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# Economical comparison of urban transport systems

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**Abstract**

Mobility is an important basis for the social participation and the welfare of the population. The benefits are undisputed. On the other hand, urban transport causes costs for the planning, construction, maintenance and operation of urban transport infrastructure and for local public transport services. The amount of expenses and revenues that a municipality incurs for urban transport are unknown as well as its allocation to the various transport systems. This paper presents an intermodal method (based on a full cost accounting) for identifying municipal expenses and revenues in the transport sector and allocates them to the urban transport systems: pedestrian, bicycle, car, truck traffic and local public transport. The core of the business economic comparison is the development of different allocation keys, which are determined on the basis of findings of engineering science and city-specific input variables. By using these allocation keys, the monetary values recorded as joint positions (such as depreciation costs, road drainage, winter services, street lighting) can be allocated proportionately to the various urban transport systems. For a complete economic comparison, the most important external effects (accident costs, air pollution costs, climate change costs, noise costs and health benefits of walking and cycling) of urban transport were monetarised and allocated to the causers. The practical application and transferability of the method are demonstrated by exemplary application to the three German cities Bremen, Kassel and Kiel. The method allows cost transparency and determines economic indicators that can serve as a basis for discussion and decision-making in the allocation of funds for the different urban transport systems. With the approach presented here, for the first time municipalities will be able to have a complete overview of their transport-related revenues, expenses and external effects, each differentiated by urban transport system. This results in an additional and important instrument for strategic transportation planning and a next step on the road to ‘true costs in the transport sector’.


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*Keywords:* Cost Transparency in Transport Sector; Cost Allocation Method; Economy of Urban Transport

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## 1. Introduction and literature overview

Mobility is an important basis for the social participation and the welfare of the population. It generates benefits for both individuals and society. The benefits of transport are undisputed. On the other hand, urban transport causes costs for the planning, construction, maintenance and operation of urban transport infrastructure and for local public transport services. The amount of expenses and revenues that a municipality incurs for urban transport as well as their allocation to the various transport systems are unknown. In addition, motorised traffic has negative effects on humans and the environment in the form of accidents, air pollution, noise pollution and greenhouse gases.

For years, discussions have been going on in Germany about the costs of transport (for all modes of transport) and its financing at state level (taxes, fees) and through the payments made by users. These discussions often demand increased financial contributions for infrastructure by its users (‘user financing’).

Since 1969, the infrastructure costs (costs for the construction, maintenance and operation of transport infrastructure) and their allocation to specific vehicle groups have been calculated at regular intervals for German federal highways on the basis of the report by BMV (1969). With the introduction of the EU-Directive 1999/62/EG a truck toll has been applied to German federal highways since 2005, based on scientific studies (cf. Rommerskirchen et al. 2002; Rommerskirchen et al. 2007; Korn et al. 2014; Korn et al. 2018). As a result of the implementation of the EU-Directive 2011/76/EU (Annex IIIa), users (vehicles) can also be charged for transport-related external costs caused by air pollution and noise pollution. Few approaches to urban transport are discussed in the relevant literature, but these differ greatly in terms of methodology and definitions. Dobeschinsky and Tritschler (2006) analysed the transport-related municipal costs of the city of Stuttgart. Positions that could not be fully allocated to a specific transport system were estimated by experts based on percentage shares. The ICLEI-Study is also based on percentage shares by expert estimates, whereby only passenger car traffic is considered (cf. ICLEI 2001). The ‘Least Cost Transportation Planning’ Method (LCTP) examines the economic and ecological effects of different transport systems on the basis of a system cost assessment (cf. Bracher et al. 2002). The LCTP considers the transport system as a virtual ‘company’ providing a ‘mobility service’. The ‘mobility service’ described in the study is provided by various actors, resulting in a combination of user costs (e.g. fuel costs, vehicle maintenance costs) and municipal costs.

## 2. Aim and structure of the study

As outlined in the literature overview, there is currently no intermodal and standardised method which allows an economic comparison of urban transport systems in a municipality. In this paper, a method is presented to identify municipal expenses and revenues in the urban transport sector and to allocate them to the urban transport systems of foot, bicycle, car, truck and public transport. An economic comparison of urban transport systems would be incomplete if it did not include external effects. Therefore, this paper also takes the most important transport-related external effects (costs related to accidents, climate change, air and noise pollution and the health benefits of walking and cycling into account in the allocation calculation. The practical application and transferability of the method are demonstrated by exemplary application to the three German cities Bremen, Kassel and Kiel.

This paper is structured as follows: Section 3 presents the method for a business economic comparison of urban transport systems and the results of the application to the three example cities. Section 4 describes the monetarisation of the transport-related external effects and the results of the application in the three cities. For accident costs and noise costs, further allocation methods were developed, because a direct allocation according to the polluter-pays-principle was not possible. The final section of this paper presents a conclusion.

## 3. Method and results for a business economic comparison

The economic comparison of the urban transport systems is based on a full-cost accounting, where the municipal expenses and revenues in the transport sector are recorded and then allocated to the different urban transport systems, truck (vehicles > 3.5 tons), car (vehicles ≤ 3.5 tons), bicycle, pedestrian traffic and local public transport, based on a top-down-approach. This full-cost accounting considers the total consumption of resources of a municipality caused by the provision and the use of transport infrastructure and local public transport services (e.g. operating and maintenance costs as well as depreciation costs for transport infrastructure). Public grants and subsidies from the state, the federal authorities and the European Union are deliberately ignored in order to allow for a transparent and unadulterated comparison of urban transport systems in a municipality. The process flow of the business economic allocation method is illustrated in Fig. 1.

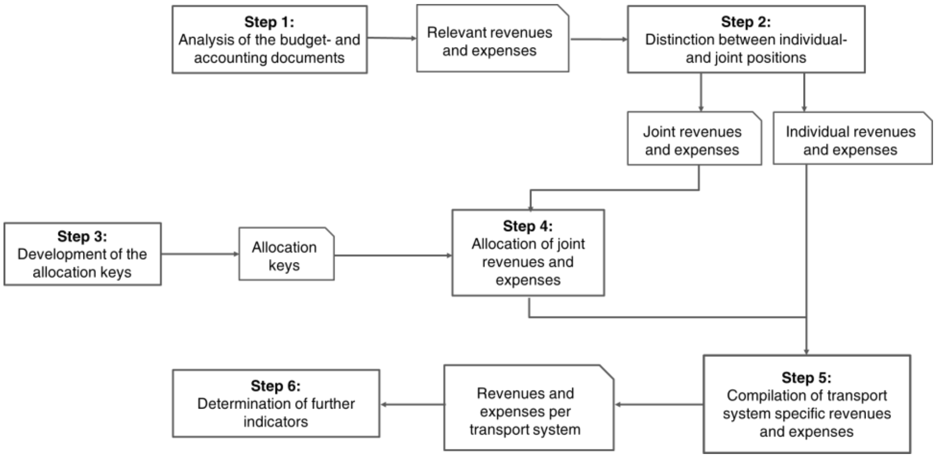


Fig. 1. Process flow of the business economic allocation method (Saighani and Sommer 2019)

In the first step, all expense and revenue positions are identified from the relevant accounting documents and compiled as an input variable of the method. In the consective second step, a distinction is made between individual and joint positions for each of these expense and revenue positions. Individual positions can be fully allocated to a transport system because the transport system is the causer. Joint positions are characterised by the fact that they have to be allocated to several transport systems, since they are caused by more than one transport system (e.g., street cleaning, winter road maintenance, road drainage, street lighting). Fig. 2 illustrates the monetary meaning of the individual and joint positions for transport-related revenues and expenses in the city of Kassel. The most substantial blocks of expenses (EUR 61.7 million) and revenues (EUR 35.5 million) are allocated to local public transport (tram and public bus services). The comparison of transport-related revenues and expenses shows that the expenses for urban transport of approx. EUR 126.3 million cannot be covered by their revenues of approx. EUR 55.6 million.

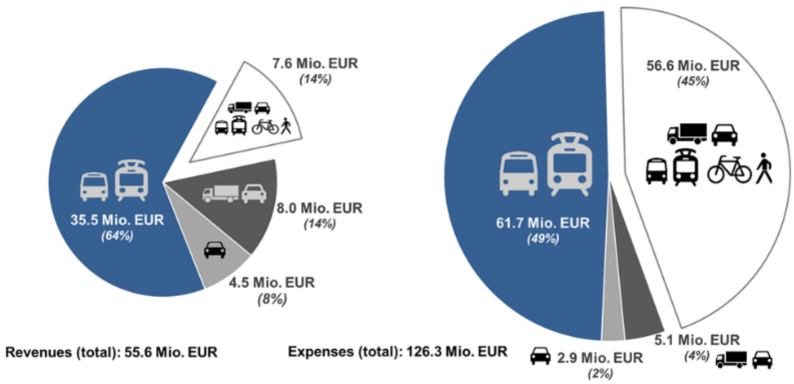


Fig. 2. Transport related revenues and expenses in the city of Kassel (shares of individual and joint positions, averaged 2009 – 2011, Saighani and Sommer 2019)

In order to allocate these joint revenues and joint expenses to the various transport systems, allocation keys have been developed (step 3). The basic principle of the developed allocation keys is based on the polluter-pays principle and determines the specific share caused by different users. Besides a system specific allocation (full allocation to a specific transport system), the developed city-specific allocation keys are based on the following allocation principles, which are also used in combination:

- *Usage-dependent allocation*: The indicator for use is the mileage on the one hand, and the average daily traffic volume of the various vehicles (users) on the various urban road traffic facilities on the other.
- *Capacity-dependent allocation*: If a vehicle (user) requires more capacity than others when performing his transport-related activity, the size of the vehicles is weighted more strongly in the allocation. In the literature, the capacity requirements of the various users will be indicated by Passenger Car Units (PCUs) (cf. e.g., Al-Kaisy et al. 2002; Adnan 2014; Hidayati et al. 2016; Giuffrè et al. 2015; Shalini and Kumar 2014; Link 2015). In this paper, the PCUs are taken from the German 'Guidelines for dimensioning road traffic facilities' (HBS 2015).
- *Weight-dependent allocation:* The higher axle loads of heavy goods vehicles cause higher wear costs and reduce the lifecycle of the transport infrastructures (e.g. road pavement, bridges, tunnels). In order to allocate these additional costs to the polluters, the weight-dependent allocation is based on the 'incremental costs approach'. The basic idea of the concept is to determine the incremental costs caused by heavy vehicles (trucks and buses) and then allocate them to the different types of heavy goods vehicles (cf. Doll 2005; Scazziga 1984; Infras et al. 2012). The present approach analyses the additional costs of heavy goods vehicles compared to a hypothetical dimensioning of roads without heavy goods vehicles. Fig. 3 shows as an example the calculated incremental costs of the individual road sections in the road transport network of the city of Kassel.

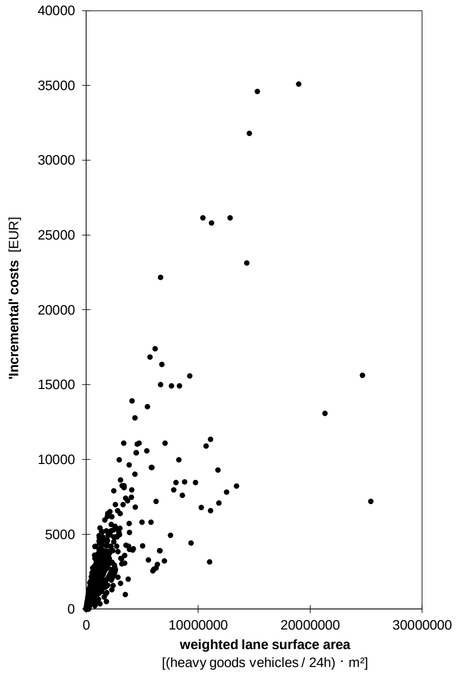


Fig. 3. Calculated ‚incremental-costs' in relation to weighted lane surface area in the road transport network of the city of Kassel

In total, the eight allocation keys shown in Tab. 1 were developed. The developed allocation keys are based on city-specific input data, generated by merging and analyzing several different data sources (e.g. fusion of geoinformation-data from road surfaces with the corresponding traffic volumes from a transport demand model). The allocation keys reflect the causation rate a transport system has in the budgetary positions of a specific thematically defined field of application. Using these allocation keys, the monetary values recorded as a joint position can be allocated to the urban transport systems. The correct selection of the allocation key depends on which allocation key corresponds to the relevant position according to the polluter-pays principle. Tab. 1 shows the most important methodological elements of the allocation keys and typical fields of application.

Tab. 1. Overview of the most important methodological elements of the allocation keys and typical fields of application

| Allocation Key | Quantity Structure | Principle of Allocation | Fields of Application (selection) |
|---|---|---|---|
| Motor Traffic | • (motor vehicle) annual mileage in car and truck traffic in the road network of the considered municipality (without federal highways) | • Proportional to mileage | • Administrative offences (traffic control), Vehicle registration etc. |
| Traffic Area | • Areas of various road transport infrastructures (e.g. Lanes, Sidewalks, Cycle tracks, Bus lanes) | • Usage- and capacity-dependent attribution factors per road transport infrastructure | • Positions where the polluter pays principle can best be taken into account on the basis of the area used (e.g. Road drainage, Roadside greenery etc.) |
| Depreciation Costs and Maintance | • (fictitiously calculated) depreciation costs of various road transport infrastructures | • Allocation to the ‚incremental costs approach' | • Depreciation of transport infrastructure assets (e.g. Depreciation of infrastructure assets, Planning, construction, maintenance of road transport infrastructures) |
| Street Cleaning | • Areas of various road transport infrastructures that are cleaned as part of road cleaning (weighted according to frequency of cleaning or level of charges) | • Usage- and capacity-dependent attribution factors per road transport infrastructure | • Cleaning of road transport infrastructures (e.g. Street cleaning charges; Street cleaning costs) |
| Winter Maintenance | • Areas of various road transport infrastructures that are cleared as part of winter maintenance (weighted according to priority in winter maintenance) | • Usage- and capacity-dependent attribution factors per road transport infrastructure | • Removal of snow and ice (e.g. Winter maintenance costs and charges) |
| Street Lighting | • (fictitiously determined) number of lights | • Usage- and capacity-dependent attribution factors per road transport infrastructure | • Construction, operation and maintenance of street lighting (e.g. electricity costs) |
| Traffic Signals | • Number of traffic signals (weighted by size and energy consumption) | • Attribution factors per traffic signal type and proportional to mileage | • Control and operation of traffic signals (e.g. electricity costs, maintenance and service of traffic computers etc.) |
| General | • is calculated automatically from the other allocation keys for each sub house-hold | | • General position with no clear category |

Tab. 2 shows the transport system-specific causation rates of the allocation keys for the city of Kassel (in Annex A these are presented for Bremen (Tab. A.1) and for Kiel (Tab. A.2)). With regard to the allocation keys, it should be noted that the non-traffic function of the urban transport infrastructure (particularly important for pedestrian facilities) is not excluded in the present approach. Furthermore, it should be considered that any access and exit to other modes of transport is done at pedestrian facilities.

Tab. 2. Causation rates of urban transport systems in the allocation keys in the city of Kassel

| Allocation Key | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic |
|---|---|---|---|---|---|
| Motor Traffic | 0.04 | 0.96 | --- | --- | --- |
| Traffic Area | 0.05 | 0.56 | 0.07 | 0.04 | 0.28 |
| Depreciation Costs | 0.16 | 0.61 | 0.07 | 0.01 | 0.15 |
| Street Cleaning | 0.05 | 0.48 | 0.11 | 0.03 | 0.33 |
| Winter Maintenance | 0.03 | 0.92 | 0.03 | 0.01 | 0.01 |
| Street Lighting | 0.02 | 0.62 | 0.03 | 0.01 | 0.31 |
| Traffic Signals | 0.04 | 0.85 | 0.00 | 0.00 | 0.12 |
| General | is calculated automatically from the other allocation keys for each sub household | | | | |

* Tram and public bus services

For each joint-position, the calculated allocation keys can be used to allocate revenues and expenses to the various urban transport systems. The first result is the total (annual) expenses and revenues for each urban transport system. Subsequently, indicators were calculated to enable comparisons between the transport systems and for monitoring.

Tab. 3 summarises the results of the allocation method for the city of Kassel. In Annex B, the results for the cities of Bremen (Tab. B.1) and Kiel (Tab. B.2) are presented. An inter-municipal comparison (benchmarking) is not appropriate given the great differences between the cities (e.g. the stock and the condition of the urban transport infrastructure and its monetary assessment, transport services/offerings in local public transport (public buses, trams, etc.), settlement structure and the quality of the city-specific input variables). The main results of the businnes economic comparison of the three cities can be summarised as follows: The non-motorised transport modes (bicycle and pedestrian) received the lowest financial subsidies in all the cities studied (9% to 21%) and the motor vehicle traffic (car and truck) the highest (45% to 55%). The subsidy for local public transport in Kassel (42%) and Bremen (35%) is higher than in Kiel (27%) due to the greater extent of transport offers and transport services in local public transport (bus and tram). The results of the business economic comparison in all the cities studied show that the cost-coverage-ratio 'full-cost' as an economic efficiency indicator is highest in local public transport (55% in Kassel, 60% in Bremen and 82% in Kiel) and lowest in truck traffic (7% in Bremen, 12% in Kassel and 30% in Kiel).

Tab. 3. Results of the business economic comparison in the city of Kassel (selected economic indicators, averaged and rounded 2009 – 2011)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Total Expenses [EUR million] | 6.7 | 42.5 | 65.5 | 0.7 | 10.8 | 126.3 |
| Total Revenues [EUR million] | 0.8 | 16.2 | 36.3 | 0.2 | 2.1 | 55.6 |
| Total Subsidy[(1)] [EUR million] | 5.9 | 26.3 | 29.3 | 0.5 | 8.7 | 70.7 |
| Relative Subsidy [%] | 8% | 37% | 42% | 1% | 12% | 100% |
| Cost-Modal-Split in Passenger Transport [%] | --- | 41% | 45% | 1% | 13% | 100% |
| Cost-Coverage-Ratio 'Full-Cost' [%] | 12% | 38% | 55% | ---[(2)] | ---[(2)] | --- |
| Subsidy per inhabitant [EUR/inh.] | 30 | 135 | 150 | 2 | 45 | 361 |

* Tram and public bus services; [(1)] results from the difference between expenses and revenues; [(2)] are not reported because there are no direct income

## 4. External effects

This paper examines the allocation-relevant external effects caused by transport operations: accidents, air pollution, greenhouse gas and noise emissions. The costs resulting from upstream and downstream processes for providing energy for the operation of transport modes (fuel- and electricity production) are not considered. According to Tinbergen (1968), these external costs should be internalised directly in the upstream and downstream processes and not in the transport sector. The paper also considers external benefits of 'active mobility' of pedestrians and cyclists. External effects determined based on existing national and international methods which can be monetised with corresponding (accepted) cost factors from literary sources. The assessment of external effects follows a cautious estimate of the expected real costs or benefits according to the 'at-least approach'. External effects caused by urban transport within the administrative boundary of a municipality are projected ('territoriality principle'). An exception is the external (health) benefit of walking and cycling. Here, the benefits generated by the inhabitant of the respective municipality are being considered.

### *4.1. Accident costs*

Traffic accidents cause both personal injury and property damage, leading to high economic costs. In accordance with Becker et al. (2002), property damage is not considered in the present study, because it is usually covered by insurance (already internalised) (cf. also van Essen et al. 2011). An assessment of accident costs requires a differentiated analysis of the accident-related consequences. The classification of personal injuries (casualties) in Germany is split into three categories: (a) accident with fatalities, (b) accident with severe injuries and (c) accident with slight injuries. All traffic accidents and their characteristics reported by the police according to the defined characteristics of the German ‘Road Traffic Accident Statistics Law’ (StVUnfStatG) are the data basis (unreported accidents are not considered). Accidents are rare incidents, therefore data from at least 36 consecutive months is used to make statistically reliable calculations in accident research.

The cost factors determined by the German Federal Highway Research Institute (BASt) are used to calculate the costs of personal injury. Based on the damage cost approach, specific accident cost factors per fatality, seriously injured and lightly injured person were determined in Baum et al. (2010). The following cost components are taken into account: (a) reproduction costs (e.g. medical care and administrative costs, insurance) (b) human capital losses (e.g. losses due to reduced production, losses caused by incapacity to work, replacement costs) (c) non-market costs (e.g. losses added in the household economy). In addition to the cost factors of Baum et al. (2010), in the present study, the immaterial costs (human losses e.g. lifetime shortening, suffering, pain, sorrow) are estimated with EUR 1.70 million EUR per fatality based on the recommended ‘value-of-statistical-life’ (VSL) by Korzhenevych et al. (2014) (severely injured 13.3%, slightly injured 1% of VSL, see Tab. 4). Following Becker et al. (2002), it is assumed that the person causing the accident pays the immaterial costs on his own (see Tab. 4). In the present study, similar to Becker et al. (2002), Dahl (2010) and Neumann (2016), only the insurance payments for motor vehicle liability are considered as internalised costs, because these are paid by the corresponding traffic users in the form of risk-dependent contributions. If pedestrians and cyclists cause accidents, all accident costs of the non-accident causing persons are considered as external costs (see Tab. 4). The cost factors applied in this paper are summarised in Tab. 4.

Tab. 4. Cost factors for casualties in traffic accidents differentiated in injury severity and accident culpability (costs per casualties in EUR according to Baum et al. 2010; Korzhenevych et al. 2014; Becker et al. 2002 and Neumann 2016)

| | Fatality | | Severe injury | | Slight injury | |
|---|---|---|---|---|---|---|
| | Causer | Non-Causer | Causer | Non-Causer | Causer | Non-Causer |
| Total of: Reproduction costs, human capital losses and non-market costs | 553,158 | 553,158 | 100,485 | 100,485 | 2,263 | 2,263 |
| Immaterial costs | --- | 1,700,000 | --- | 226,100 | --- | 17,000 |
| Cost factor (total)* | 553,158 | 2,253,158 | 100,485 | 326,585 | 2,263 | 19,263 |
| Reduction of liability payments | --- | -354,086 | --- | -22,201 | --- | -7,326 |
| Cost factor (total)** | 553,158 | 1,899,072 | 100,485 | 304,384 | 2,263 | 11,937 |

* Cost factor if accident is caused by non-motorised modes of transport (pedestrian or cyclist)
** Cost factor if accident is caused by motorised modes of transport

In addition to the external cost components and the internalizing contributions by insurances, the selection of the cost-allocation method is decisive for the result of an intermodal comparison. There are different approaches for the allocation of accident costs to the transport modes involved in accidents in the relevant literature:

- *Monitoring approach:* In the monitoring approach, the accident costs are allocated to the mode of transport used by when the accident occured (cf. Ecoplan 2002; van Essen et al. 2011).
- *Causation approach (polluter-pays-principle):* In contrast to the monitoring approach, in the causation approach the accident costs are allocated to the mode of transport ‘causing’ the accident (cf. Ecoplan and Infras 2014; ProgTrans 2013).
- *Damage potential approach (intrinsic risk):* The damage potential approach assumes that the use of different modes of transport is associated with a certain damage potential (intrinsic risk) for other users (cf. Vermeulen et al. 2004; van Essen et al. 2011; Becker et al. 2012; Aarnink und Schroten 2015; Sansom et al. 2001).

In this paper, the allocation of accident costs is based on the combination of the causation approach and the damage potential approach. According to BASt (1984), the consequences of an accident are physically more severe the greater the energy converted in the accident. According to Sobhani et al. (2011) the movements of vehicles result in kinetic energy which is released in the case of an accident. The kinetic energy *(Ekin)* depends on the mass *(m)* and the speed *(v)* and can be physically defined by the equation (1).

$$\mathrm{Ekin} = \frac{1}{2}\mathrm{m}\cdot\mathrm{v}^2 \quad (1)$$

Numerous studies have investigated the correlation between the severity of the accident and the impact speed and mass of the vehicles involved in the accident (cf. Aarts and van Schagen 2006; Elvik 2009; Nilsson 2004; Rosén and Sander 2009). Based on the findings of accident research, it is assumed that the damage potential is reflected by the kinetic energy. For the transport mode causing the accident, the external accident costs of all its passengers (driver and passenger) are allocated in full (causation approach). In addition, the external accident costs of the passengers of all non-accident-causing transport modes are allocated pro rata to the causer of the accident on the basis of the factor *ε* (see equation 2).

$$\mathrm{CUV}_{i,vs} = \left(\sum_{inj}\left(\mathrm{nVF}_{i,inj}\cdot \mathrm{cuv}_{inj} + \mathrm{nVMF}_{i,inj}\cdot \mathrm{cunv}_{inj}\right)\right) + \left(\varepsilon_{i,vs}\cdot\sum_{vsnv}\sum_{inj}(\mathrm{nNVI}_{i,vsnv,inj}\cdot \mathrm{cunv}_{vsnv,inj})\right) \quad (2)$$

$\mathrm{CUV}_{i,vs}$ … external allocated accident costs of the transport mode causing the accident (vs) per accident (i) [EUR/accident]
vsnv … non-accident-causing transport mode
inj … injury severity (fatally injured, severe injured, lightly injured)
nVF … driver of the accident-causer transport mode (casualties) [1 Pers.]
nVMF … number of passengers of the accident-causer transport mode (casualties) [Pers.]
cuv … specific cost factor for accident-causer [EUR/Pers.]
cunv … specific cost factor for non-accident-causer [EUR/Pers.]
nNVI … number of passengers of the non-accident-causer transport mode (casualties) [Pers.]
$\varepsilon_{i,vs}$ … allocation factor per transport mode involved in the accident [-]

The allocation factor *ε* results from the relation of the kinetic energy of a transport mode involved in an accident to the total kinetic energy of all transport modes involved in an accident (see equation 3)

$$\varepsilon_{i,vs} = \frac{\mathrm{Ekin}_{i,vs}}{\sum_{p}\mathrm{Ekin}_{i,vs(p)}} \quad (3)$$

Analogous to Vermeulen et al. (2004) and van Essen et al. (2011), the present approach takes into account in the allocation of accident costs that heavier vehicles have a significantly higher damage potential for other road users. The external accident costs of the non-accident-causers *(CUNV)* are calculated by multiplying the allocation factor *ε* with the total external accident costs of the passengers of the non-accident-causing transport modes (see equation 4).

$$\mathrm{CUNV}_{i,vs} = \varepsilon_{i,vs}\cdot\sum_{vsnv}\sum_{inj}(\mathrm{nNVI}_{i,vsnv,inj}\cdot \mathrm{cunv}_{vsnv,inj}) \quad (4)$$

Based on this, the total external accident costs of an accident are calculated from the allocated accident costs of the accident causing transport mode *(CUV)* and the total of the accident costs of the non-accident causing transport modes *(CUNV).*

### *4.2. Air pollution costs*

The urban area is especially affected by air pollution, because the air pollutants emitted, such as PM and NOx, are locally effective and both the main victims (urban population) and the main emitter (road traffic) are concentrated here (cf. EEA 2018). Transport-related air pollutants are associated with various negative impacts (e.g. health damage, damage to buildings, damage to ecosystems and biodiversity, cf. UBA 2012; Preiss et al. 2012; van Essen et al. 2011). The method used in this paper to estimate the costs of transport-related air pollutants (according to the impact pathway approach) is based on the approach of van Essen et al. (2011) and Korzhenevych et al. (2014). To estimate the costs of air pollutants, the total annual ammount (tons) of emissions of different types of air pollutants from road traffic are calculated using an emission model, based on the specific annual mileage of the vehicles in question (vkm) and on emission factors (g/vkm). The use of an emission model is necessary to determine the transport-related air pollutant and greenhouse gas emissions (see section 4.3) to allow a differentiation by polluter. The estimation of the annual mileage (vkm) is based on the specific urban travel demand models. The ‘Handbook emission factors for road transport' (version 3.3) is used (cf. HBEFA 3.3) to determinethe emission factors. The recommended cost factors of the German UBA Method Convention (version 2.0) are used to calculate the costs of road transport-related air pollutants (cf. UBA 2012). Tab. 5 shows the average cost factors used for air pollutant emissions for intra-urban road transport. The recommended cost factors are based on damage costs and include the damage components health, materials and harvests as well as biodiversity losses. The cost factors were determined on the basis of the studies by Preiss et al. (2008), Müller et al. (2010), Torras (2010) and Friedrich et al. (2011).

Tab. 5. Air pollution cost factors in EUR/ton (price basis 2010, according to UBA 2012)

| Air pollutant | Cost factor (average) |
|---|---|
| Particulate Matter (PM, $PM_{2.5}$) | 364,100 |
| Particulate Matter (PM, $PM_{10}$) | 33,700 |
| Nitrogen Oxides ($NO_x$) | 15,400 |
| Sulphur Dioxide ($SO_2$) | 13,200 |
| Volatile Hydrocarbons without Methane (NMVOC) | 1,700 |
| Ammonia ($NH_3$) | 26,800 |

## *4.3. Climate change costs*

The emissions of anthropogenic greenhouse gases have a measurable negative impact on the global climate (cf. IPCC 2013). The resulting global increase in temperature leads to sea level rise, increased incidence of extreme weather phenomena, damage to ecosystems and human health. The volume and timing of the medium to long-term damages are extremely uncertain due to complex impact mechanisms (cf. Bickel and Friedrich 1994; Schreyer et al. 2006; IPCC 2013). To calculate the negative impacts of greenhouse gas emissions, in the literature the damage cost and the avoidance cost approaches are used. Both approaches are based on a realistic estimate of the costs per ton of carbon dioxide emissions, but answer different questions and both are characterised by considerable uncertainties. Similar to other air pollutant emissions, greenhouse gas emissions (carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$)) are estimated on the basis of an emission model (see section 4.2). Subsequently, the amount of greenhouse gas emissions is converted into $CO_2$-equivalents according to their 'global warming potential' weighted by factors from UBA (2014) based on Blasing (2012). The resulting total amount of $CO_2$-eq is multiplied by a specific cost factor. Based on compliance with the global 2-degree goal, numerous studies use avoidance cost factors to estimate climate change costs (e.g. Korzhenevych et al. 2014; Ecoplan and Infras 2014; van Essen et al. 2011; Becker et al. 2012; Maibach et al. 2008; Schreyer et al. 2006). In this paper, the recommended value of EUR 77 per ton $CO_2$-eq for 2010 according to Wille et al. (2012) based on the meta-analysis of Kuik et al. (2009) is used (avoidance cost factor).

## *4.4. Noise costs*

Noise can be harmful to human health and well-being, affecting both mental and physical health (cf. Babisch 2006). Literature distinguishes between annoyance impacts and health impacts when considering noise impacts on humans (cf. Ecoplan 2000; Giering 2010; Friedrich et al. 2012; Ecoplan and Infras 2014). Korzhenevych et al. (2014) assume that both categories (annoyance and health impacts) occur independently of each other and therefore both categories of damage must be considered when calculating the costs of noise impacts. Due to the short distances between noise source and immission location and the high population densities, the greatest noise impacts occur in urban areas (cf. Heinrichs 2016). To determine noise exposure, the number of noise-affected inhabitants per sound pressure level class ($L_{DEN}$, day-evening-night level) for road transport and light-rail transport is identified using the parameters of the EU Environmental Noise Directive (EU-Directive 2002/49/EC). The mapping of road transport noise also includes the inhabitants affected by federal highways. A clear attribution of noise-affected inhabitants to specific road categories and sections is not immediately possible because various noise-generating roads overlap at the location of immissions. The energetic-approach described by Popp (2016) can be used to estimate the shares of different road categories in total noise pollution. For this purpose, the noise pollution caused by the individual noise sources must first be modelled and calculated separately, to subsequently determine the proportions of the respective noise sources. For the present study, the respective noise models of the cities considered were not available. Therefore, a simplified approach was chosen to estimate the portion of the population affected by noise from federal highways within the administrative city boundary. For this purpose, the areas of the isophone bands of road transport are first merged with georeferenced population data from the Census (2011) on the basis of a one-hectare grid in a geoinformation-system (see Fig 4). The noise-affected inhabitants, who are located within the areas of the isophone bands, are then allocated to the road section that has the shortest linear distance to the inhabitant grids and therefore to the inhabitants' residential buildings. The basic idea behind these simplified assumptions is that the spatial distance between the noise emission location and the noise immission location significantly influences the level of traffic noise exposure. This portion of the population, differentiated by sound pressure level, is proportionally subtracted in the cost calculation.

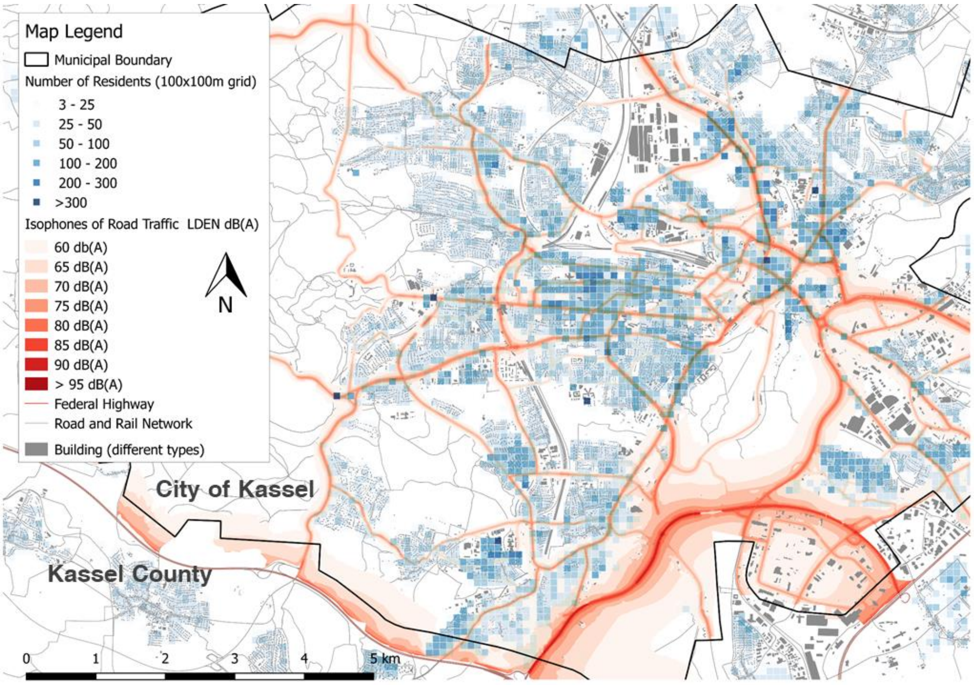


Fig. 4. Population distribution and isophone bands of road transport in the city of Kassel (excerpt). Data basis: HLUG (2013), Census (2011)

Subsequently, the number of inhabitants affected by noise is multiplied by specific cost factors from Friedrich et al. (2012) for road and rail transport (see Tab. 6). The cost factors include the monetarised noise effects of the two damage categories annoyance and negative health effects.

Tab. 6. Recommended cost factors of noise pollution per year and exposed person by sound pressure level for road and rail transport (according to Friedrich et al. 2012, in EUR, price basis 2010)

| Sound pressure level $L_{DEN}$ dB(A) | Road Transport | Rail Transport |
|---|---|---|
| 45 dB (A) | 0 | 0 |
| 50 dB (A) | 10 | 0 |
| 55 dB (A) | 51 | 10 |
| 60 dB (A) | 101 | 51 |
| 65 dB (A) | 152 | 101 |
| 70 dB (A) | 203 | 152 |
| 75 dB (A) | 337 | 286 |
| 80 dB (A) | 422 | 372 |
| > 81 dB (A) | 439 | 388 |

While the noise costs of light-rail-systems can be fully allocated to local public transport, the external noise costs of road transport must be allocated to various vehicle types. Due to vehicle-specific characteristics (e.g. engine noise, type of propulsion (diesel fuel, petrol)) different vehicles cause different levels of noise emissions. Based on this, it is assumed that the different vehicles are responsible to different degrees for the noise emissions caused by road transport and, accordingly, for the noise costs. For the allocation of road transport-related noise costs (based on 'top-down-approach'), the so called 'noise weighting factors' for different vehicle classes by van Essen et al. (2003) are used (see, e.g. Korn et al. 2014; Maibach et al. 2008; van Essen et al. 2011). For the passenger car (veh. ≤ 3.5 t) and truck traffic (veh. > 3.5 t), which are a mixture of different vehicle types (e.g. size, motorisation, type of propulsion), new mileage-weighted ‚noise factors' were determined in Saighani (2019) for urban roads on the basis of the German 'vehicle mileage survey 2014' (cf. Bäumer et al. 2017). The weighting factor of 9.8 for buses on urban roads is taken directly from van Essen et al. (2003). The factors aggregated for specific transport systems are summarised in Tab. 7.

Tab. 7. Mileage weighted 'noise weighting factors' for urban roads (according to Saighani 2019)

| | Noise weighting factors for urban roads |
|---|---|
| Passenger car (vehicles ≤ 3.5 tons) | 1.1 |
| Truck (vehicles > 3.5 tons) | 11.8 |
| Bus | 9.8 |

The allocation key 'road transport noise' *($\lambda_{RTN}$)* is calculated using the specific annual mileages *(aml)* of motorised transport systems and the 'noise weighting factors' *(nwf)* (see equation 5). Then the road transport-related noise costs are allocated to the various vehicles according to equation (5).

$$CNOIST_{mts} = \sum_k (popst_k \cdot cnoist_k) \cdot \lambda RTN_{mts}$$
$$\text{with}$$
$$\lambda RTN_{mts} = \frac{nwf_{mts} \cdot aml_{mts}}{\sum_i (nwf_i \cdot aml_i)} \qquad (5)$$

$CNOIST_{mts}$ … noise costs of road transport per motorised transport system [EUR/a]
$popst_k$ … exposed inhabitants due to road transport noise per level class (k) [inh./level class]
$cnoist_k$ … cost factor for road transport per inhabitant and level class (k) [EUR*inh./level class]
$\lambda RTN_{mts}$ … allocation key 'road transport noise' per motorised transport system [-]
$nwf_{mts}$ … noise weighting factor per motorised transport system [-]
$aml_{mts}$ … annual mileage per motorised transport system [vkm/a]
mts, i … motorised transport system {Truck, Car, Bus}

### *4.5. Benefits of non-motorised transport*

A quantitative assessment of the benefits of 'active mobility' (walking and cycling) has received little attention in literature and is only occasionally included in studies (cf. Götschi and Kahlmeier 2012; Ecoplan and ISPMZ Zurich 2013; Ecoplan and Infras 2014; Woodcock et al. 2009). As part of an international project, the World Health Organisation (WHO) developed a calculation method (HEAT Tool - Health Economic Assessment Tool) that quantifies the health benefits of cycling and walking (cf. WHO 2014). The 'HEAT-Tool' used in this paper, is a simple but robust approach designed for a wide range of applications. To estimate the health benefits of walking and cycling, specific mobility behaviour data (weekly travel time) is required for pedestrians aged 20 to 74 and for cyclists aged 20 to 64. City-specific data on mobility behaviour from the household survey 'Mobility in Cities' in Germany (SrV, 2008) are used. The relationship between weekly walking and cycling durations and reduced mortality risk is quantified by 'relative risks' (RR) from epidemiological studies (for walking from a summary of nine long-term studies and for cycling from a long-term study, cf. Kahlmeier et al. 2010). In research, these positive correlations could only be quantified for adults. The reduced mortality risk is limited to a maximum of 45% for cycling (458 minutes per week) and 30% for walking (450 minutes per week), according to WHO (2014). Even when the dose-response relationship between physical activity and mortality is probably non-linear, a linear function has been selected in HEAT to avoid additional data requirements. The calculated mortality risk is then used to calculate 'prevented deaths'. In this context, the reduced mortality risks of the various age groups, considering the mortality rate of the population for 20 to 74 year-olds (501.45 per 100,000 inhabitants) and 20 to 64 year-olds (266.55 per 100,000 inhabitants) in Germany by Statistisches Bundesamt (2010), are converted into ‘prevented deaths’. The estimated number of 'prevented deaths' is then monetised using the 'value of statistical life' (EUR 1.7 million) (similar to the estimation of immaterial costs for accident costs).

### *4.6. Results external effects*

If the external effects (accidents, air pollution, greenhouse gas and noise emissions) are taken into account in the allocation, it becomes apparent that the largest share of total external costs is attributable to accident costs (48% to 58%) and the lowest to noise costs (4% to 9%). The main part of the external costs of approx. 80% to 86% is caused by motor vehicle (cars and trucks) and only approx. 10% to 17% by the environmental transport systems (local public transport, bicycle and pedestrian traffic). In a comparison of passenger transport systems, car traffic is responsible for the highest external costs (57% to 73%) and pedestrian traffic for the lowest (1% to 3%). Pedestrians and cyclists not only cause very low external costs, they also generate significantly high benefits (negative costs). In the case of the allocated accident costs for pedestrians and cyclists, it should be noted that if they are involved in an accident or are even to blame for it, they are mostly suffering serious personal injury. Tab. 8 summarises the monetarised external effects of urban transport in the city of Kassel and their allocation to the various transport systems (in Annex C these are presented for Bremen (Tab. C.1) and for Kiel (Tab. C.2).

Tab. 8. Results of the external effects in the city of Kassel (price level 2010, without federal highways)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Accident costs [(1)] [EUR million] | 3.1 *(7%)* | 31.3 *(72%)* | 1.8 *(4%)* | 2.5 *(6%)* | 2.1 *(5%)* | 43.3 [(1)] *(58%)* |
| Air pollution costs [EUR million] | 3.2 *(25%)* | 8.9 *(70%)* | 0.7 *(5%)* | --- | --- | 12.8 *(17%)* |
| Climate change costs [EUR million] | 1.5 *(13%)* | 10.2 *(85%)* | 0.3 *(3%)* | --- | --- | 12.0 *(16%)* |
| Noise costs [EUR million] | 1.8 *(27%)* | 4.4 *(66%)* | 0.5 *(7%)* | --- | --- | 6.7 *(9%)* |
| External Costs Total [EUR million] | 9.6 *(13%)* | 54.8 *(73%)* | 3.3 *(4%)* | 2.5 *(3%)* | 2.1 *(3%)* | 74,8 |
| (Health) benefits of cycling and walking [(2)] [EUR million] | --- | --- | --- | -13.4 | -75.6 | -89.0 [(2)] |
| External costs per inhabitant [EUR/inh.] | 50 | 284 | 17 | 13 | 11 | 387 |
| (Health) benefits of cycling and walking per inhabitant [(2)] [EUR/inh.] | --- | --- | --- | -69 | -391 | --- |

* Tram and public bus services [(1)] incl. other vehicles (Motorcycle, Moped, Train, non-classifiable motor vehicles etc.), averaged from data of 2009 to 2011; [(2)] are shown negative (negative costs)

## 5. Conclusion

For the first time, the novel method allows a complete and intermodal overview of the economic impacts of the urban transport sector. In the business economic comparison (based on a full cost accounting), the municipal expenses and revenues in the transport sector are identified and allocated to the various urban transport systems. The core of the business economic comparison is the development of different allocation keys, which are determined on the basis of findings of engineering science and city-specific input variables. The allocation of the joint positions is determined on the one hand by the characteristics of the urban transport infrastructure and on the other hand by the characteristics of the various transport systems (user groups). By using these allocation keys, the monetary values recorded as joint positions (such as depreciation costs, road drainage, winter services, street lighting) can be allocated proportionately to the various urban transport systems. For a complete economic comparison, the most important external effects (accident costs, air pollution costs, climate change costs, noise costs and health benefits of walking and cycling) of urban transport were monetarised and allocated to the causers. In order to demonstrate the practicability of the method, the method was exemplarily applied in three sample cities of different sizes in Germany.

The method allows cost transparency and determines economic indicators that can serve as a basis for discussion and decision-making in the allocation of funds for the different urban transport systems. Therefore, the first step is a complete and cause-related cost allocation by applying the method described here. Besides that, it can be used directly to seek out goal indicators in urban development and transportation planning. With the approach presented here, for the first time municipalities will be able to have a complete overview of their transport-related revenues, expenses and external effects, each differentiated by urban transport system. This results in an additional and important instrument for strategic transportation planning and a next step on the road to 'true costs in the transport sector'. Moreover, the method can be used for strategic transport planning by combining with an urban transport demand model. In this context, the intermodal method and the consideration of interactions between transport supply, transport demand and economic impacts can quantify the overall effects of individual measures or bundles of measures on the overall 'urban transport'.

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## Appendix A. Allocation keys

Tab. A 1. Causation rates of urban transport systems in the allocation keys in the city of Bremen

| Allocation Key | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic |
|---|---|---|---|---|---|
| Motor Traffic | 0.10 | 0.90 | 0.00 | 0.00 | 0.00 |
| Traffic Area | 0.07 | 0.63 | 0.04 | 0.06 | 0.20 |
| Depreciation Costs | 0.20 | 0.62 | 0.10 | 0.02 | 0.06 |
| Street Cleaning | 0.06 | 0.61 | 0.08 | 0.07 | 0.18 |
| Winter Maintenance | 0.08 | 0.82 | 0.03 | 0.07 | 0.00 |
| Street Lighting | 0.06 | 0.61 | 0.03 | 0.08 | 0.22 |
| Traffic Signals | 0.09 | 0.85 | 0.01 | 0.00 | 0.04 |
| General | is calculated automatically from the other allocation keys for each sub household | | | | |

* Tram and public bus services

Tab. A 2. Causation rates of urban transport systems in the allocation keys in the city of Kiel

| Allocation Key | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic |
|---|---|---|---|---|---|
| Motor Traffic | 0.05 | 0.95 | 0.00 | 0.00 | 0.00 |
| Traffic Area | 0.06 | 0.51 | 0.06 | 0.09 | 0.29 |
| Depreciation Costs | 0.18 | 0.55 | 0.10 | 0.03 | 0.14 |
| Street Cleaning | 0.05 | 0.53 | 0.06 | 0.09 | 0.27 |
| Winter Maintenance | 0.04 | 0.83 | 0.04 | 0.08 | 0.02 |
| Street Lighting | 0.02 | 0.55 | 0.02 | 0.09 | 0.32 |
| Traffic Signals | 0.05 | 0.93 | 0.00 | 0.00 | 0.02 |
| General | is calculated automatically from the other allocation keys for each sub household | | | | |

* Public bus services

## Appendix B. Results business ecoonomic comparison

Tab. B. 1. Results of the business economic comparison in the city of Bremen (selected economic indicators, averaged and rounded 2009 – 2011)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Total Expenses [EUR million] | 24.0 | 99.2 | 169.2 | 4.5 | 14.4 | 311.3 |
| Total Revenues [EUR million] | 1.6 | 16.7 | 102.1 | 0.3 | 0.8 | 121.6 |
| Total Subsidy(1) [EUR million] | 22.4 | 82.5 | 67.1 | 4.2 | 13.6 | 189.8 |
| Relative Subsidy [%] | 12% | 43% | 35% | 2% | 7% | 100% |
| Cost-Modal-Split in Passenger Transport [%] | --- | 49% | 40% | 2% | 8% | 100% |
| Cost-Coverage-Ratio 'Full-Cost' [%] | 7% | 17% | 60% | ---(2) | ---(2) | --- |
| Subsidy per inhabitant [EUR/inh.] | 41 | 151 | 123 | 8 | 25 | 346 |

* Tram and public bus services; (1) results from the difference between expenses and revenues; (2) are not reported because there are no direct income

Tab. B. 2. Results of the business economic comparison in the city of Kiel (selected economic indicators, averaged and rounded 2009 – 2011)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Total Expenses [EUR million] | 4.8 | 28.9 | 45.7 | 2.2 | 7.8 | 89.4 |
| Total Revenues [EUR million] | 1.4 | 16.1 | 37.0 | 0.8 | 2.3 | 57.5 |
| Total Subsidy(1) [EUR million] | 3.4 | 12.8 | 8.7 | 1.4 | 5.4 | 31.8 |
| Relative Subsidy [%] | 11% | 41% | 27% | 4% | 17% | 100% |
| Cost-Modal-Split in Passenger Transport [%] | --- | 46% | 30% | 5% | 19% | 100% |
| Cost-Coverage-Ratio 'Full-Cost' [%] | 28% | 56% | 81% | ---(2) | ---(2) | --- |
| Subsidy per inhabitant [EUR/inh.] | 14 | 54 | 37 | 6 | 23 | 135 |

* Public bus services; (1) results from the difference between expenses and revenues; (2) are not reported because there are no direct income

## Appendix C. Results external effects

Tab. C. 1. Results of the external effects in the city of Bremen (price level 2010, without federal highways)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Accident costs (1) [EUR million] | 6.5 *(7%)* | 57.3 *(59%)* | 4.1 *(4%)* | 19.0 *(20%)* | 4.1 *(4%)* | 97.4 (1) *(52%)* |
| Air pollution costs [EUR million] | 20.4 *(49%)* | 19.9 *(47%)* | 1.6 *(4%)* | --- | --- | 41.9 *(22%)* |
| Climate change costs [EUR million] | 9.4 *(28%)* | 22.8 *(69%)* | 0.8 *(2%)* | --- | --- | 33.0 *(17%)* |
| Noise costs [EUR million] | 7.7 *(47%)* | 6.7 *(41%)* | 2.1 *(13%)* | --- | --- | 16.5 *(9%)* |
| External Costs Total [EUR million] | 44.0 *(23%)* | 106.7 *(57%)* | 8.6 *(5%)* | 19.0 *(10%)* | 4.1 *(2%)* | 188,8 |
| (Health) benefits of cycling and walking (2) [EUR million] | --- | --- | --- | -138.9 | -155.5 | -294.4 (2) |
| External costs per inhabitant [EUR/inh.] | 80 | 195 | 16 | 35 | 7 | 345 |
| (Health) benefits of cycling and walking per inhabitant (2) [EUR/inh.] | --- | --- | --- | -254 | -284 | --- |

* Tram and public bus services (1) incl. other vehicles (Motorcycle, Moped, Train, non-classifiable motor vehicles etc.), averaged from data of 2009 to 2011; (2) are shown negative (negative costs)

Tab. C. 2. Results of the external effects in the city of Kiel (price level 2010, without federal highways)

| | Truck-Traffic (veh. > 3.5 t) | Car-Traffic (veh. ≤ 3.5 t) | Local Public Transport* | Bicycle-Traffic | Pedestrian-Traffic | Total |
|---|---|---|---|---|---|---|
| Accident costs [(1)] [EUR million] | 2.2 *(5%)* | 31.2 *(68%)* | 2.0 *(4%)* | 6.5 *(14%)* | 0.2 *(0%)* | 46.0 [(1)] *(48%)* |
| Air pollution costs [EUR million] | 7.0 *(28%)* | 15.7 *(64%)* | 1.9 *(8%)* | --- | --- | 24.6 *(25%)* |
| Climate change costs [EUR million] | 3.2 *(14%)* | 18.0 *(81%)* | 0.9 *(4%)* | --- | --- | 22.1 *(23%)* |
| Noise costs [EUR million] | 1.2 *(31%)* | 2.5 *(64%)* | 0.2 *(5%)* | --- | --- | 3.9 *(4%)* |
| External Costs Total [EUR million] | 13.6 *(14%)* | 67.4 *(70%)* | 5.0 *(5%)* | 6.5 *(7%)* | 0.2 *(0%)* | 96,6 |
| (Health) benefits of cycling and walking [(2)] [EUR million] | --- | --- | --- | -56.7 | -95.2 | -151.9 [(2)] |
| External costs per inhabitant [EUR/inh.] | 58 | 286 | 21 | 28 | 1 | 409 |
| (Health) benefits of cycling and walking per inhabitant [(2)] [EUR/inh.] | --- | --- | --- | -240 | -403 | --- |

* Public bus services [(1)] incl. other vehicles (Motorcycle, Moped, Train, non-classifiable motor vehicles etc.), data of 2009; [(2)] are shown negative (negative costs)

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