Effects of Bicycle Facility Provision on Mortality Prevention and GHG Reduction: Cost-Benefit Analyses within the BICY Project

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***Abstract*—**Cost-benefit analysis (CBA) has been conducted to examine the estimated effects of the provision of new bicycle infrastructure in a range of cities in Central Europe, based on results of the BICY Project. In particular, anticipated reductions in greenhouse gas (GHG) emissions, and all-cause mortality (as found with WHO Europe's HEAT tool) are presented here. The key finding: investing in bicycle infrastructure is strongly anticipated to return benefits valued at many times the initial investment, magnified by rapid action. A range of policy actions are considered.

***Keywords*—**bicycling, infrastructure, cost-benefit analysis, CBA, HEAT, health impact assessment, HIA, active travel, bicycle transportation, transport economics, life expectancy, transport policy.

I. INTRODUCTION

ANALYZING the justification for bicycle facilities has been a vexing goal for generations.

As early as 1977 the literature shows earnest efforts [1].

The complexity of the inquiry, coupled with a lack of large-scale studies, and a shortage of real-world environments in which to base such studies, made such analyses difficult until recently, despite ample anecdotal and theoretical indications that bicycle facilities provide great benefits.

The concern that bicycling might be so risky as to negate any health benefits through countering health risks continues to this day, in fact even the cost of the "insecurity felt" by bicyclists has been tallied [2]; however, recent studies have formed a solid argument to the contrary; in 1992 the British Medical Association the health benefits of bicycling outweigh the risks [3] by as much as 20:1 [4]. A recent health impact analysis of predicted mortality in Barcelona, limited to traffic incidents and air pollution, found that an increase in bicycling would save lives: not only bicyclists would fare better, but all residents would, due to reduced air pollution; the benefits of a shift to bicycling were greater than those of shifting to public transport [5]. The literature is now complete enough to include powerful studies conducted in major cycling cities allowing predictions across many cities [6]-[8].

These and many more studies consistently find that the benefits outweigh the risks; for example a recent major review focusing on the Netherlands, an area where cycling is relatively very well understood, found "on average, the estimated health benefits of cycling were substantially larger than the risks relative to car driving for individuals shifting their mode of transport" [9].

A relatively comprehensive effort at CBA for bicycling has been conducted by the City of Copenhagen, Denmark, the West's leading bicycling city along with Amsterdam, where it was found that on balance, society received 1.22 Danish Kroner (DKK) for each km of bicycle travel, while losing a net 0.69 DKK for each km traveled by private automobile [10]. This is emphasized in Fig. 1, below. Copenhagen has further published a guide to its CBA [11].


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Economic Benefits

+ 1.22

- 0.69

Jason N. Meggs: *Cycling Priorities in Sweden.* Stockholm, Sept. 26, 2012

This project implemented via the Central Europe Programme co-financed by ERDF

Fig. 1 Visualization of CBA as found by the City of Copenhagen.

Some thematic areas where, at least in theory, benefits of bicycling might be demonstrated via CBA analysis include:

- Economic benefits, both local and national
- Environmental benefits, including reduction of air and noise pollution, and wildlife protections
- Worker productivity
- Social benefits, including community cohesion
- Mental health and intelligence benefits
- Emissions reductions, including greenhouse gas (GHG) reductions

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These benefits should only increase as bicycling increases, for an array of reasons including the expected “Safety in Numbers” effect [12], whereby the risk to each cyclist is would be reduced with each additional cyclist, thus promising exponentially increasing, rather than linear, returns.

Unfortunately there is only limited data, and few studies are available, for most of these thematic areas, despite the theoretical basis that major benefits to individuals and society would be found, and externalities are not always easy to monetize. However, it is possible to study some or all of these benefits, and more.

A. Potential to Estimate Carbon Emissions Reductions

Because GHG emissions are relatively easy to quantify, of the topics listed only reductions in GHG emissions which may intensify anthropogenic climate change, are addressed here, along with the use of the HEAT tool for CBA.

An ambitious EU goal of 10% CO2 reduction from the transport sector by 2020 has been put forth, with additional future targets [13]. Cycling can help to achieve this goal: “if levels of cycling in the EU-27 were equivalent to those found in Denmark, bicycle use would help achieve 12 to 26% of the 2050 target reduction set for the transport sector, depending on which transport mode the bicycle replaces”[14]. Investments in cycling can reduce carbon emissions [15].

Although carbon reduction gains from bicycling might be relatively small in light of targets, large levels of bicycling could in theory provide substantial GHG reductions, particularly if coupled with other measures compatible with supporting and augmenting a bicycling society, such as localization of food and goods production, and simply conservation and curtailment, in a wide array of potential cases.

B. Health Economic Assessment Tool (HEAT) Calculations

New research [6]-[9] formed the basis for a succession of versions of the Health Economic Assessment Tool (HEAT), produced by the World Health Organization (WHO) of Europe beginning in 2007 and continuing to the present day.

The tool is available as an online web interface [16] which seeks to be “as easy as possible to use” with accompanying Methodology and User Guide [17] and home websites [18]. The HEAT team was very responsive to inquiries and provided a special unpublished Excel version of HEAT to assist the BICY Project in its analyses.

The HEAT tool predicts the effects on all-cause mortality for persons ages 20-60, based on changes in the rates of walking and bicycling, in combination with a relative Risk (RR) which for bicycling was taken as 0.72 [9]. Subsequently it produces a cost-benefit estimate over time, depending on a wide array of inputs.

This prediction method requires preliminary predictions for anticipated changes in rates of walking and/or bicycling. Such modeling was made possible by methods developed in the BICY Project [19].

C. BICY Project Predictive Models

The BICY project has been a comprehensive effort designed to identify and implement measures that would best increase cycling across Central Europe. The project included a data collection and analysis phase intended to inform successful policy-making. Funded by the European Regional Development Fund (ERDF), and spanning seven of the eight countries in Central Europe (all but Poland), the BICY project has resulted in a complementary array of approaches and results which like the HEAT tool are extensible to additional places.

This work presents the low-cost analysis framework developed for the BICY project, a framework that allows a deeper understanding of the cycling situation within and between cities, enabling researchers and policy-makers to reveal important findings and make further progress on increasing cycling.

The BICY Project’s scientific team, based at the University of Bologna, provided such a method that could in turn be combined with the HEAT tool for Cost-Benefit Analysis.

Efforts to establish norms for data collection in bicycle transport research [20] led to the BICY survey methodology [21] which in turn produced a series of predictive tools [22] available for use in this inquiry.

After conducting intercept surveys in 14 cities in Central Europe (target n>=1500) and analyzing a variety of data sources, including official indicator data cross-validated with OpenStreetMap online spatial analysis resources, a surprisingly strong linear relationship was found for response to investment in bicycle facilities.

Bicycling was found to increase in direct linear proportion to the length of bikeways provided per capita ($R^2 = 0.916$ for cities larger than 100,000 in population, $R^2 = 0.891$ for towns smaller than 100,000; see Fig. 2).

For this purpose, bikeways are defined as any facility intended exclusively for travel by bicycle and similar means of conveyance (e.g., bicycle paths, bike lanes, and cycle tracks).

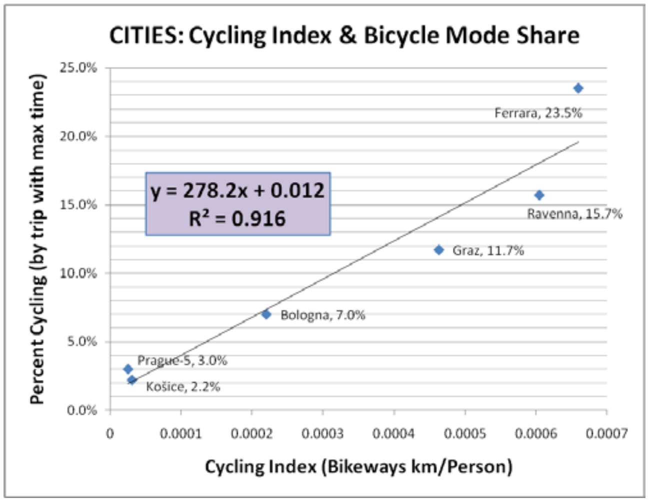


Fig. 2 Correlation, bicycling with infrastructure (bikeways/person) for cities larger than 100,000 in population.

The rate of increase was larger for cities with greater than 100,000 in population (slope 278.2, versus 158.0 for smaller places; Y-intercepts 0.012 and 0.020 respectively), thus promising more “bang for the buck” when investing in cities. Although the highest data point of the study was 23.5%, data for several Swedish cities was consistent up to 40.0% (Fig. 3).

Note that Stockholm as reported here presents the largest aberration from the linear relationship, with lower bicycling levels than anticipated. Bicycling levels are thought to be suppressed in Stockholm by the competing availability of high quality public transport coupled with unpredictable extremes of wet and cold weather that can discourage bicycling.

However, an independent researcher has just reported that bicycling has increased 50% in recent years, citing the economy and new initiatives as some of the factors. If so, the linear fit would be even stronger ($R^2 = 0.949$), with Stockholm falling almost exactly on the line. (Swedish cities were considered due to an invitation for a BICY presentation to Members of Parliament [23].)

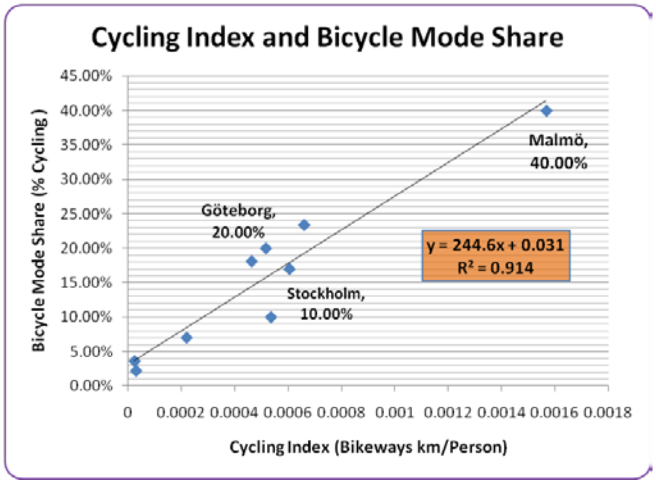


Fig. 3 Correlation, with three Swedish cities included.

The strength of these relationships may have been possible to describe here in part due to the uniformity of the data; bicycle data is notoriously inconsistent and often simply unavailable. Consistency and comparability of results is one great benefit of the BICY methodology. In addition, the data used (population, and length of facilities) is some of the most reliable available. The BICY survey in turn provided an unusually uniform measure of the amount of bicycling.

II. METHODOLOGY

A. Target Cycling Levels

It is safe to say there’s no upper limit for bicycling goals, however the theoretical maximum of 100% is considered impossible, as walk trips and longer trips are essential in human behavior; targets represent minimum short-term goals to rapidly increase cycling to the levels that can and must be attained. In general, the myriad benefits of bicycling continue to accrue as bicycling increases, although some benefits may be exponential, some linear, and some may find maximums or even reductions at varying levels; disadvantages of bicycling such as conflicts with pedestrians can also be argued by case.

Many targets have been adopted by policy and even by law in recent years. The Charter of Brussels, 2009, was signed by at least 36 cities, including BICY partners Graz and Ferrara, along with Budapest, Brussels, Ghent, Milan, Munich, Seville, Edinburgh, Toulouse, Bordeaux, Gdańsk, Timisoara, and more [24]. The Charter commits the signatories to achieve at least 15% of bicycling modal share by 2020, and calls upon European institutions to do likewise. Other commitments have included 10% by 2010, and 20% by 2020 [25]. Twenty percent by 2020 is also a leading EU goal for climate change reductions [26]. These are arbitrary targets borne of the political process and ripe with poetry. In contrast, in the context of the BICY Project, a range of real-world target bicycling levels can be generated based on projections of reasonable results expected from interventions. From these, cost-benefit analyses may be performed.

In this paper, maximum targets average 50% based on the calculations detailed below in Methodology (Section II). Although a 40% bicycling might be more realistic, due to that being the maximum observed value consistent with the model when including Swedish numbers, and in considering maximum levels for the top western bicycle cities (e.g., Copenhagen, average of 36% 2006-2010 [27]), higher figures are possible and indeed, it is noteworthy that Copenhagen has adopted a target that by 2015, “at least 50% will go to their place of work or education by bike” [27]. The official levels for Copenhagen and Amsterdam are already nearing 40%, for Copenhagen, with Copenhagen reputedly achieving 55% of trips by bicycle in the center [28]. Groningen, Netherlands, is a special case with reportedly nearly 60% trips by bicycle as of 2009 [29],[30]. Upper limits are unknown and would vary by place and circumstance; historic European bicycle usage has been estimated to have reached even 80% in some cities [31].

There are important assumptions built into using the linear relationship described in the introduction in this manner. It is unknown whether there are additional factors which preclude any given city from reaching a maximum level. Clearly there are factors which help or hinder bicycling: topography (hills) are a discouragement, as is weather, but neither has been absolutely exclusive, for example Trondheim in Norway has cold winters and hills, yet is widely cited near 10% bicycling. However, long average distances due to lower density living may decrease the potential for biking in favor of other modes. For example, 44% of trips in the Netherlands, 37% in Denmark and 41% in Germany were under 2.5km, whereas in the United States and Great Britain, where cycling rates are much lower, only 27% and 30% were under 2.5 km, respectfully; the low cycling countries have higher levels of low density “sprawl” development [28].

It should be mentioned that the absolute potential for bicycling was found to be quite high in the course of the BICY project. Based on the survey respondents, and an analysis of distance to regular destinations, it was found that in many cities 80% or more of people were able and/or willing to complete their regular journeys by bicycle. Such high levels would clearly be a “game changer” with many implications for municipalities, but are presumed beyond the scope of this paper and so are not analyzed here. However again it should be mentioned that historic bicycle usage has been estimated to have reached such levels, and could occur in the future particularly if economic conditions and resource availabilities change.

B. Data Sources and Modeling

Each municipality in the BICY Project was queried for “Indicator Data” including cost of marked and constructed, exclusive bikeways (bicycle lanes and cycle tracks) along with a wide variety of additional data such as population demographics, roadway network characteristics, and traffic injury data. The methods used and the data are detailed in the Common Indicators Report of the BICY Project (Work Package 3.2.3) [32].

The rates of urban bicycling are calculated from the detailed mobility survey as described in the introduction, upon which the cross-sectional linear model introduced above was generated.

In terms of modeling, an alternative method to model future bicycling response to infrastructure utilizes stated preferences from the survey. Respondents expressed the conditions they required before converting to bicycle use for their regular trips. Three scenarios were generated:

Scenario 1

- Cycle ways / traffic limitations, ALL regular travel path
- Secure bicycle parking at all destinations

Scenario 2

- All of the above, and:
- Cycle hire facilities at all destinations

Scenario3

- All of the above, and:
- Bike path with sun, wind and rain protection

Whichever modeling approaches are utilized, it is important to recognize that the survey is only measuring regular trips (typically the commute, but all kinds of regular trips) and that the models are thus only predicting such regular trips. This means by definition that the estimates are an underestimate, however if assumptions are adopted, they can be extrapolated to all bicycle use for estimating all bicycling.

In fact the underestimate can be quite large; the commute trip between home and work is a relatively small fraction of overall trips, generally estimated as 20% but varying by place. For example, in all of Great Britain commuting accounts for 15% of all trips” [33]. In the USA in 1995, work trips had declined to 20% of all travel, from previously higher levels [34]. In a more focused lens, in 2009 among non-telecommuting workers, the work trip represented 42.98% of all travel by those workers on a given work day [35]. Another detailed look was found for Belgium, for example, where the commute between home and work was 21% of all trips, however it represented 35% of all travel kilometers for Flanders [36] with nearly identical figures for the comparison city of Wallonia (22.6% and 38% respectfully) while transport represents 20% of total GHG emissions in Belgium, 14% worldwide [37].

It is thus quite possible that the proportions of trips by mode will vary between cities as well as between work and non-work trips within each city, perhaps substantially, depending on many socioeconomic and other factors, and that the length of those trips also varies, independent of time. Moreover, combined trips such as commute-with-shopping trip chaining add another dimension of complexity.

Thus for purposes of CBA general and unverified estimates must sometimes be considered, and it is hoped that the BICY methodology, by asking for all regular travel (thus including school and shopping trips with work trips), will be more accurate.

The key BICY data feeding the model that feeds into the HEAT tool are: population of workers ages 20-60; population of those using the bicycle for their regular travel; total length of the bikeways network (combined, bicycle lanes and cycle tracks); and average cost of each type of bikeway.

Where there were max and min cost estimates given for a given type of bikeway for a given city, the average was taken. In some cases there was no cost estimate, so the cost was inferred from the most similar city (by country and size) available. In the case of Bologna, which was a test city for the survey, worker demographics are not yet available, so figures for Ferrara are used; Ferrara is the most similar city due to its University, however, its population is one third the size.

The 14 cities in the BICY project were split between cities in the western part of Central Europe having higher rates of urban bicycling, and cities in the eastern portion with lower rates. The intention was to facilitate knowledge exchange between New Member States and existing members of the EU. It must be noted that low and high bicycling rates can be found in some cases in both halves of Central Europe, however, they are found much moreso and in larger cities in the west, in part due to differences in historical patterns of socioeconomics.

Therefore there are two groupings for four classes of cities: low and high rates of urban bicycling; crossed with low and high population (with population 100,000 the dividing line).

Of these studied cities, two are sometimes excluded: Erfurt, Germany, due to errors in carrying out the survey methodology; for Bologna, which served as a test city, data is not adequate.

Across these four groups, a range of HEAT calculations can be carried out: for an array of target levels, as well as for an array of assumptions, discussed in the following section.

C. HEAT Methodology: All-Cause Mortality Reductions for Target Levels of Cycling

The Health Economic Assessment Tool (HEAT), developed by the World Health Organization (WHO) Europe through Project PHAN under the European Union in the framework of the Health Programme 2008–2013, is a cutting edge tool first made public in 2007, with a new release in 2011 [16] and introduced above in Section I.B. The HEAT team has been very helpful in providing support to the BICY project for the proper use of HEAT in this inquiry.

HEAT provides a framework for economic assessment of transport infrastructure and policies in relation to the health effects of walking and cycling. Recent studies form the basis.

Only regular trips are considered, and only for adults, so the effect is presumed to be an under-estimate. Investments in cycling facilities are strongly expected to increase non-regular cycling trips, as well as increasing walking.

To use HEAT with the BICY project findings, we must provide data including:

1. Current cycling levels (total number of adults making regular work trips by bicycle);
2. Future cycling levels (again, total number of adults making regular work trips by bicycle);
3. The average time spent traveling by bicycle per day, for those regular work trips;
4. The average days per year the regular bicycle commute is made;
5. Cost of the investment/intervention producing the increase in those regular bicycle work trips

The BICY Project has produced answers to those required questions:

1. Because the BICY survey has estimated the share of the population of adults who make regular work trips by bicycle, the estimated total regular work trips can be calculated, satisfying the first requirement.
2. Using any of the predictions developed (e.g., survey preferences and linear models), the effect of investments in new bikeways on cycling levels can be quantified, predicting future bicycling rates, satisfying the second requirement.
3. Because the survey asked for the time spent traveling, approximate travel times provide the average needed
4. The average number of days bicycled to work is affected by weather patterns, so the survey identified those who do not bicycle in cold and/or rain and reduced the estimated bicycling days for those bicyclists (discussed below)
5. Using the cost estimates for new bikeways as provided by partners, the final requirement, cost of the investment, may be calculated from predictive models of the infrastructure required for the change to occur.

It is important to note that the true cost of a large-scale investment, if done all at once, should be substantially lower than doing so in pieces, for many reasons (but certainly, economy of scale). Thus the above estimates are probably higher than they would be in a concerted and comprehensive effort to increase cycling quickly; moreover, doing all in one big step should allow maximum gains from the effects, by inviting maximum usage as soon as possible.

These cost calculations do not take into account the importance of promotions, incentives, and supportive programs that would help facilitate and maintain a large increase in bicycling.

The foregoing data is now ready to “plug in” to the HEAT online cost-benefit tool.

HEAT Calculation assumptions:

These figures were input to the HEAT online calculator, accepting the default assumptions for European mortality rate for each country, value of a statistical life, and for discount rate (default 5.0%) used to calculate the net present value of the investments.

For the required measure of amount of cycling in the study population, duration (average time cycled per person) was entered. This is ideal because (a) it is the direct data from the survey, and (b) it is the exact measure for the analysis. (Other options would be trips and distance.)

Time spent cycling was assumed to be 220 days per year (60% of days), to account for and exclude non-work days, holidays, weather, and other aberrations in pattern. This should be a conservative under-estimate, allowing for approximately 41 days off from cycling to work, in addition to 104 weekend days, each year. The influence of weather was further applied to each city, resulting in a unique days-per-year figure for each place.

The time spent bicycling (both the average minutes per day, and the average total days per year) are very important for HEAT calculations and certainly can vary by place. The conservative recommendation of the HEAT tool is to use 124 days/year based on observed levels in Stockholm. Stockholm bicycling is suppressed by factors such as dramatically unpredictable bad bicycling weather, and a high quality mass transport system (that is dry and warm).

A “fair weather bicyclist” ratio was generated based on the percent of regular bicyclists who said they have no experience bicycling in cold weather, AND no experience bicycling in rainy weather. This varied by place, and appears consistent with the weather conditions of those places (more people avoid bad weather in places with more unfavorable weather). A multiplier for fair weather bicyclists was chosen as 60% of the year, based on a study in Graz, Austria (one of the study cities, and geographically fairly central to the project).

From this estimate, the estimated 220 regular bicycling days was adjusted based on the 60% reduction of travel for fair weather bicyclists (estimated to ride only 132 average days per year, which is close to the Stockholm estimate). The two groups were combined uniquely for each city and for each scenario, shown in the calculations and results tables (Fig. 7-13, below).

The five scenarios chosen for illustration here were:

A. Reaching a target of 15% bicycle mode share by 2015
B. Reaching a target of 15% bicycle mode share by 2020
C. Reaching a target of 20% bicycle mode share by 2015
D. Reaching a target of 20% bicycle mode share by 2020
E. Reaching maximum theoretical potential in 10 years

Scenarios A-D: Arbitrary Policy-Based Targets

The first four scenarios (Policy Scenarios, Scenarios A-D) examine the policy positions frequently advocated for and adopted in the political framework. These are arbitrary numbers, chosen for the political process, but not based on true potential; they are an effort to step toward future potential.

By examining both the 15% and 20% targets for both a slow (8 years, from 2012 to 2020) and more aggressive approach (3 years, to 2015), policy makers might have a better understanding of the trade-offs between the different choices including the lives in the balance.

Only Eastern places were included in these calculations, with the exception of Graz (mode share low enough at 14%) which was included in the 20% calculations (Scenarios C, D). Velenje (bicycle mode share too high at 15.1%) was excluded from the 15% targets (Scenarios A,B).

Scenario E: Maximum Theoretical Potential

The last scenario (Max Potential Scenario, Scenario E), offers another approach, that of achieving a shift to bicycling as much as feasible, given realistic limits on converting existing travel to bicycling.

A scenario in which maximum potential bicycling is reached in ten years is studied for a 25-year period. This is clearly an aggressive scenario and would presumably require additional conditions to be successful (e.g., large reduction in availability of motorized personal transport, and/or large incentives and programs encouraging and facilitating such increases of bicycling).

Sources Provided to HEAT

The group of new regular adult bicycle commuters was chosen by selecting that group who previously drove and/or used public transport 30 minutes or less per day (indicating a bikeable distance), and who did not state in the survey that they would refuse to use a bicycle under any circumstances.

The time for the new bicycle commute was calculated based on the time of the existing commute, by converting. If an individual’s commute was multimodal, and both car and public transport were used, then the total time was converted to bicycle time and used only if it was less than one hour (based on the idea of a one-hour travel budget, and because a bicycle can often be more time efficient than two modes combined due to direct routes and lack of waiting, parking delays and transfers). If the total bike-converted time was longer, then only the bike-converted driving time was used.

The conversion speeds assumed were: car 25km/hr; bus 9.0 km/hr; train 13.0 km/hr; bicycle 14.0 km/hr. Walking commuters who would switch to bicycle were not included, because walking is already active transport. Further inquiry could examine whether conversion of walking trips helps or hurts overall mortality rates.

It was assumed that 100% of the increase in bicycling was due to the intervention (although in practice there can be many reasons, which may be iterative and interdependent; e.g., the evolution of a culture of cycling). In practice it would be advisable to provide a comprehensive approach to complement new infrastructure, with a commensurate investment in promotion and other services, ideally with measures to incentivize bicycling and disincentivize private automobile use. The combined cost of all measures may well be within the current cost estimates for infrastructure alone due to economies of scale; additional social and service support would come from community groups and new business initiatives, however again, the cost of support is not quantified nor is its importance determined, for purposes of these calculations. What is addressed is the apparent necessity of providing a bicycle network, given the extremely strong cross-sectional relationship found.

The time for receiving the benefits of the investment was 10 years (the recommended default) for scenarios A-D, and 25 years for the long-term maximum potential scenario. The discount rate was taken as 5.0% (the default) for A-D, although strong arguments exist for reducing it, particularly when lives are in the balance, and so this is likely an under-estimate of the true benefits. For the long-term scenario, due to the higher risk and uncertainty involved, 8.0% was chosen.

An implementation and response period of 3 or 8 years (to build the infrastructure and see its use reach a steady state) is considered possible, although aggressive in either case. However it is short enough to be true for any place committed to create new bikeways. One year is even possible for an expedient low cost network provision, leaving two more years for lifestyles to adjust to meet the three-year goal. The earlier the change begins, the earlier the benefits can begin to accrue.

The estimated costs for construction were provided uniquely from project partners in each city, based on recent municipal expenditures, and are given for both new separated cycle tracks and new painted on-road bicycle lanes (euros per km).

The cost used is the combined cost of half new bike paths, and half new painted bike lanes, representing a mix of facilities. This averaged (middle of the range) cost was chosen as most appropriate because, although cycle tracks and paths are generally preferred by society as a whole, and typically chosen in places with high levels of bicycling, the true cost of a large installation is hoped and expected to be lower than costs taken from smaller installations, particularly given demonstrated new low cost methods of rapid conversion of existing roadway space; and as a practical matter, most cities with bikeway networks mix a range of facility types . In any case, these costs are only estimates, and better data is needed, a ubiquitous truism in the world of bicycle research.

Unfortunately data on the actual mix for each city was not available for the BICY project modeling and analysis.

For the purposes of the benefit–cost calculation, total savings were calculated over the same time period as that used to calculate average annual savings (5 years).

The process is depicted in Fig. 4 and 5, below:

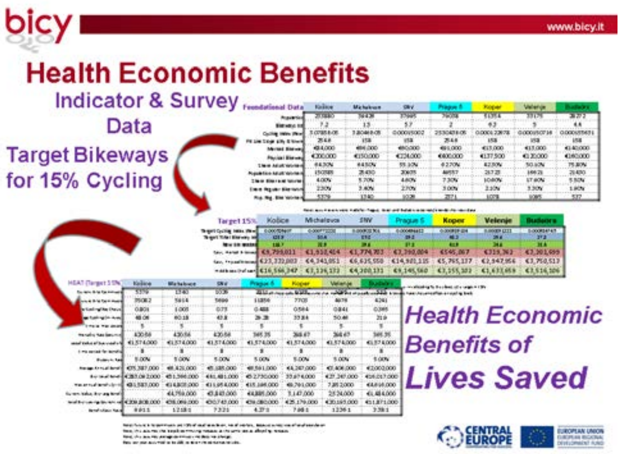
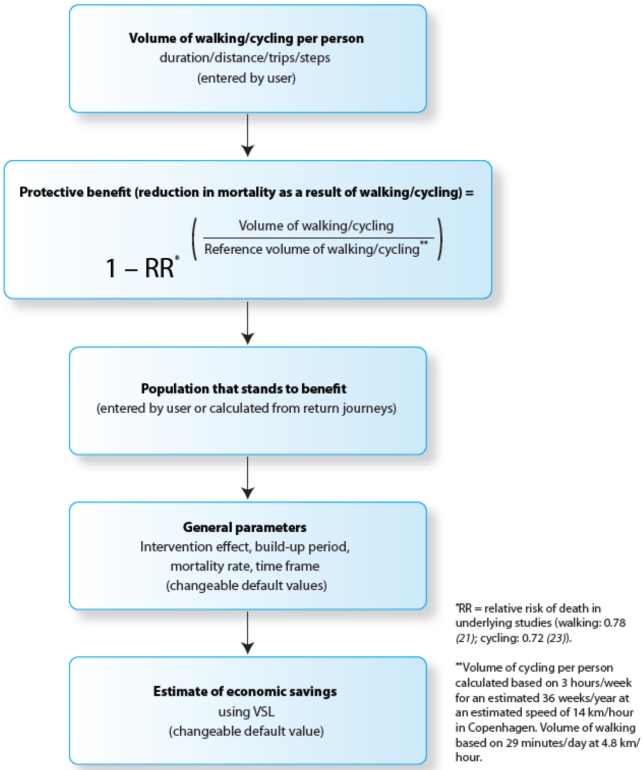


Fig. 4 Steps to obtaining the HEAT output: First basic data on bikeways, their cost, bicycle levels, working population, etc. is processed with the model; next, infrastructure needs for target levels of bicycling, and their costs, are calculated; finally, CBA output for deaths prevented (lives saved) is obtained from the HEAT calculations.

HEAT methodology includes the following major steps (Fig. 5):



*RR = relative risk of death in underlying studies (walking: 0.78 *(21)*; cycling: 0.72 *(23)*).

**Volume of cycling per person calculated based on 3 hours/week for an estimated 36 weeks/year at an estimated speed of 14 km/hour in Copenhagen. Volume of walking based on 29 minutes/day at 4.8 km/hour.

Fig. 5 Major steps in HEAT tool process.

E. Climate Change Methodology: GHG Reductions

Estimating GHG reductions via the BICY survey can be done in two primary ways: first, by estimating future bicycle use given an investment in bikeways, using the linear model; and second, by using the knowledge of what mode the respondents are using, and their stated prediction of travel behavior given investments. The latter (second) method has the advantage of knowing the original mode and time using the mode, so a more accurate initial GHG emissions profile can be generated. At the same time it has the disadvantage that it is based on stated preferences from the survey, which are by nature not validated and only collected hypothetical personal estimates by individuals. However, it is quite likely this has led to an underestimate, given that respondents may not have experienced a bicycling city with extensive infrastructure, and thus respondents may not completely infer their future preference for bicycling, were a bicycle culture to develop in their city.

A key consideration, critical for modeling future mode shares, is the competition between modes; in the BICY project it was observed that public transport and bicycling appear to compete, likely moreso than bicycling and driving [38],[39]. Arbitrary assumptions as to future modeshare must take these interdependencies into account. A model is being investigated within the BICY project, but is not available at this time; thus a range must be considered (high and low values).

The average value of avoided carbon emissions is a key element of this analysis, but disagreement and uncertainty exists over the true cost. Moreover, the cost varies by place; in one country the value might be much higher than in another.

For purposes of illustration in the case of Central Europe, a range of 17 to 100 euros is arbitrarily taken based on European carbon tax proposals, with 17 euros per ton of CO2 being the average of a tax proposal for the EU (ranging from 4-30 euros) [40], and 100 euros being based on Sweden's tax of approximately 100 euros per ton of CO2 in 2007 [41]. These sources are not to be confused with carbon markets, which are not pegged to the true cost of their externalities and can vary widely with politics and economic pressures, and in fact have been highly volatile in the EU [42]; in the EU market in particular there is a widely recognized crisis in its function [43]. Nor should these estimates be confused with the value at which effective action is taken by industry.

Similarly, there is strong disagreement over basic assumptions such as the discount rate (to estimate the value to future generations). In the USA, the central estimate of the cost of carbon has been given as $21/metric ton by the Obama administration, yet by an independent estimate, the center would be $100/metric ton with a maximum of $266 [44]. This stems from a recent study which found up to 12 times higher value of a ton of carbon than that estimated by a government government estimated "Social Cost of Carbon" (SCC) in the USA in 2010 [45] by varying the discount rate. The discount rate is a highly flawed mechanism, whose assumptions include that future generations will be wealthier and that individuals would prefer to receive benefits as soon as possible. Given the potential upheaval due to climate change, and the separation of large groups of affected individuals by place and generation, these assumptions are inherently unreliable. What if future generations are not wealthier, but in fact face more fundamental challenges due to climate change and other constraints? Indeed, it has been argued that a negative discount rate is needed for climate change calculations [46],[47].

As with all climate change predictions, it must be emphasized that the median estimate falls far short of worst-case scenarios, necessarily making this exercise a highly limited ("conservative") estimate at the outset, and even if the scenario estimated is accurate, not all externalities may have been accounted for and some may not be able to be valued. There is inherent controversy in the true value of externalities.

The life-cycle carbon emissions of a single bicyclist (on either a standard bicycle or an electric bicycle) is given as approximately 1/13 that of a car passenger, and approximately 1/5 that of a bus passenger, per km traveled, on average (approximately 21 g/km) [14]. As a life-cycle assessment, in fact this figure includes the carbon emissions embedded in the manufacture of the bicycle and emitted in the provision of the food that the bicyclist eats.

III. RESULTS

Results for both HEAT and GHG reductions follow. Full tables illustrating the data used and the results obtained for each city, for each scenario, are provided, grouped by eastern places (with low bicycling levels) and western places (with high bicycling).

A. HEAT Results: All-Cause Mortality Reductions

The five scenarios resulted in cost-benefit ratios that were highly favorable in every case. Results from each scenario, including the calculations tables, are provided below.

The reader is thus free to test these calculations and to try additional scenarios. The source data and spreadsheets which dynamically adjust to new assumptions are available from authors. Unfortunately it was not possible to obtain a dynamic spreadsheet of the latest version of HEAT, although it may be available post publication. Authors also sought to present a single formula describing HEAT, but this was not possible due to unknowns within the online model that were not available. The WHO HEAT team was very forthcoming with a large portion of the latest equations, which is due for public release.

The tables of source data, calculations and results are presented for each of the scenarios in this section.

Foundational data consists of the data obtained through the BICY project process. Data relevant to HEAT is presented for both eastern cities and western cities, in Tables I and II, respectively:

TABLE I
EASTERN CITIES FOUNDATIONAL DATA FOR HEAT TOOL CALCULATIONS

Foundational Data	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Population	233880	39426	37995	79038	51354	33175	28272
Bikeways km	7.2	1.5	5.7	2	6.3	5	4.4
meters/person	0.031	0.038	0.150	0.025	0.123	0.151	0.156
Cycling Index	3.0785E-05	3.8046E-05	0.00015002	2.53043E-05	0.000122678	0.000150716	0.000155631
Fit-Line Slope	278.2	158	158	278.2	158	158	158
Y-Intercept	0.012	0.02	0.02	0.012	0.02	0.02	0.02
Marked Bikeway	€84,000	€66,000	€60,000	€91,000	€13,000	€13,000	€140,000
Physical Bikeway	€200,000	€150,000	€224,000	€400,000	€137,500	€120,000	€160,000
Share Adult Workers	64.30%	64.50%	55.10%	62.70%	42.30%	50.10%	75.80%
Pop. Adult Workers	150385	25430	20935	49557	21723	16621	21430
Biker & Worker %	4.00%	5.70%	4.60%	7.30%	10.60%	17.90%	5.50%
Regular Bike-Work %	2.30%	3.40%	2.70%	3.00%	2.10%	3.30%	1.90%
Pop. Reg. Bike-Work	5379	1340	1026	2371	1078	1095	537
Fairweather Bikers %	33.30%	50.00%	37.50%	81.20%	63.60%	51.70%	100.00%
Average Days Biking	191	176	187	149	164	175	132

Note: assumptions were made for Prague, Koper and Budaörs to correct/provide their cost data

Note: only adult workers (age 17-59) are counted, including study (school) commuting

Days per year assumed to be 220, then modified so fairweather bikers avoid 40% of biking days due to rain and/or cold

TABLE II
WESTERN CITIES FOUNDATIONAL DATA FOR HEAT TOOL CALCULATIONS

Foundational Data	Ferrara	Comacchio	Ravenna	Cervia	Graz
Population	134464	23157	155997	28542	259038
Bikeways km	7.2	1.5	5.7	2	6.3
meters/person	0.054	0.065	0.037	0.070	0.024
Cycling Index	5.35459E-05	6.47752E-05	3.65392E-05	7.00722E-05	2.43208E-05
Fit-Line Slope	278.2	158	278.2	158	158
Y-Intercept	0.012	0.02	0.012	0.02	0.012
Marked Bikeway	€22,000	€18,500	€22,000	€18,500	€26,000
Physical Bikeway	€250,000	€200,000	€250,000	€200,000	€377,500
Share Adult Workers	55.20%	48.90%	48.10%	53.80%	53.60%
Pop. Adult Workers	74224	11324	75035	15356	138844
Biker & Worker %	4.00%	5.70%	4.60%	7.30%	10.60%
Regular Bike-Work %	5.80%	3.90%	16.10%	17.40%	14.20%
Pop. Reg. Bike-Work	7799	903	25116	4966	36783
Fairweather Bikers %	26.90%	34.60%	24.30%	65.80%	17.50%
Average Days Biking	196	190	199	162	205

Note: only adult workers (age 17-59) are counted, including study (school) commuting

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

Note, Erfurt and Bologna excluded (methodology issues/incomplete data respectively)

Calculations and results for Scenarios A-E are presented in tables, in the sections that follow.

Scenario A Results: 15% by 2015

Eastern cities' calculations and HEAT tool results for Scenario A (15% bicycling by 2015) are presented in the following tables: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables III-VI, respectively. Foundational data for eastern and western BICY study cities, used to generate the projections and cost estimates, was provided above in Tables I and II, respectively.

TABLE III
Projected Bicycling, Scenario A (15% by 2015)

Projected Bicycling	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Current Bike Mode %	2.20%	3.50%	2.50%	3.50%	6.70%	1.90%
Theoretical Potential	43.70%	31.90%	63.60%	31.90%	63.40%	20.10%
TARGET BIKE %	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%
Target Cycling Index	0.000496046	0.000822785	0.000822785	0.000496046	0.000822785	0.000822785
New v. Old % Ratio	6.82	4.29	6.00	4.29	2.24	7.89
New Work-Bikers	36677	5745	6155	10162	2414	4241
Total Work-Bikers	42056	7085	7181	12533	3493	4778
Target Bikeway km	116.0	32.4	31.3	39.2	42.3	23.3
New Bikeway km	108.8	30.9	25.6	37.2	36.0	18.9
New meters/person	0.496	0.823	0.823	0.496	0.823	0.823
Marked Bikeways €/m	€9,140,480	€2,041,982	€1,533,703	€3,385,790	€467,393	€2,640,648
Physical Bikeways €/m	€21,763,048	€4,640,867	€5,725,823	€14,882,594	€4,943,578	€3,017,884
Avg Bkwy Cost €/km	€15,451,764	€3,341,424	€3,629,763	€9,134,192	€2,705,485	€2,829,266

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE IV
Inputs to HEAT Tool, Scenario A (15% by 2015)

HEAT INPUT	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Current Work-Bikers	5379	1340	1026	2371	1078	537
Minutes Commuting	59.7	69.5	49.9	44.3	43.1	36.5
Avg Days Biking/yr	191	176	187	149	164	132
Future Work-Bikers	42056	7085	7181	12533	3493	4778
New CommuteTime	24.5	24.7	22.5	32.2	32.9	21.8
Combined Times	28.96	33.20	26.39	34.52	36.07	23.49
Years to Steady State	3	3	3	3	3	3
Yrs to Health Benefits	5	5	5	5	5	5
Mortality Rate	420.56	420.56	420.56	365.35	298.67	365.35
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	10	10	10	10	10	10
Discount Rate	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide. All eastern countries' mortality rates 2009

TABLE V
HEAT Results, Scenario A (15% by 2015)

HEAT RESULTS	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
AVG Annual Benefit	€33,826,000	€5,112,000	€5,135,000	€8,115,000	€1,760,000	€3,344,000
TOTAL BEN (10yr)	€338,259,000	€51,116,000	€51,352,000	€81,147,000	€17,598,000	€33,437,000
Max Ann Ben (yr 9)	€52,443,000	€7,925,000	€7,962,000	€12,581,000	€2,728,000	€5,184,000
Cur Val, Avg Ben/Yr	€24,099,000	€3,642,000	€3,659,000	€5,781,000	€1,254,000	€2,382,000
Cur Val, Total (10yr)	€240,995,000	€36,418,000	€36,586,000	€57,814,000	€12,538,000	€23,822,000
Benefit-Cost Ratio	15.60:1	10.90:1	10.08:1	6.33:1	4.63:1	8.42:1

TABLE VI
Lives Saved And Cost/Life, Scenario A (15% by 2015)

LIVES SAVED	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Lives Saved/Year	33.32	5.03	5.06	7.99	1.73	3.29
Cost / Life (1 yr.)	€ 463,738.42	€ 664,299.07	€ 717,344.40	€ 1,143,203.00	€ 1,563,864.25	€ 859,959.22
Cost / Life (10 yrs.)	€ 46,373.84	€ 66,429.91	€ 71,734.44	€ 114,320.30	€ 156,386.43	€ 85,995.92
Cost / Life (25 yrs.)	€ 18,549.54	€ 26,571.96	€ 28,693.78	€ 45,728.12	€ 62,554.57	€ 34,398.37

Scenario B Results: 15% by 2020

Eastern cities' calculations and HEAT tool results for Scenario A (15% bicycling by 2020) are presented in the following tables: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables III-VI, respectively. Foundational data for eastern and western BICY study cities, used to generate the projections and cost estimates, was provided above in Tables I and II, respectively.

TABLE VII
Projected Bicycling, Scenario B (15% by 2020)

Projected Bicycling	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Current Bike Mode %	2.20%	3.50%	2.50%	3.50%	6.70%	1.90%
Theoretical Potential	43.70%	31.90%	63.60%	31.90%	63.40%	20.10%
TARGET BIKE %	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%
Target Cycling Index	0.000496046	0.000822785	0.000822785	0.000496046	0.000822785	0.000822785
New v. Old % Ratio	6.82	4.29	6.00	4.29	2.24	7.89
New Work-Bikers	36677	5745	6155	10162	2414	4241
Total Work-Bikers	42056	7085	7181	12533	3493	4778
Target Bikeway km	116.0	32.4	31.3	39.2	42.3	23.3
New Bikeway km	108.8	30.9	25.6	37.2	36.0	18.9
New meters/person	0.496	0.823	0.823	0.496	0.823	0.823
Marked Bikeways €/m	€9,140,480	€2,041,982	€1,533,703	€3,385,790	€467,393	€2,640,648
Physical Bikeways €/m	€21,763,048	€4,640,867	€5,725,823	€14,882,594	€4,943,578	€3,017,884
Avg Bkwy Cost €/km	€15,451,764	€3,341,424	€3,629,763	€9,134,192	€2,705,485	€2,829,266

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE VIII
Inputs to HEAT Tool, Scenario B (15% by 2020)

HEAT INPUT	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Current Work-Bikers	5379	1340	1026	2371	1078	537
Minutes Commuting	59.7	69.5	49.9	44.3	43.1	36.5
Avg Days Biking/yr	191	176	187	149	164	132
Future Work-Bikers	42056	7085	7181	12533	3493	4778
New CommuteTime	24.5	24.7	22.5	32.2	32.9	21.8
Combined Times	28.96	33.20	26.39	34.52	36.07	23.49
Years to Steady State	8	8	8	8	8	8
Yrs to Health Benefits	5	5	5	5	5	5
Mortality Rate	420.56	420.56	420.56	365.35	298.67	365.35
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	10	10	10	10	10	10
Discount Rate	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide. All eastern countries' mortality rates 2009

TABLE IX
HEAT Results, Scenario B (15% by 2020)

HEAT RESULTS	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
AVG Annual Benefit	€21,043,000	€3,180,000	€3,195,000	€5,082,000	€1,095,000	€2,080,000
TOTAL BEN (10yr)	€210,429,000	€31,799,000	€31,946,000	€50,818,000	€10,948,000	€20,801,000
Max Ann Ben (yr 9)	€52,443,000	€7,925,000	€7,962,000	€12,665,000	€2,728,000	€5,184,000
Cur Val, Avg Ben/Yr	€14,556,000	€2,200,000	€2,210,000	€3,515,000	€757,000	€1,439,000
Cur Val, Total (10yr)	€145,558,000	€21,996,000	€22,097,000	€35,152,000	€7,573,000	€14,388,000
Benefit-Cost Ratio	9.42:1	6.58:1	6.09:1	3.85:1	2.80:1	5.09:1

TABLE X
Lives Saved And Cost/Life, Scenario B (15% by 2020)

LIVES SAVED	Košice	Michalovce	SNV	Prague 5	Koper	Budaörs
Lives Saved/Year	33.32	5.03	5.06	8.05	1.73	3.29
Cost / Life (1 yr.)	€ 463,738.42	€ 664,299.07	€ 717,344.40	€ 1,134,682.23	€ 1,563,864.25	€ 859,959.22
Cost / Life (10 yrs.)	€ 46,373.84	€ 66,429.91	€ 71,734.44	€ 113,468.22	€ 156,386.43	€ 85,995.92
Cost / Life (25 yrs.)	€ 18,549.54	€ 26,571.96	€ 28,693.78	€ 45,387.29	€ 62,554.57	€ 34,398.37

Scenario C and D Combined Results for Graz, Austria:20% by 2015 or 2020

Graz, Austria is the only western city with lower than 20% bicycle mode share, thus for space efficiency and for closer comparison, the tables for Graz for both Scenario C and D are combined here (Fig. 8).

Calculations and HEAT tool results for Graz, both Scenarios C and D (20% bicycling by 2015 and 2020, respectively) are presented in the following tables: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables XI-XIV, respectively. Foundational data for eastern and western BICY study cities, used to generate the projections and cost estimates, was provided above in Tables I and II, respectively.

Note in particular the nearly doubled cost-benefit ratio for acting faster; and the additional lives saved over the timespan of the network could fill several buses.

TABLE XI
Projected Bicycling, Graz,
Scenarios C and D (20% by 2015 and 2020)

Projected Bicycling	Scenario A	Scenario B
Current Bike Mode %	14.00%	14.00%
Theoretical Potential	32.30%	32.30%
TARGET BIKE %	20.00%	20.00%
Target Cycling Index	0.001189873	0.001189873
New v. Old % Ratio	1.43	1.43
New Work-Bikers	52548	52548
Total Work-Bikers	89331	89331
Target Bikeway km	308.2	308.2
New Bikeway km	301.9	301.9
New meters/person	1.190	1.190
Marked Bikeways €/m	€7,849,983	€7,849,983
Physical Bikeways €/m	€113,975,717	€113,975,717
Avg Bkwy Cost €/km	€60,912,850	€60,912,850

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE XII
Inputs to HEAT Tool, Graz,
Scenarios C and D (20% by 2015 and 2020)

HEAT INPUT	Scenario A	Scenario B
Current Work-Bikers	36783	36783
Minutes Commuting	36.0	36.0
Avg Days Biking/yr	205	205
Future Work-Bikers	89331	89331
New CommuteTime	42.2	42.2
Combined Times	39.67	39.67
Years to Steady State	3	8
Yrs to Health Benefits	5	5
Mortality Rate	253.13	253.13
Statistical Val of Life	€1,574,000	€1,574,000
Assessment Period	25	25
Discount Rate	8.00%	8.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide.

TABLE XIII
HEAT Results, Graz,
Scenarios C and D (20% by 2015 and 2020)

HEAT RESULTS	Scenario A	Scenario B
AVG Annual Benefit	51,169,000	29,896,000
TOTAL BEN (10yr)	511,688,000	298,962,000
Max Annual Ben (yr 9)	79,331,000	74,508,000
Cur Val, Avg Ben/Yr	36,456,000	20,680,000
Cur Val, Total (10yr)	364,555,000	206,798,000
Benefit-Cost Ratio	5.98:1	3.39:1

TABLE XIV
Lives Saved And Cost/Life, Graz,
Scenarios C and D (20% by 2015 and 2020)

LIVES SAVED	20% by 2015	20% by 2020
Lives Saved/Year	50.4	47.34
Cost / Life (1 yr.)	€ 1,208,588.30	€ 1,286,709.98
Cost / Life (10 yrs.)	€ 120,858.83	€ 128,671.00
Cost / Life (25 yrs.)	€ 48,343.53	€ 51,468.40

Scenario C Results: 20% by 2015

Eastern cities' calculations and HEAT tool results for Scenario C (20% bicycling by 2015) are presented in the following tables: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables XV-XVIII, respectively. Foundational data for eastern and western BICY study cities, used to generate the projections and cost estimates, was provided above in Tables I and II, respectively.

TABLE XV
Projected Bicycling, Scenario D (20% by 2020)

Projected Bicycling	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Bike Mode %	2.20%	3.50%	2.50%	3.50%	6.70%	15.10%	1.90%
Theoretical Potential	43.70%	31.90%	63.60%	31.90%	63.40%	57.80%	20.10%
TARGET BIKE %	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
Target Cycling Index	0.000675773	0.001139241	0.001139241	0.000675773	0.001139241	0.001139241	0.001139241
New v. Old % Ratio	9.09	5.71	8.00	5.71	2.99	1.32	10.53
New Work-Bikers	48902	7660	8207	13549	3219	1450	5654
Total Work-Bikers	54281	9000	9233	15921	4298	2545	6192
Target Bikeway km	158.0	44.9	43.3	53.4	58.5	37.8	32.2
New Bikeway km	150.8	43.4	37.6	51.4	52.2	32.8	27.8
New meters/person	0.676	1.139	1.139	0.676	1.139	1.139	1.139
Marked Bikeways €/m	€12,671,379	€2,865,436	€2,255,127	€4,678,468	€678,659	€426,326	€3,893,205
Physical Bikeways €/m	€30,169,950	€6,512,354	€8,419,139	€20,564,693	€7,178,127	€3,935,316	€4,449,377
Avg Bkwy Cost €/km	€21,420,664	€4,688,895	€5,337,133	€12,621,580	€3,928,393	€2,180,821	€4,171,291

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE XVI
Inputs to HEAT Tool, Scenario D (20% by 2020)

HEAT INPUT	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Work-Bikers	5379	1340	1026	2371	1078	1095	537
Minutes Commuting	59.7	69.5	49.9	44.3	43.1	63.0	36.5
Avg Days Biking/yr	191	176	187	149	164	175	132
Future Work-Bikers	54281	9000	9233	15921	4298	2545	6192
New CommuteTime	24.5	24.7	22.5	32.2	32.9	45.4	21.8
Combined Times	27.95	31.40	25.52	34.03	35.48	52.96	23.11
Years to Steady State	3	3	3	3	3	3	3
Yrs to Health Benefits	5	5	5	5	5	5	5
Mortality Rate	420.56	420.56	420.56	365.35	298.67	298.67	365.35
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	10	10	10	10	10	10	10
Discount Rate	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide. All eastern countries' mortality rates 2009

TABLE XVII

HEAT RESULTS, SCENARIO D (20% BY 2020)

HEAT RESULTS	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
AVG Annual Benefit	€44,869,000	€6,745,000	€6,820,000	€10,884,000	€2,345,000	€1,471,000	€4,454,000
TOTAL BEN (10yr)	€448,688,000	€67,453,000	€68,202,000	€108,845,000	€23,448,000	€14,714,000	€44,544,000
Max Ann Ben (yr 9)	€69,564,000	€10,458,000	€10,574,000	€16,875,000	€3,635,000	€2,281,000	€6,906,000
Cur Val, Avg Ben/Yr	€31,967,000	€4,806,000	€4,859,000	€7,755,000	€1,671,000	€1,048,000	€3,174,000
Cur Val, Total (10yr)	€319,670,000	€48,057,000	€48,591,000	€77,547,000	€16,705,000	€10,483,000	€31,736,000
Benefit-Cost Ratio	14.92:1	10.25:1	9.10:1	6.14:1	4.25:1	4.81:1	7.61:1

Scenario D results for western city Graz, Austria, are shown separately (Tables XI-XIV, above).

TABLE XVIII

LIVES SAVED AND COST/LIFE, SCENARIO D (20% BY 2020)

LIVES SAVED	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Lives Saved/Year	44.2	6.64	6.72	10.72	2.31	1.45	4.39
Cost / Life (1 yr.)	€ 484,630.41	€ 706,158.91	€ 794,216.21	€ 1,177,386.23	€ 1,700,602.99	€ 1,504,014.62	€ 950,180.21
Cost / Life (10 yrs.)	€ 48,463.04	€ 70,615.89	€ 79,421.62	€ 117,738.62	€ 170,060.30	€ 150,401.46	€ 95,018.02
Cost / Life (25 yrs.)	€ 19,385.22	€ 28,246.36	€ 31,768.65	€ 47,095.45	€ 68,024.12	€ 60,160.58	€ 38,007.21

Scenario D results for western city Graz, Austria, are shown separately (Tables XI-XIV, above).

Scenario D Results: 20% by 2020

Eastern cities’ calculations and HEAT tool results for Scenario D (20% bicycling by 2020) are presented in the following tables: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables IIX-XXII, respectively. Foundational data for eastern and western BICY study cities, used to generate the projections and cost estimates, was provided above in Tables I and II, respectively.

TABLE IXX

PROJECTED BICYCLING, GRAZ, SCENARIOS C AND D (20% BY 2015 AND 2020)

Projected Bicycling	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Bike Mode %	2.20%	3.50%	2.50%	3.50%	6.70%	15.10%	1.90%
Theoretical Potential	43.70%	31.90%	63.60%	31.90%	63.40%	57.80%	20.10%
TARGET BIKE %	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
Target Cycling Index	0.000675773	0.001139241	0.001139241	0.000675773	0.001139241	0.001139241	0.001139241
New v. Old % Ratio	9.09	5.71	8.00	5.71	2.99	1.32	10.53
New Work-Bikers	48902	7660	8207	13549	3219	1450	5654
Total Work-Bikers	54281	9000	9233	15921	4298	2545	6192
Target Bikeway km	158.0	44.9	43.3	53.4	58.5	37.8	32.2
New Bikeway km	150.8	43.4	37.6	51.4	52.2	32.8	27.8
New meters/person	0.676	1.139	1.139	0.676	1.139	1.139	1.139
Marked Bikeways €/m	€12,671,379	€2,865,436	€2,255,127	€4,678,468	€678,659	€426,326	€3,893,205
Physical Bikeways €/m	€30,169,950	€6,512,354	€8,419,139	€20,564,693	€7,178,127	€3,935,316	€4,449,377
Avg Bkwy Cost €/km	€21,420,664	€4,688,895	€5,337,133	€12,621,580	€3,928,393	€2,180,821	€4,171,291

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE XX

INPUTS TO HEAT TOOL, SCENARIOS C AND D (20% BY 2015 AND 2020)

HEAT INPUT	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Work-Bikers	5379	1340	1026	2371	1078	1095	537
Minutes Commuting	59.7	69.5	49.9	44.3	43.1	63.0	36.5
Avg Days Biking/yr	191	176	187	149	164	175	132
Future Work-Bikers	54281	9000	9233	15921	4298	2545	6192
New CommuteTime	24.5	24.7	22.5	32.2	32.9	45.4	21.8
Combined Times	27.95	31.40	25.52	34.03	35.48	52.96	23.11
Years to Steady State	8	8	8	8	8	8	8
Yrs to Health Benefits	5	5	5	5	5	5	5
Mortality Rate	420.56	420.56	420.56	365.35	298.67	298.67	365.35
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	10	10	10	10	10	10	10
Discount Rate	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide. All eastern countries' mortality rates 2009

TABLE XXI

HEAT RESULTS, SCENARIOS C AND D (20% BY 2015 AND 2020)

HEAT RESULTS	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
AVG Annual Benefit	€27,913,000	€4,196,000	€4,243,000	€6,771,000	€1,459,000	€915,000	€2,771,000
TOTAL BEN (10yr)	€279,125,000	€41,962,000	€42,428,000	€67,712,000	€14,587,000	€9,154,000	€27,710,000
Max Ann Ben (yr 9)	€69,564,000	€10,458,000	€10,574,000	€16,875,000	€3,635,000	€2,281,000	€6,906,000
Cur Val, Avg Ben/Yr	€19,308,000	€2,903,000	€2,935,000	€4,684,000	€1,009,000	€633,000	€1,917,000
Cur Val, Total (10yr)	€193,077,000	€29,026,000	€29,348,000	€46,837,000	€10,090,000	€6,332,000	€19,168,000
Benefit-Cost Ratio	9.01:1	6.19:1	5.50:1	3.71:1	2.57:1	2.90:1	4.60:1

Scenario D results for western city Graz, Austria, are shown separately (Tables XI-XIV, above).

TABLE XXII

LIVES SAVED AND COST/LIFE, SCENARIOS C AND D (20% BY 2015 AND 2020)

LIVES SAVED	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Lives Saved/Year	44.2	6.64	6.72	10.72	2.31	1.45	4.39
Cost / Life (1 yr.)	€ 484,630.41	€ 706,158.91	€ 794,216.21	€ 1,177,386.23	€ 1,700,602.99	€ 1,504,014.62	€ 950,180.21
Cost / Life (10 yrs.)	€ 48,463.04	€ 70,615.89	€ 79,421.62	€ 117,738.62	€ 170,060.30	€ 150,401.46	€ 95,018.02
Cost / Life (25 yrs.)	€ 19,385.22	€ 28,246.36	€ 31,768.65	€ 47,095.45	€ 68,024.12	€ 60,160.58	€ 38,007.21

Scenario D results for western city Graz, Austria, are shown separately (Tables XI-XIV, above).

Scenario E Results: Maximum Potential in 10 years

Scenario E calculations and HEAT results for eastern cities are presented below: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables XXIII-XXVI, respectively. Foundational data for eastern BICY study cities, was provided above in Table I.

TABLE XXIII

PROJECTED BICYCLING, EASTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

Projected Bicycling	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Bike Mode %	2.20%	3.50%	2.50%	3.50%	6.70%	15.10%	1.90%
Theoretical Potential	43.70%	31.90%	63.60%	31.90%	63.40%	57.80%	20.10%
TARGET BIKE %	45.90%	35.40%	66.10%	35.40%	70.10%	72.90%	22.00%
Target Cycling Index	0.001606758	0.002113924	0.004056962	0.001229331	0.004310127	0.004487342	0.001265823
New v. Old % Ratio	14.78%	21.26%	19.57%	14.35%	26.80%	16.74%	18.97%
New Work-Bikers	34574	8383	7437	11342	13765	5554	5364
Total Work-Bikers	39953	9723	8463	13713	14843	6649	5901
Target Bikeway km	375.8	83.3	154.1	97.2	221.3	148.9	35.8
New Bikeway km	368.6	81.8	148.4	95.2	215.0	143.9	31.4
New meters/person	1.607	2.114	4.057	1.229	4.310	4.487	1.266
Marked Bikeways €/m	€30,961,434	€5,401,676	€8,906,656	€8,659,915	€2,795,549	€1,870,278	€4,394,228
Physical Bikeways €/m	€73,717,699	€12,276,535	€33,251,517	€38,065,559	€29,568,308	€17,264,108	€5,021,975
Avg Bkwy Cost €/km	€52,339,567	€8,839,106	€21,079,087	€23,362,737	€16,181,929	€9,567,193	€4,708,101

Formula: x2 = (y2-y1 + m*x1)/m, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE XXIV

INPUTS TO HEAT TOOL, EASTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

HEAT (Max Theor.)	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Work-Bikers	5379	1340	1026	2371	1078	1095	537
Minutes Commuting	59.7	69.5	49.9	44.3	43.1	63.0	36.5
Avg Days Biking/yr	191	176	187	149	164	175	132
Future Work-Bikers	39953	9723	8463	13713	14843	6649	5901
New CommuteTime	24.5	24.7	22.5	32.2	32.9	45.4	21.8
Combined Times	29.20	30.91	25.80	34.32	33.66	48.27	23.17
Years to Steady State	10	10	10	10	10	10	10
Yrs to Health Benefits	5	5	5	5	5	5	5
Mortality Rate	420.56	420.56	420.56	365.35	298.67	298.67	365.35
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	25	25	25	25	25	25	25
Discount Rate	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide. All eastern countries' mortality rates 2009

TABLE XXV
HEAT RESULTS, EASTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

HEAT RESULTS	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
AVG Annual Benefit	€35,543,000	€8,195,000	€6,889,000	€10,146,000	€6,556,000	€6,235,000	€4,703,000
TOTAL BEN (10yr)	€888,579,000	€204,882,000	€172,234,000	€253,643,000	€163,906,000	€155,881,000	€117,584,000
Max Ann Ben (yr 9)	€49,503,000	€11,414,000	€9,595,000	€14,131,000	€15,507,000	€8,684,000	€6,551,000
Cur Val, Avg Ben/Yr	€11,216,000	€2,586,000	€2,174,000	€3,202,000	€1,834,000	€1,968,000	€1,484,000
Cur Val, Total (10yr)	€280,398,000	€64,652,000	€54,350,000	€80,039,000	€45,839,000	€49,189,000	€37,105,000
Benefit-Cost Ratio	5.36:1	7.31:1	2.58:1	3.43:1	2.83:1	5.14:1	7.88:1

TABLE XXVI
LIVES SAVED AND COST/LIFE, EASTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

LIVES SAVED	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Lives Saved/Year	31.45	7.25	6.1	8.98	9.85	5.52	4.16
Cost / Life (1 yr.)	€ 1,664,215	€ 1,219,187	€ 3,455,588	€ 2,601,641	€ 1,642,835	€ 1,733,187	€ 1,131,755
Cost / Life (10 yrs.)	€ 166,422	€ 121,919	€ 345,559	€ 260,164	€ 164,284	€ 173,319	€ 113,176
Cost / Life (25 yrs.)	€ 66,569	€ 48,767	€ 138,224	€ 104,066	€ 65,713	€ 69,327	€ 45,270

Scenario E calculations and HEAT results for western cities are presented below: projected commuter bicycling levels; HEAT inputs; HEAT results; and predicted lives saved, including cost per life over various time frames; are presented in Tables XXIII-XXVI, respectively. Foundational data for western BICY study cities, was provided above in Table II.

TABLE XXVII
PROJECTED BICYCLING, WESTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

Projected Bicycling	Ferrara	Comacchio	Ravenna	Cervia	Graz
Current Bike Mode %	23.90%	18.60%	17.50%	28.50%	14.00%
Theoretical Potential	27.70%	33.30%	40.70%	19.00%	32.30%
TARGET BIKE %	51.60%	51.90%	58.20%	47.50%	46.30%
Target Cycling Index	0.001811646	0.003158228	0.002048886	0.002879747	0.00285443
New v. Old % Ratio	9.13%	4.29%	19.41%	7.17%	29.19%
New Work-Bikers	12270	992	30283	2046	75611
Total Work-Bikers	20069	1896	55399	7012	112394
Target Bikeway km	243.6	73.1	319.6	82.2	739.4
New Bikeway km	236.4	71.6	313.9	80.2	733.1
New meters/person	1.812	3.158	2.049	2.880	2.854
Marked Bikeways €/m	€5,200,827	€1,325,249	€6,906,240	€1,483,584	€19,060,754
Physical Bikeways €/m	€59,100,302	€14,327,016	€78,480,005	€16,038,747	€276,747,491
Avg Bkwy Cost €/km	€32,150,564	€7,826,133	€42,693,123	€8,761,165	€147,904,123

Formula: $x2 = (y2-y1 + m*x1)/m$, x1=initial CI x2=target CI, y1=initial cycling %, m=slope, y2=target biking %

Note: assumes marked v. physically separated bikeways have equal influence on bicycling

Note: Assumes future bikers proportional to new mode share (major commute mode % by max distance)

TABLE XXVIII
INPUTS TO HEAT TOOL, WESTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

HEAT (Max Theor.)	Ferrara	Comacchio	Ravenna	Cervia	Graz
Current Work-Bikers	7799	903	25116	4966	36783
Minutes Commuting	40.4	40.0	30.9	35.4	36.0
Avg Days Biking/yr	196	190	199	162	205
Future Work-Bikers	20069	1896	55399	7012	112394
New CommuteTime	35.6	39.3	38.9	39.6	42.2
Combined Times	37.48	39.60	35.30	36.65	40.19
Years to Steady State	10	10	10	10	10
Yrs to Health Benefits	5	5	5	5	5
Mortality Rate	209.25	209.25	209.25	209.25	253.13
Statistical Val of Life	€1,574,000	€1,574,000	€1,574,000	€1,574,000	€1,574,000
Assessment Period	25	25	25	25	25
Discount Rate	8.00%	8.00%	8.00%	8.00%	8.00%

Assumes that future commute patterns unchanged; existing trips converted to bicycle.

Days per year assumed 220, modified (fairweather bikers avoid 40% due to rain or cold)

New commuters' travel time converted from previous mode time (survey).

Combined future commute time is averaged from old and new groups

New commuters' time is total daily travel time converted from prev. mode, in minutes.

Mortality rate by country. Statistical value of life is EU-wide.

TABLE IXXX
HEAT RESULTS, WESTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

HEAT RESULTS	Ferrara	Comacchio	Ravenna	Cervia	Graz
AVG Annual Benefit	€8,659,000	€739,000	€23,344,000	€1,347,000	€76,934,000
TOTAL BEN (10yr)	€216,463,000	€18,476,000	€583,604,000	€33,681,000	€1,923,358,000
Max Ann Ben (yr 9)	€12,059,000	€1,029,000	€32,513,000	€1,876,000	€107,151,000
Cur Val, Avg Ben/Yr	€2,732,000	€233,000	€7,366,000	€425,000	€24,277,000
Cur Val, Total (10yr)	€68,306,000	€5,830,000	€184,161,000	€10,628,000	€606,930,000
Benefit-Cost Ratio	2.12:1	0.80:1	4.31:1	1.21:1	4.10:1

TABLE XXX
LIVES SAVED AND COST/LIFE, WESTERN CITIES,
SCENARIO E (10 YRS. TO MAX. THEORETICAL POTENTIAL)

LIVES SAVED	Ferrara	Comacchio	Ravenna	Cervia	Graz
Lives Saved/Year	7.66	0.65	20.66	1.19	68.08
Cost / Life (1 yr.)	€ 4,197,202	€ 12,040,204	€ 2,066,463	€ 7,362,324	€ 2,172,505
Cost / Life (10 yrs.)	€ 419,720	€ 1,204,020	€ 206,646	€ 736,232	€ 217,250
Cost / Life (25 yrs.)	€ 167,888	€ 481,608	€ 82,659	€ 294,493	€ 86,900

Scenario Results Summary Comparisons

When comparing the predicted value and effect of investments across Scenarios A-E, immediately evident is the penalty for waiting.

Illustrated in Fig. 13, the average cost-benefit ratio for each scenario, calculated across all cities, shows a dramatic roughly 65% higher CBA ratio for acting by 2015 rather than by 2020; and for the long-term scenario, a comparison is made between the discounted and non-discounted cost-benefit analysis.

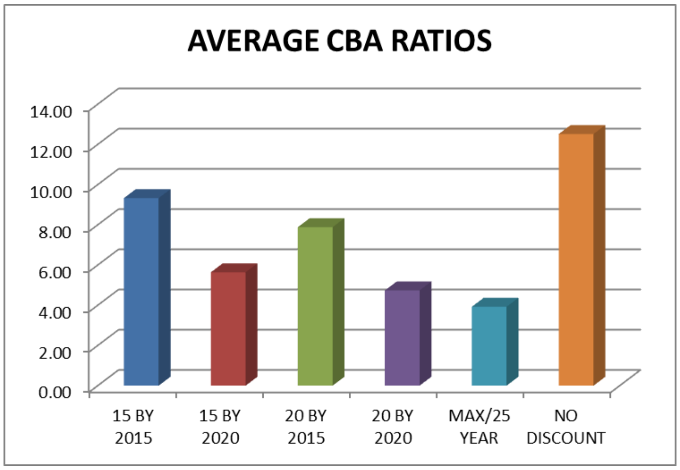


Fig. 13 Average cost-benefit ratio of each scenario, across all included cities for Scenarios A-E and for Scenario E when calculated without a discount rate. The ratio was found to be 65% higher for acting sooner (2015 v. 2020) and more than three times higher for Scenario E when no discount rate is applied.

The total savings (undiscounted) in each city, for each scenario, were calculated as follows (Table XXXI):

TABLE XXXI

TOTAL UNDISCOUNTED SAVINGS BY CITY AND SCENARIO

	SCENARIO A	SCENARIO B	SCENARIO C	SCENARIO D	SCENARIO E
	15 BY 2015	15 BY 2020	20 BY 2015	20 BY 2020	MAX/25 YEAR
Košice	€338,259,000	€210,429,000	€448,688,000	€279,125,000	€888,579,000
Michalovce	€51,116,000	€31,799,000	€67,453,000	€41,962,000	€204,882,000
SNV	€51,352,000	€31,946,000	€68,202,000	€42,428,000	€172,234,000
Prague 5	€81,147,000	€50,818,000	€108,845,000	€67,712,000	€253,643,000
Koper	€17,598,000	€10,948,000	€23,448,000	€14,587,000	€163,906,000
Velenje			€14,714,000	€9,154,000	€155,881,000
Budaörs	€33,437,000	€20,801,000	€44,544,000	€27,710,000	€117,584,000
Ferrara					€216,463,000
Comacchio					€18,476,000
Ravenna					€583,604,000
Cervia					€33,681,000
Graz			511,688,000	298,962,000	€1,923,358,000

The discounted savings for each city, for each scenario, were calculated as shown here (Table XXXII):

TABLE XXXII

TOTAL DISCOUNTED SAVINGS PER CITY, PER SCENARIO

	SCENARIO A	SCENARIO B	SCENARIO C	SCENARIO D	SCENARIO E
	15 BY 2015	15 BY 2020	20 BY 2015	20 BY 2020	MAX/25 YEAR
Košice	€240,995,000	€145,558,000	€319,670,000	€193,077,000	€280,398,000
Michalovce	€36,418,000	€21,996,000	€48,057,000	€29,026,000	€64,652,000
SNV	€36,586,000	€22,097,000	€48,591,000	€29,348,000	€54,350,000
Prague 5	€57,814,000	€35,152,000	€77,547,000	€46,837,000	€80,039,000
Koper	€12,538,000	€7,573,000	€16,705,000	€10,090,000	€45,839,000
Velenje			€10,483,000	€6,332,000	€49,189,000
Budaörs	€23,822,000	€14,388,000	€31,736,000	€19,168,000	€37,105,000
Ferrara					€68,306,000
Comacchio					€5,830,000
Ravenna					€184,161,000
Cervia					€10,628,000
Graz			364,555,000	206,798,000	€606,930,000

The discounted cost-benefit ratio, for each city, for each scenario, with an average for each scenario across all cities, were calculated as shown here (Table XXXIII):

TABLE XXXIII

DISCOUNTED COST-BENEFIT RATIO, PER CITY, PER SCENARIO

	SCENARIO A	SCENARIO B	SCENARIO C	SCENARIO D	SCENARIO E	SCENARIO E
	15 BY 2015	15 BY 2020	20 BY 2015	20 BY 2020	MAX/25 YEAR	NO DISCOUNT
Košice	15.6	9.42	14.92	9.01	5.36	16.98
Michalovce	10.9	6.58	10.25	6.19	7.31	23.18
SNV	10.08	6.09	9.1	5.5	2.58	8.17
Prague 5	6.33	3.85	6.14	3.71	3.43	10.86
Koper	4.63	2.8	4.25	2.57	2.83	10.13
Velenje			4.81	2.9	5.14	16.29
Budaörs	8.42	5.09	7.61	4.6	7.88	24.97
Ferrara					2.12	6.73
Comacchio					0.8	2.36
Ravenna					4.31	13.67
Cervia					1.21	3.84
Graz			5.98	3.39	4.1	13.00
AVERAGE	9.33	5.64	7.88	4.73	3.92	12.52

The predicted number of lives saved, for each city, for each scenario, were calculated as shown here (Table XXXIV):

TABLE XXXIV

LIVES SAVED PER YEAR

	SCENARIO A	SCENARIO B	SCENARIO C	SCENARIO D	SCENARIO E
	15 BY 2015	15 BY 2020	20 BY 2015	20 BY 2020	MAX/25 YEAR
Košice	33.32	33.32	44.2	44.2	31.45
Michalovce	5.03	5.03	6.64	6.64	7.25
SNV	5.06	5.06	6.72	6.72	6.1
Prague 5	7.99	8.05	10.72	10.72	8.98
Koper	1.73	1.73	2.31	2.31	9.85
Velenje			1.45	1.45	5.52
Budaörs	3.29	3.29	4.39	4.39	4.16
Ferrara					7.66
Comacchio					0.65
Ravenna					20.66
Cervia					1.19
Graz			50.4	47.34	68.08

The cost per life over ten years for the predicted lives saved, for each city, for each scenario, were calculated as shown here (Table XXXV):

TABLE XXXV

COST PER LIFE, TEN YEAR SPAN

	SCENARIO A 15 BY 2015	SCENARIO B 15 BY 2020	SCENARIO C 20 BY 2015	SCENARIO D 20 BY 2020	SCENARIO E MAX/25 YEAR
Košice	€ 46,373.84	€ 46,373.84	€ 48,463.04	€ 48,463.04	€ 166,421.52
Michalovce	€ 66,429.91	€ 66,429.91	€ 70,615.89	€ 70,615.89	€ 121,918.70
SNV	€ 71,734.44	€ 71,734.44	€ 79,421.62	€ 79,421.62	€ 345,558.80
Prague 5	€ 114,320.30	€ 113,468.22	€ 117,738.62	€ 117,738.62	€ 260,164.10
Koper	€ 156,386.43	€ 156,386.43	€ 170,060.30	€ 170,060.30	€ 164,283.54
Velenje			€ 150,401.46	€ 150,401.46	€ 173,318.71
Budaörs	€ 85,995.92	€ 85,995.92	€ 95,018.02	€ 95,018.02	€ 113,175.51
Ferrara					€ 419,720.16
Comacchio					€ 1,204,020.42
Ravenna					€ 206,646.29
Cervia					€ 736,232.39
Graz			€ 120,858.83	€ 128,671.00	€ 217,250.47

B. *Climate Change Results: GHG Reductions*

A detailed analysis of carbon reductions from increased cycling is beyond the scope of this report due to the many unknowns and disagreements regarding climate change, as well as the lack of complete data on carbon emissions in partner places (although partners were encouraged to provide these if available, and estimates can be made). However, given the percentage of reductions in carbon emissions predicted herein, these reductions will be substantial and significant.

A rough analysis of the annual CO2 savings from new commuter cyclists based on the 15% target generated for the HEAT calculations (above) is thus presented here (Table XXXVI):

TABLE XXXVI
VALUE OF REDUCED CARBON EMISSIONS (15% TARGET)

	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Bike Commuters	5379	1340	1026	2371	1078	1095	537
Future Bike Commuters	35082	5914	5699	11856	7703	4976	4241
Average Cycling/Day (hours)	0.801	1.003	0.73	0.488	0.564	0.841	0.365
Average Cycling (minutes)	48.06	60.18	43.8	29.28	33.84	50.46	21.9
Estimated distance/day (km)	9.612	12.036	8.76	5.856	6.768	10.092	4.38
Yearly distance (km)	2114.64	2647.92	1927.2	1288.32	1488.96	2220.24	963.6
Min value ton of CO2	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00
Max value ton of CO2	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00
Tons CO2 saved v. car/person	0.52866	0.66198	0.4818	0.32208	0.37224	0.55506	0.2409
Value car-to-bike/yr (min)	€ 8.99	€ 11.25	€ 8.19	€ 5.48	€ 6.33	€ 9.44	€ 4.10
Value car-to-bike/yr (max)	€ 898.72	€ 1,125.37	€ 819.06	€ 547.54	€ 632.81	€ 943.60	€ 409.53
Tons CO2 saved v. bus/person	0.00076896	0.00096288	0.0007008	0.00046848	0.00054144	0.00080736	0.0003504
Value bus-to-bike/yr (min)	€ 0.01	€ 0.02	€ 0.01	€ 0.01	€ 0.01	€ 0.01	€ 0.01
Value bus-to-bike/yr (max)	€ 0.08	€ 0.10	€ 0.07	€ 0.05	€ 0.05	€ 0.08	€ 0.04
New bike commuters	29702.76	4573.416	4673.385	9484.56	6624.666	3881.475	3703.632
Min annual savings over bus	€ 388	€ 75	€ 56	€ 76	€ 61	€ 53	€ 22
Max annual savings over bus	€ 2,284	€ 440	€ 328	€ 444	€ 359	€ 313	€ 130
Min annual savings over car	€ 266,945	€ 51,468	€ 38,278	€ 51,931	€ 41,921	€ 36,626	€ 15,167
Max annual savings over car	€ 26,694,524	€ 5,146,767	€ 3,827,783	€ 5,193,138	€ 4,192,142	€ 3,662,568	€ 1,516,748

Factor of 5 Estimate

Annual min, all new bicycling	€ 1,941	€ 374	€ 278	€ 378	€ 305	€ 266	€ 110
Annual maxall new bicycling	€ 133,472,619	€ 25,733,834	€ 19,138,914	€ 25,965,690	€ 20,960,708	€ 18,312,838	€ 7,583,742

Fig. 14 Table calculating estimated annual economic savings thanks to carbon reductions from an increase to15% commuter cycling resulting from investments in cycling infrastructure. Total economic equivalent for car, or for bus.

For a target of 30% bicycling, the results are (Table XXXVII):

TABLE XXXVII
VALUE OF REDUCED CARBON EMISSIONS (30% TARGET)

	Košice	Michalovce	SNV	Prague 5	Koper	Velenje	Budaörs
Current Bike Commuters	5379	1340	1026	2371	1078	1095	537
Future Bike Commuters	93552	15770	15198	31615	20542	13270	11309
Average Cycling/Day (hours)	0.801	1.003	0.73	0.488	0.564	0.841	0.365
Average Cycling (minutes)	48.06	60.18	43.8	29.28	33.84	50.46	21.9
Estimated distance/day (km)	9.612	12.036	8.76	5.856	6.768	10.092	4.38
Yearly distance (km)	2114.64	2647.92	1927.2	1288.32	1488.96	2220.24	963.6
Min value ton of CO2	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00	€ 17.00
Max value ton of CO2	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00	€ 100.00
Tons CO2 saved v. car/person	0.52866	0.66198	0.4818	0.32208	0.37224	0.55506	0.2409
Value car-to-bike/yr (min)	€ 8.99	€ 11.25	€ 8.19	€ 5.48	€ 6.33	€ 9.44	€ 4.10
Value car-to-bike/yr (max)	€ 898.72	€ 1,125.37	€ 819.06	€ 547.54	€ 632.81	€ 943.60	€ 409.53
Tons CO2 saved v. bus/person	0.00076896	0.00096288	0.0007008	0.00046848	0.00054144	0.00080736	0.0003504
Value bus-to-bike/yr (min)	€ 0.01	€ 0.02	€ 0.01	€ 0.01	€ 0.01	€ 0.01	€ 0.01
Value bus-to-bike/yr (max)	€ 0.08	€ 0.10	€ 0.07	€ 0.05	€ 0.05	€ 0.08	€ 0.04
New bike commuters	88172.76	14429.916	14172.135	29244.06	19463.166	12175.225	10771.632
Min annual savings over bus	€ 1,153	€ 236	€ 169	€ 233	€ 179	€ 167	€ 64
Max annual savings over bus	€ 6,780	€ 1,389	€ 993	€ 1,370	€ 1,054	€ 983	€ 377
Min annual savings over car	€ 792,428	€ 162,389	€ 116,078	€ 160,122	€ 123,164	€ 114,886	€ 44,113
Max annual savings over car	€ 79,242,799	€ 16,238,937	€ 11,607,829	€ 16,012,176	€ 12,316,447	€ 11,488,567	€ 4,411,306

Factor of 5 Estimate

Annual min, all new bicycling	€ 5,763	€ 1,181	€ 844	€ 1,165	€ 896	€ 836	€ 321
Annual max, all new bicycling	€ 396,213,996	€ 81,194,684	€ 58,039,144	€ 80,060,878	€ 61,582,236	€ 57,442,833	€ 22,056,532

Fig. 15 Table calculating GHG benefits for target 30% bicycling.

Because the survey allowed identifying the former mode of new bicyclists (e.g., did the new bicyclist previously use a private automobile for her or his regular trips), GHG reductions estimates were based on the change of transport mode. Estimates were generated, shown below in Fig. 16:

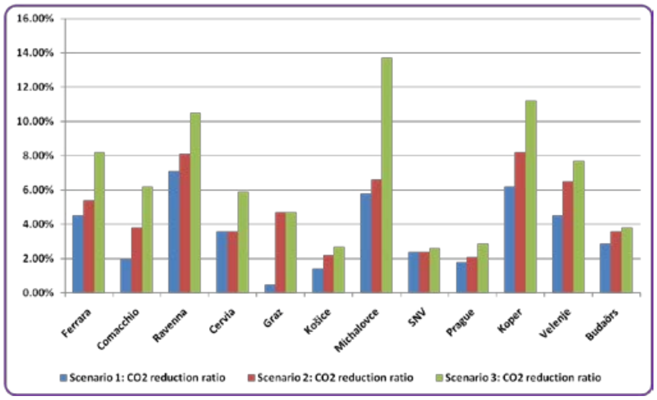


Fig. 16 GHG reductions for three scenarios based on survey stated preferences (individual prediction of behavior change given a new transport offer).

An average reduction of 3.56% in CO2 emissions was projected for Scenario 1. The maximum reduction was nearly 13.7%, for Michalovche in the Košice region, Slovakia, for Scenario 3 (in which protection was provided against weather protection; it's interesting that Michalovce receives more snow than most study areas). An analysis and discussion of the survey scenarios, including public transport scenarios, has been published [38].

II. DISCUSSION

Discussion for both HEAT and GHG CBAs follows.

A. *Predictive Methods*

Is it realistic to predict large scale increases in bicycle use due to rapid provision of a bikeway network? Certainly many cities have seen remarkable increases such as doubling or tripling of bicycle use after making investments in infrastructure and other measures [48]. Moreover, in times of extreme pressure such as energy shortfalls or economic disruption, bicycle rates can change dramatically overnight such as during the oil embargo of Cuba, or more recently, bicycling in the United States increased 15% (23% in the top 31 bicycling cities) during the price spike in 2008 [49] with additional effects seen over time [50]. During a prolonged crisis, bicycling might very well rise to the highest historical levels due to these pressures [51].

At the same time, the case histories of cities with the highest bicycle use suggest that an evolution over time occurs, involving both cultural adaptation along with physical adaptation. Surely the economy adapts as well, including land use changes such as a new distribution of shops and services, however this has not been adequately studied.

As is shown above with regard to GHG reduction, the BICY models include the opportunity to estimate the effect of additional types of investments, such as the provision of a bicycle sharing system, and the generation of scenarios such as the three detailed. However, these are based on stated preference predictions and so lack the benefit of validation. Bikeshare systems have been associated with rapid increases in places with low bicycle levels, as seen in Barcelona [47],[52].

B. *HEAT Discussion: All-Cause Mortality Reductions*

As discussed previously, the HEAT tool investigates only a limited, but powerful and important, aspect of the CBA of investment-generated increases in bicycling.

It is important to emphasize again that only regular work trips are studied here. The survey is only measuring regular trips (e.g., commuting), and as discussed above (Section II.B), the model in turn only predicts new regular adult work trips. This is only a fraction of all trips, so additional health benefits, perhaps very substantial benefits, are not included in this analysis. Limitations include:

- Only studies regular commuters, roughly ages 17-60 years (ignores majority of travel, and large groups of travelers)
- Assumed up to 8 years to build bikeways and attain target levels of bicycling for policy scenarios, 10 years for theoretical maximum scenario (1-year network build can be feasible)
- Only counted benefits for 10 years for Policy Scenarios (25 years for Maximum Potential), yet maximum benefits may be reached later, and the bikeway network benefits should continue much longer than ten years
- Only accounting for economic value of life (from “all cause mortality”) – ignoring many other benefits: health, social, economic, environmental, and more. For example, the HEAT tool does not consider prevention of disease and disability due to regular exercise.

Thus the CBA as utilized here has substantially understated the potential benefits of investments aimed at increasing bicycling.

What about the large body of bicycling behavior that is not a regular work trip? What about irregular yet frequent errands, shopping trips, and social outings? These may outweigh the work trip by many times; given the general relationship of work to non-work trips (also discussed in Section II.B), it might be an acceptable assumption to apply a factor of up to five to the magnitude of any predicted effects assigned to regular commuters, greatly amplifying what are already impressive results from this limited inquiry. However, this would be a mistake in this case (but not in other cases, in general), because HEAT is focused on the ultimate end goal, all-cause mortality. Thus, ancillary benefits of all kinds should be neatly included in its result (the reduction in mortality seen is not only for those who commute, but for the entire population, so every effect of bicycling increase, including subtle effects, should be combined in this limited question of mortality).

Underlying all these cost data are real lives saved. Taking a different perspective, rather than attempting to put an economic value on life, it is worth looking at the lives themselves, rather than the estimated economic value. Another perspective worth considering is the cost to save each life. For example, under the Policy Scenarios, for Košice, the number of deaths prevented per year was estimated to be 153.86, after a total cost of 45.296M euros.

For the single, first year, this equates to almost 300K euros per life; but over 25 years, the average cost per life is only 11,776 euros each, before considering any other benefit including other individual health benefits such as prevention of disease and disability; and improvements to overall well-being.

C. *Climate Change: GHG Reductions*

There are many assumptions required to produce these GHG reduction estimates, which could be questioned, such as what the effect will be of the amount of food and type of food a typical cyclist eats per km traveled; however, for purposes of this cost-benefit evaluation there is strong support that the overall annual benefits would be positive for a wide range of assumptions.

Although the economic values predicted can be small, they combine with other benefits to promise even more strongly that bikeways investments pay for themselves many times over. While the minimum annual value (where only bus riders, not car drivers, are coaxed onto bicycles and the minimum value of carbon is used) is only 1,153 euros for Košice city, it is nearly 80M euros for the maximum case for the same city, in the case of all new bicyclists switching from driving, using the highest value of carbon (100 euros per ton of CO2 avoided).

The ratio of minimum to maximum annual reductions is a staggering 68,750 times difference depending on whether all new bicyclists switch from the bus, or from the private car. Of course in reality this would be a mixture, and include some switching from walking as well.

The maximum values estimated may seem incredibly large, and illustrate the risk of relying on any single prediction. However, because of the great uncertainty in predicting climate change, the value of avoiding carbon emissions may have an even higher maximum than these assumptions show; avoiding carbon emissions may in fact be priceless, if all life depends on it.

As with the HEAT calculation, this is a conservative estimate and only a limited view: only commuter cyclists are considered. If we assume that the commuters considered here are only 20% of all travelers, and all trips, the overall CBA ratio improves in concert.

If adjusted to include an estimate of all bicyclists, in Košice city alone, for example, a shift to 15% bicycling would add approximately 133.5M euros in carbon benefits over ten years if all new cyclists switched from car travel. For 30%, the estimated benefit would be nearly 400M euros. This is for the already conservative method of accounting for carbon benefits.

III. CONCLUSIONS

The economics of investing in bicycle facilities are overwhelmingly supportive. It cannot be emphasized enough that the figures presented here are under-estimates. From the cost of providing a bikeway network, to the discount rate, to the limited scope of the two types of cost-benefit analyses presented, the degree of under-estimation has been very large.

The cost-benefit analyses shown here, in terms of reduced carbon emissions and the economic value of lives saved, is thus only a truncated view, and a view limited from a much larger bounty of strongly expected rewards.

These analyses already indicate that bikeways more than pay for themselves, but if the additional benefits of reduced illness; reduced noise and air pollution; reduced damage to roadways and historic buildings; myriad social benefits; and the local economic benefits from cyclists' increased spending power coupled with increased local shopping; plus a more attractive and livable urban environment and the retention of local funds from imported oil, are considered in tandem, an even more impressive and robust economic argument emerges.

The Health Economic Assessment Tool (HEAT) provides a powerful but limited longitudinal CBA for investment-generated increases of walking and/or bicycling. Very high ratios of return on investment have been demonstrated. Because only a limited view of the benefits are seen, the true benefits are likely much higher.

Similarly, in modeling greenhouse gas reductions, a very wide range was seen, depending in part on the true value of curtailing each ton of CO2, and depending on whether the new bicyclists are converted from driving, or other modes such as public transport and walking. The extreme cases are staggering in their magnitude and importance. Driving is by far the most harmful individual travel activity, so attracting drivers should be the top priority. Additional cause to consider this an under-estimate, as discussed above, is the discount rate; results are greatly affected by the rate, and its assumptions may not be valid. A negative discount rate would be appropriate for climate change, if the worst scenarios are true; for health, and lives saved, is a discount rate ever appropriate or even ethical? In any event the default rate of 5% is much higher than current economic conditions warrant, a bias here that understates the expected benefits of investing in bicycle infrastructure. When the discount rate is ignored for the long-term scenario (the most realistic scenario), the benefit ratio is magnified by three.

Are these models valid for all cities? It is important to recognize that use of the linear model may not be accurate for all cities, despite the strong linear relationship. There may be additional reasons why bicycle networks have not developed in the cities with low cycling. Many factors influence bicycling rates, including topography, weather and climate, and more. However, given the very high ratio of benefits to costs shown even for this cautious and limited inquiry, and the many examples of relatively high bicycling in places with adverse conditions, given a bikeway network, it seems very likely that an implementation of bikeways will result in higher cycling providing more benefits to society than the costs to provide them.

Can these high levels of bicycling be attained in a short time frame? Certainly this is not guaranteed; a comprehensive approach is necessary to attract high ridership. Natural limits such as congestion and fuel price spikes have strong effects, but policy actions to reduce car use where bicycling can replace it are also effective. Investment in more than just bikeways – but all the infrastructure, services and accessibility that bicyclists need to rely on a bicycle for their daily travel – must be sought as well. The leadership provided by Copenhagen and The Netherlands serves as an example of successful transport management.

It is not by chance that places with high cycling tend to fare better than neighboring places with lower cycling in a wide array of areas. An investment in bicycling has every promise of strong returns not only for the health and well-being of a place, and its people, but for the sustainability and health of its economic future as well.

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