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GHG-emission models for assessing the eco-friendliness of road and rail freight transports

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ABSTRACT

Intermodal rail/road transportation is an instrument of green logistics, which may help reducing transport related greenhouse gas (GHG) emissions. In order to assess the environmental impact of road and rail transports, researchers have formulated very detailed microscopic models, which determine vehicle emissions precisely based on a vast number of parameters. They also developed macroscopic models, which estimate emissions more roughly from few parameters that are considered most influential. One of the goals of this paper is to develop mesoscopic models that combine the preciseness of micro-models while requiring only little more information than macro-models. We propose emission models designed for transport planning purposes which are simple to calibrate by transport managers. Despite their compactness, our models are able to reflect the influence of various traffic conditions on a transport's total emissions. Furthermore, contrasting most papers considering either the road or the rail mode, we provide models on a common basis for both modes of transportation. We validate our models using popular micro- and macroscopic models and we apply them to artificial and real world transport scenarios to identify under which circumstances intermodal transports actually effect lower emissions. We find that travel speed and country-specific energy emission factors influence the eco-friendliness of intermodal transports most severely. Hence, the particular route chosen for a transnational intermodal transport is an important but so far neglected option for eco-friendly transportation.

1. Introduction

Energy, in its various forms such as electricity and heat, is required for almost all social and economic activities in modern societies. A large part of the required energy is generated by combusting fossil fuels such as coal, natural gas or crude oil. Problematically, the combustion of fossil fuels also produces environmentally harmful emissions. These by-products can be categorized into greenhouse gases (e.g. carbon dioxide, methane, nitrogen dioxide) and air pollutants (e.g. nitrogen oxide, sulphur dioxide), see IPCC (2006). Greenhouse gases (GHGs) are considered responsible for the anthropogenic global warming whereas air pollutants are toxic and cause e.g. the acidification of soils and the eutrophication of waters. The transportation of freight and passengers is a major source of such emissions being responsible for about 14–22% of all GHG emissions (IPCC, 2014). The largest part of these emissions is caused by road transportation, which is why political efforts promote

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more eco-friendly transportation modes like rail or ship. However, using eco-friendly vehicles like trains or ships in the main haulage of a transport process usually calls for drayage transportation by truck, which often includes a detour compared with direct door-to-door shipping by road transportation. Therefore, intermodal transports are considered a key to eco-friendly transportation (Black et al., 2003), but it needs to be determined under which conditions they actually effect lower emissions than a unimodal road transport.

To account for the environmental effect of unimodal and intermodal transports, reliable models are needed for estimating the transport-related consumption of fuel or energy and for calculating the corresponding GHG emissions. Those emissions that directly result from the consumption of fuels within a transport are called tank-to-wheel (TTW) emissions (McKinnon and Piecyk, 2010). However, to achieve a fair comparison of fuel-driven and electric-driven vehicles, also the so-called well-to-tank (WTT) emissions caused by the production and distribution of a unit of fuel (respectively electricity) need to be taken into account. The sum of TTW and WTT yields the total well-to-wheel (WTW) emissions, which are a proper instrument for decision makers to compare the GHG emissions of different transport solutions. In order to determine the total emissions of a freight transport operation, the consumed amount of fuel respectively electricity needs to be known, which actually requires to estimate the physical energy that is required for the transport process.

In this paper, we provide emission models for rail and road transports based on an estimation of the energy demand of freight trains and trucks. In contrast to the already available models, our models are designed such that they include just those factors (speed, weight, traffic conditions, etc.) that influence the energy demand most. To model the effect of traffic conditions, a compact formulation for a vehicle's acceleration energy demand is introduced. The obtained advantage is that the models deliver more accurate estimates than established models. At the same time, both models are set up such that they can be parameterized easily by haulage managers. To reach this goal, we provide in Section 2 an overview on key concepts for measuring emissions of transport processes and we review the available literature on emission models for rail and road transports. Section 3 describes the developed emission models for trucks and freight trains. Section 4 validates the proposed emission models by comparing their results with existing emission models. In Section 5 our models are used for identifying those factors that influence the emissions of intermodal and unimodal transports most. In order to show additional degrees of freedom in planning urban unimodal and transnational intermodal transports, Section 6 provides two case studies. Section 7 concludes the paper.

2. Review of estimation models for transport-related GHG emissions

To assess the eco-friendliness of a transport operation, the amount and the composition of emitted GHGs have to be quantified. For making different types of GHGs comparable, a so-called CO_2 equivalence factor (CO_2e) is defined for each of them (IPCC, 2007). This factor expresses the global warming potential of one unit of a GHG compared with one unit of CO_2. E.g. Methane has a CO_2e-factor of 25, i.e. one ton of Methane has the same global warming effect as 25 tons of CO_2 (Edwards et al., 2014). Since combusting one liter of a fossil fuel effects particular amounts of certain types of GHGs, the amount of CO_2e per liter of a certain fuel type is fix. These so-called emission coefficients k are shown for diesel and fuel oil in Table 1. The table also shows the energy coefficient p, i.e. the amount of fuel that needs to be combusted for providing one kWh of energy to the transport process.

Given these emission coefficients and the total amount of fuel consumed by a vehicle (truck, plane, ship, or diesel locomotive) in a transport operation, the resulting total emissions are directly derived by multiplication. For vehicles with external energy supply, like electric cars or locomotives, the energy consumed within the transport process needs to be multiplied by a WTW emission coefficient that expresses the amount of GHG emitted for generating the consumed electricity. This coefficient varies from country to country as it depends on whether electricity is produced by nuclear power, coal power, wind power, etc. or a mixture thereof.

Calculating emissions from the amount of fuel or electricity consumed in a transport operation is referred to as the *consumption-based* emission calculation approach (Schmied and Knörr, 2013). This approach is suitable for transports that took place already. However, for the eco-oriented planning of future transports, GHG emissions have to be estimated based on specific data such as the vehicle to be used, the distance of the projected route, and the expected speed. For this purpose, numerous estimation models have been proposed in the literature but mostly for road transportation, see Demir et al. (2011, 2014). These models are categorized into *microscopic models* and *macroscopic models*. Microscopic models estimate fuel consumption and emissions very precisely. They use numerous vehicle-specific and trip-specific characteristics for a detailed simulation of the physics of the moving vehicle and the energy demand expected for a transport process. More specifically, the vehicle's speed during the trip (the so-called driving cycle) is analyzed to compute the driving resistances,

Table 1
Emission coefficients and energy coefficients (Schmied and Knörr, 2013)

	Emission coefficient k (kg CO_2e/l)		Energy coefficient p (l/kWh)	
	TTW	WTW	TTW	WTW
Diesel	2.49	3.15	0.1000	0.0811
Fuel oil	3.15	3.41	0.0889	0.0816