biclaR: Estimating the socio-environmental impacts of car substitution by bicycle and public transit using open tools

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Abstract. This paper estimates the potential for cycling combined with public transit (PT) as a substitute for car trips in the Lisbon metropolitan area and assesses its socio-environmental impacts using open data and open source tools. A decision support tool that facilitates the design and development of a metropolitan cycling network was developed (*biclaR*). The social and environmental impacts were assessed using the *HEAT for Cycling* and the *HEAT as a Service* tools. The impacts of shifting car trips to PT were also estimated and monetized. The results indicate that 10% of trips could be made by bicycle + PT combination. Shifting to cycling for the first-and-last mile stages can reduce annual CO_2eq emissions from 3,000 tons/day, with benefits over 10 years of at least €125 million. For the PT leg, the transfer from car avoids of up to 20,500 tons of CO_2eq emissions per year. This evidence can support policymakers to prioritize interventions that reduce the reliance on private motor vehicles.

Keywords: Active transport · Intermodality · First and last mile · Health economic assessment · Environmental impacts · Open methods

1 Introduction

Combining public transportation (PT) and cycling for the first and last mile in metropolitan areas can significantly replace private car trips [1, 2]. This approach requires interventions and programs to make bicycling more appealing, and the resulting public investments can have significant social and environmental benefits.

According to the latest mobility survey conducted in 2018 [3], the LMA registered a total of 5.3 million daily trips, with only 0.5% by bicycle. Car modal share was 58.4%, while PT accounted for 15.5%. The number of intra-municipal trips — with origin and destination in the same municipality — amounts to 3.5 million trips. This exceeds the number of inter-municipal trips (1.8 million trips), involving travel between different municipalities. Cars and public transport are the most used modes for intercity trips, with cars being the predominant choice for all journeys.

To achieve the cycling targets set by the Portuguese national cycling strategy for 2025 and 2030 (4% and 10%, respectively), the Lisbon's Metropolitan Department of Transport introduced *biclaR*[3], a decision support tool that facilitates the design and development of a metropolitan cycling network [4].

biclaR builds on the Propensity to Cycle Tool[4] (PCT), a web application and research project funded by the UK's Department for Transport in 2015 which launched nationally in 2017 as part of the government's Cycling and Walking Investment Strategy. The PCT initially used only origin-destination data for commuting trips as the basis of estimates of cycling potential at zone, route and route network levels [5]. However, to the best of our knowledge, this is the first time that the method has been integrated with public transport data using multi-modal routing to estimate the potential and benefits of multi-stage cycling and PT trips.

This paper estimates the potential for combining cycling and PT to substitute car trips in the LMA. After presenting the methods used, it assesses its socio-environmental impacts using open data and open-source tools.

2 Methods

2.1 Modeling Origin-Destination trips

The mobility survey data [3] is the basis for this project and defines the baseline scenario. Despite being conducted in the pre-pandemic period (2017), this dataset represents the most comprehensive and up-to-date information on urban mobility in Portuguese metropolitan areas (Lisbon and Porto).

We used a method for disaggregating the origins and destinations of trips between the centroids of two districts (same as "parish") to ensure that a district is not solely characterized by a single point of origin and destination for its trips. The OD Jittering method breaks down a single point (i.e., the centroid of an area) into multiple random points on the existing and neighboring road network, using OpenStreetMap as a reference [6]. Using the `odjitter` R package, we employed a maximum disaggregation level of 100 trips per O-D pair for this project. Although this method provides a more realistic representation of the trips undertaken compared to the traditional approach, it does not fully align with the actual O-D pairs of trips, which remain unknown due to data privacy regulations.

2.2 Modeling routes

The mobility survey collects the origin and destination of trips but does not include the respective routes. Modeling the realistic cycling + PT routes between

[3] See biclar.tmlmobilidade.pt.
[4] See pct.bike.

OD pairs depends on assumptions regarding the characteristics of the cycling and road networks and the location of public transport interfaces.

The selected route choice algorithm was the `r5r` R package [7], which allows for great flexibility in configuring estimated route types. `r5r` can calculate multi-modal routes using PT combined with other modes. It enables the identification of the most direct or safest cycling routes, using the Level of Traffic Stress[5] (LTS) scale. The routes were estimated for the base scenario for both types of networks: *direct* and *safe*, using LTS 4 and LTS 3, respectively.

The `r5r` model used the OpenStreetMap road network and the GTFS metropolitan data aggregated and validated. This information is crucial for an accurate PT trip and route estimation.

2.3 Modeling intermodality

The intermodality scenario considers trips combining PT and cycling for the first and last legs. In a conservative approach, we have restricted our analysis to the first and last legs with a combined length of up to 5 km (for instance: 1 km from origin to interface A plus 4 km from interface B to destination) or up to 25 minutes on bike. Furthermore, we have imposed restrictions on PT usage to include only trips with no PT transfers, and up to 2 hours (120 min). Additionally, we have only included PT modes that can easily accommodate bicycles, such as trains, ferries, trams, and inter-municipal bus lines equipped with bike racks (Figure 1). Figure 2 illustrates the resulting bicycle routes to access the main PT interfaces in the LMA.

2.4 Assessing socio-environmental benefits

For the cycling legs of the journey (first and last legs), socio-environmental impacts were estimated on the shifting from car to cycling, using the HEAT for Cycling tool v5.0 [8] from the World Health Organization, and the `HEATaaS` R package[6]. We considered two dimensions: *social* — including the physical activity of cyclists, air pollution exposure, and road casualties; *environmental* — including CO_2eq emissions and other pollutants.

For the second leg of the journey, we estimate the additional environmental impacts of shifting car trips to PT (between the PT interfaces).

To estimate the car emissions, we used the EMEP/EEA's COPERT software v5 methods and reference values [9] for a Tier 3 detail level. Regarding PT, we considered the emission factor values reported in the environmental and sustainability reports of the PT operators in the LMA. The conversion of avoided emissions into avoided welfare loss and respective monetary valuation was based on the EU Guide to Cost-benefit Analysis [10] and the best up-to-date reference values for the various gases.

[5] see docs.conveyal.com/learn-more/traffic-stress.
[6] `HEATaaS` is under development. For more information contact heatwalkingcycling.org.

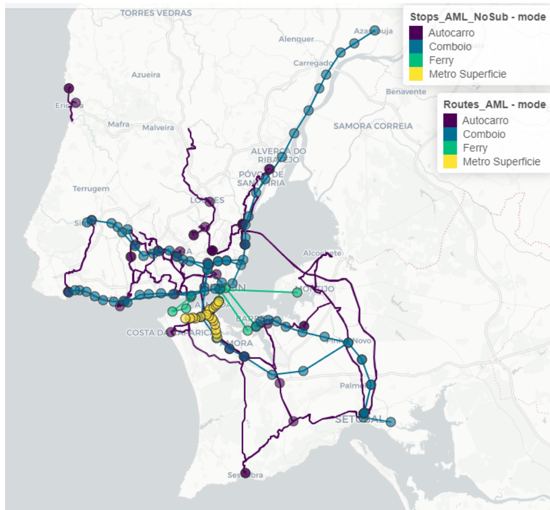

Fig. 1. Interfaces and lines considered, by transport mode, in the Lisbon metropolitan area

3 Results and Discussion

Table 1 presents the LMA total daily trips that can be made with cycling + TP combination (with the aforementioned restrictions), the trips in the baseline scenario and corresponding new trips to achieve the national strategy targets (4% and 10%), for different route profiles. For the cycling legs of the journey (first and last legs), the environmental avoided emissions and monetized socio-environment (SE) benefits are also presented, resulting from replacing car trips with cycling.

Table 1. Summary of the cycling potencial of intermodality scenario and its socio-environmental benefits for the cycling legs.

Target	Routing	Total trips	Baseline Cycling + PT	Potencial Cycling + PT	Avoided CO2eq (ton/yr)	SE Benefits for 10 years (thousand €)
4%	safe	538 514	2 312	20 385	2 958	115 780
4%	direct	500 880	2 274	18 944	3 004	113 030
10%	safe	538 514	2 312	52 323	7 590	297 510
10%	direct	500 880	2 274	48 609	7 694	289 290

For both *direct* and *safe* route profiles, 10% of the daily trips have the potential to be made by a combination of PT and cycling (up to 5 km on bike).

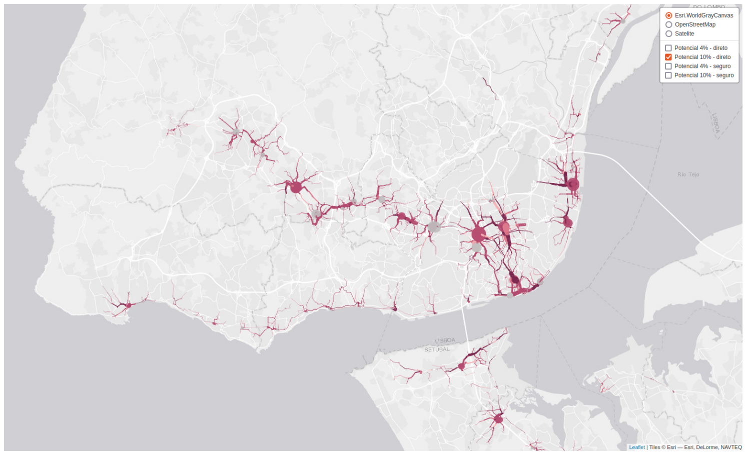

Fig. 2. Bike routes with highest potential to serve as first and last leg when replacing cycling and PT from car trips (screenshot of the interactive online tool).

This unveils the potential of cycling as a complementary mode of PT, with the potential to uptake the number of PT trips within the LMA area by as much as 6.3% (in addition to the 825 thousand PT trips reported in the mobility survey).

Regarding the PT mode to replace the second leg of the journey, in combination with cycling, trains offer the greatest potential for substitution (88%). When comparing the existing PT interfaces (Figure 1) with the bike routes with highest potential to serve as first and last legs (Figure 2) it becomes clear that the Train interfaces are the ones that have the highest potential to attract car-to-PT substituting trips, if their accessibility by bicycle is improved to be safe.

Regarding the PT segment, the shift from private car usage would lead to the mitigation of CO_2 equivalent emissions to 8,500 to 20,800 tons annually, valued in €1.4 million to €3.5 million yearly.

The sum of CO_2eq avoided emissions from the potential car trips shifted to bike (first-and-last legs) in combination with PT (second leg) in the LMA is presented on Table 2, for both national cycling strategy targets and routing profiles, and the socio-environmental benefits monetized in €, for a 1-year and 10-year time periods.

Shifting from car to cycling + PT can reduce annual CO_2eq emissions emissions by 11,500 to 28,500 tons per year, and the 10-year socio-environmental benefits account for €125 million to €325 million, depending on the cycling targets

The environmental impacts represent less than 2% of the socio-environmental benefits (in value) from replacing car trips to bicycle in first-and-last legs. For the PT segment, we did not estimate the social impacts from substituting car trips, although its health benefits would not be as high as shifting to cycling.

The emissions of CO_2eq that are avoided during both the initial and final journey segments account for about 74% of the emissions avoided during the PT

Table 2. Summary of the avoided CO2eq emmissions (ton/year) and the estimated social and environmental benefits (monetized in thousand €) by replacing car trips with cycling in combination with PT.

Target	Routing	Avoided CO2eq (tons)	SE Benefits 1yr (k€)	SE Benefits 10yrs (k€)
4%	safe	11 551	14 380	127 534
4%	direct	11 706	14 135	125 016
10%	safe	28 217	36 861	325 814
10%	direct	28 487	35 905	318 062

segment. This finding, while expected – due the zero cycling emissions, should not be overlooked when promoting the PT use. Improving the safe accessibility to PT interfaces to cyclists and providing bicycle-friendly amenities such as parking facilities can potentially lead to a higher reduction in CO_2eq emissions, compared to a scenario where individuals shift from car travel to car + PT combination.

Our findings show that cycling *in combination* with PT could replace 10% of current LMA trips, with an additional 6% of PT journeys prone to further substitution, based on conservative assumptions.

4 Conclusion

The information on socio-economic benefits can support policy-makers in prioritizing interventions to reduce the reliance on individual motorized transportation, and to better communicate their decisions by providing the expected avoided GHG and air pollutant emissions and the monetized socio-economic benefits for short and long terms.

The information available at *biclaR* tool – an open access website – can be downloaded and used with any GIS software. This allows users to, for example, gain insights into which potential cycling connections have the highest socio-environmental impacts, quantified in tons of avoided CO_2eq emissions, or in long term social benefits.

By making the research process publicly accessible in a code repository, this research enables the replication of similar estimates for socio-environmental impacts, resulting from a modal shift from car to bicycle in combination with PT, in other metropolitan areas.

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