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The lifetime cost of driving a car

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ABSTRACT

The car is one of the most expensive household consumer goods, yet there is a limited understanding of its private (internal) and social (external) cost per vehicle-km, year, or lifetime of driving. This paper provides an overview of 23 private and ten social cost items, and assesses these for three popular car models in Germany for the year 2020. Results confirm that motorists underestimate the full private costs of car ownership, while policy makers and planners underestimate social costs. For the typical German travel distance of 15,000 car kilometers per year, the total lifetime cost of car ownership (50 years) ranges between €599,082 for an Opel Corsa to €956,798 for a Mercedes GLC. The share of this cost born by society is 41% (€4674 per year) for the Opel Corsa, and 29% (€5273 per year) for the Mercedes GLC. Findings suggest that for low-income groups, private car ownership can represent a cost equal to housing, consuming a large share of disposable income. This creates complexities in perceptions of transport costs, the economic viability of alternative transport modes, or the justification of taxes.

1. Introduction

There is much evidence that the private automobile is one of the costliest items for many households, and imposes many economic, social and environmental costs on communities. For example, in the European Union's member states, transport expenditure is exceeded only by the cost of housing and features before food and non-alcoholic beverages (EC, 2020). Cars are expensive because of their high purchasing cost, depreciation, as well as the additional cost incurred by insurance, repairs, fuel purchases and residential parking. Cars also influence transport behaviour, because the high sunk cost of vehicle purchases make it more economical to then use this transport mode rather than public transport modes. Empirical studies suggest that car owners tend to significantly underestimating the full costs of car ownership. Andor et al. (2020) propose that car purchases would significantly decline were consumers aware of the 'true' cost of automobiles. In contrast, Moody et al. (2021) suggest that US residents would have to be paid very significant sums to give up privately owned cars. Better insight into the cost structures of automobility is thus called for, specifically as there is, apart from the private cost of car ownership, a social (or "external") cost of car ownership. This represents the cost of car use not covered by taxes and fees paid by vehicle users, for example including road and parking facility costs not paid directly by user fees, plus negative externalities such as air pollution, noise, or uncompensated crash damages (Gössling et al., 2019). The true scale of social costs is rarely considered, as assessments by transport planners only consider a limited number of cost items. Social costs, including market and non-market costs, thus represent significant subsidies forwarded to vehicle owners, with far-reaching implication for transport behaviour and traffic outcomes. These are defined in this paper as the external cost imposed on society.

Against this background, the purpose of the paper is to present a comprehensive cost assessment for privately owned cars in Germany. The evaluation details cost parameters and unit costs, both private and social, to approximate the actual cost of automobility. It considers different scales of analysis by determining the cost per km, per year, and over a lifetime of car ownership. In particular this latter dimension has never been investigated. Figures are presented for three popular German car models and compared to income levels in different employment groups.

2. Theoretical background

Transportation has central relevance for societies, with evidence that a significant share of personal income is invested in travel, irrespective

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of culture or country (Schäfer and Victor, 2000). Income is thus considered the single most relevant explanatory variable of transport demand (Schäfer et al., 2009), also in the context of the car (Liddle, 2009). There are complexities, however, in regard to real versus perceived costs. This was investigated by Andor et al. (2020) in a study of German vehicle users ($n = 6233$), of whom 88% believed to know their monthly cost of car ownership and use. However, the total cost of owning a car was underestimated by half of the respondents, at €221 per month or 52% of the actual cost. Andor et al. (2020) conclude that knowledge of the "true" cost of driving a car would reduce car ownership by an estimated 37%. As car use and alternative transport choices are in an equilibrium (Mogridge et al., 1987), cost perceptions also shape transport mode preferences. Andor et al. (2020) investigate this interrelationship for public transport, finding that an accurate understanding of car cost increases willingness to pay for public transport by 9% to 22%. The study finds that while car owners have a good understanding of the cost of fuel, the most relevant operational cost, they undervalue fixed cost items including depreciation, repairs, tax and insurance.

Andor et al. (2020: 455) acknowledge that "critics might argue that cost is merely one of many factors that influence individuals' decisions to own a combustion-engine car […]." Indeed, the car is much more than a transport mode (Steg, 2005), and transport behavioral decisions are complex (Schwanen and Lucas, 2011) with vast differences in transport cultures between countries and within countries (Barter, 2011; Klinger et al., 2013; Scheiner et al., 2020). This explains why other studies find that motorists place a value on car ownership that exceeds its private cost: Moody et al. (2021) deduct a willingness to give up access to private cars at an average $11,197 for residents in four US metro areas, an amount exceeding the actual estimated private cost of vehicle ownership (at US$9000). It should be noted that findings in the Moody et al. (2021) study are based on an online stated preference survey in automobile-dependent communities.

More generally, the private cost of transportation is a solid indicator of transport demand and transport mode choice (Schäfer et al., 2009). This has various implications for this paper, as a large share of vehicle costs are fixed and sometimes subsidized as in the case of company cars. Once a household obtains a car, this is considered a sunk cost, with the implication that the cost of driving an additional distance is perceived as low (Arkes and Blumer, 1985; Krämer, 2017). Company car analyses illustrate these effects, with data for Germany suggesting that company cars are driven more (for private purposes) than privately-owned cars, over-representing larger car segments, and inducing additional car purchases per household (Metzler et al., 2019).

In addition, automobile travel imposes an external cost on society that has been a research focus for decades (e.g. Calthrop and Proost, 1998; Mayeres et al., 1996; Proost and Van Dender, 2008; including many reports, i.e., Becker et al., 2012; CE et al., 2011; EEA (European Environment Agency), 2007; NZTA, 2020; Swiss ARE, 2010; Vermeulen et al., 2004; VTPI (Victoria Transport Policy Institute), 2020). When households purchase a vehicle, they assume that governments will provide roads and traffic services, and that businesses will provide off-street parking facilities for their use. These infrastructure demands represent a major cost for federal governments, cities and communities that exceeds fees and taxes paid by vehicle owners (Gössling et al., 2019). Negative externalities of car use also include congestion delays to other vehicles, "barrier effect" delays to pedestrians and bicyclists, noise, air pollution, exhaust fumes, climate change, injuries, or health effects. For many of these, there are no markets, and even where these are politically established, they may not internalize adequate cost levels. Examples include the loss of life years caused by air pollutions or climate change, where the German government's carbon tax of €25 per ton is significantly lower than scientific cost assessments suggest (Ricke et al., 2018). In the absence of markets for negative externalities, vehicles incur a significant social cost, with estimates of €1600 per car and year in Germany (Becker et al., 2012) or €2000 in Switzerland (Bundesamt für Raumentwicklung, 2016). Notably, these assessments appear to be conservative, as they exclude some important but difficult-to-quantify cost items such as economic and environmental costs of vehicle, fuel and infrastructure production, and sprawl-related costs.

Car subsidies also have important social equity implications. For example, a large share of German households does not own cars: 19% of total households and 38% in large cities (Infas, 2018). In contrast, it is in particular low-income households that are most exposed to negative impacts such as noise or air pollution (Gössling, 2016). This means that households that drive less than average bear more costs than they impose, and tend to subsidize the transportation costs of households that drive more than average.

3. Methodology

3.1. Cost analysis

To assess private and social car costs, a list of parameters was developed on the basis of EC (2019); Gössling et al. (2019), and VTPI (Victoria Transport Policy Institute) (2020). This list includes a total of 23 (private, or internal) and 10 (social, or external) cost items, divided into five private cost categories (value depreciation, operating cost, fixed cost, repairs and maintenance, other cost) and three social cost categories (health, infrastructure, environment). All items are defined in the Supplement, for an overview see Table 1 (external cost parameters) and 3 (social and private costs). Private car costs are derived from German Allgemeiner Deutscher Automobil Club (ADAC), a road assistance and automobile lobby organization. Cost data is available for each car brand and model, including depreciation, repair and maintenance, operating costs and fixed costs (ADAC, 2021a). As ADAC serves the interests of car drivers, the data is assumed to represent an approximation of "true" costs; here the paper follows Andor et al. (2020), who also relied on this source. Yet, ADAC does not consider all private car costs, and a number of parameters have been added. These include the carbon tax recently introduced by the German government (at €25 per ton CO_2); the cost of driving licensure; parking facility costs (private or public); as well as the time cost of congestion (see Table 3). All data was compared and controlled to avoid double-counting.

Social costs include negative externalities arising out of vehicle ownership that are not covered by user fees and taxes, comprising aspects for which no markets exist, or where a cost is only partially internalized. Social vehicle costs are calculated based on data from the Handbook on the External Costs of Transport (EC, 2019) and data provided by the Victoria Transport Policy Institute Canada (VTPI (Victoria Transport Policy Institute), 2020). Social costs include, for example, infrastructure construction and maintenance costs not fully covered by user fees (van Ommeren et al., 2014). For example, many businesses provide vehicle parking facilities to employees and customers that are unpriced or priced below their full production costs (including land, construction and operating expenses), while providing no comparable benefit to those who travel by other modes. Social costs also include congestion delay and accident risk imposed on other road users, plus

Table 1
External cost parameters and unit cost values.

Social (external) costs	Parameters	€ / km
	Uncompensated crash damages	0.01
	Air pollution	0.10
Health	Noise	0.01
	Land use and infrastructure	0.08
	Traffic infrastructure maintenance	0.00
	Barrier effects	0.02
	Curbside parking	0.07
Infrastructure	Resource requirements	0.01
	Subsidies	0.00
Subsidies & Environment	Climate change	0.03

environmental costs, such as noise, air pollution plus uncompensated climate change damages (here the difference between the CO_2 tax charged by the federal government and the substantially higher cost determined by scientists; Ricke et al., 2018). Some costs can be difficult to quantify and monetize. However, in recent years new data sources and evaluation methods have facilitated comprehensive transportation cost analysis. Wherever possible, this study uses market prices to determine costs. For example, vehicle, fuel, road and parking facility costs are based on what consumers would typically pay for these goods. Where necessary, non-market costs such as congestion delay, human health and injury costs, and environmental damages, are valued using methods such as hedonic pricing, willingness-to-pay or willingness-to-accept (see Supplement). Many of these costs vary significantly depending on time, location and vehicle factors. For example, congestion, crash and pollution costs per vehicle-kilometer tend to increase with traffic and development density, vehicle size, and other factors. All values represent averages.

3.2. Choice of car models and unit costs

The cost of car ownership depends to a considerable degree on car brand and model, and dictates additional costs related to maintenance and repair, fuel or insurance. For this reason, it is meaningful to discuss vehicle choices in relation to income groups, rather than the average cost of a car in relation to an average income. To reflect on these complexities, the study provides calculations for three popular car models, based on statistics of new car registrations published by the German Federal Motor Transport Authority for 2020 (KBA, 2021b). Cars are divided into ten segments by KBA, with most new registrations representing full size SUVs (21%), compact cars (21%) and small cars (15%). From each of these categories, the most popular model was chosen, i.e. the Mercedes GLC (SUV), the VW Golf (compact cars), and the Opel Corsa (small cars) (KBA, 2021c).

Unit cost calculations are adjusted to the car models chosen. For example, emissions are proportional to fuel use, and derived from ADAC (2020). Some cost items are averaged, as they are unrelated to the car model (e.g. time loss due to congestion) (EC, 2019; VTPI (Victoria Transport Policy Institute), 2020; EC, 2019). Per km values are calculated based on 15,000 average annual kilometers per vehicle, based on Germany's ADAC (2020). In the real world, this demand will vary significantly (Metzler et al., 2019). Where data is available in foreign values and for years in the past (VTPI (Victoria Transport Policy Institute), 2020; Ricke et al., 2018), it is inflation-adjusted using the US Department of Labor's Inflation Calculator (www.bls.gov/data/inflation_calculator.htm) and converted to Euro using exchange rates derived from Oanda Currency Converter (www.oanda.com/eu-en). Where economic data is derived from Canadian, Danish and European Union studies, values are adjusted to Germany at 106%, 76% and 154% of the GDP of these countries (IMF, 2021; Eurostat, 2021) (see Supplement).

3.3. Income classes and annualized car costs

To compare the cost of a car to income, data was derived from the German Federal Statistical Office, which provides series of "earnings and labor costs" detailing the net income of different professional groups (Destatis, 2020a). This data does not consider affluent groups in society, for whom wealth is a better indicator than income. Credit Suisse (2020) suggests, for example, that the group with assets of between €100,000 and €1 million represents 37% of the German adult population, while only 3.2% of the adult population hold assets exceeding €1 million. To consider these high-income takers/asset holders, Table 2 includes the lifetime net income of different professions, based on Destatis (2020a). Two additional groups – the "millionaires" and the "wealthy" are included with high net earnings of €100,000 and €1,000,000 per year. These latter groups will also possess significant (inherited) wealth (DIW Berlin, 2016). For comparison with the lifetime car ownership cost, estimates consider a lifetime income also set at 50 years. In reality, Germans may drive cars for longer periods of time, as there is no age limit to driving. Income levels, on the other hand, are likely to change dynamically with careers, and they may be available during shorter periods than 50 years, as many high-income professions require significant time for study (e.g. medical doctors). Data needs to be interpreted in light of these simplifications. Calculations on lifetime income can be found in the Supplement.

Table 2
Lifetime net income.

Professional group	Net lifetime income/wealth (€)
Wealthy	52,654,323
Millionaires	5,265,432
Senior employee	2,726,707
Professional	1,857,901
Specialist	1,372,493
Semi-skilled worker	1,118,376
Unskilled worker	990,982

Source: Destatis (2020a), Credit Suisse (2020).

Income can be compared to the cost of car ownership for different periods of time. As indicated, car ownership in Germany may last for 50 years, and is used to illustrate the lifetime cost of driving a car (Supplement). To calculate this as a 2020 cost, the annualized car investment is averaged for 25 years into the past and future. Values are adjusted for inflation on the basis of observed inflation rates for 1996–2020, derived from the European Central Bank (ECB) Statistical Data Warehouse using the German Harmonized Index of Consumer Prices (HICP; ECB, 2021a). For the years 2021 and 2025, the extrapolation uses ECB's specific estimates of inflation rates of 1.5% (2021), 1.2% (2022) and 1.4% (2023), as well as 1.7% as the "longer term" inflation rate for 2024 and 2025 (ECB, 2021b; ECB, 2021c). The ECB's monetary policy is to achieve price stability for the Euro area "below, but close to, 2%". For this reason, 1.9% was set as the inflation rate for 2027 and until 2045 (ECB, 2021d). For the years 2024 and 2026, for which no forecasts are available, the rates are interpolated between 2025 and 2027 (1.5% in 2024 and 1.8% in 2026). It should be noted that the expectation is that Germany will see strong growth after the COVID-19 pandemic (BMF, 2021; EC, 2021), with the implication that the German inflation rate may be higher than that of the Euro area. Calculations of the lifetime cost of car driving need to be considered within this range of uncertainty. The calculation of the annual car ownership cost for the different time periods relies on the following formula, where annual values are adjusted for inflation:

Return calculations for every single year between 1996 and 2020:

$$PV = \frac{FV}{(1+\pi)}$$

Every single year between 2021 and 2045:

$$FV = PV \times (1+\pi)$$

With:

$$PV = Present\ value$$

$$FV = Future\ value$$

$$\pi = Inflation\ rate.$$

3.4. Limitations

Calculations are partially based on estimates, including extra- and interpolations, to determine averages. This does not consider the dynamic nature of some aspects, such as wages. The private cost of car use depends on the model and the number of kilometers driven, but also on driving style or locational context (e.g. urban/rural). Social costs may develop in dynamic ways as well; for instance, it is possible that CO_2 taxes will increase under a new government, which will imply a shift from social to private cost. Data should thus be considered as a snapshot of the German 2020 situation under the given assumptions.

4. Results

Results are presented for three car models per km, month, year, and over a lifetime of owning a car. To organize the complex calculations, private costs are presented first, followed by the comparison with social costs. Findings confirm that car ownership is costly, specifically if accumulated over a period of 50 years. Table 3 illustrates private cost categories and items for the three car models, showing that total private cost averages range between 45 and 86 Cents per vehicle-kilometer. This is 12% to 15% more than data by ADAC (ADAC, 2021a) suggests, mostly because the addition of costs related to parking and congestion. Actual car costs are thus also higher than reported by Andor et al. (2020). The underestimate is specifically large, in relative terms, for the Opel (15.3%), but highest in absolute terms for the Mercedes (8.9 Cent per km). Results need to be interpreted as averages, and can be influenced by location: For instance, an Opel Corsa owner may live in a (cheaper) rural area, where on-street parking is provided for free. In contrast, a Mercedes owner may live in a (more expensive) larger city, where the cost of residential parking is €50 (or higher) per month, equivalent to an additional cost of 4 Cent per km.

Further insights can be derived from the calculation of annual and lifetime ownership costs. This is shown in Table 4, which provides a comparison of the private ownership cost of the three models per km, year and during a lifetime. The Opel Corsa as one of the least costly car choices is half the cost of the Mercedes, with an annual cost of €6704 in comparison to the €12,899 for the Mercedes. Aggregated over a lifetime, the Opel Corsa is an investment of €352,974 and the Mercedes of €679,167.

Table 5 shows how the cost of car choice compares to the income in different employment groups. For any of the wealthy in the country, the car is hardly a cost. Even an expensive car model such as the Mercedes GLC will not consume more than 1% of their income. This increases to 13% for the group of the millionaires with lifetime earnings exceeding €5 million, and 25% for senior employees accumulating 2.7 million. The situation is the right opposite for the lowest income groups: As Table 5 illustrates, an unskilled worker would have to spend 69% of his lifetime

Table 3
Social and private cost of car ownership, three car models.

Private Costs	Parameters	Opel Corsa 1.2			VW Golf 1.0 TSI			Mercedes GLC 200 4MATIC 9G-TRONIC		
		€ / km	€/month	€/year	€ / km	€/month	€/year	€ / km	€/month	€/year
	Recommended retail price									
Vehicle depreciation	Used car value (after five years)	0.14	180.00	2160.00	0.21	259.00	3108.00	0.47	590.00	7080.00
	Model changes and depreciation									
	Transfer/registration fees									
	Fuel			1106.00			1118.00			1202.00
Operating costs	Engine oil	0.09	113.00		0.09	114.00		0.10	121.00	
	Car wash and care			250.00			250.00			250.00
	Emissions (5.3 l/100 km)	0.00	0.04	45.00	0.00	0.04	45.00	0.01	0.06	80.00
	Taxes			46.00			71.00			322.00
	Liability premium 50%			448.00			390.00			520.00
	Full insurance premium 50%. €500 retention			437.00			487.50			729.00
Fixed costs	Parking fees	0.08	94.00		0.08	96.00		0.12	148.00	
	Navigation									
	Inspections			200.00			200.00			200.00
	Other fees									
	Driving licensure	0.00	3.63	43.60	0.00	3.63	43.60	0.00	3.63	43.60
	Maintenance and repairs									
	Oil change									
Repairs and maintenance	Tire wear and small repairs	0.04	54.00	648.00	0.04	52.00	624.00	0.08	96.00	1152.00
	Other repairs									
	Tire replacement									
	Sum	0.36	444.67	5383.60	0.42	524.67	6337.10	0.77	958.70	11,578.60
	Residential parking	0.05	63.75	765.00	0.05	63.75	765.00	0.05	63.75	765.00
Other costs	Congestion costs	0.04	46.25	555.00	0.04	46.25	555.00	0.04	46.25	555.00
	Sum of private costs	0.45	554.67	6703.60	0.51	634.67	7657.10	0.86	1068.70	12,898.60

Social Cost	Parameters	Opel Corsa 1.2			VW Golf 1.0 TSI			Mercedes GLC 200 4MATIC 9G-TRONIC		
		€ / km	€/month	€/year	€ / km	€/month	€/year	€ / km	€/month	€/year
	Uncompensated crash damages	0.01	6.25	75.00	0.01	6.25	75.00	0.01	6.25	75.00
Health costs	Air pollution	0.10	124.67	1495.00	0.10	124.67	1495.00	0.10	124.67	1495.00
	Noise	0.01	10.00	120.00	0.01	10.00	120.00	0.01	10.00	120.00
	Land use and infrastructure	0.08	97.26	1167.17	0.08	104.03	1248.32	0.10	119.42	1433.00
	Traffic infrastructure maintenance	0.00	2.50	30.00	0.00	2.50	30.00	0.00	2.50	30.00
Infrastructure	Barrier effects	0.02	18.75	225.00	0.02	18.75	225.00	0.02	18.75	225.00
	Curbside parking	0.07	83.75	1005.00	0.07	83.75	1005.00	0.07	83.75	1005.00
	Resource requirements	0.01	7.50	90.00	0.01	7.50	90.00	0.01	7.50	90.00
	Subsidies	0.00	2.66	31.88	0.00	2.66	31.88	0.00	4.32	51.88
Subsidies & Environmental costs	Climate change	0.03	36.25	435.00	0.03	36.25	435.00	0.05	62.32	747.83
	Sum of social costs	0.31	389.59	4674.05	0.32	396.35	4755.19	0.35	439.48	5272.70
	Total sum of all categories	0.76	944.26	11,377.65	0.83	1031.02	12,412.29	1.21	1508.17	18,171.30

Source: (ADAC, 2021d; ADAC, 2021a; ADAC, 2021b; ADAC, 2021c); BMVI (2016); Bundesregierung (2021); Coady et al. (2017); De Bruyn and De Vries (2020); EC (2019); EEA (2010); EIA (2017), Inrix (2017), KBA (2015); Moving (2021); Ricke et al. (2018); Transport Analytics (2017); VDA (2017); VTPI (Victoria Transport Policy Institute) (2020).

Table 4
Comparative private cost for different car models.

Car model	Cost per km (€)	Cost per year (€)	Lifetime cost (€)
Opel Corsa	0.447	6704	352,974
Volkswagen Golf	0.511	7657	403,179
Mercedes GLC	0.860	12,899	679,167

Table 6
The effect of shared car-ownership, Opel Corsa.

Private lifetime car costs as percentage of an unskilled worker lifetime net income				
Net income (€)		shared	used car	halving mileage
		352,974 €	278,942 €	190,035 €
Single person household	990,982	36%	28%	19%
Two person household	1,981,964	18%	14%	10%

earnings to pay for a Mercedes GLC. However, even the smallest car choice, an Opel Corsa, still represents a significant investment for the lower income groups, consuming 36% of the lifetime income of an unskilled worker. An amount of €350,000 is also equivalent to or exceeding the cost of residential housing in most parts of Germany.

The lower income groups will engage in efforts to mitigate the cost of car ownership (Table 6). For example, on the household level, two income earners may combine their wages to afford a car. For two unskilled workers, this would half the cost of car ownership to about 18% of lifetime earnings (Opel Corsa), provided the overall distance driven does not increase. Another strategy is to buy a used car rather than a new car, bringing down the cost of car ownership to 28% on the single person household level, or 14% on the two-person household level. This estimate does however not consider an increase in the cost of repairs or the greater fuel requirements of an older, less efficient car. Yet another strategy is to drive less. For example, driving 7500 km/year rather than the German average of 15,000 km/year will reduce the variable cost of car ownership, and reduce the cost to 19% on the single-person household level. In all of these models, the private cost of car ownership nevertheless remains high and may explain the popularity of different financing models such as car leasing that would seem to make car ownership cheaper or more affordable. In reality, financing represents an additional cost, not a saving, as the overall total cost of car ownership increases as a result of rents and fees. The high cost of car ownership may also explain the comparably large share of households in large cities without cars (38%; Infas, 2018), indicating that where cars are not functionally necessary, a status symbol, or endorsed with affective functions (Steg, 2005), households may choose to not own vehicles. This also underlines that findings by Moody et al. (2021) may be specific for the USA, where public transport options are more limited in car-adopted urban designs, resulting in higher values placed on car ownership. Affordability is defined as households being able to spend less than 45% of their budgets on housing and transportation combined (CNT, 2020). For a typical household that spends 30% of their budget on housing, this leaves 15% for transportation. This analysis of private costs indicates that car ownership is not affordable to most lower-income households and many moderate-income households, unless they have very low housing expenses.

The calculation of social costs (Tables 1, 3) indicates that health, infrastructure and environmental externalities not covered by fees and taxes amount to 31 Cents (Opel Corsa) to 35 Cents (Mercedes GLC) per km. Fig. 1 illustrates the distribution of private in comparison to social costs on the basis of cost calculations for one year, 2020. Bars show private (bottom) and social (top) cost of car ownership for three different car models. The figure illustrates that the annual private cost ranges from €6704 for an Opel Corsa to €12,899 for a Mercedes GLC, and a corresponding social cost ranging from €4674 to €5273 per year. The social cost incurred by the Mercedes owner is thus €600 per year higher than the social cost of the Opel Corsa; this is mostly a result of additional pollution, including emissions of greenhouse gases, caused by larger cars. As a share of total costs, the subsidy paid by society in support of car ownership is 29% of the overall (social and private) cost of the Mercedes; 38% of the VW Golf; and 41% of the Opel Corsa.

Findings suggest that over a period of 50 years, a car such as the VW Golf is subsidized with €250,381 in social costs not covered by fees or taxes. These costs vary depending on vehicle size, weight, mass, volume and travel conditions. For example, a Fiat Panda 1.0 Hybrid GSE with its length of 3.65 m and width of 1.64 m requires 5.99 m^2 of space, while a Hummer H3 3.5 Comfort (4.74 m × 1.92 m) occupies 9.10 m^2 (ADAC, 2021d; ADAC, 2021e), and so requires far larger parking spaces. An Opel Corsa at about 1000 kg is half the weight of the Mercedes GLC, and a quarter of the Ford F450 Super Duty Crew Cab at 4.3 t. Weight influences injuries: The US Department of Transportation concluded, for instance, that reducing large vehicle weight will reduce fatality risks (NHTSA, 2016). Volume is also an issue in injury risks, as higher cars reduce visibility, specifically in cities. Last, motorization is related to emissions of air pollutants and greenhouse gases (Gössling and Metzler, 2017). The development of car fleets in regard to model specifics thus has direct repercussions for social costs.

Last, Table 7 shows the effect of internalizing the car's negative externalities, as an illustration of the true cost of car ownership. Were subsidies removed, the lifetime income invested in the car will increase to €599,082 for an Opel Corsa, €653,561 for a Volkswagen Golf, and €956,798 for a Mercedes GLC. As the Table illustrates, the overall cost of driving a more expensive new car then becomes equal to the lifetime net earnings of an unskilled worker.

Table 5
Lifetime earnings in comparison to private car ownership cost.

Lifetime car costs as percentage of net income/wealth				
Net income - 1-Person Household		Opel Corsa	VW Golf	Mercedes GLC
		352,974	403,179	679,167
Wealthy	**52,654,323 €**	1%	1%	1%
Millionaires	**5,265,432 €**	7%	8%	13%
Senior employee	**2,726,707 €**	13%	15%	25%
Outstanding specialist	**1,857,901 €**	19%	22%	37%
Specialist	**1,372,493 €**	26%	29%	49%
Semi-skilled worker	**1,118,376 €**	32%	36%	61%
Unskilled worker	**990,982 €**	36%	41%	69%

Source: Destatis (2020a), Credit Suisse (2020).

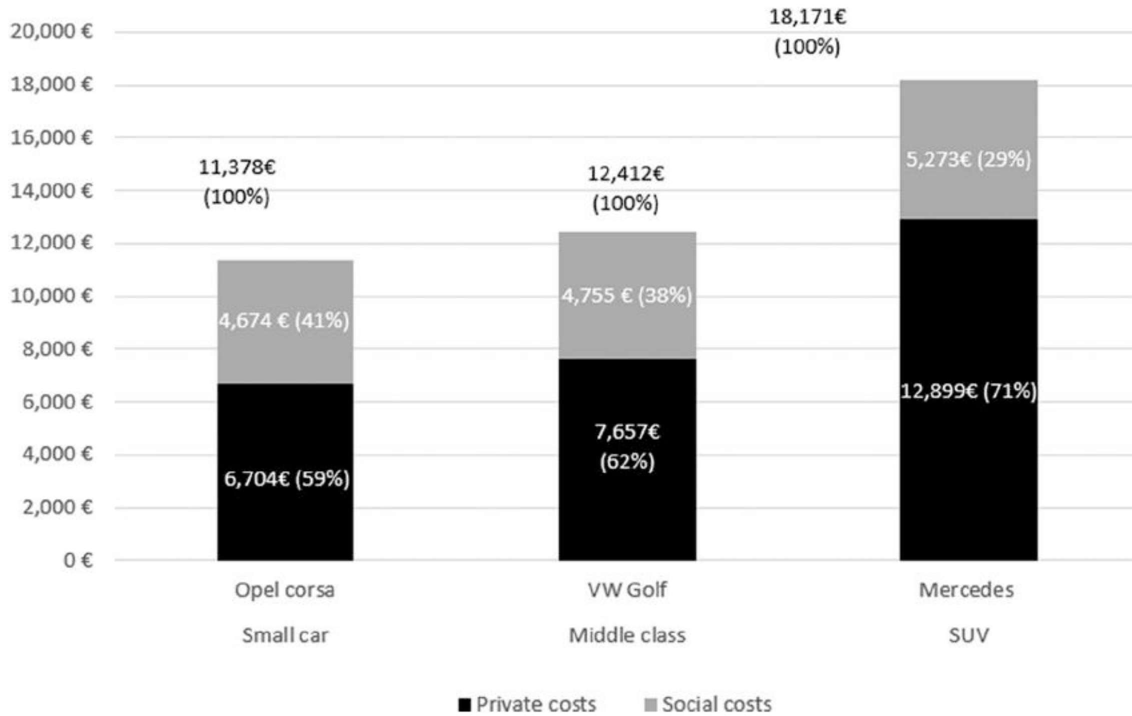

Fig. 1. Comparison of private and social cost of car ownership.

Table 7
Private and social cost of car ownership.

Lifetime car costs as percentage of net income/wealth				
Net income - 1-Person Household		**Opel Corsa**	**VW Golf**	**Mercedes GLC**
		599,082	653,561	956,798
Wealthy	52,654,323 €	1%	1%	2%
Millionaires	5,265,432 €	11%	12%	18%
Senior employee	2,726,707 €	22%	24%	35%
Outstanding specialist	1,857,901 €	32%	35%	51%
Specialist	1,372,493 €	44%	48%	70%
Semi-skilled worker	1,118,376 €	54%	58%	86%
Unskilled worker	990,982 €	60%	66%	97%

5. Discussion

5.1. Private costs: fixed and variable

The evaluation of vehicle costs shows that automobile organizations (ADAC, 2021a) and scientific studies (Andor et al., 2020) usually underestimate the full costs of automobile travel, because many costs are overlooked or undervalued. Conclusions that car ownership levels would decline were the scale of the investment in cars known to motorists need to be seen in light of this (Andor et al., 2020), though with a view to alternative transport availability, as well as symbolic and affective car functions. This study adds that car costs are particularly relevant for low-income groups, since car ownership is often unaffordable: For an unskilled worker, purchasing and operating a new VW Golf is equivalent to 41% of net income, a value that is comparable to the average housing cost for a single-person household in Germany (37%; Destatis, 2020b). As a result, car ownership is only affordable to lower-income households that have minimal housing costs, and many moderate-income household can only afford one car that is shared by multiple drivers, and are burdened if every adult must own a personal vehicle.

Results also have relevance for transport behaviour, as they confirm a large fixed cost of car ownership in the order of about 75–80% of total private car cost (Opel Corsa). High fixed costs make it rational for motorists to maximize their driving, as they are likely to only consider the variable travel cost. The spending of thousands of Euros annually on fixed costs, in combination with thousands of Euros in road and parking subsidies make it seem rational to buy a car, and, once the car is bought, not to consider other transport modes such as trains or busses, which appear costly in comparison. Because of this price structure, driving is cheaper than public transit travel for most trips. These effects have even greater relevance for company cars, which are perceived as a bonus, thus creating an understanding of representing a highly subsidized, and hence cheap, transport mode. Even though not investigated in this paper, electric cars, which have higher retail prices and are currently subsidized by government, are likely to have problematic outcomes for the transport system, as they are much cheaper to drive due to their significantly lower fuel cost. The current cost structure of automobility in Germany thus encourages car ownership, rewarding those driving more with greater subsidies, while forcing those who drive less than average to subsidize people who drive more than average.

5.2. Social costs and subsidies

As highlighted, automobile ownership and use impose large social costs. For the car models evaluated in this paper, this cost is equivalent to 29% to 41% of the total vehicle cost. Social costs are a subsidy to car owners that is either born by all residents in the country, including the share of households not owning cars, or, in the case of climate change, future generations. For larger car models, this subsidy is in the order of €5000 per year. In Germany, subsidies are forwarded to car drivers at national, regional ('Bundesland'), or community levels. As a request to the federal parliament showed, the German government subsidizes car manufacturers through investments, research & development grants, charging infrastructure for electric cars, or vehicle purchases (Deutscher Bundestag, 2017a). During the financial crisis in 2008, the federal government incentivized car purchases by paying €2500 to anyone scrapping an old car in order to buy a new one, with an overall subsidy amounting to €5 billion (BAFA (Bundesamt für Wirtschaft und Ausfuhrkontrolle), 2010). Since 2016, electric car purchases are subsidized with a bonus that was extended with an "innovation premium" in 2020, raising the overall subsidy to €9000 for electric car purchases with a net list price below €40,000 (Bundesregierung, 2020). Subsidies also include tax rebates on diesel fuel, or tax losses due to company benefits and commuter flat rates (Deutscher Bundestag, 2017b). Regional governments provide different forms of subsidies for companies located within jurisdictions, and there are additional subsidies at the community level, particularly costly parking facilities not financed by users. For example, the city of Berlin currently charges motorists €20.40 for a two-year parking pass (Service-Portal Berlin, 2021), an amount far below the total costs of providing an urban parking space, including land, construction and maintenance costs.

In light of this, it is important to consider policy reforms to more efficiently price automobile ownership and use in order to achieve various community goals including congestion reduction, infrastructure cost savings, reduced traffic congestion and barrier effects, increased traffic safety, pollution emission reductions, and increased fairness. Due to the diversity and magnitude of these external costs, a variety of policy reforms are needed to increase efficiency and social equity. These can start with removing direct subsidies such as company car benefits and subsidies for vehicle and fuel production, plus efficient pricing of roads, parking facilities, traffic congestion, barrier effects, traffic congestion, accident risk and pollution emissions (Calthrop et al., 2000; Eliasson et al., 2009; Levinson, 2010; Litman, 2021). Policies that improve and encourage use of resource-efficient travel modes (walking, bicycling, carsharing, public transport, and telework) are also justified on second-best grounds, and to correct for a century of policies and planning practices that favor automobile travel. There may also be a need for social marketing to help address the excessive social status of automobile travel that often biases transportation decisions.

5.3. Internalizing social costs - complexities

This analysis indicates that most automobile costs are either fixed (not directly affected by the amount that a vehicle is driven) or external (not paid directly by users), resulting in significant underpricing. Although costs total thousands of euros per vehicle-year, motorists are likely to only consider a few cents per kilometer in fuel expenses, plus road tolls and parking fees for some trips; they ignore other costs, such as road and parking subsidies, the congestion delays and crash risks they impose on road users, plus the pollution emissions and environmental damages caused by vehicle and fuel production. This is economically inefficient and inequitable, particularly for lower-income households. Various policy reforms that would convert fixed costs into variable costs, internalize external costs, and improve non-auto travel options are justified to correct these distortions, creating a more cost-effective and fair transportation system.

With more efficient pricing, including distance-based insurance and registration fees, cost-based road and parking facility fees, and higher fuel taxes that internalize pollution costs, motorists would drive significantly less than they do now (Litman, 2021; Zhang and Lu, 2012).

However, it is important to recognize the challenges that such reforms face. Most modern communities are, to various degrees, automobile dependent. Excepting cities, specifically in Europe, it is generally more comfortable, easier, faster and higher status to travel by car than to use other modes. For car owners, it is generally cheaper to drive than to use public transit. As a result, many citizens oppose efficient transportation pricing and other policies that limit automobile ownership and use, despite theoretical benefits.

For example, a rise in fuel taxes of €0.065 per liter for diesel and €0.029 for petrol as a climate change mitigation measure sparked violent protests in France (BBC, 2018). At first glance, this would seem unjustified. At 6.5 Cents per liter (diesel) and 2.9 Cents per liter (petrol), the tax translates into a cost increase of €0.0034/€0.0015 per km (Opel Corsa; diesel/petrol engine). While this doubles the private cost of emissions, the measure increases the cost of fuel by just 3% and the cost of car ownership by even less, 0.8%. However, comparison with a more expensive car shows that the fuel tax represents a greater burden for low-income groups. The Mercedes GLC uses 8.3 l of premium gasoline. The tax of 2.9 Cents will translate into a cost increase of €0.0024 per km. This represents a 50% increase in the cost of emissions, yet only a 2.5% increase in the cost of fuel, and a 0.3% increase in the cost of car ownership. The example illustrates why low-income takers have been affected disproportionally by the carbon tax (which remains true even if comparing only diesel cars). Proportional CO_2 taxes are thus unlikely to force owners of larger cars to reconsider their car choices, even though they pollute more. To be equitable, increases in driving costs should thus be disproportionally higher for more fuel-consuming cars, and implemented with improvements to other transport modes and more affordable housing in accessible locations.

Conditions are even worse in North America, where many people, including those with low incomes, can hardly imagine living car-free, and are willing to spend more than is cost effective to own a personal car for status sake (Moody et al., 2021). As a result, efforts to internalize automobile costs through fuel taxes, road tolls and parking fees are often opposed as being regressive and unfair to poor people, while the benefits to lower-income people, such as improved walking and bicycling conditions, more efficient public transit services, reduced pollution exposure, and reductions in other, more regressive taxes, are ignored (Manville and Goldman, 2018).

These examples illustrate that any shift of social costs to private costs will lead to a perceived significant additional burden for low-income earners. There is, for example, a great resistance in some population groups to vehicle taxes and fees, even if these are, as shown, rather small in relation to other costs. The underlying issue may be cost awareness. Motorists ignore their large fixed costs and compare fuel taxes, road tolls and parking fees with their current vehicle operating costs, so even modest increases seem large (Andor et al., 2020). Given the already high share of their budgets that low-income motorists spend on vehicles, increased fuel taxes, road tolls and parking fees may seem burdensome and unfair. This is a major challenge to internalizing social costs.

Better information concerning the cost of automobility may help creating greater awareness of the relevance of fixed versus variable costs, the overall amount of money placed on cars, as well as the alternatives. For example, a monthly public transport pass is on average €77.50 for adults, or €930 per year, in large cities in Germany (ADAC, 2019). Even if further transport is added, such as the cost of railway or taxi trips, the cost of a car exceeds the cost of alternative transportation by at least a factor four. Active transportation, such as urban cycling, can further reduce the cost of non-car mobility, as some cities have started to work on commuter cycle tracks connecting suburban areas to city centers. Electric bicycles with speeds reaching 45 km/h make it feasible to cover even distances of 10 km, again at a cost that is far below automobility.

Findings in this paper suggest that car ownership may also be considered a form of economic lock-in that depletes a large share of the discretionary income of low-income groups. Related to this, the difference in commuting by car compared to cycling – where feasible – is measurable in years of prolonged life and better health for cyclists (Oja et al., 2011). Combined strategies to improve transport alternatives and to communicate active transport health benefits may reduce car attachment. That car ownership in many contexts does represent an option is confirmed by considerable differences in household car ownership levels, which are far lower in German large cities.

More comprehensive information on the full costs of automobile travel can be helpful in several ways. First, they can help decision-makers better understand and evaluate policy and planning decisions. For example, many cities mandate that property owners provide an abundance of off-street parking in order to make driving more convenient. Such policies are generally evaluated based only on the parking facility costs compared with the benefits to motorists. However, by subsidizing automobile ownership and use, these parking managements increase automobile travel and therefore traffic congestion, pedestrian delays, crashes and pollution emissions.

Second, they can help households better understand the full costs they will bear when purchasing an automobile. As previously noted, motorists frequently underestimate the full costs of owning and operating a car; they may recognize their car loan payments and fuel costs, but tend to overlook or underestimate insurance and registration fees, future repair costs, uninsured crash costs, traffic citations, and residential parking costs. It can be useful to give consumers information on the full costs burdens that they will face if they purchase a car, and the large potential savings they can gain from reducing their car ownership.

Third, better information on external costs can contribute to discussions about the unfairness of policies that favor automobile travel over other modes, and therefore people who drive more than average over those who drive less than average. Fuel taxes, tolls and parking fees are often described as "punitive," as if motorists are being arbitrarily harmed – it can be useful to point out that operating an automobile harms other people, and ultimately everybody in a community, so everybody can benefit from pricing reforms that internalize and reduce external costs, particularly if a portion of revenues are used to improve resource-efficient alternatives.

Finally, results have implications in regard to some peculiarities of the German car system. Company car rules have already been discussed. The political treatment of very old cars (30-year+) as "oldtimers" is another issue. These very old cars receive tax rebates, and can be driven in cities without having to comply with clean air legislation. The number of oldtimers in Germany has risen continuously, to almost 1 million in 2021, as has the average fleet age which is now 9.8 years (KBA, 2021a). A larger fleet of older cars increases air pollution levels and contributes more to climate change. This illustrates how current German legislation creates social costs because i) there exist no markets (climate change, air pollution, exhaust fumes), ii) there are preferential treatments (oldtimers, company cars), and iii) other subsidies (residential parking permits, free on-street parking). Even though all cars incur social costs, these are greater for specific models, such as the rapidly growing segment of SUVs, and multiply where households own several cars.

Overall, economically and socially justified transport policies may thus focus on improving affordable and resource-efficient transport alternatives and the communication of the economic and health benefits of car-free living. This will contribute to social norm change and growing acceptance of transport system changes.

6. Conclusions

This paper assembles various data to estimate the full costs of owning and operating typical cars in Germany. It confirms that car ownership is a very costly, and higher than commonly-used estimates such as those by the ADAC, the German road assistance organization. These costs are particularly burdensome to low-income motorists who must invest a large share of their net income to own and operate a private vehicle. This has many implications for households, policy makers and practitioners.

To be efficient and fair, a transportation system must reflect certain principles including consumer sovereignty (the system offers users diverse travel options, so users can choose the combination that best serves their demands) and cost-based pricing (users pay directly for the costs they impose unless a subsidy is specifically justified). This analysis indicates that the German transportation system, and the transportation systems in most other countries, are inefficient and unfair; they favor expensive modes over cheaper modes, and impose large external costs.

This analysis indicates that most lower-income and many moderate-income households are harmed overall by policies that favor automobile travel over more affordable and resource-efficient modes. Such policies force many households to own more vehicles than they can afford, and imposes large external costs, particularly on people who rely on walking, bicycling and public transit. Because vehicle value and mileage tends to increase with income, automobile subsidies tend to be regressive. Company car benefits, low fuel taxes, road and parking subsidies, and electric vehicle subsidies primarily benefit wealthy motorists. As a result, people who drive less than average essentially subsidize the automobile travel of others who drive more than average, by subsidizing their road and parking facility costs, and bearing congestion delays, crash risk and pollution damages.

Declaration of Competing Interest

The authors declare not to have competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2021.107335.

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