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Electric bikes get things rolling
The environmental impact of pedelecs and their potential

For our Environment

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Synopsis / Abstract

Riding a pedelec is like riding a bike with the wind at your back – one can take longer journeys than on a conventional bike, without arriving drenched in sweat. Some 1.6 million electric bikes are currently in use on German roads. With a 95% market share, pedelecs – bikes assisted by an electric motor – constitute the majority of electric vehicles in Germany. Cycling is trendy, and increased use of pedelecs can help support the German federal government in achieving its aim of increasing the cycling rate from its current level of 10% to 15%. Electric bikes offer a diverse range of advantages and possible uses: they make it easier for users to travel longer distances, allow them to transport larger loads and to more easily overcome natural obstacles, such as inclines and headwinds. Furthermore, pedelecs are an alternative to company cars and an ideal transport option for recreational activities and bike tours. The faster speeds that they sometimes attain in comparison to conventional bikes and the greater demands with regard to secure parking require investment in infrastructure.

Common questions regarding pedelecs involve their potential for sustainable mobility, and, above all, their environmental impacts. This paper provides answers to these queries. A pedelec puts more stress on the environment than a conventional bicycle without an electric motor, but the relatively low environmental impact level of pedelecs is certainly offset when pedelecs are used in lieu of cars for trips.

The amount of energy a pedelec requires for a 10 km trip is roughly equal to the energy needed to bring 0.7 litres of room-temperature water to a boil. Given Germany's current energy mix, generating electricity continues to emit pollutants; however, the proportion of pollutants resulting from generating electricity for pedelecs is only a fraction of that caused by a combustion engine used to travel the same distance. The production and disposal of lithium-ion batteries – currently the most common battery type on pedelecs – burdens the environment with 22-30 kg CO_2e. When that is contrasted with the 21.5 kg CO_2e saved per 100 km not driven in a car, after only 100 kilometres of travel on a pedelec the battery's greenhouse gas emissions have been balanced out. Sensible recycling of rechargeable batteries and of the bikes themselves further conserves resources.

As part of an integrated transport planning scheme, pedelecs are an important component of sustainable mobility in cities, but also, most notably, in rural areas. From an environmental perspective, this type of electric vehicle should be embraced, actively promoted and encouraged in order to make pedelecs appealing to more user groups as an attractive, inexpensive and environmentally sound form of transport that constitutes an alternative to private motorized transport.

Definition of terms

The terms pedelec, electric bike and e-bike are often used synonymously, yet also commonly used to mean different things. As such, we have defined these terms below as we construe them to roughly explain the differences.

Pedelecs are electric bikes that are propelled with physical strength; additionally, up to a speed of 25 km/h, propulsion is assisted by an electric motor with a maximum power output of 250 W. Pedelecs differ very little from conventional bicycles in how they are operated.

E-bikes are bicycles with electric motors that can be ridden without pedalling, i.e. entirely electrically powered.

Electric bicycles is the general term for power-assisted bicycles, i.e. for pedelecs and e-bikes.

1. Status Quo

Mobility plays a major role in the society we live in. Preserving it for future generations – particularly considering the increasing scarcity of resources, and environmental protection and conservation issues – presents a great challenge. Increased cycle traffic can provide a good solution to this challenge.

According to the survey Mobility in Germany 2008 (MiD 2008)[1], bicycle traffic accounted for a 10% share of all trips; altogether, sustainable modes of transport (public transport, pedestrian and bicycle traffic) held a 42% share. The growth of motorized private transport has diminished since the 2002 survey, while sustainable modes of transport have gained relevance.[2]

The German federal government is committed to sustainability, which itself serves as an engine for social and political progress.[3] The federal government has formulated specific tasks and targets in its national strategy for sustainable development "Perspectives for Germany". The main sphere of action is climate and energy (a 50% reduction in global greenhouse gas emissions by 2050 compared to 1990). Germany aims to achieve a 40% reduction in its own greenhouse gas emissions compared to 1990 by 2020, and an 85-95% reduction by 2050 in comparison to 1990. However, a look at CO_2 emissions from all sectors since 1990 shows that only the transport sector had no reduction in emissions; in fact, they rose. Technical developments to reduce CO_2 were offset by a heavy growth in traffic (kilometres travelled by car) in recent years.[4]

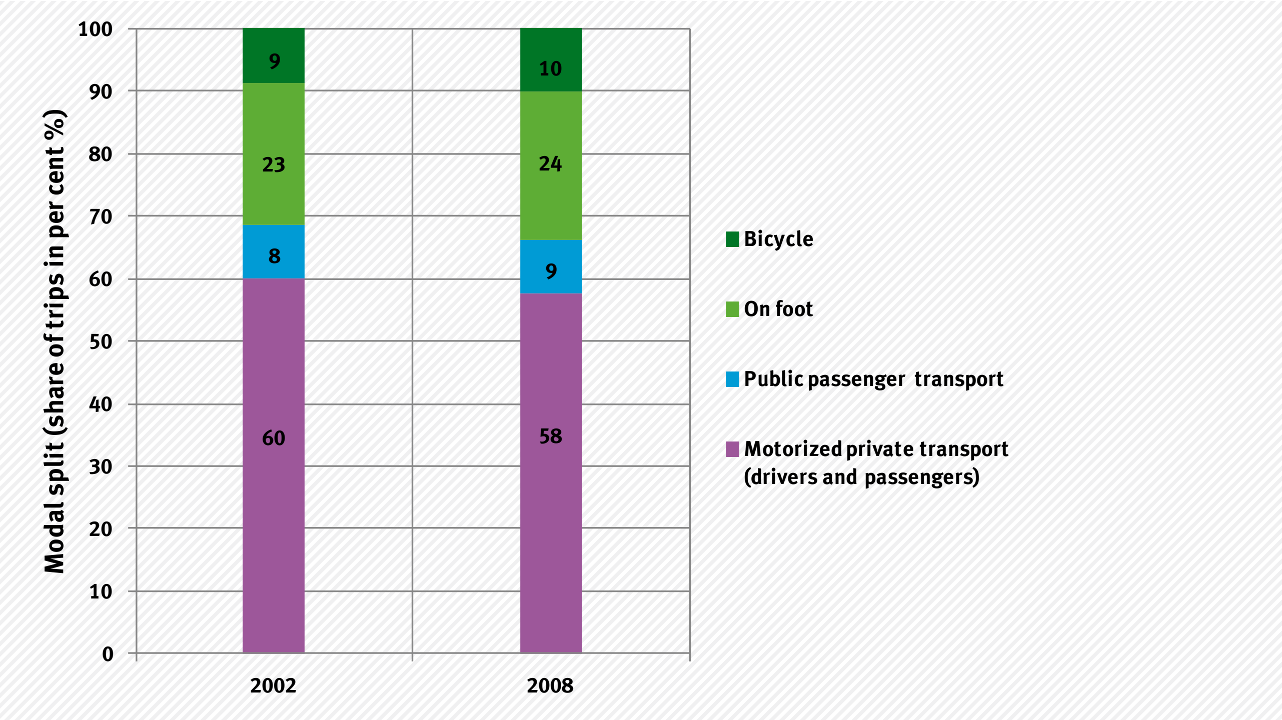
Motorized private transport constitutes roughly 80% of the total kilometres travelled for passenger transport. This leads to correspondingly high energy consumption, emissions of CO_2 and other air pollutants per kilometre travelled. Walking and cycling are environmentally friendly modes of transport that cause almost no harmful emissions.

A Dresden University of Technology (TUD) study commissioned by the German Federal Environment Agency (UBA)[5] examined the question of whether cycling can contribute to a reduction in greenhouse gas emissions in Germany. It came to the conclusion that intelligent and environmentally sustainable transport with integrated solutions is necessary for the future: employment of low or zero-emission vehicles, cycling short trips, generally opting for shorter trips to closer destinations and improving conditions for the increased use of sustainable modes of transport (walking, cycling, public transport, car sharing, bicycle sharing schemes, etc.). Various measure-related scenarios in the study calculated a potential for CO_2 reduction of between 10 and 30% in passenger traffic through an increase in cycling traffic.[6,7,8]

The aim of the federal government's National Cycling Plan 2020 (NRVP 2020)[9] is to increase the cycling rate for all trips to 15% until 2020. According to the survey MiD 2008, more than 75% of all trips are 10 km or less. The federal government sees electric bikes as having exceptional potential to increase the cycling rate for trips in that distance range.[10]

Fig. 1

Comparison of modal split in 2002 and 2008 (share of trips in %)



Source: Graph based on MiD 2008 (report on findings)

Electric bikes: facts and figures

In contrast to electric cars, growing demand has been observed in the bicycle sector in recent years. While the automobile industry continues to invest considerable sums in the development of electrically powered vehicles (registered vehicles in Germany in 2013: 7,114 electric cars and 64,994 hybrid vehicles)[11,12], electrically powered bicycles have firmly established themselves on German roads, with roughly 1.6 million such vehicles in use. The market for electric bikes has a distinct focal point: bikes with electric motors that assist riders; they are commonly called pedelecs, which is a portmanteau created from "pedal electric cycle". Insurance is not required for such bikes, and they can be ridden without a driving licence or moped certificate. They are legally classified as bicycles and can be ridden on cycle paths; riders are not required to wear helmets and pedelecs can also be taken on public transport. Pedelecs constitute a 95% market share of all of the electrically powered bicycles sold in Germany.[13] The remaining 5% are electric bicycles (e-bikes) that must be licensed and registered, have a greater power output range and can be propelled without pedalling.

The German Two-Wheeler Industry Association (ZIV)[14] estimates that electric bikes can make up a 15% share of all bicycles in the medium term; that would be 10.65 million e-bikes. According to ZIV statistics, about 70,000 e-bikes were sold in 2007. By 2013 that figure had risen to 410,000 bikes (cf. Fig. 2).[15] More than one in ten new bikes sold in Germany in 2013 was an e-bike. The retail market currently offers over 1,500 different models and types of e-bikes from over 70 bike manufacturers.[16]

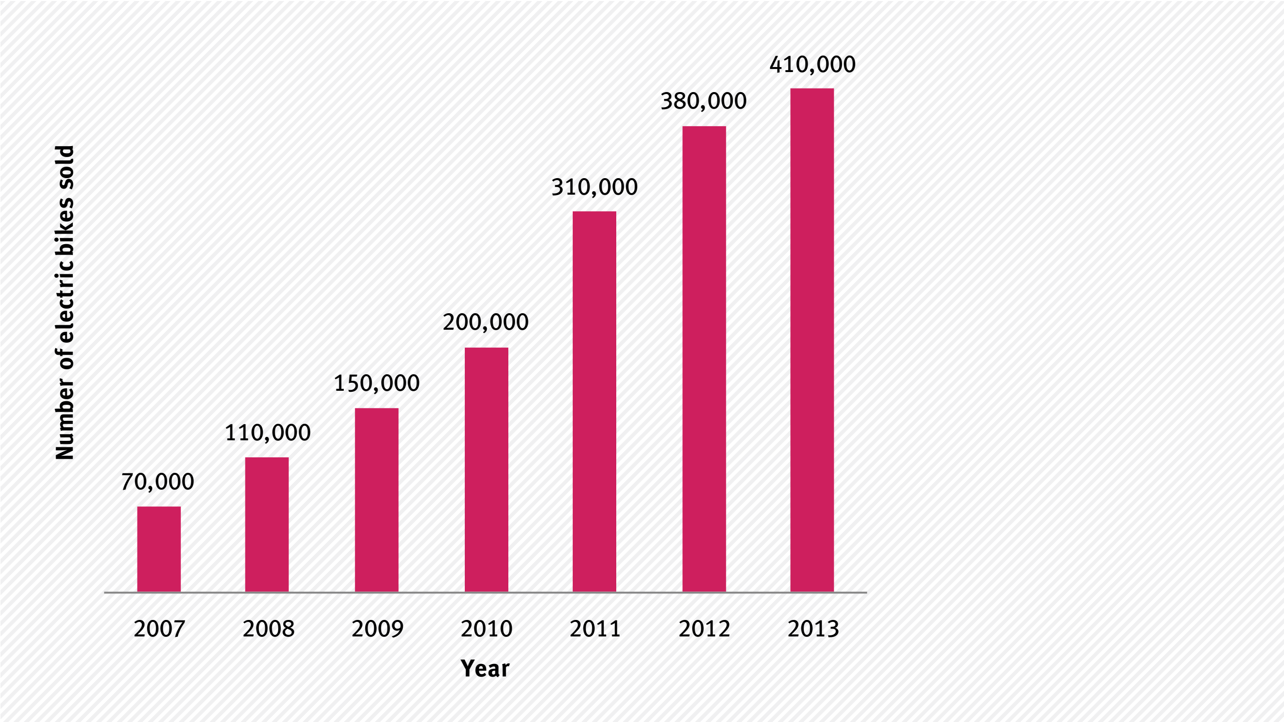
According to a representative survey, 90% of people are familiar with e-bikes and pedelecs.[18] Twelve per cent of Germans have already at least test ridden one of these new types of bikes, 47 per cent are interested in an electrically assisted bike, and 27% of Germans would be more likely to buy a bike with an electric motor than a conventional bike. People over 50 are especially likely to consider buying this new type of bicycle. In recent years, the popularity of and familiarity with electric bikes have grown.[19] Pedelecs are priced in the range of high-end bikes, which has had a positive effect on sales volume in the bicycle retail sector, despite a slight drop in the number of bicycles sold.[20]

The Research Institute for Regional and Urban Development (ILS)[21] in Dortmund conducted an online survey on electric bikes in 2012.[22] Over 2,000 people were questioned; one quarter of them owned a pedelec. The study showed that those surveyed had a definite interest in the topic; roughly half of them had already tried an electric bike. All in all, nearly 70% could imagine purchasing a pedelec. Another interesting aspect of the findings is the distribution of pedelec ownership based on location and topography: pedelecs enjoy a particularly high degree of popularity in more rural and/or hillier areas.

Research on the topic of electric bikes, pedelecs and e-bikes in Germany is only in the initial stages. Due to this fact, this background paper takes a special look at findings from neighbouring European countries.

Fig. 2

Number of electric bikes sold in Germany annually



Source: ZIV, own depiction[17]

2. Possible applications and potential benefits of pedelecs

2.1 Pedelecs – possible applications

Electric bikes can, in part, replace passenger cars. Like bicycles, they are a sustainable mode of transport. They offer all the application possibilities of conventional bikes, and more. Hardly anything changes for users with regard to how they are operated.

Riding an electric bike produces hardly any emissions and, based on actual need, no or very little energy is used. Furthermore, it is a virtually noiseless, space-saving, health-promoting and low-cost means of transport. Pedelecs have still further environmental relevance due to their varied application possibilities and, by extension, due to the change in mobility behaviour associated therewith. Electric bikes offer a high degree of flexibility and increase the potential to replace car trips with electric bike trips. Electric bikes broaden the sphere of activity of bike travel, especially for trips of distances between 5 and 20 km and the transport of cargo/shopping and/or children.

A pedelec expands the usage possibilities of a bike, in these areas in particular:

1. **Pedelecs make it easier to travel longer distances**
2. **Pedelecs make it possible to transport greater loads**
3. **Pedelecs make it easier to overcome natural obstacles, such as inclines and headwinds**
4. **Pedelecs offer an alternative to company cars**
5. **Pedelecs are also ideal for recreational activities**

1. Pedelecs make it easier to travel long distances. People can travel significantly further with the same amount of physical exertion (e.g. for travelling to work, educational facilities, training centres, shops, etc.). They make cycling easier for people with lower physical fitness levels (e.g. elderly and physically impaired individuals).

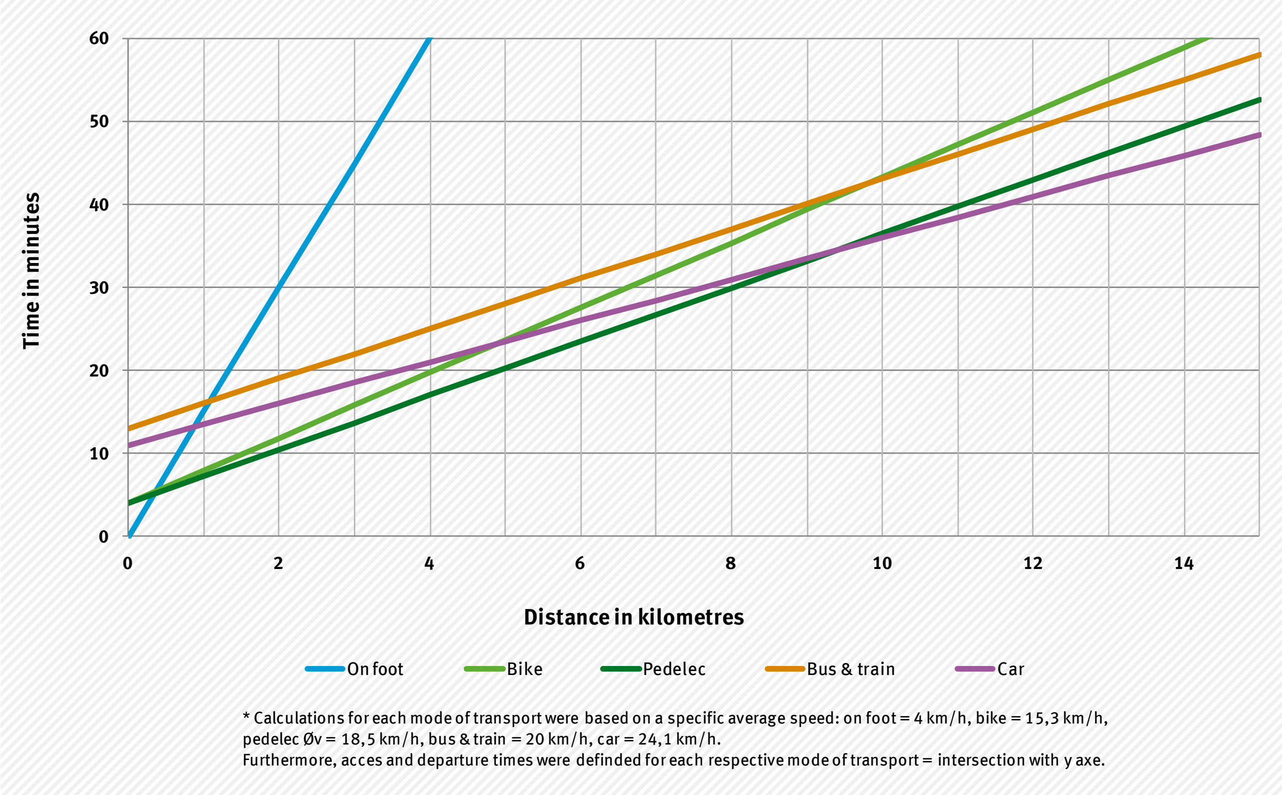
The graph comparing trip distances and travel times in Fig. 3 shows that a bike can be the fastest means of transport in a city for trips of up to 5 km.[23] Pedelecs even compete favourably with cars for trips of up to 10 km. Distances of up to 20 km are unproblematic on a pedelec – even at such a distance the time difference compared to a car is marginal. Furthermore, if one considers the time spent searching for car parking at one's destination and the higher costs (insurance, fuel, garage costs, etc.), it becomes evident that a pedelec is a true alternative to a car. The UBA sees a particularly large potential for commuters who travel distances of 5 to 20 km to work to shift those journeys from cars to pedelecs. After analysing currently existing studies, it is fair to assume that the distribution of the modal split will shift in favour of sustainable modes of transport (walking, bicycles/pedelecs, buses and trains) in the medium term, resulting in a correspondingly positive impact on the environment, the climate and human health through decreased emissions of CO_2, air pollutants and noise.

Studies of modal shift (a shift from motorized private transport for travel to other, sustainable modes of transport) with a specific focus on pedelecs are not currently available in Germany. However, studies from other countries do indicate positive effects on modal shift: a qualitative long-term study was conducted as part of the Austrian project Landrad (Rural Bike).[24] The use of pedelecs led to a shift from cars and conventional bicycles to pedelecs. The cycling rate increased to as much as 50%, and sustainable modes of transport were bolstered to a total of 34% among Landrad users. A study from the Netherlands identified great potential to increase bike travel among commuters – also ascertaining a cycling rate growth of 50%.[25] The cycling rate grows according to further studies as well, albeit less drastically[26] or at the expense of other sustainable modes of transport.[27]

Transport experts see a great potential for relief in large cities as a result of a shift from car trips (by commuters) to pedelec trips. The cities Copenhagen and Berlin have already formulated concepts to that end in order to motivate commuters to switch to pedelecs. The cycling rate in Copenhagen is currently 44%. A network of high speed cycling paths is meant to conduct the additional cyclists quickly and safely from residential areas into the city centre, and from railway stations to key destinations, such as university campuses.[28]

Fig. 3

Trip comparison: door-to-door in city traffic*



Source: UBA expert estimate, as of July 2014

A similar trend can be observed in the traffic mix in Berlin. While the share of motorized private transport in areas in the centre of the city comprises only 32% and sustainable modes of transport play a very prevalent role, commuter traffic from outside the city is a different story: for such commutes, the share of motorized private transport is 62%. Due to this, the Senate of Berlin is constructing a pedelec corridor for commuters within the framework of a pilot project for electromobility to conduct commuters from suburban areas south of the city into Berlin's inner city on comfortable cycle paths. At key destinations along the route they plan to create secure bike parking and offer pedelecs for hire.[29]

Half of all car trips are less than 5 km. This indicates a vast potential for a shift from cars to bikes. No conclusive scientific findings on just how great the potential of pedelecs in Germany is are available as yet. Existing studies from Austria, Switzerland and the Netherlands have resulted in values ranging from very low percentages up to 50%. However, these results are not sufficiently reliable or representative due to the research methods used (too few interviewees, very short survey periods). With the project Pedelection,[30] the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)[31] has initiated the first broader analysis of pedelec usage in Germany; the results have yet to be presented.

Pilot schemes with pedelecs in the region Haaglanden, Netherlands

In 2011, the region of Haaglanden, which is the metropolitan area surrounding The Hague, published a representative study on pedelec use. It was estimated that the number of trips made by bike could be increased by up to 5% while the number of trips travelled by car could sink by up to 1.5%. The region hopes to further increase the cycling rate by constructing a high-speed cycling path. As part of the study Elektrische fiets in Haaglanden, Dutch traffic planners analysed pilot projects in which participants were given the opportunity to test electric bikes for a temporary trial period. The average distance of a trip to work was around 12 km; the majority of the test subjects normally commuted by car. After the trial, roughly a quarter of the participants indicated they were planning to switch to an electric bike.[32]

Austria: Representative study and analysis of pedelecs for women
Around 50 to 60% of the population can potentially purchase and use a pedelec, independent of age and respective intended purpose of use. This conclusion was drawn from the 2010/2011 Austrian study FEMEL-BIKE, which comprised 4,600 interviews.[33] It also concluded that electric bikes are equally appealing to women and men. A further 1,000 women were surveyed for the study. To a certain extent, they have different demands when it comes to pedelecs. For women, a bike's suitability for daily use and roadworthiness (lights, etc.), its weight, battery weight and ease of operation are of primary importance.

Long-term profile of electric bike buyers in Basel
Electric bike buyers differ from average citizens in Basel: as a general rule, they have higher incomes, are more educated, are largely employed and are more likely to have driving licences, yet less likely to own their own cars. They also more frequently use car sharing services and buy monthly passes for local public transport less often. The study did not ascertain differences with regard to the age or gender of pedelec buyers. These conclusions were derived from a long-term study profiling electric bike buyers in Basel.[34]

Emission savings through switching trips from cars to pedelecs (modal shift)

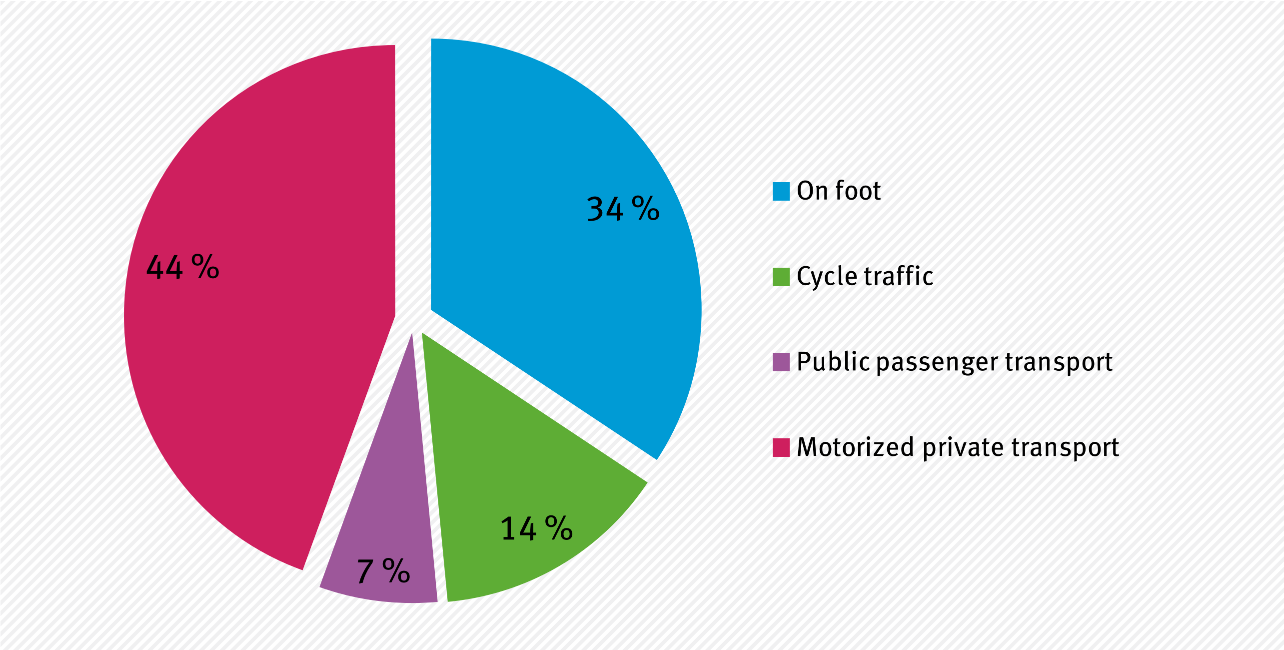
The DUT study Potenziale des Radverkehrs für den Klimaschutz (Potential of Cycling to Reduce Emissions in Road Transport),[35] which was commissioned by the UBA, assumes that a significant share of car trips that are within a feasible cycling distance could be shifted to bikes. Subsequently, the UBA estimates that one out of two trips of 10 km or less could be shifted to a bike (Fig. 4 and Fig. 5). A Federal Highway Research Institute (BASt)[36] study also sees an enormous potential for a shift in trips from motorized private transport to bikes, and especially for the deployment of pedelecs in areas with varied topography.[37]

The following calculation also accounts for pedelecs. According to Fig. 3 (trip comparison) a pedelec is the fastest mode of transport in city traffic – it even shows that trip distances of up to 20 km are unproblematic with a pedelec.

According to the MiD study, the respective share of trips up to 10 km[38] can be broken down as follows: 34% on foot, 14% by bike, 44% with motorized private transport and 7% on public transport.

Fig. 4

Share of trips in per cent (%) for distances of up to 10 km

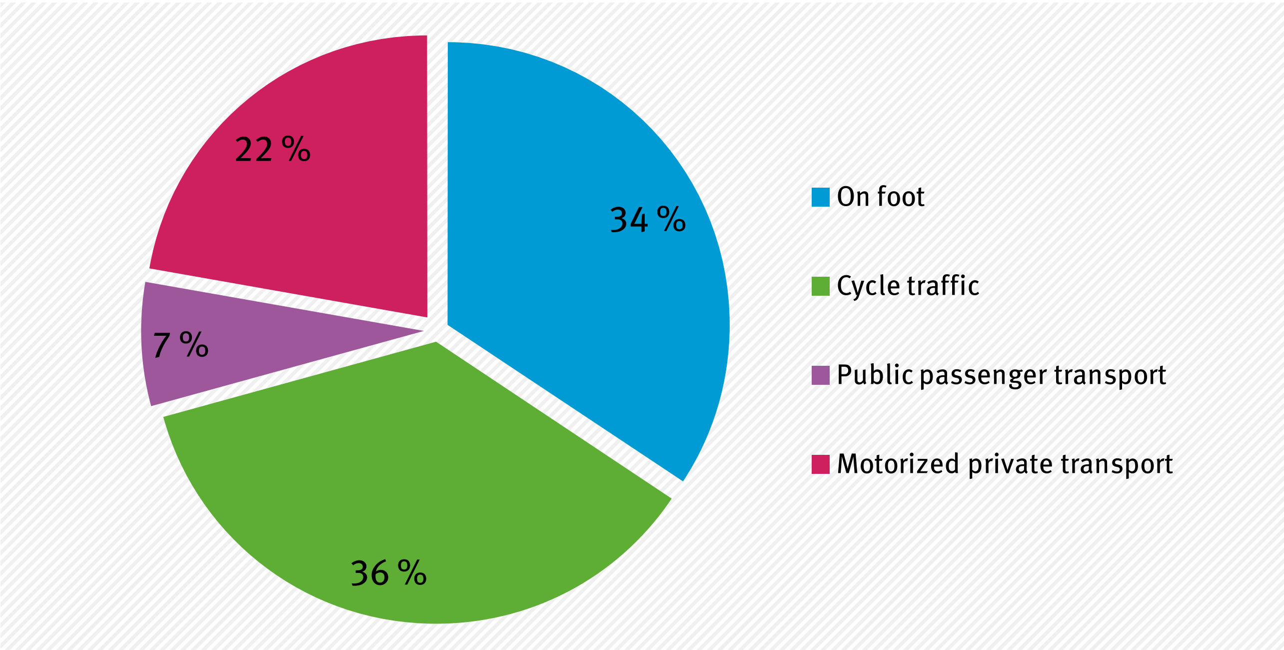


Source: MiD 2008

The assumption: 50% of car trips are instead travelled with bikes and/or pedelecs; this would increase the cycling rate from 14 to 36%. Still further potential rests in an additional shift for trips between 10 and 20 km.

Fig. 5

Share of trips in per cent (%) for distances of up to 10 km if people shift from cars to bikes and pedelecs to make trips



Source: UBA estimate

2. Furthermore, thanks to power assistance, these bikes can also be used **to transport larger loads and/or further passengers**, e.g. shopping and children (see also image on page 13).

In areas where urban business traffic is prevalent, cargo bikes and electric cargo cycles are especially well suited to replace compact vans, cars and motorcycles. The distribution of parcels, freight and merchandise can be conducted quickly, emission-free and at a lower cost using cargo cycles. These advantages over motorized transport pay dividends, particularly in tightly packed and busy inner cities.

The Deutsche Post AG has been relying on electric cargo bikes for postal delivery transport since the year 2000; it currently deploys a total of 6,000 electric bikes throughout Germany. This eases the transport of letter carrying bags, which can weigh up to 50 kg.[39]

Long postal delivery routes in regions with lower population densities can be completed more quickly with a pedelec than with a conventional bike, and in a significantly eco-friendlier manner than with a small delivery van. In 2012, a pizza delivery service that operates across Germany launched a trial that entailed switching to an entirely electric-powered fleet of delivery vehicles. As they generally transport solely small and light goods, they primarily deployed electric bikes and scooters.[40]

From 2012 to 2014 the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) is sponsoring a project titled "Ich ersetze ein Auto" ("I'm replacing a car"). The goal is to test how cargo cycles can replace car courier trips. The 40 electrically assisted cargo cycles deployed have a load capacity of over 100 kg. It is estimated that 85% of all courier trips by car can be substituted with electric cargo cycle trips and that, as a result, an appreciable emissions reduction will occur in comparison to delivery trips by car.[41]

The German Traffic Club (VCD)[42] has created an online information portal about the use of cargo cycles for commercial and freight traffic:[43] among other things, the project Lasten auf das Rad ("Cargo on bikes") highlights the potential and application possibilities of cargo cycles – primarily with electric assist – in commercial traffic.

With the project Pflegedienste machen mobil – Mit dem Elektrorad zur PatientIn (Nursing services get it rolling – visiting patients on electric bikes), Friends of the Earth Germany in Bremen (BUND Bremen e.V.) was able to show that it is possible for mobile nursing services to substitute trips previously made by car with electric bike trips within the inner-city. Nursing staff drive up to 50 km a day to visit patients.[44] In addition to the positive environmental effects, such as CO_2 reduction, lower space requirements, noise reduction and beneficial health impacts for users, the project also ascertained clear cost benefits for nursing companies. Companies can purchase an electric bike at no net cost by reducing the distance travelled by a single car just 600 km a month.[45]

Table 1

Cost comparison for the deployment of cars and pedelecs by mobile nursing services

	Car	Pedelec
Monthly financing rate	€143	€59
Insurance, liability insurance, taxes	€55	€11
Maintenance costs for the financing period (monthly)	€25	€25
Fuel costs per month (17,000 km per annum at €1.60/litre, or 25.3 cents/KWh of energy)	€170	€3.30
	€393	**€98.30**

Source: own depiction, adapted from Friends of the Earth, Bremen.[46]

3. Natural obstacles such as inclines and headwinds can be offset via electric assistance, making it appealing to cycle in locations previously considered inhospitable to cycling.

Campaign: Azubi-E-Bike ("Commuting with the trainee e-bike"), Baden-Württemberg
A project within the scope of the National Cycling Plan that runs until the end of 2014 is testing the use of electric bikes among a target group of trainees and university students. The Reutlingen Chamber of Industry and Commerce (IHK Reutlingen)[47] is implementing the project. A series of pedelec road shows in the region offers young adults the opportunity to test ride various electric bikes, and to borrow an e-bike for everyday use over a trial period of five to seven days. Participants are interviewed and the findings are evaluated with a special focus on the question of whether electric bikes could constitute a vital mode of transport for this target group in a region with varying altitudes.

The pedelec proved a suitable means to offset the drawbacks of a bike for taking routes with uphill climbs. The city of Tübingen recognized this and is taking a targeted approach to promoting the purchase of electric bikes by offering a €100 subsidy. The city's aim is to increase the cycling rate for all trips made to 50% by 2030.[48] The acquisition of pedelecs is also directly subsidized in Austria, Switzerland and France.

4. Companies can provide employees with **company pedelecs as an alternative to company cars**, and/or provide them with financial assistance to acquire them.

Due to the new "one-percent regulation", pedelecs are now treated just as company cars in regards to taxation. With the appropriate finance lease, companies can provide employees with a pedelec to travel to and from work and for private trips for a low monthly sum. The employee must pay a monthly tax on 1% of the list price of the non-cash benefit from his or her private use of a company bike. With such a measure, enterprises can reduce the environmental stress their employees cause through daily commutes and business trips within the scope of corporate mobility management. Moreover, they can use such schemes to motivate employees and bolster their health, which leads to fewer missed working days. A bevy of benefits for companies, the environment and employees.

5. The appeal of **electric bikes** extends beyond everyday commutes – their popularity is also growing **among recreational users.**

Bicycle hire companies, tourism regions[49] and bike tour companies have already been offering customers pedelecs for some years now. Such services make biking holidays attractive even to cyclists who are less keen on athletically challenging endeavours. Pedelecs have thus become an increasingly important component of cycling tourism, which has grown into a significant economic factor in Germany thanks to initiatives like the German Cycle Network (Radnetz Deutschland).

Six per cent of all cycle tourists now own an electric bike that they use recreationally and while on holiday (Trendscope study).[50]

2.2 Infrastructure requirements and parking

The question often arises as to whether existing segregated cycling facilities can accommodate electric bikes or whether new cycle paths and infrastructure must be created. Individual travel speeds increase with the use of electric bikes.[51] According to the National Cycling Plan, this does, in part, raise the demands on infrastructure and street planning and design: this primarily applies to the breadth of cycle paths, large curve radiuses, anti-skid surfaces, the avoidance of bollards, stairs and other obstacles. These are, however, general requirements of cycle paths for conventional bicycles; a fact supported by a study commissioned by the Ministry of Transport, Building and Regional Development in Mecklenburg-Vorpommern.[52] As such, the existing 2010 German Guidelines for Cycling Facilities (ERA 2010)[53] are in large part sufficient for this new type of vehicle.

However, it must be noted that the standards it recommends with regard to minimum widths, surface quality and uniformity of cycling facilities have not yet been achieved in many cities and municipalities. A great deal of action must be taken by respective local administrative authorities to actually achieve the defined quality standards.[54]

High-speed cycling paths should reduce travel times for cycle traffic and increase travelling speeds. The construction standards for such facilities far exceed those demanded by the ERA and are thus particularly suitable for electric bikes. They allow riders nearly junction-free routes to their destinations and provide ample space to overtake other bikes. In Germany there is consensus that high-speed cycling paths sensibly supplement existing cycle path networks in conurbations. The first segments have already been opened; furthermore, many on-going feasibility studies and planning measures indicate a growing implementation of high-speed cycling paths in Germany.[55]

The lack of safe, ground-level bike parking is commonly cited as a significant obstacle to the purchase and use of electric bikes. Sufficient secure parking facilities and secure charging stations, where required, are often lacking in both urban areas near blocks of flats and at destinations, such as workplaces, retail shops, recreational facilities and points of transfer to other modes of transport (bus stops, railway stations, carsharing stations). The UBA therefore recommends searching for solutions and pressing ahead to implement those solutions in order to eliminate barriers to pedelec use. Here, too, it is fundamentally true that no new systems must be developed; parking facilities for conventional bicycles are equally suitable for pedelecs (e.g. parking must allow riders to lock bikes up to the frame; there must be ample distance to the next bike rack; generally, bikes must be easily accessible). However in addition, it is important to create ground-level parking facilities for pedelecs due to their greater weights and to supply more parking facilities with surveillance.

Innovative bicycle parking systems do exist, and include, for example, large automated bicycle parking stations (where pedelecs and other electric bikes can be charged), cycle parks near bus stops and housing complexes, and even traditional bicycle parking facilities and bike lockers – they must only be expanded to cover greater areas, and, more specifically, adapted to suit demand. This applies primarily to parking at public transport stops, railways stations and other destinations.

Good technical solutions and examples of bicycle theft prevention measures already exists, yet must still be firmly established. In the Netherlands. a locking system was developed that allows stolen bikes to be traced.[56] Yet another model works in combination with a smart phone, also allowing owners to trace their bikes if they are stolen.[57] Both of these solutions are also suitable for conventional bikes. The Charge & Lock Cable was presented at the 2013 EUROBIKE trade show; it allows bikes to be secured and charged simultaneously.[58]

A hybrid bus service to link important destinations is provided within the framework of the pilot project INMOD – elektromobil auf dem Land (INMOD Electromobility in rural areas)[59] in Mecklenburg-Vorpommern. Pedelecs for hire provide connections to smaller localities. In this context, it is interesting to note that hire pedelecs can be parked securely in bike lockers with integrated charging stations (see also image on page 22).[60] Among other accolades, this project won the 2012 E-Bike Award.[61,62]

3. Environmental impact of pedelecs

3.1 Reduced energy consumption and CO_2 emissions

Due to their extended operating range, flexibility and manoeuvrability, pedelecs can most certainly compete with cars in city traffic (cf. Fig. 3, Chapter 2.1). Yet, even in sparsely populated areas where the prevalence of bikes has until now been below average, pedelecs can replace many trips once travelled by car.

Table 2 shows a comparison of the average energy consumption for pedelecs and cars. The Transport Emission Model, a model to calculate the greenhouse gas und air pollutant emissions of motorized traffic, was used to compute the figures for cars. The proportion of energy from upstream (indirect emissions), which accounts for the expenditure of energy to produce the fuel, or, as it were, the electric energy, has been included. For a pedelec, this is the energy required to generate the power needed to charge the battery. As such, the total carbon emissions of a car with a petrol engine are 39 times higher than those of a pedelec. The fuel costs per 100 km are 47 times higher for a car than for a pedelec. The amount of energy a pedelec requires for a 10 km trip is roughly equal to the energy needed to bring 0.7 litres of room-temperature water to a boil.

Overall, it can be concluded that switching from a car to an electrically assisted bike can lead to considerable emissions savings. Although, in comparison to bikes powered solely using physical strength, pedelec use does cause emissions and consume energy (charging the battery); however, on the whole, the positive effects of more people riding bikes instead of cars outweighs this apparent drawback.

Table 2

Comparison of average energy consumption and carbon emission based on vehicle type for cars and pedelecs, reference year 2011[63]

	Energy carrier	Energy source	Energy consumption per 100 km	CO_2 emission per 100 km in kg			Energy costs per 100 km
				Upstream (indirect emissions)	Direct emissions[64]	Total emissions	
Car (petrol engine)	petrol	crude oil	7.9 litres	3.24	18.84	22.08	€12.008[65]
Car (diesel engine)	diesel	crude oil	6.7 litres	1.72	17.43	19.14	€9.447[66]
Pedelec	electric energy	2011 German electricity mix	1 kWh[67]	0,564	0.00	0.564[68]	€0.253[69]

Source: Federal Environment Agency (UBA)

3.2 Reduced impact on air quality

Air pollutants such as nitrogen oxides (NO_X), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter (PM_{10}) can be hazardous to humans, animals and ecosystems when they exceed certain limits. They negatively affect plants, bodies of water, soils and buildings[70] and are responsible for ozone formation in the summer (especially NO_X). Information on effects and limits can be found on the UBA webpage at http://www.umweltbundesamt.de/themen/luft/luftschadstoffe.

EU stipulated clean air plans require municipalities to take measurements, which are conducted at a multitude of measuring stations in areas of urban traffic in Germany. The levels of health endangering air pollutants NO_X, SO_2 and PM_{10} currently exceed air quality limit values at many measuring stations.[71]

Table 3 shows a comparison of air pollutants (in this case only PM_{10} and NO_X) for specific vehicle types.

Table 3

Comparison of air pollutant emissions for specific vehicle types, reference year 2010[72]

	NO_x emission per 100 km in g			PM_{10} emission per 100 km in g		
	Upstream (indirect emissions)	Direct emissions	Total emissions	Upstream (indirect emissions)	Direct emissions	Total emissions
Car (petrol engine)	8.60	22.04	30.64	0.0	0.36	0.36
Car (diesel engine)	6.68	62.72	69.40	0.0	2.69	2.69
Pedelec	0.52	0.0	0.52	0.02	0.0	0.02

Source: Federal Environment Agency (UBA)

3.3 Reduced space consumption and noise

Frugal, ecologically and socially sound land use is a decisive and crucial element of sustainable settlement and transport policy. Natural areas should be protected and preserved.[73] In the year 2000, roughly 130 hectares of land were consumed per day. The German federal government is aiming to cut land consumption for settlement and transport infrastructure to a maximum of 30 hectares per day.[74] By the year 2010, land use had already been reduced to 77 hectares a day (or rather 87 hectares a day in the rolling four-year average). However, these cuts primarily arose in the areas of building spaces, open spaces and factory spaces and were less a result of a reduction in space dedicated to transport infrastructure, which has remained stable in recent years.[75]

In cities, capacity gains can be realized through the use and promotion of space-saving modes of transport, such as pedestrian traffic, bike traffic and local public transport. Simply converting or redesigning selected car parking places can make an area significantly more welcoming, and – beyond allowing the construction of bike parking – offers the chance to unseal and green surfaces or create areas for play and recreation.[76]

Pedelecs take up roughly the same amount of space as bikes and, due to their space efficiency, can meet citizens' demands for mobility, short journeys, welcoming spaces and peaceful residential environments.[77] Between six and ten bikes can be parked in one car parking space (cf. image below). Significant space savings can be achieved if the potential of pedelecs to replace one or several cars is exploited.

In general, the noise emissions from bikes are low; this is also true of pedelecs. Traffic noise can be reduced by shifting to quieter modes of transport. Bikes and cargo bikes, both with and without electric assistance, possess untapped potential in this realm. Quieter surroundings are yet another reason people and the environment profit from a growing cycling rate. The largest reduction in noise can be accomplished by converting roads into bike roads and pedestrian zones and introducing 30 km/h speed limits. At

Conversion of a car parking space into bicycle parking (Ex. Malmö, Sweden)

30 km/h, electric bikes can easily keep up with the flow of traffic. Furthermore, the introduction of such a speed limit simultaneously increases the safety for all road users.

3.4 Characteristics and environmental effects of battery types currently used in pedelecs

Pedelecs derive their energy from rechargeable batteries of numerous varieties and designs. Pedelecs in Germany are currently almost exclusively equipped with lithium-ion batteries (Li-ion), and in rare cases with nickel-metal hydride (NiMH) batteries.[78,79] As such, this paper does not address rechargeable batteries with lead-acid (Pb) and nickel-cadmium (NiCd) chemical combinations, which are still sometimes found in other countries. Each type of rechargeable battery exhibits special characteristics, so selection for the various types of applications generally occurs through a process of comparing and weighing up the demands the battery must meet. For example, lithium-manganese-oxide batteries ($LiMn_2O_4$), which are known for their stability and safety, have a lower energy density than lithium-cobalt-oxide batteries ($LiCoO_2$); therefore, those who desire a battery of equal weight that will allow them to travel the furthest distance on their pedelecs may have to reach a compromise between safety needs and range. In the table below (cf. Table 4), the rechargeable battery types currently available on the market are compared and selected summary statements are made regarding their lifespans, ingredients, safety behaviour, costs and energy density.

Table 4

Typical characteristics of rechargeable battery types used in Pedelecs

Battery type	Energy density in Wh/kg	Components/ ingredients	Lifespan/maximum no. of charge cycles depending on use	Advantages and disadvantages
Lithium-ion ($LiMn_2O_4$)	110 - 130	lithium manganese copper aluminium graphite	Up to 1,000 charge cycles	+ low self-discharge + high level of stability and safety + low costs
Lithium-ion ($LiFePO_4$)	110 - 130	lithium iron phosphate copper aluminium graphite	over 1,000 charge cycles possible	+ low self-discharge + very high level of stability and safety + can be charged quickly + long lifespan + good raw material availability
Lithium-ion ($Li(NixCoyMnz)O_2$)	140 - 160	lithium cobalt nickel manganese copper aluminium graphite	over 1,000 charge cycles possible	+ low self-discharge + high energy density + long lifespan
Lithiumionen ($LiCoO_2$)	140 - 160	lithium cobalt nickel copper aluminium graphite	up to 1,000 charge cycles possible	+ low self-discharge + high energy density - high costs
Nickel-metal hydride (NiMH)	55 - 100	nickel iron cobalt rare earths (lanthanum, cerium, neodymium, praseodymium)	up to 1,000 charge cycles possible	+ very high level of stability and safety + low costs - Very high self-discharge rate (approx. 20% per month) - low energy density

Source: summary depiction[80]

Heavy metal content

Based on a study from the Federal Institute for Materials Research and Testing (BAM)[81] commissioned by the UBA[82], it can be concluded that lithium-ion batteries are among the batteries containing the lowest amounts of the hazardous heavy metals mercury, cadmium and lead as per Batteries Act regulations. The aforementioned study examined the heavy metal content of commercially available batteries and rechargeable batteries, including eight different Li-ion batteries, that are used in mobile phones. With maximum values of 0. 7 mg/kg of mercury, 0.5 mg/kg of cadmium and 7.6 mg/kg of lead, all the Li-ion batteries tested in the sample remained well below the limit values and labelling thresholds (limit values: 5 mg/kg of mercury, 20 mg/kg of cadmium; labelling threshold: 40 mg/kg of lead).

Environmental impacts of rechargeable battery manufacturing

The issue of the potential environmental impacts (life-cycle assessments) arising from the manufacture of batteries for pedelecs has, as yet, been examined for two lithium-ion batteries with $LiMn_2O_4$ electrodes for application in electric bikes and for lithium cobalt oxide electrodes. These life-cycle assessments (LSAs) conclude[83] that the manufacture of rechargeable batteries, i.e. the production of input materials and the manufacturing process, accounts for the largest portion of their environmental impact. However – due to the high cost of the recycling process – the net effect of recycling with respect to global warming potential is quite low. In total, the net respective CO_2e emission[84] per kWh of battery for manufacture and disposal amounts to 55 kg CO_2e/kWh for the Li-ion battery ($LiMn_2O_4$) and 75 kg CO_2e/kWh for the Li-ion battery with lithium cobalt electrodes.

If these key figures are applied to the capacity (around 0.4 kWh) of a typical pedelec battery, then the manufacture and disposal of such a battery causes greenhouse gas emissions (CO_2e) of 22 to 30 kg (55 to 75 kg CO_2e/kWh x 0.4 kWh). Depending on the life of the battery, one or two additional batteries may possibly have to be added to this calculation over a pedelec's lifetime.

Furthermore, a pedelec contains additional and essential components that are not needed on bikes without electric assistance, such as an electric motor. For battery electric cars it has already been established that, of all the additional components specifically required for electric vehicles, battery production is the primary cause of environmental damage. The same applies to electric bikes. Due to the additional components required for pedelecs, bikes without power assistance are the more ecological choice with regard to climate change effects from production.

However, when measured against cars (with petrol engines), pedelecs have the clear advantage. One of the conclusions delineated in Chapter 3.1 was that pedelecs could most certainly compete with cars in city traffic due to their extended operating range, flexibility and manoeuvrability. A simple comparison of the 22-30 kg of greenhouse gas emissions arising from the manufacture of a pedelec battery with the 21.5 kg of greenhouse gas emissions saved per each 100 km not driven in a car (cf. Table 2: 22.08 kg CO_2 (car); 0.564 kg CO_2 (pedelec) – including indirect/upstream emissions) shows that the battery's greenhouse gas emissions have been balanced out after travelling only 100 kilometres on a pedelec.

The long lifetimes of pedelec batteries

Due to the high environmental relevance of battery manufacturing, a battery's lifespan is the decisive parameter when it comes to the climatic and environmental impacts of a pedelec: the longer a battery's life, the lower the environmental impact. In practice, a pedelec rider's cycling behaviour has an especially great influence on a battery's lifespan. Taking simple measures during pedelec use can as much as double the life of a battery. Some examples of influencing factors are:

- Temperature: excessively high (over 50 °C) or low (under -10 °C) outside temperatures can irreversibly lower a battery's capacity; temperatures between 10 and 25 °C are ideal.
- Charging: avoid full charge and deep discharge; battery management systems provide optimal regulation of this.
- Storage conditions: while storing a battery over the winter, keep it at room temperature and charge it after a maximum of six months. Ideally, a battery should be charged to 30-40% capacity during storage.

The UBA battery advice brochure[85] provides comprehensive descriptions of suitable measures to lengthen battery life.

3.5 Returning and recycling pedelecs and rechargeable batteries

Due to various ageing processes that depend upon time (calendrical ageing), environmental conditions and user behaviour (cf. Section 3.4), the available battery capacity decreases with a pedelec's use. As a rule, a battery has reached the end of its lifetime when 80% of the nominal capacity originally specified by the manufacturer can no longer be reached. Thus, as the number of pedelecs sold annually grows (cf. Fig. 2), in future, a time-delayed heavy increase in the quantity of discarded rechargeable batteries will ensue.
Lithium-ion batteries contain many recyclable materials (cf. Table 4). As such, it is important to channel old batteries onto the right disposal and recycling routes.

Battery collection

The German Batteries Act (BattG)[86] stipulates that old batteries be collected separately from household waste to facilitate the environmentally friendly recycling and disposal of spent batteries. As pedelec batteries are used to power electric vehicles, they fall into the "industrial batteries" category as legally defined in the Batteries Act. Distributors take back old industrial batteries free of charge. This applies to Li-ion and NiMH batteries, as well as all other types of pedelec batteries that might stem from older pedelec models. In addition, commercial battery disposal facilities can also collect old industrial batteries.

In practice, the Foundation for a Common Battery Collection Scheme (GRS)[87] and the ZIV have instituted an initiative for the collection of old pedelec batteries; 30 pedelec manufacturers and over 2,000 bike shops are participating (as of 2012). With appropriately designed dedicated collection boxes for pedelec batteries and information materials on how to deal with old batteries (e.g. pole isolation), this battery collection scheme accounts for the fact that Li-ion batteries must be packed and transported as per the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR).
Due to the characteristics of lithium and lithium compounds and the high energy density in Li-ion batteries, particular caution should be exercised when dealing with such batteries. Typical hazards arise through internal short-circuiting (resulting from damage to the batteries caused by mechanical stress), external short circuits (e.g. via contact with water, touching both poles) and through overheating of the lithium accumulator cells. In light of this, following the prescribed procedures for collection and recycling is extremely important.

The collection rate for old batteries containing lithium remains low. The collection rate for portable lithium batteries, i.e. the share of old batteries collected in proportion to the quantity introduced to the market, was only 6% in 2011.[88] The collection rate for pedelec batteries was roughly the same. The main reason for this is the long service lives of these batteries, which results in a lag in return time for recycling for as long as the market continues to grow. Another probable factor in this is interim storage in households and, quite possibly, improper disposal in residual waste bins.

Collection of old pedelecs

As electric-powered sports equipment, electric bikes fall within the scope of the Electrical and Electronic Equipment Act[89] (ElektroG,[90] Category 7) as long as they are considered vehicles that do not require type approval. Old electrical equipment, and subsequently old pedelecs, can be returned at no cost to municipal collection points such as recycling centres.

Owing to the potential hazards and special requirements concerning the handling of batteries containing lithium, the UBA strongly recommends the separate collection of Li-ion batteries and pedelecs. Given the current legal framework, this could, for example, be realized if consumers removed spent rechargeable batteries from pedelecs before returning them, turning in old pedelecs to local municipal collection centres and old batteries to bike retailers (where similar types of new batteries are sold).

Recycling

Recycling old pedelecs encompasses standard bike components, which are primarily made of aluminium and steel, and, most importantly, the electrical components (electric motor and battery).

Among other materials, the motor contains copper, steel and – in the permanent magnets – rare earths, primarily neodymium. As considerable insecurity exists surrounding the availability of rare earths, they have been deemed critical raw materials.[91] According to a prognosis, in the year 2020 the potential amount of neodymium Germany can expect to recover from old pedelecs is 5.6 t, which is more than the projected amount of neodymium that can potentially be recovered from old wind turbines in 2020 (2.9 t).[92] Technical processes to reuse and recycle permanent magnets containing rare earths from waste streams are currently in development; these efforts are primarily motivated by the growth of electromobility.[93]

Li-ion batteries consist of a housing (e.g. steel), an electronics component (battery management system) and battery cells. These components contain (cf. Table 4) various metals such as lithium, copper and aluminium, and in some cases cobalt, nickel and/or manganese. Due to the overall growth in electromobility and to further emergent areas of application, the demand for these metals will grow in future. The resource availability of cobalt – which the EU has likewise categorized as a critical raw material[94] – and of lithium, was forecasted in view of growing demand.[95] While experts estimate that geological lithium reserves will cover demand for all applications for decades to come, the cumulative consumption of cobalt could already exceed the 7.3 million tonnes of cobalt reserves currently known to exist sometime between 2040 and 2050; this is because global demand for cobalt is expected to increase eight to 20 times by 2050. Because of these batteries' long lifespans, recycling can only make a notable contribution over the long term to cover demand.

In Europe, recycling facilities for Li-ion batteries currently exist in Germany and Belgium. Thanks to the recovery of metals – for example iron (housing), copper, nickel and cobalt – in 2011 the efficiency of recycling processes for old lithium batteries reached 65%, thereby exceeding the EU target of 50% on average for recycling procedures[96] (figure for portable batteries, the values for pedelecs are analogous). Lithium is not yet reclaimed. Since 2009 several joint research projects have been, and are being, sponsored within the framework of electromobility research; they have resulted in (e.g. LithoRec, LiBRi)[97] and are resulting in (e.g. LithoRec II, EcoBatRec)[98] the development of reuse and recycling processes for Li-ion batteries from electric vehicles that attain a high degree of recycling efficiency, some include processing stages to reclaim lithium. Analysis of the environmental impacts of two of the newly developed processes via life-cycle assessments[99] shows that, overall, the net effect of recycling Li-ion batteries with respect to global warming potential is quite low due to the high cost of the recycling processes, and particularly of the process stages for recovering lithium. Definite net impacts from recycling can be attained in the other impact categories examined, such as acidification potential and eutrophication. This is largely due to the high recovery rates for cobalt, nickel, manganese, lithium compounds and components, such as housings, PCBs and cables.

4. Recommendations for action

The UBA recommends that **political decision-makers at various levels** (federal, state, municipal) provide ample financial and human resources for the development of bike-friendly infrastructure. The often higher speeds of pedelecs compared to traditional bikes and the greater demands regarding secure parking require targeted investments. Moreover, even a small investment in cycling can make a great impact. Promoting cycling contributes to solving many societal challenges: protecting climate and environment, health issues, traffic problems, securing mobility in light of demographic developments, allowing all to participate in social life and improving quality of life in cities and in rural areas. The formulation of strategic aims by the federal government, states and municipalities also helps overcome these challenges. Promoting cycling is a cross-sectional task within government administration; the appointment of a cycling commissioner is advisable for its coordination.

Businesses can implement pedelecs in a variety of ways in commercial traffic. This potentially includes employing cargo cycles for transport tasks and pedelecs for business trips and commuter journeys to work premises. Many car and compact van trips can instead be made using pedelecs or bikes. Economically, such uses pay off. For instance, employees can be inspired to use bikes and pedelecs in the context of workplace mobility or health management programmes. In lieu of a company car, **employers** have the opportunity to provide their **employees** with a company pedelec that can also be used privately.

Planners should respect the current technical standards when planning cycling facilities. Pedelec users are especially dependent on compliance with planning arrangements for transport infrastructure (in particular, ERA 2010[100], the German Guidelines for Traffic Signals (RiLSA 2010)[101] and the Suggestions For Cycling Traffic Signage (HBR)[102]) for their safety in road traffic. Frequently, however, these standards have not yet been implemented, and existing and new cycling infrastructures should be brought into line with the currently valid recommendations within a reasonable time frame.

Generally speaking, electric bikes are upmarket and are heavier than normal bikes; as such, users require particularly good, secure and ground-level parking at their destinations, such as at the workplace, train stations and public transport stops, shopping centres, recreational and educational facilities and at their homes. Their construction is not solely a task for public authorities; **businesses, transport services, housing associations and companies and educational institutions** have an obligation to provide ample parking facilities.

Consumers should consider whether they can employ a pedelec for trips that they normally travel in a car, and whether purchasing a pedelec for such an application is worthwhile. Riding a pedelec keeps people fit and saves money. Pedelec batteries are subject to special disposal rules. Batteries that consumers can remove of their own accord can be returned at bicycle retail shops (wherever similar types of new batteries are sold). From there, the batteries are collected and safely reprocessed. Old pedelecs can be recycled. Just as televisions and toasters, they are collected at municipal collection points (recycling centres) and then recycled. In general, due to the potential risks of and special requirements for handling lithium-based batteries, the UBA would like to point out that Li-ion batteries and pedelecs should be collected separately.

Taking simple measures during pedelec use can as much as double the **lifespan of a battery**. A temperature range of 10-25 °C is ideal. When charging, avoid continued charging of a fully charged battery as well as deep discharge. When a battery is going to be in storage for an extended period of time, it should be kept at room temperature and be charged to 30-40%. The battery should be recharged after a maximum of six months.[103]

Bike retailers inform customers about important legal stipulations pertaining to the use of pedelecs and e-bikes. The same is true of **cycling associations**. This includes information about the diverse range of potential applications for these vehicles and possibilities to test ride, lease and hire them.

Additional resources:

http://www.nationaler-radverkehrsplan.de/pedelec
http://www.vcd.org/elektrofahrraeder.html
ExtraEnergy: http://extraenergy.org/main.php
German Two-Wheeler Industry Association: http://www.ziv-zweirad.de/
E-Rad Hafen: http://www.eradhafen.de/
http://www.adfc.de/pedelecs

Pilotproject "INMOD – elektromobil auf dem Land" (INMOD – Electromobility in rural areas) in Mecklenburg-Vorpommer: hybrid bus with pedelec connection. Hire pedelecs are available from secure bike lockers with integrated charging stations.

List of abbreviations

ADFC	German Cyclists' Association
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
BAM	Federal Institute for Materials Research and Testing
BASt	Federal Highway Research Institute
BattG	Batteries Act
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (formerly BMU)
BMVI	Federal Ministry of Transport and Digital Infrastructure (formerly BMVBS)
BUND	Friends of the Earth Germany
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
ElektroG	Electrical and Electronic Equipment Act
EPAC	Electric Power Assisted Cycle
ERA	German Guidelines for Cycling Facilities (ERA 2010)
FZV	Vehicle Registration Ordinance
GRS	Foundation for a Common Battery Collection Scheme
ILS	Research Institute for Regional and Urban Development
KWh	Kilowatt hour
LEV	Light electric vehicles
$LiCoO_2$	Lithium cobalt oxide
Li-ion	Lithium-ion
$LiMn_2O_4$	Lithium manganese oxide
MiD 2008	Mobility in Germany 2008
Modal shift	A shift from one mode of transport to another, e.g. a shift from trips with motorized private transport to sustainable modes of transport
Modal split	The relative share of individual modes of transport, e.g. proportion of total trips
NiCd	Nickel-cadmium
NiMH	Nickel-metal hydride
NOX	Nitrogen oxide
NRVP	National Cycling Plan
Pb	Lead
PflVG	Compulsory Insurance Act
PM_{10}	Particulate matter <= 10µg
Rare earths	Metals such as lanthanum, cerium, neodymium, praseodymium – these elements are found only in scarce concentration in minerals.
SO_2	Sulphur dioxide
StVG	German Road Traffic Act
StVRAusnV	Ordinance on Exceptions to Road Traffic Regulations
TREMOD	Transport Emission Model, a model to calculate the greenhouse gas and pollutant emissions of motorized traffic
UBA	German Federal Environment Agency
VCD	German Transport Club
WHO	World Health Organization
ZIV	German Two-Wheeler Industry Association

Notes

[1] Mobilität in Deutschland 2008.

[2] Federal Ministry of Transport, Building and Urban Development [ed.] (2010), "Mobility in Germany 2008 – Report on findings," Bonn/Berlin, in Bundesministerium für Verkehr, Bau und Stadtentwicklung (2012): National Cycling Plan 2020 – Joining forces to evolve cycling, Berlin, p. 5.

[3] Die Bundesregierung: Nachhaltigkeit – ein politisches Leitbild, http://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Nachhaltigkeit/0-Buehne/2014-01-03-ein-politisches-leitprinzip.html, accessed on 7 April 2014.

[4] Cf. German Federal Environment Agency [ed.] (2013c), Daten zum Verkehr. guidebook, 2012 edition, Berlin, p. 46.

[5] Umweltbundesamt.

[6] German Federal Environment Agency [ed.] (2013c), Potenziale des Radverkehrs für den Klimaschutz, UBA-Texte 19/2013, Dessau Roßlau.

[7] Cf. Federal Highway Research Institut (BASt) [ed.] (2013), Einsparpotentiale des Radverkehrs im Stadtverkehr. Bericht zum Forschungsprojekt: FE 70.0819/2008 – Berichte der BASt, Verkehrstechnik, No. V 227, Bergisch-Gladbach. -> According to this study, a potential reduction in car traffic of between 3 and 13% is feasible.

[8] Cf. German Federal Environment Agency [ed.] (2013d), Weiterentwicklung des Analyseinstruments Renewbility. RENEWBILITY II – Szenario für einen anspruchsvollen Klimaschutzbeitrag des Verkehrs, UBA-Texte 84/2013, Dessau-Roßlau. According to this scenario, the share of motorized private transport sinks in favour of cycling, walking and public transport if ambitious measures are realized, leading to a reduction in road traffic emissions.

[9] Nationaler Radverkehrsplan 2020

[10] Federal Ministry of Transport, Building and Urban Development [ed.] (2010): "Mobility in Germany 2008 – Report on findings," Bonn/Berlin, in Bundesministerium für Verkehr, Bau und Stadtentwicklung (2012): National Cycling Plan 2020 – a common plan to promote cycling, Berlin, p. 9.

[11] 64,994 hybrid vehicles: of those, 1,119 are plug-in hybrids (hybrid vehicles that are charged externally), the other 63,875 vehicles are hybrid vehicles that cannot be charged externally.

[12] Kraftfahrtbundesamt 2013, "Fahrzeugzulassungen, Bestand nach Umwelt-Merkmalen," 1 January 2013, p. 12; or: brief study commissioned by the BMVI, Schott, B., A. Püttner, T. Nieder, F. Maas et al. (2013): "Entwicklung der Elektromobilität in Deutschland im internationalen Vergleich und Analysen zum Stromverbrauch," Bremen, p. 8. (http://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CDMQFjAA&url=http%3A%2F%2Fwww.zsw-bw.de%2Fuploads%2Fmedia%2FPaper_Monitoring_EMobilitaet_Final_akt.pdf&ei=AjpNU-b7BMnTsgbq44CICw&usg=AFQjCNGmBSctpT9OID26PmDC8ZwQLznCxw&sig2=ZSzo-eu_JKe7GD6-Q957Pw&bvm=bv.64764171,d.Yms), accessed on 15 April 2014.

[13] Two-Wheeler Industry Association (ZIV) http://www.ziv-zweirad.de/faq.html (as of May 2011), accessed on 27 February 2014.

[14] Zweirad Industrieverband.

[15] ZIV press release, 25 March 2014: "E-Bike bescheren der Fahrradindustrie weiterhin gute Umsätze." http://www.ziv-zweirad.de/public/pm_25.03.2014_e-bikes.pdf, accessed on 31 March 2014.

[16] VCD - E-bike database. http://e-radkaufen.vcd.org/datenbank1.html, accessed on 4 February 2014.

[17] ZIV presentation (2013), "Zahlen – Daten – Fakten zum Fahrradmarkt in Deutschland," Slide 23. http://www.ziv-zweirad.de/public/pk_2013-ziv-praesentation_20-03-2013_ot.pdf, accessed on 4 February 2014.

[18] Sinus Markt- und Sozialforschung GmbH [ed.] (2014), "Fahrrad-Monitor Deutschland 2013. Ergebnisse einer repräsentativen Online-Befragung." http://www.adfc.de/monitor/fahrradland-deutschland---der-fahrrad-monitor-2013, accessed on 10 March 2014.

[19] Ibid.

[20] ZIV presentation (2013), "Zahlen – Daten – Fakten zum Fahrradmarkt in Deutschland," Slide 13. http://www.ziv-zweirad.de/public/pk_2013-ziv-praesentation_20-03-2013_ot.pdf, accessed on 4 February 2014.

[21] Institut für Landes- und Stadtentwicklungsforschung.

[22] Research Institute for Regional and Urban Development GmbH (ILS) [ed.]: "Einstellungsorientierte Akzeptanzanalyse zur Elektromobilität im Fahrradverkehr," ILS-Forschung 01/2013. p. 33ff.

[23] See also: http://www.nationaler-radverkehrsplan.de/neuigkeiten/news.php?id=2456, accessed on 4 February 2014, short study commissioned by the BMVI, Schott, B., A. Püttner, T. Nieder, F. Maas et al. (2013), "Entwicklung der Elektromobilität in Deutschland im internationalen Vergleich und Analysen zum Stromverbrauch," Bremen, p. 8; or: TNO [ed.] (2009): "Regelmatig fietsen naar het werk leidt tot lager ziekteverzuim. Preventie en Zorg. Leiden." As well as: UBA [ed.] (2013c), "Potenziale des Radverkehrs für den Klimaschutz," UBA-Texte 19/2013, Dessau-Roßlau, p. 7 -> Here, it is considered feasible to shift from motorized private transport to bicycles for trips of up to 10 km.

[24] Kairos Wirkungsforschung und Entwicklung gGmbH [ed.], "Landrad. Neue Mobilität für den Alltagsverkehr in Vorarlberg – Endbericht", Bregenz, 2010. http://landrad.at/fileadmin/downloads/110103_bericht_landrad.pdf, accessed on 03 February 2014.

[25] Hendriksen, I. [et al.] (2008), "Elektrisch Fietsen. Marktonderzoek en verkenning toekomstmogelijkheden." https://www.tno.nl/content.cfm?context=thema&content=prop_publicatie&laag1=891&laag2=902&laag3=70&item_id=382&Taal=1, accessed on 17 February 2014.

[26] Stadsgewest Haaglanden [ed.] (2011), "Elektrische fiets in Haaglanden," Haaglanden. (http://www.fietsberaad.nl/library/repository/bestanden/Elektrische%20fiets%20in%20Haaglanden%20-%20vervolgonderzoek.pdf), accessed on 7 January 2014.

[27] Prof. Dr. Haefeli, U. (2012), "Interface. Begleitforschung New Ride 2012. Langzeitprofil der E-Bike Käuferschaft in Basel." http://www.newride.ch/documents/forschung/NR_BerichtLangzeitprofil2012_E-Bike_2012_08_28.pdf, accessed on 3 February 2014.

[28] "Cykel Super Stier Kobenhavn." http://www.cykelsuperstier.dk, accessed on 7 January 2014.

[29] "Pedelec-Korridor." http://www.difu.de/projekte/2013/pedelec-korridor.html, accessed on 25 March 2014; and http://www.stadtentwicklung.berlin.de/verkehr/planung/e_mobilitaet/de/e_fahrrad.shtml, visited 1 April 2014.

[30] "Pedelection." Funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). http://pedelection.de, accessed on 26 February 2014.

[31] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorensicherheit.

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