The potential of cycling for climate protection and livable urban centers and regions

New methods for forecasting supply and demand in Germany as a cycling nation up to 2035

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The potential of cycling for climate protection and livable urban centers and regions

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1 Objectives and overview

In this study, the potential of cycling is assessed in Germany on a regionally differentiated basis, assuming the systematic implementation of the vision "Germany as a cycling nation". Traditional traffic forecasts calculate changes in people's transport habits primarily on the basis of traveling times and costs. This systematically underestimates the potential of cycling and walking with the numerous subjective factors that influence them. Therefore, in this study we explicitly take into account actual observed behavior patterns of road users in response to changes in their personal environment, in mobility services and in the different regions. With this broad approach, the study aims to quantify the potential contribution of cycling to the transport transition and to climate protection, free from the limitations of conventional forecasting methods.

The study investigates the potential of cycling as part of the vision of "Germany as a cycling nation" in 2035. This vision embraces and simultaneously extends the concept of the German government's National Cycling Plan 3.0 (NCP 3.0) for 2030, (BMVI 2021). Among other things, we define and expand the vision of the NCP 3.0 to include a threefold increase in the number and quality of cycle paths, better access to public transport for cyclists, especially in rural areas, and redesigning all towns and municipalities to improve the quality of life and make them more friendly to cyclists and pedestrians at the expense of private motorized transport.

The goal of the NCP 3.0's Vision 2030 is for significantly more people to cycle and cover longer distances, while at the same time significantly increasing enjoyment and safety when cycling. In figures, this means that the modal split of trips made by bicycle is set to increase from 11% in 2017 to 15% in 2030. However, this merely represents the target already set in the NCP 2020 (BMVBS 2012). At the same time, the distance traveled by bike is set to increase by 60% from 3.7 km in 2017 to 6.0 km. This means that the share of cycling in terms of transport performance, i.e. the total number of kilometers covered, is set to double from 3% in 2017 to 6% by 2030.

In 2021, which was characterized by the COVID-19 restrictions but also by a high demand for Pedelecs, the length of journeys made by bicycle increased from 4.0 km in 2017 to 4.6 km and thus the transport performance of cycling increased by 13% (BMDV 2023). At the same time, the modal share of cycling in pioneering German cities such as Münster and Oldenburg has already risen to 47% and 43% respectively. Finally, despite increasingly difficult conditions, German towns rate climate protection (59%) and mobility (38%) as the most important issues for the future (Kühl et al. 2023).

This study takes a general look at the potential for using and switching to bicycles in urban centers and different regions, without looking in detail at the specifics of origin-destination relationships. To do this, we are using statistical regression methods[1] and linking data sets from the "Mobility in Germany 2017 (MID 2017, (Nobis et al. 2018))", survey, the "ADFC Bike-Friendly Cities Rating" (ADFC 2022) and the OpenStreetMap data portal to develop a new forecasting approach to expand classic modal choice models.

The statistical model developed in this study assumes that the reaction of people to changes in urban areas, infrastructure and transport systems observed in 2017 will remain stable over the coming decade even in the event of major changes. With the comprehensive measures outlined in the vision of "Germany as a cycling nation", we are assuming a shift in people's values and attitudes

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[1] A multinomial logistic regression model was used. This allows the simultaneous estimation of probabilities for the selection of all means of transportation (car, public transport and bicycle).

towards active mobility. This assumption offsets the fact that the statistical model developed here does not replicate real route chains and daily routines with their constraints and limitations.

2 Strategies of bicycle-friendly urban centers in Germany and abroad

The analysis of 105 international specialist articles and studies compares the most bicycle-friendly urban centers in Germany, such as Münster, Bremen and Oldenburg, with positive European examples such as Amsterdam, Antwerp and Ghent. Although the German frontrunners also achieve between 30 - 40 % of everyday trips made by bicycle, these remain exceptions in relation to all other urban centers and regions in Germany. In contrast, the share of trips made by bicycle in the leading locations in the Netherlands and Belgium is 40% higher and more widely distributed across the municipalities.

There is a consensus in the literature that the availability of a good cycling infrastructure and, in particular, cycle paths that are separated and protected from motorized individual transport (MIT) is the most important prerequisite for more cycling. Key characteristics of cycling networks are their density, seamlessness, safety and comfort. It is important that the planning and design of cycling infrastructure is based on a network and not on individual cycle paths. This network should be well designed both for uninterrupted routes in urban centers with main cycle paths, cycle bridges and level crossings, as well as for connections between the main routes and districts for short local journeys. The combination of main routes and local connections creates a finely meshed network of cycle paths that makes it easy to reach different destinations in urban centers by bike. Short, gap-closing connections can be created cost-effectively. The planning and implementation should be based on a hierarchy of transportation modes. This means that pedestrians have the first priority, cycling the second, public transport the third and MIT the last. In practice, this means that at intersections involving bicycle and car traffic, the intersection is adjusted so that bicycle traffic has priority.

It is important that urban centers and regions are well equipped with uninterrupted cycle path networks, but this alone is not enough to encourage people to switch from MIT to cycling. A more positive cycling culture is also essential. This can be created through pull measures such as campaigns or bonuses in combination with push measures such as speed limits, traffic control measures to calm traffic in residential areas, as well as regulation and charging for MIT. However, changing established urban structures, legal and organizational frameworks and public administrative culture takes time. In Germany, there is still no consistent approach comparable to the long-standing tradition of Dutch transport policy for the development of a high-quality cycle network and an inspiring cycling culture that caters for all the everyday needs of the various road users. However, there are also positive examples in this country, such as the network designs in Münster, Oldenburg and Karlsruhe.

3 Methodology and potential developments

With this study, we have developed a new approach to forecasting transport behavior based on surveys of mobility behavior and data on the infrastructure facilities of municipalities. This makes it possible to use "soft" factors such as the perceived quality and availability of transport and the

density and attractive design of cycling networks to analyze future scenarios. By combining the data sets of the survey "Mobility in Germany (MID)" with the results of the ADFC Bike-Friendly Cities Rating, analyses via the OpenStreetMap programming interface and regional data from the German Federal Statistical Office, a broad data set on transport behavior, available mobility tools, regional characteristics and infrastructure offers was generated. Finally, a statistical regression method [2] was used to estimate the probabilities for modal switching (odds ratios[3]) for all modes of transport, areas and distances as well as for all parameters used to define the modules of the vision "Germany as a cycling nation". This is then used to derive mode shares, transport performance and greenhouse gas emissions.

As drivers for these behavioral changes and thus for the construction of scenarios, 11 variables are available, ranging from driving license, car and (e-)bicycle ownership to quality scores for public transport and bicycle traffic to the density and perceived quality of the bicycle infrastructure. The strength of the model's effect were estimated using these and seven additional control variables[4] such as age structure, proportion of students, topography and weather for the 402 counties and district-free towns in Germany in 2017.

With this approach, we are able to include variables that are otherwise rarely considered in forecasting models, such as the perceived quality of the mode of transport, in forecasts of mobility behavior. The comparison of the effects shows that these factors, in addition to the availability of cycle paths or proximity to public transport stops, are decisive for people's travel behavior. The official forecasts of the German government, such as the medium-term forecasts of the German Ministry for Digital and Transport (BMDV, (Intraplan 2022)) or the long-term scenarios of the German Ministry for Economic Affairs and Climate Action (BMWK: (Wietschel et al. 2022)), do not take such variables into account. Accordingly, these studies hardly show any shifting trends towards cycling, even in scenarios for sustainable mobility. In contrast to these traditional approaches, the model presented here offers a perspective of the potential role that cycling can play in improving quality of life and climate protection that has been broadened to include people's views and consistently implemented in line with the NCP 3.0 vision of "Germany as a cycling nation".

The modeling of the effects on modal shift in this study is limited to trips up to 30 km in length. We chose this approach because the statistical significance of the response of cyclists to changes in the underlying conditions is limited due to the low number of longer bicycle journeys in the base year 2017. Furthermore, for trips over 30 km in length modal shifts to cycling and therefore cycling's impact on climate emissions are limited.

The statistical approach adopted offers the potential to further develop the quality of the forecast and to embed it in traditional models for mobility behavior patterns and sustainability. The statistical model itself could benefit above all from incorporating the results of the "Mobility in Germany 2023/2024 (MID)" survey, which are not yet available here, in order to illustrate changes in mobility patterns over the past six years and, above all, the much higher market penetration of Pedelecs. Methodologically, enhanced statistical forecasting methods, the use of non-linear target functions or additional tests on scenario and control variables could further improve the differentiation and quality of the forecasts. However, these approaches are time-consuming and are still limited by the rather small sample size of mobility surveys, especially in rural districts.

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[2] A multinomial logistic regression model was used. This allows the simultaneous estimation of probabilities for the choice of all modes of transport (car, public transport and bicycle).

[3] Odds ratios describe the probability of choosing a mode of transportation in relation to a specific alternative; in this case walking.

[4] Control variables describe the influence of certain variables on the results, but are not themselves used as variables for defining scenarios.

4 Essential modules of the vision for "Germany as a cycling nation"

In this study, we look at three interrelated modules of the vision of "Germany as a cycling nation". The vision describes a medium-term future around the year 2035 in which the concepts of sustainable mobility, with the bicycle at the center, are implemented throughout urban centers and regions. The three modules considered here describe different types of measures that must be implemented in order to achieve the vision of "Germany as a cycling nation" with all of its different aspects. The modules should not be seen as alternative ways of achieving sustainable mobility, but rather as interlinked. These range from the development of a user-friendly and safe infrastructure to the multimodal integration of bicycles as part of ecomobility[5], the design of attractive streetscapes and the creation of an environment of equitable coexistence, including clear measures for climate-friendly transport in towns and municipalities.

These modules are described in more detail below:

1) Module 1: Inviting infrastructure
2) Module 2: Bicycles as part of ecomobility
3) Module 3: Cycle-friendly municipalities

The modules developed for the "Germany as a cycling nation" vision relate to a time horizon of around 2035 and are not tied to political, administrative, legal and financial restrictions on their implementation. The scenarios or modules build on each other in the analysis in order to be able to present their effects in detail. In practice, however, they should be implemented concurrently and in an integrated manner.

Module 1: Inviting infrastructure	With broad support from the German federal and state governments, urban centers, municipalities and regions in Germany are increasing the length of their cycle networks threefold to create a continuous network of cycle paths throughout the country. Following the example of the Netherlands, concepts for safe and comfortable cycle path networks, safe intersection design and bicycle parking facilities are being implemented on a large scale to make cycling considerably safer and more comfortable for everyone. At the same time, the legal framework and regulations for equitable coexistence are being further developed for the benefit of vulnerable road users. As a result, all municipalities in the ADFC Bike-Friendly Cities Rating have moved up to the top of the class in their respective area type in terms of safety, comfort and infrastructure.
Module 2: Bicycles as part of ecomobility	The second expansion stage of Germany as a cycling nation describes the integration of cycling into a high-quality and affordable public transport system (PT).[6] Measures aimed at integrating bicycles include adequate and secure parking facilities at all stops and stations, quicker access to public transport stops by bicycle and - through extended and flexible types of service, especially in rural areas - attractive vehicles with sufficient space for carrying bicycles, as well as the development of digitalization for the seamless integration of

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[5] Alliance of all sustainable transport modes: public transport, cycling, walking and shared modes.

[6] PT includes local public transport (LPT) with buses and trains as well as regional and long-distance transport throughout Germany.

	bicycles into information and booking systems. This will improve the accessibility of public transport for the last mile by bicycle on intermodal trips.[7]
Module 3: Cycle-friendly municipalities	The final expansion stage of "Germany as a cycling nation" supplements modules 1 and 2 with a portfolio of push and pull measures with investment, urban development, regulatory and pricing policy measures. This will increase active mobility on foot and by bike and noticeably reduce the length of everyday journeys for work, errands and leisure. In line with the concept of the 15-minute city, local amenities will also be improved, particularly in peripheral rural areas. This package goes well beyond the proposals of the NCP 3.0 by making urban centers and municipalities more bicycle and pedestrian-friendly, more attractive to live in and less car-based.

Source: Fraunhofer ISI

In contrast to the NCP 3.0 target year of 2030, 2035 is chosen as the time horizon in this study in order to make the considerable investments feasible that the "Germany as a cycling nation" vision entails. However, depending on financial and administrative capacities as well as political will, full implementation of the modules may also be further in the future or, under ideal circumstances, sooner.

The results of these three modules are presented in relation to a comparative or reference scenario for 2035, which serves to illustrate the potential of the "Germany as a cycling nation" vision compared to a scenario that continues the current trend without high policy ambition and within the given financial, staffing and legal constraints of the local authorities.

5   Key results for modal split and greenhouse gas emissions

The results of this study illustrate cycling's potential for implementing the vision of "Germany as a cycling nation" without financial, organizational and legal restrictions. They therefore do not represent forecasts in the traditional sense, but rather illustrate the potential of cycling if it is comprehensively expanded and promoted nationwide. In addition, the estimated potential assumes that road users embrace the newly designed infrastructure, transport services and residential areas in line with the behavioral patterns observed in 2017.

The modules selected to implement "Germany as a cycling nation" have a significant influence on people's choice of mode of transport. If the conditions for cycling are optimized accordingly, the share of cycling across all area types and distances and in relation to all trips up to 30 km in length can triple from 15 % in the reference scenario 2035 to an average of 45 % in the most intensive expansion stage "Cycle-friendly municipalities". The greatest potential is shown by the regiopolitan urban regions[8] (regiopolis), with a possible bicycle share of 63%. Compared to metropolitan areas (up to 40 % cycling modal share), regiopolis generally have a lower density of alternative mobility options and shorter distances. Compared to rural areas (38% to 43% cycling modal share), car dependency in regional towns is less pronounced due to their urban character (Figure 1).

The biggest and most important step in the implementation of "Germany as a cycling nation" is the significant expansion of the cycle path network with a threefold increase in the density of cycle

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[7] Intermodal trips are trips on which the mode of transport changes. Examples: Switching from bike to PT (Bike and Ride) or from car to PT (Park and Ride)

[8] Medium-sized and large towns that form the hub and driving force behind the development of a larger region (spatial planning category)

paths and their upgrading so that cyclists can reach all destinations safely and comfortably. In module 1, this results in a growth in the modal split of 18 percentage points compared to the 2035 reference. In this scenario, public transport also benefits with a gain of 2 percentage points at the expense of MIT (- 16 percentage points) compared to the assumed development in the reference scenario.

The significantly improved integration of cycling into high-quality PT encourages the use of the bicycle as an alternative to the private car, particularly in conjunction with a high-quality, well-developed cycling infrastructure. The chosen analysis approach cannot directly map intermodal routes or safe and adequate bicycle parking facilities at PT stops and stations. However, its effect can be simulated structurally through a combination of improved cycling infrastructure, shorter distances to the nearest PT stop and a higher quality of PT. As a result, in module 2 both the bicycle share increases by 4 % and the PT share by 2 % across all region types compared to module 1. At the same time, the MIT share decreases by 4 %.

Finally, a combination of push and pull measures in towns and municipalities has an additional and decisive effect on the modal split of cycling (module 3: +8 percentage points compared to module 2). These include a consistent redistribution of urban space in favor of walking and cycling and for more enjoyable urban spaces, giving less space to stationary and moving car traffic, making 30 km/h the standard speed limit in urban areas and pricing policy measures to reduce MIT to a necessary minimum.

**Figure 1:   Modal split of transport volume in 2035 by type of region**
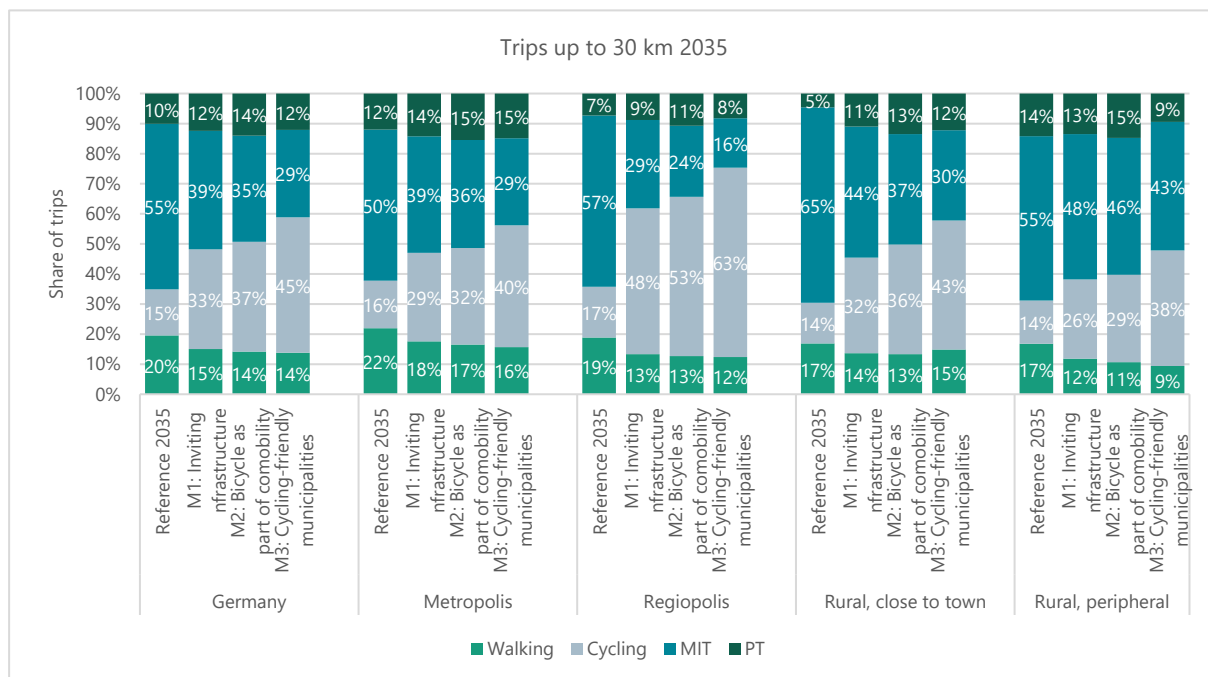
Source: Fraunhofer ISI

The modules for implementing the "Germany as a cycling nation" vision can potentially contribute to a reduction in greenhouse gas emissions (GHG emissions) from passenger transport on all routes up to 30 km in length up to 19 megatons of carbon dioxide equivalents (Mt CO_2e) or 33.5 % compared to the 2035 reference scenario. Nearly half of these savings, -8.5 Mt CO_2e, are achieved through module 1 "inviting infrastructures". The contribution of an integrated, multimodal mobility

policy (module 2 "Bicycles as part of ecomobility": -2.0 Mt CO_2e compared to module 1) is significantly lower than the contribution of a consistently bicycle-friendly design of the municipalities with restrictions for cars (module 3: as well -8.5 Mt CO_2e compared to module 2), see Figure 2.

Figure 2: **GHG emissions according to individual modules 2035**
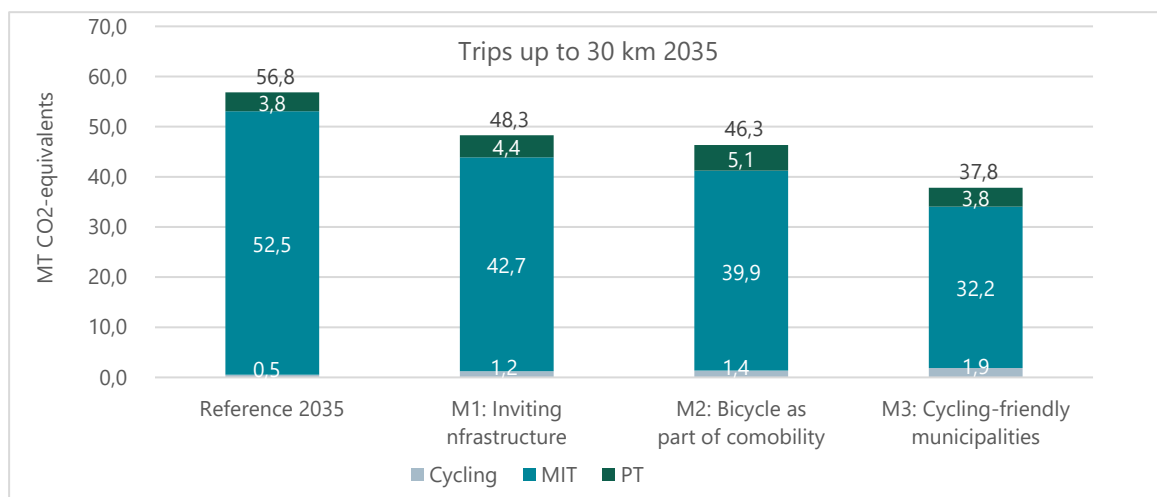
Source: Fraunhofer ISI

To determine the relative reduction in greenhouse gas emissions for passenger transport, we have estimated the traffic volume, traffic performance and greenhouse gas emissions for trips over 30 km in length for passenger transport by bicycle, car and public transport based on the data from MiD 2017 and the assumptions on population development by area type and the emission factors to be expected in the future. We assume constant trip rates and make the simplifying assumption that the modules of "Germany as a cycling nation" do not affect the choice of mode of transport for trips over 3 in the 2035 reference. The contribution of the "Germany as a cycling nation" vision for reducing emissions in passenger transport excluding aviation and shipping is therefore 6.7 % if module 1 "Inviting infrastructure" is implemented and 15 % if all three modules are implemented.

6 Recommendations for further action and outlook

The objective of this study is to estimate the potential of cycling assuming systematic implementation of the "Germany as a cycling nation" vision and without political, administrative or financial restrictions. This was achieved through the detailed evaluation of the "Mobility in Germany (MiD) 2017" survey and additional key data from German counties and district-free towns. This newly developed approach maps the behavior of the German population and takes into account the facilities and perceived quality of the regions with transport infrastructures, mobility services and local amenities. If all three modules of "Germany as a cycling nation" are systematically implemented, it is possible to achieve a threefold increase in the modal split of cycling throughout all region types and an annual reduction in greenhouse gas emissions in passenger transport of 19 megatons of carbon dioxide equivalents (Mt CO_2e) compared to the continuation of the current transport policy. These results apply for the time horizon 2035 and for all passenger trips up to 30 km in length.

A differentiated look at the findings of this potential analysis leads to the following recommendations for action for transport and municipal policy:

1) **With the necessary political will and sufficient resources, Germany has the potential to become a cycling nation.**

   Based on the 2017 modal split of 11 %, we estimate a share of 15 % for cycling in the 2035 reference scenario without additional policy ambitions. If all three modules of "Germany as a cycling nation" are systematically implemented, we calculate a 45% share for cycling for all trips of up to 30 km in passenger transport in Germany. This potential applies if

   - the behavior patterns of people observed in 2017 remain unchanged,
   - the cycle path network density increases to three times the current level combined with a higher perceived quality,
   - cycling is consistently integrated into the ecomobility network, and
   - if towns and regions use urban planning and transport policy concepts to work comprehensively towards a high quality of life and bicycle-friendliness, even to the detriment of the car.

   This means that it takes political will, courage and the necessary financial and personal resources from the central, state and local governments to implement the vision of "Germany as a cycling nation". Based on concrete behavioral observations, this study shows that the considerable efforts will pay off. The central and state governments have the task of supporting smaller municipalities in particular in their efforts and providing the necessary resources. In this respect the German government's National Cycling Plan 3.0 points the way forward.

2) **The threefold increase in cycling networks requires good concepts, less bureaucratic planning procedures and facilitating the public's involvement.**
   We have applied the "Recommendations of the National Mobility Platform for Cycling" in module 1 "Inviting infrastructure" (NPM 2021). This represents a threefold increase in the cycling infrastructure throughout Germany compared to the current level. Regional data from the "OpenStreetMap"[9] data portal shows the ratios of districts with the highest versus the lowest cycling network density out of six for metropolitan regions and 20 for all other types of areas.

   However, it is not the density of cycle paths alone that is decisive for people switching to bicycles, but their quality. For all modules of the "Germany as a cycling nation" vision, we assume that all areas will improve by one grade in the ADFC Bike-Friendly Cities Rating. This means that all cyclists feel safe and find cycling comfortable everywhere. Under these conditions, we calculate a growth in the cycling share in Germany from 15% in the reference scenario to 33% in module 1 "Inviting infrastructure" for all journeys up to 30 km in length in passenger transport for the target year 2035.
   For the implementation of the "Germany as a cycling nation" vision, this means acting on three levels:

   - develop network concepts
   - rapidly expand cycle paths
   - upgrade the quality of the existing cycling infrastructure.

   Network concepts should be based on lessons learned from the Netherlands, Belgium or Denmark. Here, for example, a distinction is made between three levels of efficient and fast arterial routes, a well-developed secondary network and routes connecting and accessing residential areas. The expansion of cycle path networks can also be achieved in the short term using infrastructure that is integrated into the road space without costly structural measures, such as pro-

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[9] Link: https://wiki.openstreetmap.org/wiki/DE:Bicycle/Radverkehrsanlagen_kartieren

tected bike lanes, protected crossings or pop-up cycle paths, together with secure parking facilities. Cities abroad and in Germany such as Paris or Seville, Münster, Oldenburg and Karlsruhe provide good examples for this.

However, in order to increase the length of cycle paths threefold in the near future, the German government must review the administrative workload and requirements for the construction of cycle paths in favor of shorter planning and construction times. The local authorities must involve the population through early and low-threshold communication and participation procedures, as more cycle paths are not possible without restrictions for cars when space is limited.

3) **The transformation of municipalities into attractive, cycle-friendly places must be communicated positively and implemented quickly.**

Module 3 "Cycle-friendly municipalities" describes a portfolio of different municipal and regional policy approaches and transport policy measures. This includes a comprehensive mix of pull measures for cycling and walking and for improving the quality of life and living environment, as well as push measures to the detriment of the car. The most important component of this is the upgrading and redistribution of space in favor of cycle paths, cycle parking facilities, footpaths and recreational areas. To this end, lanes and parking spaces for cars must be reduced. Building on modules 1 and 2, this package of measures increases the bicycle share by an additional eight percentage points to an average of 45% across all region types for journeys of up to 30 km. A higher quality of life in the municipalities and better local amenities will lead to a reduction in greenhouse gas emissions of 8.5 Mt CO_2e per year. This effect is comparable to the threefold increase and upgrading of the cycling infrastructure in module 1.

In terms of transport policy, this means creating a supportive framework of road and building regulations that focus on people and their needs and gives local authorities extensive freedom in shaping mobility. The possibility of introducing a recommended speed limit of 30 km/h across the board, as demanded by numerous German municipalities, would be an important step in this direction (Ringwald et al. 2019). Building regulations should also be reformed to better reflect the urban character of streets with different usage requirements (BBSR 2023). However, it is also crucial that local authorities are aware of the legal options that already exist. In addition to the central and state governments, the municipal umbrella organizations need to provide urban centers and municipalities with the necessary legal framework.

When it comes to improving everyone's quality of life in the municipalities, early and unbureaucratic citizen involvement in the design process is even more important than when it comes to building cycling infrastructure. In many European urban centers, digital participation formats, visualizations, city-walks and an active suggestion scheme ensure less distance between the population and the administration. Ideally, these formats can help to speed up processes. Good communication of the advantages of bicycle-friendly redesigned districts and residential areas as well as rapid implementation are of central importance for the acceptance of change - especially if this means restrictions on the use of private cars.

4) **The great potential offered by cycling in regiopolitan areas should be used as a catalyst for transformation in rural areas.**

If all three modules of the "Germany as a cycling nation" vision are implemented, the statistical model of this study estimates a potential cycling share of 63 % for trips of up to 30 km in regiopolitan urban regions. Münster (47 %), Oldenburg (43 %) and Karlsruhe (approx. 30 %) are already the cities in Germany with the highest cycling shares and the best ratings in the "ADFC Bike-Friendly Cities Rating". Cycling in regiopolitan urban regions benefits both from the less dense competition from alternative transport options compared to metropolitan areas and from urban structures with good local amenities, short distances and a lower dependency on cars compared to rural areas. The figure "two thirds of all journeys" by bicycle seems extremely

high - however, it does not represent a forecast, but "merely" the potential of cycling assuming current behavioral patterns and without political, administrative or financial restrictions.

Among the four types of region examined (from metropolitan urban regions to peripheral rural areas), the promotion of cycling appears to be most successful in regiopolitan urban regions. These can act as examples and role models for other types of region if they make effective use of the potential identified for cycling. Medium-sized and large towns generally have considerably more know-how and resources in terms of transport policy and urban design than smaller and peripheral municipalities. There is also considerable potential for cycling in rural areas. However, here there is a great need to catch up in terms of infrastructure in municipalities that often have little know-how and limited resources for bicycle traffic planning.

Which areas the German federal and state governments should focus their bicycle funding on is a matter for policy makers and cannot be answered conclusively in this study. The assumed higher efficiency of funding in regiopolitan urban regions must be weighed up against the catch-up funding required for improving living conditions in peri-urban and peripheral rural areas.

5) **The potential of cycling for climate protection is significant and should be harnessed as quickly as possible.**

With a reduction potential of up to 19 Mt CO_2e, the transport policy around bicycle-friendliness and quality of life in municipalities is one of the major ways of achieving climate neutrality in transport. In land-based passenger transport as a whole, the study identifies a reduction potential of 15 % compared to the 2035 reference scenario. Against the backdrop of a widening gap between greenhouse gas emissions in transport and the envisaged reduction targets, the potential is considerable.

Alternative ways of reducing emissions by electrifying car traffic, using synthetic fuels or shifting people and goods to the rail network are progressing slowly. These are presumably not sufficient to reduce transport-related greenhouse gases by 55% by 2030 and 80% by 2040 as planned. In contrast to the above, the approaches required to achieve more and better quality cycling are well known and can be implemented quickly.

We were able to derive the above recommendations from the results of the potentials model that we developed here. A review of the literature on the criteria for the success of bicycle-friendly towns in Germany and Europe led to the following general recommendations for action:

6) **Cycling needs to be shaped by a creative and comprehensive strategy across all regional levels.**

Promoting cycling is an integral part of the transport transition. All modules of "Germany as a cycling nation" contribute significantly to a balanced modal split across modes of transport and to a significant reduction in GHG emissions. The powerful effects of the modules 1 "Inviting infrastructure" and 3 "Cycle-friendly municipalities" demonstrate this: A fair and socially coordinated interplay between push and pull measures is important for cycling. In addition to the bicycle-friendly redesign of municipalities and the consistent integration of cycling into public transport via information and booking systems and intermodally designed stops, it also means restrictions for cars. An across-the-board speed limit of 30 km/h in municipalities, the reduction of lanes and parking spaces in public areas as well as pricing as a means of steering are some of the possible measures.

In order to avoid social dislocation, these measures must be well communicated and embedded in an overall strategy that is comprehensible to all. An important step in this direction is the reorganization of the mostly reactive planning processes into formative strategy processes. For example, the German federal transport infrastructure plan and transport development plans of

the German federal states and municipalities should be transformed into mobility plans with targets for greenhouse gas emissions, the modal split of cycling and eco-mobility, or the attractiveness of local communities.

7) Data and evaluation are essential.

The overview of international practice shows that political decisions and any adjustments in terms of direction should be based on sound and regular data collection. In addition, continuous monitoring of the measures implemented and their effects is essential. A good example of this is the "Copenhagen - The Best Cycling City in the World"[10] program. The relatively weak culture of impact monitoring in Germany should follow such examples.

In order to avoid resource-intensive and bureaucratic hurdles, evaluation procedures can be set up with a low threshold based on a few core indicators and using automatically retrievable digital data sources. What is important in any case is to be able to learn and adapt future transport policy strategies according to the available evaluation results.

8) Promoting cycling is part of the transformation of society as a whole.

The promotion of cycling in the modules outlined here has other significant social benefits in addition to its climate impact. For example, bicycle infrastructures are space and cost efficient when well utilized. More active mobility increases people's health and life expectancy and can also contribute to saving economic costs. Finally, the transformation of towns and communities in order to improve their attractiveness and the quality of life there goes far beyond the transport sector and touches on the question of how we all want to live together in the future.

With this study, we were able to show that a meaningful combination of available data on traffic behavior, cyclists' views and traffic infrastructure can be used to develop new forecasting approaches. Despite the constraints and possibilities for further development, we consider the basic results of this exploratory approach to be valid under the assumptions of the scenarios applied. However, the results of the developed methodology represent basic potentials and not forecasts in the classic sense. It is now necessary to link this statistical approach with geographically more finely structured network models of traffic forecasting.

In terms of content, the scenario analysis confirms the findings of successful bicycle-friendly towns in Europe. Comparable with Dutch regions, we calculate a possible modal split of well over 40 % for all trips up to 30 km in length with the systematic implementation of the "Germany as a cycling nation" vision. These changes require a lot of time and considerable resources. However, rapid expansion methods such as "protected bike lanes", "protected intersections" or "pop-up infrastructures" and the use of international experience for pragmatic and rapid implementation can make the transformation process a reality in the near future.

Given the lack of technological options for a rapid decarbonization of motorized individual transport, the promotion of cycling offers an inexpensive and much faster way of reducing emissions with positive side effects for quality of life and health. As long as the ramp-up of electromobility and the appropriate expansion of public transport are slow to materialize, the potential of cycling should be exploited as quickly as possible.

This study is intended to encourage change. By drawing on the experience of advanced countries such as the Netherlands, Belgium or Denmark, it does not necessarily have to take decades to implement the vision of "Germany as a cycling nation". Positive examples from cities of different sizes such as Paris, Vienna, Copenhagen, Ghent or Seville show how the traffic turnaround can be implemented quickly with cycling and walking as central pillars. The concepts for this, such as the rapid

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[10] Link: https://urbandevelopmentcph.kk.dk/mobility-cycling/copenhagen-the-best-cycling-city-in-the-world

expansion methods or bicycle lanes, are well known. However, nationwide implementation requires both political determination and the support of the German federal and state governments, as well as an enabling and binding legal framework that focuses on the needs of people.

Abbreviations

ADFC	German Cyclist's Association (Allgemeiner Deutscher Fahrrad-Club e. V.)
BMDV	Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr)
BMVI	Federal Ministry for Transport and Digital Infrastructure (Bundesministerium für Verkehr und Digitale Infrastruktur)
BMWK	Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz)
GHG	Greenhouse gas emissions
ISI	Institute für Systems and Innovation Research
Km/h	Kilometers per hour
NCP	National Cycling Plan
MiD	Mobility in Germany (Mobilität in Deutschland)
MIT	motorized individual transport
MT CO_2e	megatons of carbon dioxide equivalents
NPM	National Mobility Platform (Nationale Plattform Mobilität)
PT	Public transport

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