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What makes and breaks active travel? A statistical model for evidence-based decision-making in transport policy for non-motorized modes

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Abstract

Promoting active travel is a promising way of mitigating the numerous negative externalities of motorized transport. However, planning and policy making in walking and cycling domains is currently rarely based on evidence thus limiting its cost-effectiveness and target achievement. We propose a largely data-driven planning approach that builds upon aggregated statistical models explaining walking and cycling modal shares through a comprehensive set of influencing factors in relevant fields such as environment, climate, infrastructure, demographic or attitudinal features. Results suggest that this approach is feasible both methodologically and in terms of its applicability in planning practice. As a first step towards evidence-based decision-making the incremental effects of individual planning measures can be simulated and thus be used to rank options according to their effectiveness. Another outcome lies in the data-driven identification of target areas for specific actions in terms of awareness, mobility behavior, infrastructure, settlement structure and other planning-relevant domains.

Keywords: active mobility; walking/cycling-determinants; statistical modeling, GIS; regional policies; transport policy; transport planning; evidence-based planning; settlement structure; accessibility; milieus, operationalization.

Disclaimer: This paper partially builds upon the work of Hackl et al. (2017) which has been presented at the REAL CORP Conference 2017. It extends the previous work through additional information regarding state of the art in research, methodology and adds the findings on a model that explains influencing factors on pedestrian shares.

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1. Introduction

1.1. Active mobility planning in Austria – a story of great plans and small steps

Increasing the share of active modes which are widely defined as consisting of walking and cycling has been an agenda for transport-related policies ever since the beginning of mass motorization. Problems that arise from the negative external effects generated along the development path of today's transport system (Merki 2008) present themselves as air-, noise and other environmental pollution, negative health effects and high accident rates as well as specific urban challenges pertaining to a lack of space (Perschon 2012). The numerous downsides of motorized traffic have been often discussed, see Buchwald, et al. (1993), Banister (2008), Knoflacher (2013) or Cervero (2013), and highlight the importance of a change in transport planning paradigms.

In quantitative terms these challenges become apparent when looking at the Austrian mobility surveys. Comparing 2013/2014 'Österreich Unterwegs' (BMVIT 2016) total shares in motorized traffic with the preceding survey in 1995 reveals that private car shares (as a driver and co-driver) increased by 6.6%. During this 21 year period, this amounts to 57.1% of total motorized traffic whereas pedestrian traffic shares dropped substantially from 26.9% to 17.4%. Cycling, featuring the lowest shares with 5.3% and 6.5% more or less stagnated[1].

In order to address the negative external effects described above, a number of policy papers with respect to active travel have been drafted in Austria: The masterplans for cycling (BMLFUW 2011; BMLFUW 2015b) aimed at boosting bicycle shares to 10% in 2015 and 13% until 2025. In contrast to those quantitative goals, the current pedestrian masterplan (BMLFUW 2015a) features no target pedestrian share. Instead its focus lies on proposing actions to prioritize pedestrian needs in newly planned settlements, awareness raising, etc. It is important to note that on both, national and federal levels, there is a general policy-emphasis on bicycle traffic. Both plans don't bear legal obligations for local planning agencies to enhance walking or cycling quality. A recent momentum regarding political commitment to walking originates from the international Charta for walking (walk21 2017). While it is popular amongst local decision makers to commit themselves to the improvement of walkability in cities and villages, there is yet no quantitative evidence that this actually results in increased pedestrian shares (rather, pedestrian share dropped significantly in the last two decades). Nonetheless some federal plans set even higher goals such as increasing active modal shares to 40% by 2035 in Carinthia (Carinthian government 2016).

On top of that, the decentralized structure of the Austrian planning system somewhat impedes coordinated actions of the federal strategies and funding programs. Since most of the legal competence for infrastructure planning is in the hands of the 2100 Austrian municipalities, planners face rather heterogeneous local premises. The main problem to be addressed is "that investments in cycling promotion are currently not always put into action where they may be most expedient, but there, where local political will is the highest" (Raffler et al. 2016) which is even more true for walking. Hence planners are confronted with increasingly difficult frame conditions: to achieve the best outcome in terms of increasing pedestrian and cycling shares, i.e. modal shift effects while at the same time being quite limited financially. This is reflected looking at the federal state of Upper-Austria and comparing planning actions (measured as number of cycling projects funded by the Austrian federal ministry of environment – BMLFUW – *klimaaktiv*) and respective cycling shares at municipality level: By looking at Figure 1 it becomes clear that current agenda setting and investment into cycling promoting measures does not reflect actual performance in terms of cycling shares. In addition to the different levels of political commitment, the weak relationship shows that the simple rationale of investing into any projects in order to boost non-motorized modal shares does not duly account for the complexity behind active mode choice and its driving forces.

In a nutshell, a general lack of knowledge about cause and effect patterns between active modes and their drivers in the respective contexts of user groups and local settings is currently impeding agenda setting and planning actions aiming at creating a substantial modal shift towards active travel. Hence, our work focuses on investigating the quantitative relationships between active modes and their respective determinants in a holistic manner.

[1] For comparability those figures refer to workdays in Autumn. The 2013/14 values for an average day of the week amount to 60,5% (motorized transport), 17,8% (walking) and 6,4% (cycling), respectively.

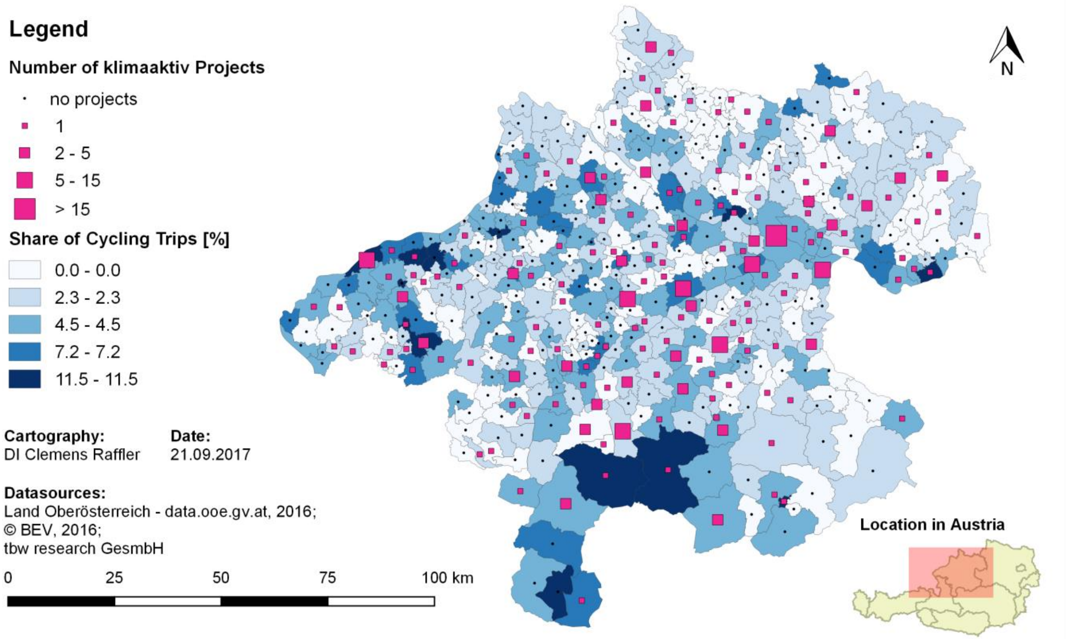

Fig. 1Comparison between the number of number of klimaaktiv projects for the promotion of cycling shares (2012)

1.2. Research as evidence based-role models: Concepts, methods and their application

International research on active mobility planning includes a broad spectrum of papers aiming at remedying the above planning problems by suggesting decision support to planners and political stakeholders. This is led by the concept of evidence-based planning as the main rationale for planners and policy makers (Faludi 2006). This approach originates from Western-European planning culture (Davoudi 2006) and can be found in papers from the UK and the Benelux-States. The paradigm is to better understand the factors that influence the respective mode-choice which then can be used as scientific evidence in the planning process. This is particularly true for research in the cycling domain and was best reflected by Heinen et al. (2010): *"In order to be able to develop sound policies that encourage cycling, it is essential to understand what determines bicycle use."* The main rationale behind investigating the determining factors of active travel is to reveal the relevant mechanisms planners may need to address in order to positively influence the development of active modal shares (e.g. changes in infrastructures, accessibility, network topology, social structures, etc.) (Parkin et al. 2007b). Another key advantage of a solid evidence base on active mobility is that funding activities can be focused on where they will provide the biggest return in terms of modal split increases, hence tackling the problem of uncoordinated (or even ineffective) initiatives (Raffler 2016). Similarly to the Austrian planning culture, an emphasis on cycling-related research can be observed at the international level. Papers on pedestrian traffic do not focus on planning support, rather they tend to have a health science perspective (eg. Leslie et al. 2005; Cerin et al. 2009; Verhoeven et al. 2016). Hence they do not explicitly propose results that are designed for the use in active planning processes; nevertheless they have an indirect implication for planning activities.

From a methodological point of view, influencing factors can generally be identified by performing simple, mono-causal correlational analyses (Leslie et al. 2005) or by setting up more sophisticated models using regression techniques. There are two main approaches (Aoun et al. 2015; Parkin et al. 2007a):

- *Aggregated models* (1) estimate walking or cycling modal shares from census or survey data at the administrative level of municipalities or origin-destination flows. Those models don't reflect individual behavior but investigate the impact of a local administrative area's properties (eg. infrastructural, socioeconomic, etc.) on active mode shares. Most approaches achieve this by estimating the impact of the respective municipal configurations applying slightly adapted OLS regression techniques as shown by Rietveld, Daniel (2004) (2004), Parkin et al. (2007b), Vandenbulcke et al. (2008), Pucher, Buehler (2006) and Cerin et al. (2009). Due to the aggregated perspective, those models are sometimes used in strategic planning contexts.
- The second approach comprises *disaggregate models* (2) which reflects the probability of choice to participate in active mobility at the individual level. The individual's preferences to walk or cycle are obtained by the collection of data on stated- or revealed individual preference. For statistical modeling, mostly binary logistic regression approaches are used. The practical application of these models is to explore and identify individual properties (e.g. socioeconomic status) that influence active mode choice

and therefore encourage bicycle promotion among specific groups. For examples, see Wardman et al. (2007) or Heinen et al. (2013).

Besides the purely scientific development of data-driven decision support, it is essential to ensure their actual application in practical planning in order to make evidence-based planning effective in the real world. This is currently rarely reported in international research. Results are often discussed in terms of general advice for practical planners, as in Rietveld, Daniel (2004) or Vandenbulcke et al. (2008). Rare references to the direct use of models in planning can be found in Parkin et al. (2007b) whose model was used for the enhancement of bicycle accessibility for the 2012 Olympic Games in London and the UK Highway Agency. The recent work of Lovelace et al. (2017) further lowers the barrier of implementing mathematical constructs in planning processes: The suggested *Propensity to Cycle Tool* provides easier access to decision support for planning-affiliated stakeholders via web-mapping applications. While there is a great deal of research investigating British, Dutch, Belgian or American contexts of active travel, there are currently no such comprehensive models for Austria. National decision support approaches are currently somewhat limited in their thematic and spatial views on active mobility as there exist only two approaches in federal states Vorarlberg and Tirol building upon accessibility analyses (Verracon GmbH 2016; Tyrolian Government 2014). Accessibility may be one of the most important determinants but it is safe to say that it doesn't resemble the only relevant factor of cycling and walking. Moreover, such mono-causal approaches may neglect other important (nested) co-influencing factors that need to be addressed by evidence-based policy. On top of this national decision support systems are currently not considering pedestrian traffic at all. Both issues call for novel approaches aiming at supporting active mobility planning in a systematic manner.

1.3. Aim of this research: a deeper understanding of spatial variation of active travel

In face of the various challenges limiting success for active mobility planning in Austria (heterogeneous political commitment, lack of knowledge about cause and effect patterns, uncoordinated actions, lacking consideration of walking), this paper aims at providing the scientific basis in order to tackle some of these problems. We build a comprehensive aggregated modeling framework for active travel modes (one each for walking and cycling) with a spatial focus on Upper-Austrian municipalities. The models examine the cause and effect patterns behind the spatial variation of active travel shares by investigating the quantitative links between active mobility and spatial, infrastructural and social influences. Based on a dedicated pool of hypotheses we devote special attention to the transparent operationalization of influencing factors. With this we aim at answering questions such as whether or not there are widely applicable generic concepts for increasing active modal shares or whether plans rather need to be custom-made for each municipality. In the latter case we aim at guiding planning by identifying the most promising fields of action and target population groups as well as estimating the potential effects of the planned measures. On this basis we establish links to real-world planning practice by laying out elements applicable for decision support and as an aid for discussion. Summing up, this paper aims at contributing to the internationally scarce research on the determinants of walking and sheds light on the discussion of heterogeneous model results in cycling travel. Against the national backdrop, both models are the first holistic and evidence based approach to aid active-mobility planners in achieving the best outcome considering their somewhat limited budget.

2. Data and Methods

2.1. Data

A crucial step predating the model building process is the choice and collection of appropriate data for the aggregate mode choice models. In order to operationalize active modal shares at the local level of municipalities we acquired data from the traffic survey of the state of Upper Austria which was conducted in October 2012 (Government of Upper Austria 2014). Although this decision narrows the spatial focus of our research through the exclusion of the other eight federal states from the analysis, Upper Austria is one of the few states that feature nearly every element of the heterogeneous Austrian spatial structure (eg. alpine regions as well as rural forests, hills, urban and semi-urban zones) and provides a reasonable sample-size of municipalities. Also Upper Austria currently holds a unique position as it is the only Austrian federal state to provide complete data on modal shares on the municipality level.

Modal shares for a total N of 444 municipalities are based on person-specific trips (specified by mode and trip purpose): numbers of trips were projected and statistically weighted in order to correct for sample bias. Active mode shares were calculated as the respective proportions of walking and cycling trips and the total number of reported trips per municipality. In order to secure a sound 95% confidence interval of the modal shares, we excluded municipalities where the number of interviewed persons was less than 200. (see Table 1, filtered). Also, we used the unweighted number of reported trips to weight cases (municipalities) when calibrating the regression models so to give relatively more weight to more robust values in the outcome variable. Those actions do not harm the models' representativeness but rather remove modal share values based on a weak empirical foundation. Related issues pertaining to the confidence levels of the non-motorized modal shares impeded a further differentiation of the models in terms of trip-purposes. Though initially planned this would have asked for substantially larger sample sizes of the mobility survey and was therefore skipped. The descriptive statistics presented in table 1 show that Upper Austrian walking shares at the municipality level are considerably larger than cycling shares.

Table 1. Descriptives of the Upper-Austrian active mode shares by municipality (Hackl et al., 2017)

mode	model-type	N [municipalities]	mean [%]	min [%]	max [%]	SD [%]
walking	unfiltered	444	11.46	0.71	32.48	4.8
	filtered	338	12.21	3.32	32.48	4.83
cycling	unfiltered	444	3.55	0	21.4	2.70
	filtered	338	3.88	0.25	17.47	2.6

Walking and cycling shares range between 0.7% and 32% and 0% and 21%, respectively. They exhibit a substantial right skew resulting from a far from normal distribution[2]. Removing municipalities with less than 200 surveyed persons reduces N by 106 while slightly increasing the mean values for both modes. Also, some of the extreme values on the outer limits of the distribution have been excluded due to the filtering. Following the trend in the national travel survey, walking shares in Upper Austria are generally higher than cycling shares (no zero-share municipalities, higher maximum and mean values) but feature a similar statistical distribution.
Alongside these traffic data numerous additional data sources have been tapped including the thriving Austrian OpenData Initiative (data.gv.at) which was used to describe local spatial, infrastructural and socioeconomic properties and hence to form model covariates. Datasets range from spatial information from the national Graph-Integration-Platform (GIP) and OpenStreetMap (OSM), digital elevation models and population density rasters, demographic and socioeconomic data by Statistics Austria as well as data on social milieus from INTEGRAL Markt- und Meinungsforschung. Weather and climate-related information was sourced from ZAMG (Zentralanstalt für Meteorologie und Geodynamik). Some data was directly obtained from representatives of the Upper Austrian state administration.

2.2. Methods

Our research approach was guided by structuring the model building procedure in four major steps (see fig. 2). Driven by literature, we first (1) specified three groups of influences that are known to have an effect on non-motorized modal choice: *spatial, environmental and climate, infrastructural and demographic/socioeconomic (including commitment of the communal decision-makers)* influences, hence to manage and structure a potentially vast amount of covariates. In a second step (2), we formulated hypotheses on the expected impact direction and strength of theoretical indicators that could be assigned to one of the three factor groups. The third working step (3) was focused on the operationalization (data acquisition, geospatial and mathematical modelling, econometric techniques) of the variables that built upon the data sources in the previous section. Figure 2 lists the main highlights of the third working steps output variables. The fourth and last step of analysis (4) constituted the statistical inference process and the formulation of multivariate regression models to predict non-motorized modal shares as the outcome variable on the municipality scale.
The following section gives a brief overview by determinant category over the 700+ variables that were gathered and computed in the course of this research. We will describe variables listed in figure 2 in more detail as those were built devoting advanced methodological attention in ways not yet presented by international research on active mode share modeling. The main tools that were applied in the variable-forming process include GIS (ArcGIS, QGIS and PostGIS) as well as the statistical software package SPSS for the data management, processing, testing and inferencing model formulations.

[2] The mean modal shares among Upper Austrian municipalities should not be mixed up with the overall Upper Austrian shares which amount to 14.6% for walking and 5.1% for cycling, respectively.

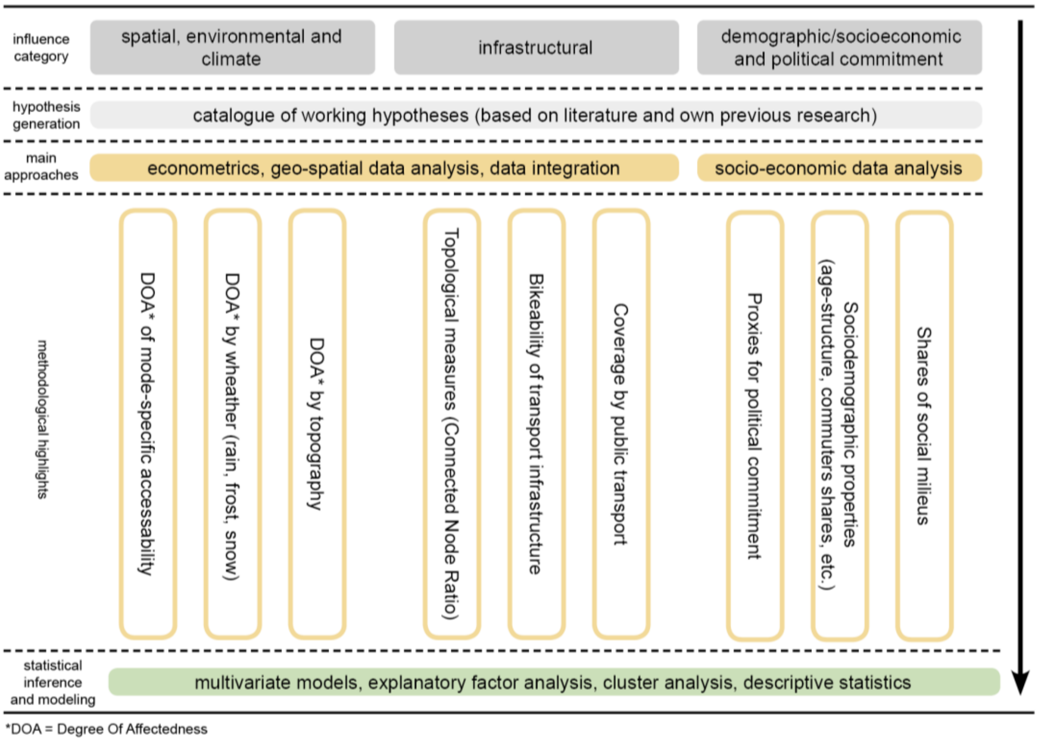

Fig. 2 Overview of workflow (Hackl et al., 2017; extended)

Spatial and environmental determinants:

When looking at the variable configurations of existing research, spatial and environmental determinants have always been a core element when investigating active mode choice. This group of factors includes determinants that can be characterized as slow-changing factors: settlement structure and various ‘static’ environmental characteristics that cannot directly be influence by planners (relief, climate). Secondly, a broad set of accessibility indicators resembling determinants that can be (directly or indirectly) influenced by planning decisions:

(1) The calculation concept for the accessibility covariates follows an extended version of the *density-based intra-zonal and external distance estimation* approach by Kordi et al. (2012): Local/regional walking, cycling and driving distances and times from the cells of a 250m population density grid to different categories of trip destinations (e.g. health services, social infrastructure, shopping) were computed using network analysis. In order to obtain a single aggregated accessibility value per municipality we used the population of the origin raster for the calculation of a weighted mean of all possible route configurations in a municipality. The population density raster provides the necessary information for the calculation of a so called degree of affectedness (DOA) of municipal population by mode specific accessibilities (see fig. 2) and was also utilized for other environmental variables.

(2) The second focus of the accessibility analysis was the reflection of *mode specific characteristics of accessibility*. Our approach integrates attributes from different data sources (number of lanes, lane-speed, cycling-infrastructure from GIP and OSM, etc.). To further reflect realistic impedance for both active modes in an alpine country like Austria, we considered street-slopes according to a 10m digital elevation model that was geographically matched to the street network. We calculated the arithmetic ratios between non-motorized travel time and its motorized pendant in order to realistically capture the rationale behind travel-time acceptance for motorized households. Access to public transport was operationalized by calculating the mean *distances to stations* by using raster based cost-path analysis. This type of routing algorithm works with traversable raster surfaces rather than road graphs. The choice for this approach was specifically related to the fact that a traversable raster surface is more suitable to model the walking or biking accessibility to public transport: They better reflect the nature of a pedestrian’s pathfinding to stations as they allow more direct routing than a graph-based approach (Graser 2015).

(3) Weights were attached to the trip-destinations of routes in order to take into account the *relative importance* of a destination (eg. visiting frequencies for pharmacies, schools, grocery stores, supermarkets, etc.) and size of their target groups. This was accomplished by adding a literature-based list of demand factors and empirical findings on target groups.

(4) Approaches related to above step (1) of the accessibility analysis were applied for the operationalization of

environmental variables. Examples are determinants that reflect climate (e.g. number of snow cover days, frost, etc.) or topography as a *DOA* of local population. Although topography is mostly considered as a negative impedance in active travel – especially in cycling (Raffler et al. 2016) – it can also be interpreted as scenically valuable. We therefore included measures by applying state-of-the-art slope- and ruggedness-index analysis through the use of GDAL algorithms.

Infrastructural determinants:
Determinants reflecting infrastructural conditions play a crucial role in this research, as they can be directly addressed by planning actions and local/regional development plans. We calculated measures describing the local topology of the road network following the approach of Tresidder (2005): Those are represented by municipal *Intersection Density* (arithmetic ratio between connecting nodes and the total municipal network length/settlement area) as well as the *Connected Node Ratio* (arithmetic ratio between the number of connecting nodes and all network-nodes in a municipality). Those variables describe the permeability of the municipal road network as these can influence the enjoyment and comfort of local active trips through more direct routes. Walkability and bikeability reflects mode-specific time advantages as well as the convenience and scenic quality of cycling routes. In order to operationalize these features we included the density of cycle tracks, the share of traffic-calmed streets or the density of traffic accident hotspots at the road graph level. This was particularly challenging as the data sources GIP and OSM comprised unstable and incomplete information on cycling and walking infrastructure at the time of the data acquisition. .

Demographic and socioeconomic factors and political commitment:
This group of covariates aims at characterizing the social dimension of local premises for active travel pertaining both to population and decision-makers. Demographic and socioeconomic factors have frequently been a major point of discussion in the context of research on non-motorized traffic (Goodman, 2012; Heinen et al, 2010). We extracted several variables from census-based surveys which include aggregate measures on demographic structures, household structure (e.g. mean household size), age groups, education, car ownership or purchase power per person/household through the application of socio-economic data analysis. A more sophisticated view on local mind sets was provided by variables on social milieus (local shares of Sinus-milieu groups) that cluster population according to lifestyles and attitudes (milieus include conservatives, hedonists, or performers, etc.). Further methodological emphasis was devoted to the operationalization of local political commitment to support active modes. For a comprehensive overview on the related variables see Hackl et al. (2017).

Regression model
We derived multivariate regression models aiming at identifying the relative importance of the determinants on the spatial variation of both active-travel modes at the scale of Upper Austrian municipalities. The outcome variable (share of walking/cycling trips in all trips in a municipality) and the regression coefficients comprise the matrix of the municipalities' characteristics in the independent variables or covariates. The final set of independent variables was derived iteratively from a pool of 700+ candidate variables adopting a hierarchical scheme of model selection and a set of complementary tests and procedures. As sample size is relatively small (338 municipalities after applying the filter) the possible number of predictor variables is somewhat limited. However, with up to 17 variables in the pedestrian model and up to 23 predictor variables in the bicycle model, the upper value following Green (1991) in minimum sample size is 234, which is well exceeded. As a guiding principle we were aiming at combining several individual variables to form combined indicators (at the time being this is the case for composite accessibility or landscape scenic quality variables) wherever feasible in order to reduce the number of covariates while increasing their explanatory power. Starting off by testing the inclusion of a basic set determinants (largely based on previous research) which were force-entered into the regression model we continued to include thematic sets of additional variables in stepwise modes (both backward and forward) in order to check for incremental improvements by adding new predictors to the equation. Each step was checked in terms of theoretical plausibility and accompanied by applying statistical tests (e.g. checking for multicollinearity or suppressor effects) so not to leave crucial modelling decisions to purely statistical criteria or let them be unduly influenced by random sampling variation. For each model variant we tested for autocorrelation (independent errors) and heteroscedasticity – both tests signalized their absence.

3. Results

Table 2 shows the main statistical results from the current pedestrian model[3]. Overall, the model explains 77,5% of the variance in pedestrian shares among Upper Austrian communities. The outcome variable is the pedestrian modal split in Upper Austrian municipalities. The determinant variables are labelled according to their respective

[3] Our research comprises models for both walking and cycling; See Hackl et al. 2017 for a presentation of the cycling model results.

factor group (see 2.2) by prefixes ENV, INF or POP, respectively. It shall be noted that while from a planner's viewpoint the focus is clearly on variables that can actually be influenced by planning actions (e.g. relating to infrastructure, behaviour, awareness) it is nonetheless crucial to include other variables in order to cover all relevant determinants as comprehensive as possible and to control for the respective effects while explaining the corresponding variance proportions in the regression outcome variable. Omitting these controlling covariates one would run the risk of falsely attributing non-related parts of variance in *y* to planning-relevant variables while they are in fact due to other factors (potentially non-controllable by planners such as weather or topology). In order to duly compare the effects of individual determinants on pedestrian shares one should consult column β containing the standardized coefficients. The large positive value for the composite variable on walking accessibility to various POIs confirms the hypothesis that compact settlement structures and relative proximity to basic amenities is a key requisite for walking (ENV_composite_acc_pot walking). This is also partly reflected by the effect of 'INF_share_urban_environment' expressing the share of land use category 'urban' along the municipal road network indicating that urban environments are in general more pedestrian-friendly. In a similar vein the share of out-commuters in the local workforce exhibits a negative effect of walking shares. The positive sign of the climate variable 'ENV_no_snow_cover_days' indicates a potential swap of modal choice during the snowy season as the same variable shows a negative sign in the cycling model.. A part of regular cyclists is switching to walking mode in case weather conditions appear unsafe or discomforting for cycling. With respect to policy relevant factors the weighted (according to type of PT) distance to public transport access points is an important predictor suggesting that the availability of adequate public transport is encouraging walking when controlling for other relevant factors.

Table 2. Pedestrian model coefficients, standardized coefficients, t-statistic, significance and correlation with pedestrian share (**p<.001, *p<.005)

Variable	B	ß	t-statistic	Sig.	correlation with y
Constant	-0.338	-	-248.841	0.000	-
ENV_composite_acc_pot_walking	0.0022	0.594	316.332	0.000	0.730
ENV_no_snow_cover_days	0.0008	0.272	308.277	0.000	0.032
ENV_landscape_scenic score	0.0089	0.054	72.098	0.000	0.177
INF_distance_PT_weighted	-2.02E-05	-0.127	-172.589	0.000	-0.210
INF_share_connected_nodes	2.5619	0.066	55.570	0.000	0.523
INF_share_urban_environment	0.0758	0.313	181.514	0.000	0.680
INF_relative_prob_accidents	-0.2328	-0.008	-11.471	0.000	0.016
POP_no_klimaaktiv_pop	0.0082	0.082	124.273	0.000	0.108
POP_share_pop_o_65y	0.0016	0.072	49.474	0.000	0.490
POP_share_pop_u_15y	0.0028	0.076	72.223	0.000	-0.398
POP_share_educ_university_lvl	-0.0012	-0.085	-44.637	0.000	0.379
POP_dummy_klimabuendnis	0.0037	0.027	37.668	0.000	0.256
POP_part_time_rate_men	0.0017	0.080	105.880	0.000	0.305
POP_share_milieu_adaptive_pragmatic	0.0047	0.212	169.723	0.000	-0.411
POP_share_milieu_post_material	0.0114	0.421	234.423	0.000	0.279
POP_share_milieu_traditional	0.0043	0.261	138.970	0.000	-0.269
POP_share_out-commute	-0.0005	-0.124	-89.936	0.000	-0.609
R	0.880				
R^2	0.775				
R^2_{adj}	0.775				

With respect to population and political commitment it can be concluded that certain features of the local population (such as relatively high shares of both older and young people; 'POP_share_pop_o_65y' and 'POP_share_pop_u_15y') as well as relative high shares of specific social milieus (adaptive pragmatic, post-materialistic or traditional) contribute to walking. In general terms milieu variables tend to have a substantial explanatory power for walking shares. To a slightly lesser degree the same is true for the proxy variables reflecting political commitment at the municipal level ('POP_no_klimaaktiv_pop', 'POP_dummy_klimabuendnis'). Finally, the relative probability of accidents and the share of third-level education in the local population have negative effects on walking shares while a high share of part-time employment among the male workforce is positively impacting walking shares. Those findings are in line with theoretical considerations (in particular when controlling for social milieus). Note that some variables show a reversed sign in the regression model compared to the direct (zero-order) correlation with the outcome variable. While this could be a potential causer for concern, it can be made plausible by considering that the inclusion of other predictors controls for several effects that are confounded in a zero-order correlation but split across dedicated covariates once they are included in the model. To quote an example, the share of tertiary-level education among the local population has a positive zero-order correlation with walking shares. However, once we control for attitudinal features through the inclusion of social milieu variables ('POP_share_milieu', etc.) the impact of high education levels on walking shares reverses. By contrast, *traditional* milieu shares are over-represented in settlement structures typically associated with low cycling shares (suburban regions, regions with agricultural land use, etc.). Once some of these effects are controlled for (through the inclusion of composite accessibility variables), the model results show that – other things being equal – attracting *traditional* population will actually help increasing the local pedestrian share.

Decision support and measure simulation

Our research is guided by aiming at outcomes that can actually be implemented in planning processes and agenda setting. Thus we need to come up with approaches dedicated to translating raw statistical model results into planning practice. As a first component of a decision support system for the Upper Austrian federal state government we developed 'active travel potential maps' such as presented in figure 3 for pedestrian traffic. Methodologically these maps are based on analysing the model residuals produced by the above aggregate models. As not the whole variance in modal shares could be accounted for in the models (and hence by the covariates included therein) there are model residuals: a positive residual indicates that the subject municipality has a higher modal share than could be expected given the local premises (environmental, infrastructural, social & attitudinal, etc.). Reversely, a negative residual can be found in areas that could potentially achieve higher active modal shares if they made best use of the local conditions. Put differently, they underachieve when it comes to active mobility. As a planning tool the maps are currently being used as a means to support strategic decisions related to the extension of the Upper Austrian cycling promotion programme fahrradberatung.at.

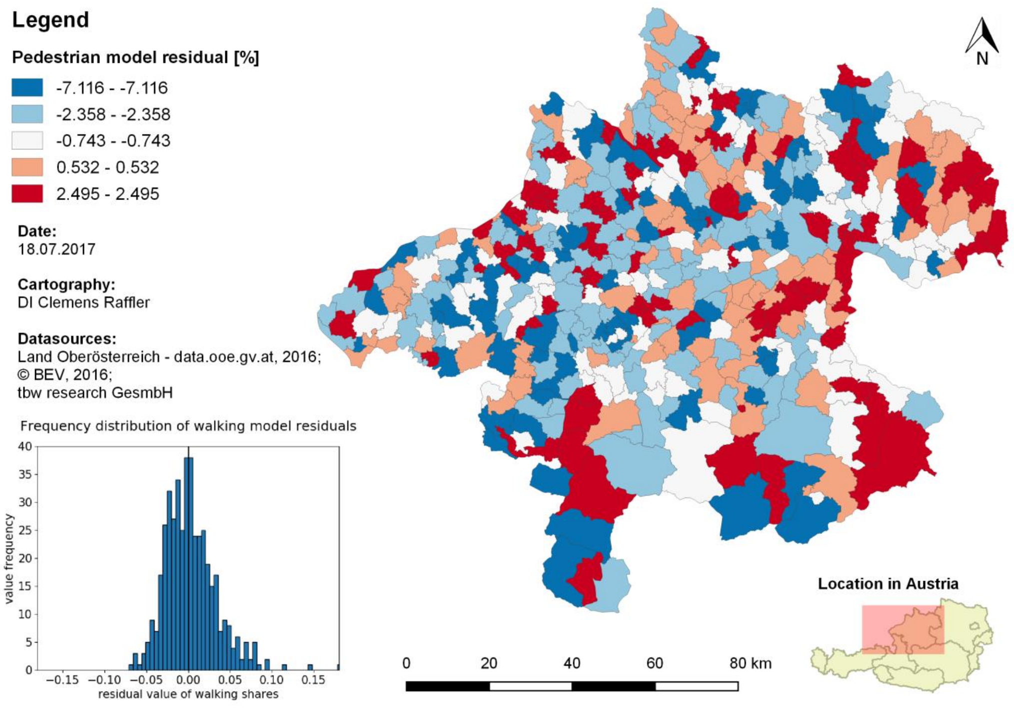

Fig. 3 Map of walking-model residuals and their statistical and spatial distribution
Negative residuals = large unused walking-potential | Positive residuals = best use of local walking conditions

From a planning perspective the areas displayed in red mark target municipalities that are likely to produce the highest return on investment in terms of pedestrian modal shares while municipalities displayed in blue mark target regions with a potential to balance out Upper Austrian disparities in walking shares (however, at the price of reduced incremental return of investment). A second element of supporting decisions in active travel planning comprises the simulation of potential measures in terms of their expected impact on pedestrian or cycling modal shares prior to their implementation. This can support planning, e.g. by prioritizing potential measures subject to their impact or target achievement. Measure simulation is facilitated by using the above models, adequately interpreting coefficients and entering modified values (according to the planning measure to be assessed) into the model equations. It should be noted however, that the measurement scale and dimensionality of the covariates as well as whether or not they are composite variables largely determine the way model coefficients need be interpreted in this context. Single variables measured on a metric percentage scale are most straightforward in terms of interpretation whereas composite variables or non-dimensional measurement scales require some preparatory work when simulating planning actions. To quote an example, increasing the share of post-materialists in the local population (e.g. by specifically attracting respective households through housing schemes, city marketing, etc.) by 10% will increase the pedestrian modal split by 1,1% (while other things are kept equal). By contrast, the composite walking accessibility variable coefficient can be generally interpreted as increasing walking accessibility to relevant destinations will boost walking modal shares. However, since the measurement scale is non-dimensional the exact impact simulation of improving accessibility needs to be based on a re-calculation of the respective indicators after changing the path network and / or its attributes reflecting the respective measures in the GIS model.

4. Conclusions and outlook

At this stage our work has demonstrated that aggregated statistical models for active travel modes are methodologically feasible and that data-driven methods can actually be used to support planning and agenda setting. First results prove that a considerable proportion of the observed variation in walking and cycling modal shares can be explained by multivariate regression models including on a comprehensive set of covariates. The added value of our research lies in providing a systematic approach to model active mode shares on a municipal level in Austria laying the foundations for evidence-based decision making in the walking and cycling domain. Our current model framework is capable of simulating the modals-shift effects of various policy-relevant and planning-relevant variables at local and regional levels.

That being said, we are aware that considerable research tasks lie ahead. Aiming at making our approach highly relevant for practical planning, widening its scope of application and improving the reliability of the model results future research threads include both methodological aspects and developing implementation tools, respectively. In terms of improving the models we aim at including additional predictor variables by forming composite variables or factors. Another research goal lies in including non-linearity and saturation effects as well as in adding variables on infrastructural qualities that were unavailable at the time of building the models. Broadening the statistical basis by re-calibrating the model with data from other regions, both national and international (facilitated by a dedicated data interoperability concept) is regarded key in terms of making the model results even more generalizable and robust. In terms of transferring model results into planning practice we aim at developing a set of tools including an expert system in order to make our approach workable for external experts in the planning domain. This includes various interfaces for planning-relevant model input data as well as coherent ways of presenting model outputs to the target groups.

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