produced battery-electric cars were introduced to the

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market around the year 2010. The number of manufacturers and the diversity of models offered has been growing since. However, battery-electric cars are still relatively expensive and suffer from short drive ranges and the absence of a widespread recharging infrastructure. It appears questionable whether battery-electric cars can penetrate the market at a large scale without policy support or substantially increasing oil prices (Weiss et al., 2012). More, immediate potentials for the electrification of road transport, notably in urban areas, may be offered by electric two-wheelers such as e-bikes, e-scooters, and e-motorcycles.

Electric two-wheelers are lightweight and require battery capacities from 0.4 kW h for e-bikes to 10 kW h for large e-motorcycles (Weinert et al., 2007b; ZM, 2013), incurring lower costs than the capacities of 18–85 kW h installed in battery-electric cars. Fully-charged drive ranges of 20–160 km (Weinert et al., 2007b; Eicher, 2010; ZM, 2013) appear to be sufficient for urban operations, where trips typically remain within a distance of 10 km (e.g., Weinert et al., 2007c; Hendriksen et al., 2008; ITRANS, 2009; Delcampe, 2010; Paffumi et al., 2013). Bag-sized portable battery systems for, e.g., e-bikes could be recharged via standard wall outlets (Cherry, 2007), rendering a dedicated recharging infrastructure superfluous.

Whether electric two-wheelers can make a noteworthy contribution to the electrification of road transportation depends on their techno-economic, environmental, and social performance relative to competing modes of transportation. It is reasonable to assume that electric two-wheelers can decrease (i) urban air pollution when substituting conventionally-powered two-wheelers and (ii) demand for infrastructure when substituting passenger cars. However, anticipated benefits could turn into shortcomings if electric two-wheelers substitute public transportation and bicycle use.

The available literature provides a comprehensive assessment of e-bikes in China (e.g., Weinert et al., 2007a, 2007b, 2007c, 2008; Cherry, 2007, 2010; Cherry et al., 2009). However, a multidisciplinary analysis that reviews and expands the established knowledge on electric two-wheelers is still missing. Here, we address this gap and provide an overview of the environmental, economic, and social performance of electric two-wheelers. Our analysis focuses predominantly on e-bikes for two reasons. First, the bulk of the literature on electric two-wheelers addresses this vehicle category. Second, e-bikes outsell globally any other category of electric two-wheelers and currently seize a rapidly growing market in Europe. The results of our research can provide rationale for (i) designing energy and transportation policies and (ii) advancing vehicle technology and urban transportation infrastructure with the objective of making road transportation more sustainable.

Methods

We define electric two-wheelers as two-wheel vehicles designed for transporting passengers by means of an electric motor alone or in combination with human force (Fig. 1; Table 1). In line with EC (2013), we differentiate:

- e-bikes: pedal assisted two-wheelers (also referred to as pedelecs) with a maximum speed of $\leqslant$25 km h^{-1} and an electric motor a maximum continuous rated power of $\leqslant$0.25 kW; e-bikes include electric two-wheelers that are exempted from type approval and also larger pedal-assisted electric-powered cycles of category L1e-A that are subject to type approval;
- e-mopeds and small e-scooters referred to here as mid-size electric two-wheelers: two-wheelers of category L1e-B without pedal assistance and a maximum speed of $\leqslant$45 km h^{-1}, equipped with an electric motor of a maximum continuous rated power of >0.25–4 kW;
- e-motorcycles and large e-scooters referred to here as large electric two-wheelers: two-wheelers of category L3e equipped with a maximum speed of >45 km h^{-1} and an electric motor of a maximum continuous rated power of >4 kW.

Fig. 1. Illustration of an e-bike, mid-size and large electric two-wheeler (from left to right); courtesy of Koga B.V., efw – suhl GmbH, Brammo Inc.