



Analysis

The Social Cost of Automobility, Cycling and Walking in the European Union

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A B S T R A C T

Cost-benefit-analyses (CBA) are widely used to assess transport projects. Comparing various CBA frameworks, this paper concludes that the range of parameters considered in EU transport CBA is limited. A comprehensive list of criteria is presented, and unit costs identified. These are used to calculate the external and private cost of automobility, cycling and walking in the European Union. Results suggest that each kilometer driven by car incurs an external cost of €0.11, while cycling and walking represent benefits of €0.18 and €0.37 per kilometer. Extrapolated to the total number of passenger kilometers driven, cycled or walked in the European Union, the cost of automobility is about €500 billion per year. Due to positive health effects, cycling is an external benefit worth €24 billion per year and walking €66 billion per year. CBA frameworks in the EU should be widened to better include the full range of externalities, and, where feasible, be used comparatively to better understand the consequences of different transport investment decisions.

1. Introduction

Transport systems need to change in very significant ways to become aligned with the UN Sustainable Development Goals (Creutzig et al., 2015; The Lancet, 2017; UNFCCC, 2015; WHO, 2011, 2016). To reduce levels of local air pollution, accidents, and congestion is a long-standing policy goal in the European Union (EU) (EC, 2011). Negative externalities of transportation congregate in cities, with a widely held consensus that these can only be resolved on the basis of new urban transport cultures in which cycling and walking have to perform important roles (Aldred, 2013; Hall et al., 2017; Pucher and Buehler, 2017). Only where the role of the car declines is it realistic to reduce traffic density and air pollution, even in a scenario where electric, autonomous automobility diminishes noise levels and collision risks (Zuurbier et al., 2010).

In European cities, cycling and walking are becoming increasingly more common (Hall et al., 2017; Pucher and Buehler, 2017). These transport modes can replace trips by car, specifically in cities, where a majority of trips are short (Blickstein and Hanson, 2001). Evidence suggests that cycling levels increase where physically separated cycle tracks have been built (Frondele and Vance, 2017), where trips are short, and where safe routes to school exist. In contrast, perceived traffic dangers, exposure to exhaust and noise, or longer trip distances all

represent barriers to cycling (Fraser and Lock, 2011; Gössling et al., 2019). As a result, cities seeking to increase cyclist numbers need to redesign urban environments (Buehler et al., 2017; Forsyth and Krizek, 2011; Larsen et al., 2013), as bicycle cultures will only evolve where the concerns and expectations of cyclists regarding safety, speed, and comfort are taken into consideration (Aldred, 2013). These insights also apply to walking, with ‘walkable’ environments being defined as traversable, compact, physically enticing, and safe (Forsyth, 2015). Apart from the politically difficult decision to treat cyclists and pedestrians preferentially in traffic, the greatest barrier to urban redesign is the issue of costs (Gössling and Choi, 2015). This assigns critical importance to cost-benefit analyses (CBA), which guide decision making in all major transport construction projects.

CBA involves the assessment of potential impacts of a policy across a specific time horizon, their monetary valuation, and the comparison of net benefits and costs (Hanley and Spash, 1993). Inclusion of negative externalities in the CBA can highlight ‘hidden’ cost issues (Bithas, 2011). This is never straightforward, as the selection of aspects to include in the CBA, as well as their valuation, is influenced by the ideological orientation of the actors involved in the analysis (Söderbaum, 2007). Yet, where the selection of analysis criteria is stated explicitly, in particular comparative approaches to transport CBA can contribute to greater consistency and transparency, providing a more informed basis

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for decision-making (Gössling and Choi, 2015).

Given the cost of implementing new transport infrastructure (Hutton, 2013; Meschik, 2012), as well as the importance assigned to the various transport modes in contemporary city planning, various studies have addressed the cost associated with in particular the car (Becker et al., 2012; CE Delft et al., 2011; Hopkinson and Wardman, 1996; Ortuzar et al., 2000; Krizek, 2007; Meschik, 2012; Rabl and de Nazelle, 2012; Rank et al., 2001). However, to date, a comparative CBA framework to juxtapose the cost of different transport modes appears to only be used in Copenhagen (COWI and City of Copenhagen, 2009). Against this background, the purpose of this paper is to review CBA frameworks for transport infrastructure development, to discuss the comprehensiveness of the parameters included, and to develop a comparative CBA framework for car, bicycle, and walking, along with unit cost estimates.

2. Cost-benefit Analysis and Its Use in Transport Contexts

Traffic infrastructure development commonly relies on CBA to guide investment decisions in public spending contexts (e.g. Boardman et al., 2010; Hanley and Spash, 1993). The use of CBA implicates that monetary value is assigned to the advantages and disadvantages of a project, which results in a net cost or benefit to society. Decisions regarding the desirability of specific investments become more transparent, as CBA helps to determine whether an investment is economically sound, or whether an alternative project is more favorable. CBA can consequently be used to justify projects economically, or to rank projects by assigning priorities (Transportation Economics, 2017). However, CBA as a decision-making tool also has weaknesses, such as the subjective choice of items to be included in the analysis; the allocation of monetary values (unit costs), for which there may be no market values; as well as the identification of appropriate time horizons, spanning generations. Further difficulties arise out of value incommensurability and issues of fairness (Bithas, 2011; Hanley and Spash, 1993). There is consequently a risk that a CBA process is reductionist, valuing impacts only in economic terms, while lacking transparency and public participation. Weaknesses also include that CBA may fail to adequately represent effects outside markets or double count effects (Annema et al., 2007).

Despite these limitations, CBA is a commonly employed and widely accepted economic tool in transportation contexts, specifically investments in infrastructure (e.g. EC, 2014a, b; for critical discussions see Bithas, 2011; Hutton, 2013; Parks and Gowdy, 2013). CBA is not a comprehensive solution to understanding a project's impacts (Hanley and Spash, 1993). However, where it is used as a component in the decision-making process that is aligned with stated policy and developed with input from a range of stakeholders and the public, its weaknesses can be mitigated (Söderbaum, 2007). Where CBA is used in non-traditional ways, such as the comparison of different transport modes, its outcomes may provide entirely new perspectives on investment decisions in transport contexts (Gössling and Choi, 2015).

Existing CBA frameworks have been based on different variables, as well as economic values assigned to these variables (Grant-Muller et al., 2001). Given the importance of CBA for transport projects (Annema et al., 2007; EC, 2014a, b; Hutton, 2013; Knudsen and Rich, 2013), guidebooks for transport planners now seek to streamline CBA methodologies. For example, the European Commission (EC, 2014a, b) published a guide to CBA of investment projects, as it “promotes the use of cost-benefit analyses for major infrastructure projects above €50 million” (ibid.: 11), of which over five hundred are expected to be implemented over the period 2014–2020 in the EU. Investment priorities include projects that support a “Single European Transport Area” in the trans-European transport network (TEN-T), projects that enhance regional mobility, and those that “develop and improve environmentally-friendly and low-carbon transport systems” (ibid.: 77). An important part of EU CBA decisions is based on demand analyses,

i.e. the forecasting of traffic volumes, and the provision of infrastructure to meet anticipated demand. Similar tools, often software-based, are in use throughout the world (Transportation Economics, 2017).

Transportation has a range of impacts, such the sector's contribution to climate change (Stern, 2006), accidents (Jacobs et al., 2000; WHO, 2015), or health, with for instance 85% of airborne particulate pollution being linked to fossil fuel combustion (The Lancet, 2017). These constitute negative externalities that need to be considered in CBA. The European Environment Agency (2003) estimated, for example, that the external cost of transport is in the order of 8% of GDP in the EU plus Norway and Switzerland. Some 58% of this total is linked to cars, including accidents, noise, air pollution, climate change, and related environmental impacts. In a more recent study, CE Delft, Infras and Fraunhofer ISI (CE Delft et al., 2011) calculated that negative transport externalities amounted to €500 billion in the EU27 plus Norway and Switzerland in 2008, or 4% of total GDP. This includes accidents, air pollution, climate change, noise and congestion, as well as other external costs linked to up and downstream processes, i.e. energy, vehicle, and infrastructure production. In a global assessment, the World Health Organization (WHO, 2015) quantified the cost of traffic deaths and injuries to be equivalent of a 3% of global GDP. The Lancet Commission (2017) calculated that air pollution, to which transportation makes a significant contribution, is responsible for 16% of deaths worldwide, incurring welfare losses of US\$4.6 trillion. Given a world GDP of US \$75.8 trillion in 2016 (World Bank, 2017), this corresponds to 6% of world GDP. Even though no comprehensive, global assessment of motorized transportation's negative externalities exists, evidence suggests that these are significant (Becker et al., 2012; Santos, 2017).

Analyses of cycling externalities are rare. Nelson (1995) discussed the implementation of bicycle access ways as seen against the costs of air pollution, congestion, or noise. Buis (2000) provided cost-benefit analyses for cycling in Amsterdam, Bogotá, Delhi and Morogoro. Wittink (2001) investigated non-motorized transport in relation to economic growth, poverty reduction and quality of urban life in the Netherlands. Saelensminde (2002) studied CBAs for walking and cycle-track networks in Norwegian cities. All concluded that cycling makes positive contributions to the economy. Only one CBA framework has been presented for walking. Litman (2004) discussed urban livability, accessibility, transport cost, health, external costs, efficient land use, economic development and equity. Studies by Meschik (2012) and Rabl and de Nazelle (2012) assessed the cost of switching from driving to bicycling (per individual or km cycled). In Copenhagen, a study by COWI and City of Copenhagen (2009) compared the cost of cars with bicycles to derive conclusions regarding the financing of transport infrastructure. This study has more recently been complemented with an economic analysis of walking in Copenhagen (Realise, 2018). In Canada, the Victoria Transport Policy Institute published a comprehensive comparison of car, bicycle, walking and other transport modes (Litman and Doherty, 2011). All studies found substantial benefits of cycling and walking over the car.

Existing CBA frameworks can be criticized from comprehensiveness and unit cost perspectives. While some studies ignore negative externalities altogether (cf. Transportation Economics, 2017), others have included a number of selected parameters (cf. EC, 2014a, b). Where negative externalities are considered, the unit cost chosen may underestimate the actual cost. Furthermore, transportation CBA is usually used to derive a ratio, i.e. benefits divided by cost, to provide an absolute measure of benefits. This omits discussion of the distribution of cost and benefits, which may accrue to the individual or society. As focus is often on one transport mode, usually the car, existing CBAs also make limited contributions to decision-making in urban contexts, where the substitutability of transportation makes it possible for planners to favor different transport modes competing for space or prioritization.

3. Method

3.1. Comparative Cost-benefit Analysis

CBA frameworks need to consider two key aspects, the decision on the parameters to be included in calculations, as well as justified unit costs. Comparative CBA can be used to assess the economic cost of a kilometer driven, cycled or walked, as well as to assess (*ex ante* or *ex post*) changes in transportation costs as a result of urban re-design or infrastructure change. The current transport system is the basis for assessments, in which costs may be external or private. The validity of any CBA will rely on the comprehensiveness of the parameters included, as well as the complexity of the effects considered, including rebounds (Santarius et al., 2016). With regard to parameters, the European Commission's 'Guide to Cost-Benefit Analysis of Investment Projects' suggests, for transport-related projects, to include travel time, vehicle operating costs, accidents/collisions, noise, air pollution, and climate change in transport CBAs (EC, 2014a, b). These parameters are also used in other countries (Litman and Doherty, 2011; NZ Transport Agency, 2016), but they inadequately represent the full cost of motorized transportation, and, given the lack of comparison, omit benefits associated with cycling or walking. In this study, four CBA assessment frameworks are compared to identify a comprehensive list of parameters, including i) The European Commission's Handbook on Transport Costs (EC, 2014a, b); ii) the city of Copenhagen's comparative CBA (COWI and City of Copenhagen, 2009) along with the city's walking CBA (Transportministeriet, 2013); iii) the European Cycle Foundation's study of 'bicycle benefits' (ECF, 2016), and the Canadian Victoria Transport Policy Institute's 'CBA for transportation' (Litman and Doherty, 2011). Identical CBA conditions are applied for the three transport modes studied, i.e. car, bicycle and walking.

To calculate unit costs, the existing literature on costs/benefits was reviewed. For many parameters, valuation cannot be based on market values. Common alternative assessment methods include market prices, stated preferences, revealed preferences, cost savings, human capital approaches, willingness-to-pay/willingness-to-accept, hedonic pricing, as well as shadow pricing (EC, 2014a, b). Values that constitute a cost are characterized as positive (+) and those that represent a benefit are negative (–). Values are current, but change over time based on emerging knowledge. The assessment of health implications and their cost, for example, has seen considerable progress over the past decade. Yet, external and private cost depends on context. As an example, the monetary value of time is vastly different between continents and countries, and also depends on the time of the day. To derive global averages, national studies are interpolated in comparison to European average per capita GDP. This implies a degree of abstraction, and a limitation of this review remains that values continue to represent an approximation. Two meta-studies, Korzhenevych et al. (2014) and Litman and Doherty (2011), provide comprehensive discussions of weaknesses and shortcomings of the various valuation methods. Of all national studies, data for Denmark appears to be the most regularly updated (Center for Transport Analytics, 2017). Readers are referred to these studies for reference, as any full representation of methodological approaches is outside the scope of this paper.

3.2. Transport Demand and Assumptions

Estimates of travel demand suggest that in OECD countries, 1.2 billion people travelled 11.0 trillion passenger miles (17.7 trillion passenger kilometers [pkm]), averaging > 9000 miles (14,484 km) per person in 2012 (EIA, 2017). In addition, 6 billion people in non-OECD countries travelled an estimated 12.6 trillion passenger miles (20.3 trillion pkm), averaging slightly > 2000 miles per person (3219 pkm). More than 80% of passenger travel in OECD regions and 41% of passenger travel in non-OECD countries involves light-duty vehicles (EIA, 2017). Of the 38 trillion pkm travelled by the world's population in

2012, it can be estimated that 22.5 trillion have been travelled by car and other forms of lighter motorized vehicles. In the EU28, some 4.719 trillion pkm were travelled by car in 2015 (EC, 2017), with an average occupancy rate of 1.54 persons per car (EEA, 2010). This level may have declined in industrialized countries in recent years: Data for Austria indicates, for example, an average occupancy of 1.4 persons per car in 1990, and 1.2 in 2015 (Umweltbundesamt, 2017).

Less information is available regarding cycling. The European Cyclists' Federation (2016) claims that in the EU, 134 billion km are cycled every year. Compared to EU (EC, 2017) estimates of 4.719 trillion car pkm, the ratio of car to bicycle pkm is 32:1. There appears to be no data for European walking. Bassett et al. (2008) suggest that in the USA, people walk 141 km per capita and year, i.e. < 400 m per day, while in Denmark, this value is three times higher, at 1.18 km per day, or 431 km per year. Note that this data refers to 'trips', i.e. excludes movement at home or at work. At an estimated daily walking distance of 1.2 km in the European Union (based on Bassett et al., 2008), the region's 500 million residents may walk some 180 billion km per year.

3.3. Unit Costs

All unit costs represent averaged values per passenger kilometer, though there exist considerable differences between vehicles, locality of impact, and time of the day. Equally important are differences related to economic context, i.e. where costs are income-related. All item cost values represent average values, based on official data for the EU where available (Korzhenevych et al., 2014), and complemented with data by Litman and Doherty (2011). This latter data base is regularly updated, last on 24 April 2018 (for data sources see VTPI, 2018). Cost assessments also rely on the peer-reviewed literature (e.g. Coady et al., 2017) as well as reports and datasets by institutions and organizations (e.g. Center of Transport Analytics, 2017; IEA, 2017; Lancet Commission, 2017). In a few cases, no cost assessments could be identified, for instance in the case of soil and water pollution caused by cyclists. In such cases, the authors have provided cost estimates. Only with regard to two items, Quality of Life and Branding & tourism, no data was found to support calculations, and these have to remain open. Where data is compared to Canadian (Litman and Doherty, 2011) or Danish values (Center of Transport Analytics, 2017), averaged European area values are calculated at 60% and 79% of these respective countries' GDPs (based on World Bank, 2017). All values are inflation-adjusted to mid-2017 or averaged 2017 consumer price index values (World Bank, 2017), using, for example, the US of Labour Statistics' Inflation Calculator, https://www.bls.gov/data/inflation_calculator.htm. Where necessary, values are converted to Euros at June 2017 exchange rates (www.oanda.com). All calculations and assumptions are detailed in the Annex.

3.4. Limitations

Wherever costs are averaged, this hides complexity. For example, the climate change abatement cost is expected to increase over time, as cheaper options for GHG emission reductions become unavailable. This implies a potential under/overrepresentation of older cost assessments that have been extrapolated to 2017 in this paper. As cost also depends on car choices (mass & motorization; electric versus combustion), as well as driving styles, averaged values do not always provide guidance for transport policy. However, as a general rule, the highest cost imposed by automobility is related to large cars in urban contexts. Where a cost is based on estimates, this is explained in the text. Overall, CBA portrays an equilibrium of the transport system at a given point in time. This dynamic can change, as available infrastructure influences travel time; while active transport modes have positive repercussions for health, but increase traffic risks. Costs and benefits of transport projects can also accrue over different points in time. Where cost-benefit interrelationships change, this can involve non-linear supply curves

Table 1

Comparison of parameters considered in CBA transport contexts.

Source: COWI and City of Copenhagen, 2009 ('CPH' in this table); EC, 2014a, b (EC); ECF, 2016 (ECF); Litman and Doherty, 2011 (VTPI).

Parameter	Definition	EC	CPH	ECF	VTPI
<i>Environment</i>					
1. Climate change	Cost of climate change effects linked to greenhouse gas emissions (CO ₂ , other long-lived GHG)	X	X	X	X
2. Air pollution	Cost of air pollution, including economic and health effects of CO, NO _x , PM _{2.5} , PM ₁₀ , SO _x , VOC, and O ₃ .	X	X	X	X
3. Noise pollution	Cost of noise, including amenity costs (property values, productivity or health costs)	X	X	X	X
4. Soil and water quality	Pollution of ground water and soils related to contaminants from traffic (heavy metals, hydrocarbons, road salt, etc.)			X	X
5. Land use and infrastructure	Space requirements for infrastructure construction, including parking; roadway land and parking value; loss of ecosystem service values			X	X
6. Traffic infrastructure maintenance	Cost of infrastructure maintenance, administration and traffic police		X		X
7. Resource requirements	Resources needed to build cars/bicycles, as well as the cost to recycle resources, or to deposit wastes (lifecycle based)			X	X
<i>Travel time and vehicle operation</i>					
8. Vehicle operation	Cost of owning and operating a particular transport mode, including duties and taxes, insurance, fuel and vehicle depreciation	X	X	X	X
9. Travel time	The cost of travel time associated with the use of a specific transport mode	X	X		X
10. Congestion	Cost of roadway congestion imparted on other road users, including additional travel time, operating costs, fuel costs, reliability costs, pollution, climate change, accidents, noise			X	X
<i>Health, accidents and perceived comfort</i>					
11. Health benefits (better health, productivity gains and prolonged life)	Savings to the healthcare system as a result of partaking in active transportation; reduction in sick leave days; longer lives.		X	X	X
12. Accidents (collisions)	The costs of minor and major injuries, and fatalities, attributed to medical expenses, pain and suffering, loss of life. Material damage associated with car accidents	X	X	X	X
13. Perceived safety & discomfort	Perceived accident risks in traffic as a result of exposure to motorized traffic; discomfort because of exposure to exhaust fumes			X	
<i>Quality of life, tourism and infrastructure</i>					
14. Quality of life, branding and tourism	Value derived from being considered a progressive city with a high quality of life; value of open spaces for tourism		X		

X: considered in respective study.

reflecting scarcity (e.g. land use, resources). Averaged values as presented in this paper consequently provide an indication rather than exact assessments.

4. Parameters for Comparative CBA

Standard parameters in transport CBAs include travel time, vehicle operating costs, accidents, noise, air pollution, and climate change. These are commonly considered basis requirements for CBA, even though they do not represent all externalities that constitute a cost or benefit of transportation. Where CBA compares transport modes, it is also important to consider how these incur mutual, interdependent costs. As an example, cyclists or pedestrians are exposed to various negative externalities created by cars, such as collision risks, distress, noise, pollutants, or smells. Cyclists may also face disadvantages as a result of public space and infrastructure predominantly assigned to cars, or prioritization of vehicles in traffic (e.g. red-light waiting times). Where cars clog roads, this may slow down cyclists. Pedestrians will generally use separated infrastructure, but they may also face disadvantages, as traffic systems are designed to maximize vehicle flows.

Table 1 compares the parameters included in the four different CBA assessment frameworks (COWI and City of Copenhagen, 2009; EC, 2014a, b; ECF, 2016; Litman and Doherty, 2011), ranging from six (EC, 2014a, b) to 44 parameters (ECF, 2016). ECF (2016) calculates the cost of cars as a benefit associated with the bicycle (i.e., as ‘avoided costs’), in what is essentially an assessment of the total economic value of cycling in the European Union. Hence, not all parameters of the ECF approach are equally valid for inclusion in comparative CBA:

- They represent double-counting (‘climate change costs’ *vis-à-vis* ‘related benefits of reduced CO₂ emissions’; ‘urban design’ *vis-à-vis* ‘quality of public space’);
- They are not focused on externalities (i.e., ‘economic contribution of bicycle manufacturing’, ‘sales and repairs’, ‘shopping’, ‘bicycle tourism’ or ‘induced’ effects in associated economic sectors);
- They include subjective costs/benefits assessments on which views may vary (i.e., ‘quality of time when cycling’, ‘social and gender equality’, ‘child welfare’, ‘social safety’, ‘resilience and robustness’, ‘connectivity’, ‘accessibility’).

In excluding these aspects, the analysis of the three CBA frameworks yields a total of 14 parameters that should be part of any comprehensive, comparative transport CBA. These are listed in Table 1, where ‘health benefits’ summarize ‘healthier lives’, ‘mental health benefits’, ‘health benefits for children’, ‘reductions in sick-leave’, ‘productivity gains’ and ‘prolonged lives’ (COWI and City of Copenhagen, 2009; ECF, 2016).

4.1. Climate Change

Climate change is a result of greenhouse gas emissions, of which CO₂ is the most important in road transport contexts. Transportation requires 27% of final global energy use, corresponding to emissions of 6.7 GtCO₂ or 7 GtCO₂-equivalent in 2010. By 2050, transportation is expected to emit 12 GtCO₂eq per year (IPCC, 2014); i.e., the sector will increasingly interfere with mitigation objectives (UNFCCC, 2015). Climate change is expected to cause significant economic damage (Stern, 2006). In CBA, unit costs for CO₂ have been based on the market value of the trade in CO₂, which reflect willingness-to-pay by businesses in light of expected future climate policy. Carbon market cost is not a reflection of the external cost of climate change, however, and may be better assessed on the basis of the cost of reducing emissions to a level that is in line with the international 2 °C stabilization goal (UNFCCC, 2015).

Fossil fuels are subsidized. A recent estimate by Coady et al. (2017), assesses the value of consumer prices below supply costs, and a

‘Pigouvian’ tax reflecting environmental damages. Combining air pollution, vehicle externalities, supply costs, and general consumer taxes, puts the total value of fossil fuel subsidies at €₂₀₁₇4.6 trillion (ibid., for discussion see McKittrick, 2017). Including only supply costs below consumer prices as subsidies corresponds to €₂₀₁₇504 billion, across all fossil fuels (Coady et al., 2017).

4.2. Air Pollution

The cost of air pollution includes economic and health effects of carbon monoxide (CO), nitrous oxides (NO_x), particulate matter (PM_{2.5}, PM₁₀), sulphurous oxides (SO_x), volatile organic compounds (VOC), and ozone (O₃) (Crüts et al., 2008; Klæboe et al., 2000; Künzli et al., 2000; Morelli et al., 2015). The European Environment Agency (EEA, 2016) also distinguishes black carbon (BC), ammonia (NH₃), Benzopyrene (BaP), benzene (C₆H₆, an additive to petrol), as well as toxic metals such as arsenic (As), Cadmium (Cd), Nickel (Ni), Lead (Pb) and mercury (Hg), which are linked to combustion of fossil fuels, metal production, and waste incineration. Pollutants have various health effects, including bronchitis and asthma, lung cancer and cardio-pulmonary diseases (e.g. Hoek et al., 2002; Pope III et al., 2002). Traffic exhaust can be particularly dangerous to children (Patel and Miller, 2009; Vette et al., 2013), and lead to respiratory infections, low birth weight, preterm birth and cognitive impairment (Andersen et al., 2000; Brunekreef and Holgate, 2002; Sunyer et al., 2015). Impacts also include hospital admissions, restricted activity days and work days lost (Korzhenyevych et al., 2014). Apart from these health-related costs, air pollutants also affect biodiversity, agricultural yield, as well as buildings through the soiling of facades and corrosive processes (CE Delft et al., 2011).

Various recent assessments have highlighted that air pollution is responsible for a considerable part of global morbidity (diseases) and mortality (premature deaths). While the Lancet Commission (2017) estimates that 16% of all deaths worldwide are related to pollution, European assessments concluded that air pollution is responsible for 6% of total mortality, half of this attributed to motorized transport (Künzli et al., 2000). Notably, this would indicate that air pollution contributes to at least twice as many deaths as traffic accidents (Künzli et al., 2000; see also Brauer et al., 2013). EEA (2017a, c) suggests that in the EU28, road transport accounted for 19% of total greenhouse gases (GHG, in CO₂-equivalents), 39% of NO_x, 11% of PM_{2.5} and PM₁₀, 10% of NMVOCs, 20% of CO and 29% of BC. Road transport also contributed to 1–16% of emissions of toxic metals (As, Cd, Ni, Pb, Hg).

4.3. Noise

The cost of noise from traffic consists of two elements: the cost of annoyance as well as the cost of health impacts due to noise exposure (CE Delft et al., 2011). Noise causes stress and has been linked to tinnitus, mood changes, chronic sleep disturbance and lack of recovery from tiredness, nervousness, anxiety and phobia, cardiovascular diseases, and cognitive impairment of children (Babisch, 2011, 2015; Öhrström, 1995; Poenaru et al., 1978; WHO, 2011). Economic costs of noise pollution include devaluation in house prices as a result of traffic exposure, productivity losses (poor concentration, fatigue, hearing problems), as well as the cost related to premature death or morbidity (cardiovascular diseases). There is also an indirect cost linked to property prices, which are in steep decline in proximity to busy roads (Łowicki and Piotrowska, 2015).

Exposure to noise pollution is a problem specifically in cities, with estimates that 40% of the EU population are exposed to road noise exceeding the safe health limit of 55 dB(A) (WHO, 1999). As many as “one million healthy life years are lost every year from traffic-related noise in the western part of Europe” (WHO, 2011: v). The calculation of noise impacts is complex and it is difficult to average costs, which depend on critical noise levels above 55 dB(A) and population exposure

during specific periods of the day (Korzheneych et al., 2014). The EEA (2017b) concludes that in the EU28, noise is responsible for 16,000 premature deaths, and 32 million adults annoyed by noise, as well as a further 13 million suffering from sleep disturbance. Noise cost includes amenity value loss (property prices), treatment costs for health, sick days, as well as premature deaths.

4.4. Soil and Water Quality

The construction and maintenance of transport systems, the production of transport modes, as well as fuel burn lead to the pollution of ground water and soils. This includes pollutants released to soil, water bodies and groundwater, such as hydrocarbons, non-gaseous exhaust, heavy metal particulates from the wear of mechanical components such as brake pads, as well as salt and gravel used for anti-icing or winter maintenance (e.g. Sörme and Lagerkvist, 2002). Additionally, impacts related to increased storm water runoff from impervious surfaces such as concrete and asphalt must be considered.

4.5. Land Use and Infrastructure

Space requirements for transport infrastructure, including parking, are considerable (IEA, 2013). Land use represents a negative externality as a result of land lost for other purposes, such as agriculture, as well as its value for ecosystem services (Daily, 1997). Land is often provided for free, for instance in the form of parking (Shoup, 2011). Road land should consequently be priced and taxed at the same rate as for competing uses (Litman and Doherty, 2011). The cost of land use can be calculated on the basis of a forecast of the land needed (annually) for additional infrastructure, including both the cost of land and infrastructure construction. The International Energy Agency suggests that road, rail and parking infrastructure by 2050 is expected to account for between 250,000 km² and 350,000 km² of built surface area (IEA, 2013). By 2050, under the IEA's 4DS scenario, in which light duty vehicle travel increases to 43 trillion vehicle kilometers, 25 million paved road km, as well as 44,500 km² of parking space will be added to existing traffic infrastructure.

4.6. Traffic Infrastructure Maintenance

The cost of traffic infrastructure maintenance comprises constructions, major repairs, renewal, and construction maintenance, winter maintenance, marking, cleaning, cutting, checks, as well as administrative tasks, such as traffic control (Litman and Doherty, 2011). In contrast to road infrastructure demand, which is largely driven by growth in vehicle numbers, road maintenance needs arise mostly out of freight transportation, as a result of the greater weight of trucks and their disproportionately larger impact on roads (Small and Winston, 1988). As data for the US suggests, total highway expenditures consist of maintenance & operations (26%), highway capacity expansion (23%), reconstruction, rehabilitation and restoration (19%), administration (9%), patrol and safety (8%), local road capital improvements (8%), interest on debt (4%) and other (3%) (Litman and Doherty, 2011).

4.7. Resource Requirements

Resource requirements, or the cost related to up and downstream processes, refer to the resources needed to build cars/bicycles and transport infrastructure, including all energy requirements on a life-cycle basis, the cost to maintain vehicles or bicycles, to recycle these, and to deposit wastes. The cost of these aspects is associated with emissions of CH₄, N₂O, CO₂, NO_x, or PM.

4.8. Vehicle Operation

Vehicle operation comprises the costs of driving a car, including fuel, oil & tire wear; maintenance and depreciation, parking fees and road tolls; as well as financing, insurance, registration fees and taxes.

4.9. Travel Time

Travel time is considered a (private) cost that has to be minimized by optimizing traffic flows (Hutton, 2013). The assessment of the marginal value of travel time is complex and sometimes contentious, as it depends on research method, sociodemographic factors and transport mode (Hensher, 2009; Shires and Jong, 2009). The value of travel time has also been linked to travel time reliability, i.e. the uncertainty experienced by travelers as to when they will reach their destination (Carrion and Levinson, 2012). Transport CBA usually assesses the value of travel time based on traffic participants' willingness to pay for time (Axhausen et al., 2015; Center for Transport Analytics, 2017; Korzhenevych et al., 2014; Litman and Doherty, 2011).

4.10. Congestion

Congestion is the time loss imposed on other travelers because of simultaneous use of the road network, including travel time, operating cost, fuel cost, reliability cost (arrival time), pollution, collisions, noise, as well as driver stress and reductions in subjective wellbeing (Litman and Doherty, 2011). Travel time cost is considered a private cost. As some cost aspects are already considered in other cost calculations (see previous sections), 'congestion' only includes the time cost of driving an additional km in a congestion situation compared to a situation of free traffic flow.

4.11. Health Benefits

Transport-related health effects can be external or private, and health enabling or damaging (Litman and Doherty, 2011). For example, savings to the healthcare system as a result of active transportation represent a benefit to society. Cycling is known to enable health, including a reduced risk of cardiovascular disease, various cancer types, type-2 diabetes or depression (Genter et al., 2008; Litman and Doherty, 2011; Holm et al., 2012). Cycling can also reduce obesity levels (Basset et al., 2008). Cycling benefits include reduced costs for medical treatments, fewer days of sick leave (external benefits), though there also exist private benefits (better fitness, longer life expectancy) (Genter et al., 2008; NZ Transport Agency, 2016). In Denmark, where these benefits have been quantified, cycling is estimated to prevent about 3000 deaths, > 3000 cases of type 2 diabetes, almost 6000 cases of cardiovascular disease as well as in excess of 2000 cases of cancer per year (Andersen et al., 2000; Blond et al., 2016; Rasmussen et al., 2016). In contrast, health damaging aspects associated with cars include traffic collisions, air and noise pollution, stress and anxiety, or constraints on active transport (traffic risks imposed on cyclists or other active transportation). These health damaging aspects of the car are covered in other sections (Sections 4.2, 4.3, 4.12).

4.12. Accidents (Collisions)

Collision cost comprises public services (police, rescue and treatment), the loss of net productivity, premature deaths, medical expenses, as well as the cost of pain, grief and suffering. Collisions include damages and risks to the individual, and uncompensated damages and risks imposed on society (Litman and Doherty, 2011). The external cost thus only includes damages uncovered by private insurances (Korzheneych et al., 2014). EPA (2017) suggests that mortality risks are the most significant cost factor that can be calculated on the basis of willingness to pay for reductions in the risk of dying, i.e., the value of a

Table 2
The external and private cost of car, bicycle and walking.

Parameter	Car, € ₂₀₁₇ /pkm		Bicycle, € ₂₀₁₇ /pkm		Walking, € ₂₀₁₇ /pkm	
	External	Private	External	Private	External	Private
1. Climate change						
Climate change	0.011	0	0	0	0	0
Subsidies	0.003	0	0	0	0	0
2. Air pollution						
Air pollution	0.007	0	0	0	0	0
3. Noise pollution						
Noise pollution	0.007	0	0	0	0	0
4. Soil and water quality						
Soil and water quality	0.005	0	< 0.001	0	< 0.001	0
5. Land use and infrastructure						
Infrastructure construction	0.030	0	0.002	0	0.002	0
Roadway land use	0.011	0	< 0.001	0	< 0.001	0
Parking land use	0.021	0.022	< 0.001	< 0.001	–	–
Ecosystem services	?	0	?	0	?	0
6. Traffic infrastructure maintenance						
Traffic infrastructure maintenance	0.004	0	< 0.001	0	< 0.001	0
7. Resource requirements						
Resource requirements	0.007	0	< 0.001	0	< 0.001	0
8. Vehicle operation						
Vehicle operation	0	0.250	0	0.047	0	0.041
9. Travel time						
Travel time	0	0.253	0	0.474	0	1.264
10. Congestion						
Congestion	0	0.355	0	< 0.001	0	< 0.001
Barrier effects	0	0.005	0	< 0.001	0	< 0.001
11. Health benefits						
Health benefits	0	0	–0.193	–0.134	–0.386	–0.268
Prolonged life	0	0	0.007	–0.320	0.014	–0.640
12. Accidents (collisions)						
Accidents	0.002	?	< 0.001	0.066	< 0.001	0.066
13. Perceived safety & discomfort						
Perceived safety & discomfort	?	?	–	0.014	–	0.036
14. Quality of life, branding and tourism						
Quality of life, branding and tourism	0	0	?	?	?	?
Total	0.108	0.885	–0.184	0.147	–0.370	0.499

statistical life. Apart from fatal accidents, there is also a considerable cost associated with injuries.

4.13. Perceived Safety & Discomfort

Perceived risks in traffic represent a cost for cyclists. This may include physical traffic risks, i.e. to become involved in an accident; annoyance, for instance with regard to traffic noise; as well as perceived health risks, such as exposure to pollutants. Exhaust fumes can also be perceived as a discomfort (Gössling et al., 2019). It has been highlighted that perceived traffic risks represent a cost to cyclists (COWI and City of Copenhagen, 2009), but this cost has never been quantified. Likewise, the cost of exhaust exposure smells has never been assessed. As outlined by Klæboe et al. (2000), smell is perceived as an annoyance that is interdependent with noise and other environmental pollutants, and its effects may be enhanced where smells are more strongly associated with health threats.

4.14. Quality of Life, Branding and Tourism

Quality of life is an inherently subjective concept. In transportation contexts, the concept has been linked to physical, mental, social, economic wellbeing (Lee and Sener, 2016), employment opportunities and social connectedness (Steg and Gifford, 2005). Preceding sections have captured some of these aspects, including risks of exposure to collisions, or better health. In this CBA, quality of life refers to the difference between a current life-situation in comparison to a potentially ideal life state (Gardner and Weinberg, 2013), for instance in terms of gains in mental wellbeing as a result of physical activity (Jia and Lubetkin,

2005; Lee and Sener, 2016; see also Hall et al., 2017; Saelens et al., 2003). More walkable or bikeable neighborhoods are also perceived more positively by tourists and have positive branding effects (COWI and City of Copenhagen, 2009).

5. Results & Discussion

Table 2 provides an overview of findings for the EU. Values represent approximations, confirming that the car represents a cost to society, at an average of €0.11/pkm (Table 2). This value is higher in countries with a higher GDP. The most important external cost factors are infrastructure construction, parking land provisions, roadway land use and climate change. The private cost of the car is eight times higher, at €0.85/pkm. This is largely owed to congestion and the value of travel time. Vehicle operation is also a significant cost factor.

Cycling and walking incur external benefits, at €0.18/pkm and €0.37/pkm, respectively. Benefits are largely associated with health. These health benefits are positive even in situations where cycling and walking take place under less favorable conditions, such as higher levels of air pollution (De Hartog et al., 2010). Better health also leads to a small external cost as a result of extended pension payment needs (prolonged lives).

The private cost of cycling is significantly lower than for driving, and arises mostly out of travel time, as vehicles are prioritized in traffic. Given their higher respiration rates (Panis et al., 2010), cyclists are specifically exposed to air pollutants from motorized transportation. Cyclists are known to engage in detours to avoid negative externalities of the car, at a considerable time cost (Gössling et al., 2019). This also applies to walking.

Extrapolated to the number of km driven (4.719 trillion pkm), cycled (0.134 trillion pkm) or walked (0.180 trillion pkm) in the EU, the external cost of automobility is about €500 billion per year, while cycling and walking represent benefits of €24 billion and €66 billion. In the future, these costs can be expected to change. The cost of health services may increase, for example. Other aspects can be expected to lose relevance, as motorized traffic becomes quieter and cleaner. Whether the overall cost of the transport system will increase or decrease will depend on transport governance. Current policies continue to favor the automobile (e.g. Hutton, 2013). As this paper suggests, the reason for this may be that the true cost of automobility is systematically underestimated (cf. EC, 2014a, b).

Results should have various implications for transport policy, as they indicate that the automotive system relies on significant subsidies. Active forms of transport, on the other hand, should be supported for health reasons (The Lancet, 2017). This is feasible specifically in cities, where the substitutability of transport modes is high. Policies supporting walking and cycling in cities will also be warranted from systemic development perspectives: There are widespread expectations for car numbers to increase, in a situation where transport systems face capacity limits in virtually all large cities (Dargay et al., 2007; EIA, 2017). EU cost calculations as presented in this paper suggest that to shift mobility from the car to the bicycle is worth about €0.30/pkm, and from the car to walking €0.48/pkm.

Despite its limitations, the importance of CBA in transport contexts can be expected to grow. As this paper argues, CBA needs to be comprehensive and comparative, specifically in contexts where substitutable transport modes compete for space or prioritization. Questions remain regarding the allocation of costs, specifically with regard to spillover externalities (e.g. Jansson, 1994). For example, as cars cause most accidents, it may be argued that the cost of traffic density (collisions, perceived risks) is attributable to cars. In other words, current CBA analyses accept that a considerable part of car-related externalities represents a private cost to active transport users.

6. Conclusions

This paper reviewed different transport CBA frameworks, concluding that these omit important cost parameters. As these represent significant negative externalities, a central conclusion is that transport investment projects in the European Union systematically underestimate the cost of automobility. To become more inclusive, CBA frameworks need to be expanded. Furthermore, in urban transport planning contexts where transport mode choices are often substitutable, CBA assessments should be comparative to adequately consider the implications of transport mode prioritization. Where CBA is used in non-comparative ways, and with a view to address growth in individual motorized transportation, it has a self-fulfilling nature, i.e. the conclusion will often be that adding transport infrastructure is meaningful. Fundamentally different insights may be gained from more comprehensive and comparative CBA frameworks. As this research indicates, automobility is heavily subsidized in the European Union, at an estimated €500 billion per year, while active transportation represents a benefit to society currently worth an annual €24 billion (cycling) and €66 billion (walking). Specifically in cities, the long-standing focus on automobility as the favored transport mode should consequently change.

Future research may seek to improve the database for various parameters to refine and validate cost estimates. This may also include a better distinction of cost distributions, for instance between different age or population groups. It is also warranted for comparative CBA to include public transport.

Appendix A. Supplementary Data

Supplementary data to this article can be found online at <https://>

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