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Extended ecological footprint for different modes of urban public transport: The case of Vienna, Austria

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ABSTRACT

Urbanization and population growth in urban areas are linked to increasing passenger transport and decreasing land availability. One option to cope with the negative impacts associated to this growth (i.e. emissions from and land use by traffic) is to strengthen public transport, as it has lower land requirements and higher transportation capacities if compared to private passenger transport by cars. Besides the direct land use within the city borders, transportation systems also cause land use in the hinterland, particularly for the extraction of raw materials, for energy supply, and for the sequestration of greenhouse gas emissions. The study at hand investigated these types of land uses of a multimodal public passenger transport network consisting of subway, tram, and bus transport, taking the case study of Vienna. The land uses distinguished were the direct land use in the city, the direct land use in the global hinterland to provide energy and resources, and the land needed to sequestrate the CO_2 emissions emitted. For the latter a distinction between the CO_2 emissions from energy consumption (operational energy CO_2 hinterland use), and from CO_2 embodied in goods and materials (embodied CO_2 hinterland use) was made. The overall land use of the public transport system was finally determined and illustrated using an extended ecological footprint (EF) analysis under consideration of the life cycle of used goods and materials. Results were expressed in global hectare (gha/a) for one year and further normalized to the transport capacity and performance of each transport mode.

Results indicate that the operational energy CO_2 hinterland use contributes most to the overall land use (55,000 gha/a), followed by the embodied CO_2 energy hinterland use (15,000 gha/a), the direct hinterland use (1,660 gha/a) and the direct land use within the city (620 ha). This sums up to a total of 72,500 gha/a, which, considering Vienna's population of 1.8 million inhabitants, equals 0.03 gha/capita.a. The direct land use within the city corresponds to 1.5% of city area and 1% of the EF. Divided by transport mode, the subway has the largest EF (51%) followed by busses (20%), trams (19%), and services (10%). However, the ranking changes when the transport performance is considered. In general it can be taken from the results that the specific environmental efficiency (specific land use per seat kilometer provided) is increasing with growing offer of service per route. Due to the fact that infrastructural and non-operational energy impacts (e.g. construction materials, station lighting and heating) are not increasing substantially with a higher succession of trains the effect is even higher by rail-bound systems. However, if the required transport capacity per hour falls below a certain limit, subways and trams are not only economical, but also environmental less efficient than bus systems.

1. Introduction

Humankind has been experiencing a shift from a purely rural to a predominately urban living society in which already half of the global population became urban citizens. This percentage will rise even more in coming decades (Grimm et al., 2008). Growing population and consumption of goods and services in large urban agglomerations requires more resources in terms of raw materials, energy, and land. Particularly the latter is a scarce resource in urban areas, as indicated by significant increases in land price in cities over the past few decades.

An increasing population goes along with larger volumes of traffic, which significantly impacts urban metabolism in terms of higher

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emissions, resources and land consumption (Baccini and Brunner, 2012; Barrett and Scott, 2003; Kennedy et al., 2011; Moore et al., 2013; Wackernagel and Rees, 1996). As public transport not only causes lower environmental impacts and offers higher transport capacity in comparison to individual transport, but also requires less space in the city, it is regarded as a major means of providing sustainable transportation in urban agglomerates (Chester and Cano, 2016; Codoban and Kennedy, 2008).

Like other modes of transport (e.g. passenger cars), public transport systems, however, not only have environmental impacts within the city boundaries, but also beyond (Clark and Chester, 2016). This not only counts for emissions, but also for land use. Furthermore, it is likely that this land use is not evenly distributed among different modes of public transport. For instance, rail-bound systems have on the one hand the advantage of requiring less above-ground land within a city (Pfaffenbichler, 2001; Randelhoff, 2014) while providing high transportation capacity at the same time. On the other hand, they require more materials than bus lines, i.e. for the construction elements (Andrade and D'Agosto, 2016; Chester and Horvath, 2009; Li et al., 2016), which impact on direct land consumption in the cities' hinterland for the supply of raw materials (e.g. land for gravel pits), goods (e.g. land for cement production plants), and energy (e.g. land for coal mines necessary to supply cement production or power plants to generate electricity for concrete mixing). In addition to this direct land and hinterland consumption, sustainable urban development planning should furthermore consider the compensation of greenhouse gas (GHG) emissions (e.g. CO_2 sequestration by forests). This land requirement can be assessed by means of the so-called "carbon footprint", which should always be set in context with the overall life-cycle emissions as specified in several frameworks and studies (e.g., European Commission, 2012; Matthews et al., 2008). Several studies (e.g., Barrett and Scott, 2003; Bhandari et al., 2014; Chester and Hovath, 2008; Chester et al., 2010; Chi and Stone, 2005; Lederer et al., 2016b; Tuchschmid, 2009) have already assessed the contribution from public transport systems or partial transport modes to the emissions of a region or urban area. However, none of these studies have analyzed the contribution to the overall direct land use and the different land uses in hinterlands of each transport mode. This is remarkable, as different levels of land consumption are relevant for different stakeholders (e.g. district politicians, urban planners, municipal department of the environment and sustainability) (Zeev et al., 2014). In the present study, the term „hinterland" is used as described by Baccini and Brunner, (2012), thus referring to any land beyond the city boundary without indicating any geographical vicinity. With respect of public transport systems, direct land use is directly linked to the chosen mode of transport, particularly whether a network is underground or aboveground. This is of relevance particularly for urban stakeholders, as underground networks for instance ensure a high transport capacity by avoiding traffic jams while requiring less aboveground land which can be used for other purposes. Contrary to that, indirect land use depends on the quantities of raw materials used and thus effect stakeholders in the proximate hinterland of the cities supplying these raw materials. Moreover, the land required for CO_2 sequestration caused by GHG emissions by energy generation, raw materials extraction and production of goods which are required for the provision of the urban transport service have a global relevance. Cities are increasingly becoming aware of these multidimensional impacts of their transport systems, expressed by the growing number of smart or sustainable city initiatives (e.g., City of Vancouver, 2015; City of Vienna, 2014) and respective indicators to measure how the objectives set by these initiatives have been achieved (Ahvenniemi et al., 2017). With respect to these aspects, the overall objective of the study at hand is to provide a multi-dimensional analysis of land consumption of an urban public transport system, addressing the following research questions:

- What is the total (divided by transport mode)

i direct land use of Vienna's public transport system within the city – subsequently referred as "direct land use",

ii direct hinterland use to provide materials, goods and energy for the infrastructure of the urban public transport system – referred as "direct hinterland use",

iii consumption of land to sequestrate CO_2-emissions associated with the provision of materials and goods for the infrastructure – referred to as "embodied CO_2 hinterland use"

iv land required for the sequestration of CO_2- emitted due to the energy consumption of the public transport provider – called "operational energy CO_2 hinterland use"?

- What are the specific land uses for the four categories if transport capacities (expressed by seat kilometers provided (SKP)) and carried passenger (expressed by passenger kilometers traveled (PKT)) are considered?

For this purpose the public transport system of the Austrian capital Vienna has been analyzed as a case study, as it is multi modal consisting of an extensive bus, tram, and subway network and thus comparable to the public transport system of other cities like Munich, Paris, and Shanghai. Furthermore, the reduction of land consumption has been defined as a policy goal by the city administration of Vienna in its "Smart City Framework Strategy", indicating a high interest in indicators for measuring this policy goal (City of Vienna, 2014). For the study, real inventory and energy-consumption data were used.

2. Methods, methodology and materials

2.1. General methodological setting

2.1.1. Background

The case study city of Vienna covers an area of 41,500 ha and is home to a population of 1.8 million inhabitants in the year 2012. Projections suggest that the 2 million mark will be reached by the year 2028 (MA 23, 2015). Public transport is an important mode of traffic, and the largest provider WIENER LINIEN GmbH & Co KG offers this service with its extensive network of subway, tram, and bus lines including buildings (e.g. stations, garages, workshops). Additionally, service buildings (e.g. administration) are part of the operators assets (Wiener Linien GmbH & Co KG, 2016).

2.1.2. System boundaries

In the study at hand, only the service covered by this provider is considered, and the system under investigation (*Public transport provider – Wiener Linien*) includes all activities and associated infrastructure of Wiener Linien to provide the transport service. Infrastructure not provided by Wiener Linien itself (i.e. roads also used by private transport) are included in this study only in the direct land use, but not for the hinterland uses. This inconsistency is deliberately taken into account to be able to compare the direct area efficiency of all investigated transport modes. Furthermore, due the reason that the provider can influence the direct land use of the bus network through the line management, but has no influence on the road construction and its maintenance. Due road infrastructure is not included in the study at hand no allocation between private transport and public bus transport is needed.

The investigation is carried out on a life-cycle basis, and the life-cycle components included are presented in Figure 1. The inventory data from the Wiener Linien was divided wherever applicable into traffic modes. For services (e.g. administration) which were not applicable to one single transport mode the category "services" were introduced. The reference period selected is one year (2012).

2.1.3. Overall method: ecological footprint

The overall land consumption of Vienna's public transport system