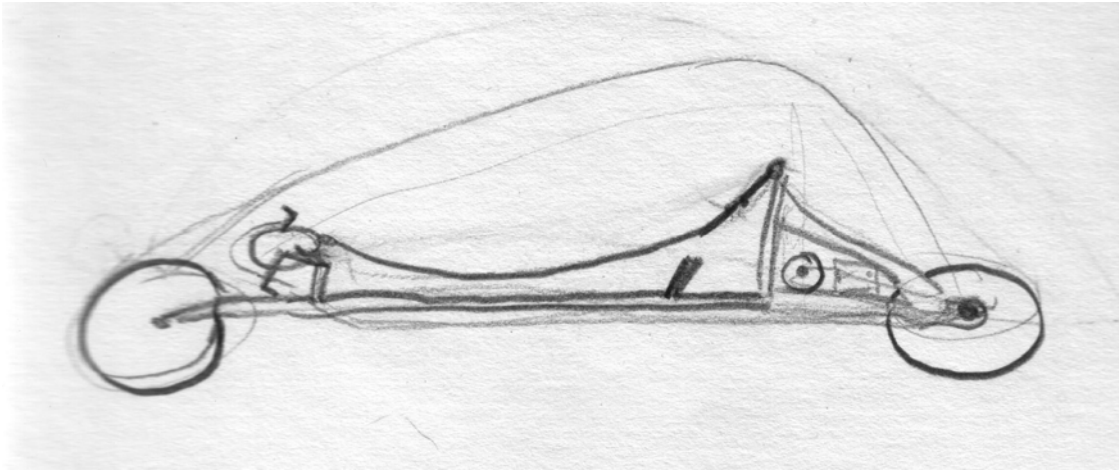


**Travel for Free:  
costs and benefits of the velomobile**



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**Long Paper prepared for  
Velocity 2007 in Munich**

**Based on research submitted to the University of East London in  
fulfilment of the thesis requirement of an MSc Architecture:  
Advanced Environmental and Energy Studies.**

**The full thesis is available from  
<http://www.porini.ca/design/travelforfree.pdf>**

## **Abstract**

A velomobile is a type of vehicle where human power is used for locomotion and where the passengers are in a more or less enclosed compartment. Though it has existed for over a hundred years as a vehicular concept, its current impact on our transportation system is minimal.

The project begins by introducing a theory that proposes a large potential role for velomobiles in our current transportation system. A useful way of perceiving that potential and barriers to achieving it is then described. Practical theories and methodologies to guide the remainder of the study are discussed and existing studies reviewed. Based on a technique for estimating behaviour change, surveys were collected from small urban and rural centres in the south of England. Data thus collected on current travel and potential for change is used to estimate lifetime emission reductions, costs and ancillary benefits.

Potential for change estimates show the velomobile to have a competitively priced emissions reduction potential for a broad segment of the population. For the modal potential user, emissions cost effectiveness is significantly better than all alternatives. Survey results show the velomobile's value to many respondents to be independent of the marginal costs of its alternative, which indicates that whether these reductions are realized is primarily dependant on the purchase price.

For many users, taking account for all the costs and benefits does result in a sort of travel for free. The velomobile has virtually no running costs and because its benefits grow with more use, their value can equal the purchase price over its lifetime. When society as a whole is considered any use has an estimate lifetime benefit of more than the purchase price, due largely to improved health and reduced noise and congestion.

The velomobile is unique for its potential to achieve many of these benefits which accrue with increased mileage rather than be diminished, as is common with most other transportation technologies. The most significant barriers to realizing the benefits include the majority of costs being borne by individuals and a lack of information and experience. A course of change is modeled to show the minimal investment needed to reduce the cost imbalance. This would realize a significant public benefit from a proven technology with a significant potential to grow once personal experiences with it are had.

The particular situation of infrastructure in the UK is judged to be significantly different to other countries where velomobiles are more common. A lack of dedicated bicycle trails suitable to velomobiles and the existence of a parallel multi-use road system in the rural south (the lanes) impacts potential use and benefits of the velomobile. In the narrow lanes the velomobile slows motorized

traffic to a pace more suitable for other non-polluting forms of travel. It is suggested that using a velomobile in the UK *takes* space for sustainable transportation, and that is a form of advocacy by itself.

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## 1. Introduction

In the U.K., as with many other parts of the world, there is a need for mobility without environmental impact. Increasingly there is also social need to make better use of the abundant energy in humans, in response to health concerns and growing obesity rates. It is difficult to convince individuals to decrease the level of comfort they are accustomed to while traveling, or to dramatically alter sedentary lifestyles. Perhaps it would be easier to look for new vehicles in which to use an abundant power source, thus approaching two problems at once.

### **Defining a velomobile**

The major characteristics of a velomobile are its

- a) using human power and
- b) having some passenger enclosure

The name velomobile is fairly new and the delineating line is sometimes contested. "The definitions vary, but it is usually understood to be fully or partial faired, human-powered and almost always three wheeled for stability."<sup>1</sup> When an engine is installed in addition to the pedals it should properly be called an assisted velomobile or power assisted velomobile<sup>1</sup>.

### ***The topic being explored***

The issue being explored is the potential environmental impact of power-assisted velomobiles, particularly in rural areas of the U.K. Among the challenges is that our question involves technology as much as human whim and fancy – sociotechnology – and we would like to relate that to measurable amounts of pollutants reduced, other benefits and the costs involved.

### **Question and hypothesis**

The questions posed by this study are

- Is the velomobile perceived as a viable alternative mode of travel by individuals in the U.K., and
- Can individuals envisage reducing their emissions by using a velomobile for some of their trips?

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<sup>1</sup> Vehicles which use human power as only part of the overall power requirements have given rise to debate about what ratio of human power to vehicle requirements defines the line separating a velomobile from an electric car. For our purposes, any vehicle without pedals regardless of the size of assist would cease to be a velomobile.

If so,

- To what extent can we expect it to reduce emissions?
- What are the potential costs and benefits?
- Can they become real?

Existing studies propose that the most significant way the velomobile could reduce transportation emissions is by replacing automobile trips by those who drive. To individuals who do not drive, the velomobile might provide increased levels of mobility. This concurrent theme considers that a portion of the population tends to have lower existing emissions and to increasingly suffer from a paucity of options for travel, particularly in rural areas<sup>ii</sup>.

If the velomobile is considered a rational alternative, it is hypothesized that the lifetime benefit to individuals and society of its use would be less than the cost, particularly the current purchase price.

At issue then is who bears the costs and feels the benefits. If individual costs do not reflect the social value of the vehicle, then strategies for optimizing any untapped potential are explored.

### **Limits of the investigation**

A wide number of sources were researched for this exercise both UK based and internationally. Some were in written papers but much information was also gathered through interviews with current velomobile owners, talks with manufacturers, future customers and the many hundreds of people encountering a velomobile for the first time while taking two velomobiles around the UK. Much of the data is necessarily qualitative approximations, and even it may at times appear precise. Figures used are rough estimates used to illustrate concepts that hopefully remain valid.

### **Structure of the paper**

The body of the full thesis is divided into seven chapters, this paper summarizes the majority of those, however the intrepid reader is advised to pursue the web link on the cover for complete information about the study. In the first chapter, the theory and methodology used throughout the paper are introduced. It is divided into conceptual and practical theories which guide and are implicit in the whole work, and practical methodologies which are applied as appropriate to the subject of the velomobile.

The second chapter of the body (chapter 3) explores existing studies, which either discuss or relate to the velomobile. In chapter 4 the process of gathering original data, primarily involving a self completed survey of public habits and

attitudes, is described and initial tests and comparisons performed are highlighted. Chapter 5 further applies the methodologies from the second chapter to relevant sections of the data collected through the survey.

The potential costs and benefits of survey participants are extrapolated based on their responses, and the values thus derived are compared to vehicles in existing studies through computer models. In contrast to these quasi-quantitative calculations, chapter 6 then takes a qualitative look at impediments and other questions posed to participants of the survey, as well as comments which arose from the process.

Returning to the most pressing barrier chapter 7 explores the question of cost, and uses a spreadsheet designed to assess the complete costs and benefits of the velomobile from public and private economic approximations. A spectrum of expected mileages are plotted and used to estimate a level of support needed to achieve actual benefits from velomobile use illustrated in earlier chapters. The approximate costs to public and private actors of this hypothetical support are estimated, then major findings are reviewed in the conclusion.

## 2. Theory and methodology

### Conceptual Theories

#### The social construction of technology

The social construction of technology is a sociological theory about technology and human action. It posits that the form of technology does not determine human action, rather that social actors shape and determine technology's form and function.

#### A sociotechnical frame

Conceived of as a plaything the bicycle and all specialty bicycles are often seen to have little role in filling the transportation needs of the UK. It has been proposed that popular conception of transportation vehicles tends to reflect an evolutionary ideal, which considers the automobile at its pinnacle. Described by Figure 2.1, the relative size and position of other alternative vehicles to the dominant car demonstrates the framework's inability to accommodate a significant role for them. Theorists have suggested that appreciating the potential of the velomobile and human power is more likely if popular conceptions about the automobile and its alternatives are reconceived, or at least bent.

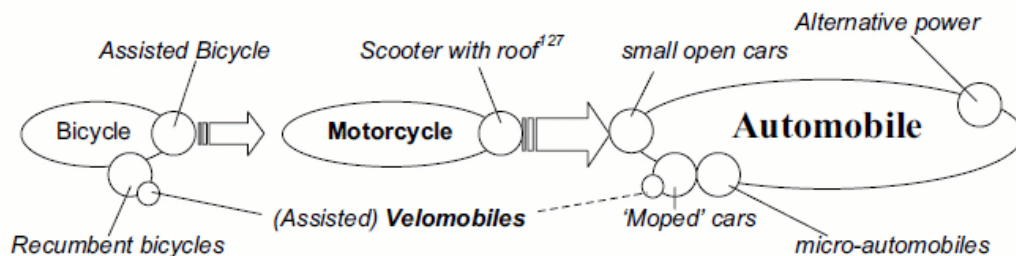


Figure 2.1 Evoliner sociotechnical frame<sup>iii</sup>

"The 'bending' is done by modifying the evoliner sociotechnical frame...with the alternative sociotechnical frame being that of the velomobile."<sup>iv</sup> This renewed frame is described as a matrix and shown graphically in Figure 2.2. The velomobile is the only vehicle in a corner without a popular and commonly understood name and is responsible for the bend. Two aspects delineate the place of vehicles in the 'new matrix sociotechnical frame': size of non-human assistance (vertical axis), and degree of enclosure (horizontal axis).

The matrix provides us with another way of looking at the whole of transportation technology, one that does not presuppose the dominance of the automobile as the logical end of technological progress. The current result of that dominance is undervaluation of non-motorized travel's potential to impact emissions. The

velomobile's marginal position in this already marginal sphere is in many ways the logical end of an evoliner framework, which implies a singular progressive direction in which to modify behaviour. The matrix shows there to be a multitude of appropriate options to fit many needs.



Figure 2.2 New matrix sociotechnical frame<sup>2</sup>

### Technological, socio-economic and market potential

The technological, economic and market potentials are a standard and useful way of assessing the environmental impact of a given technology. Used extensively by the Intergovernmental Panel on Climate Change (IPCC) and other environmental organizations in assessing new technology, its greatest strength is in providing a consistent framework and understanding of key concepts shown by Figure 2.3.

<sup>2</sup> The C5 is in the centre, next to it on the right may be its closest modern relative: the Aerorider. The Leitra is in the corner, and a partly faired windcheetah bottom centre. Top centre is a 'scooter with a roof' described in the 'evoliner frame', left centre is an uncovered version.

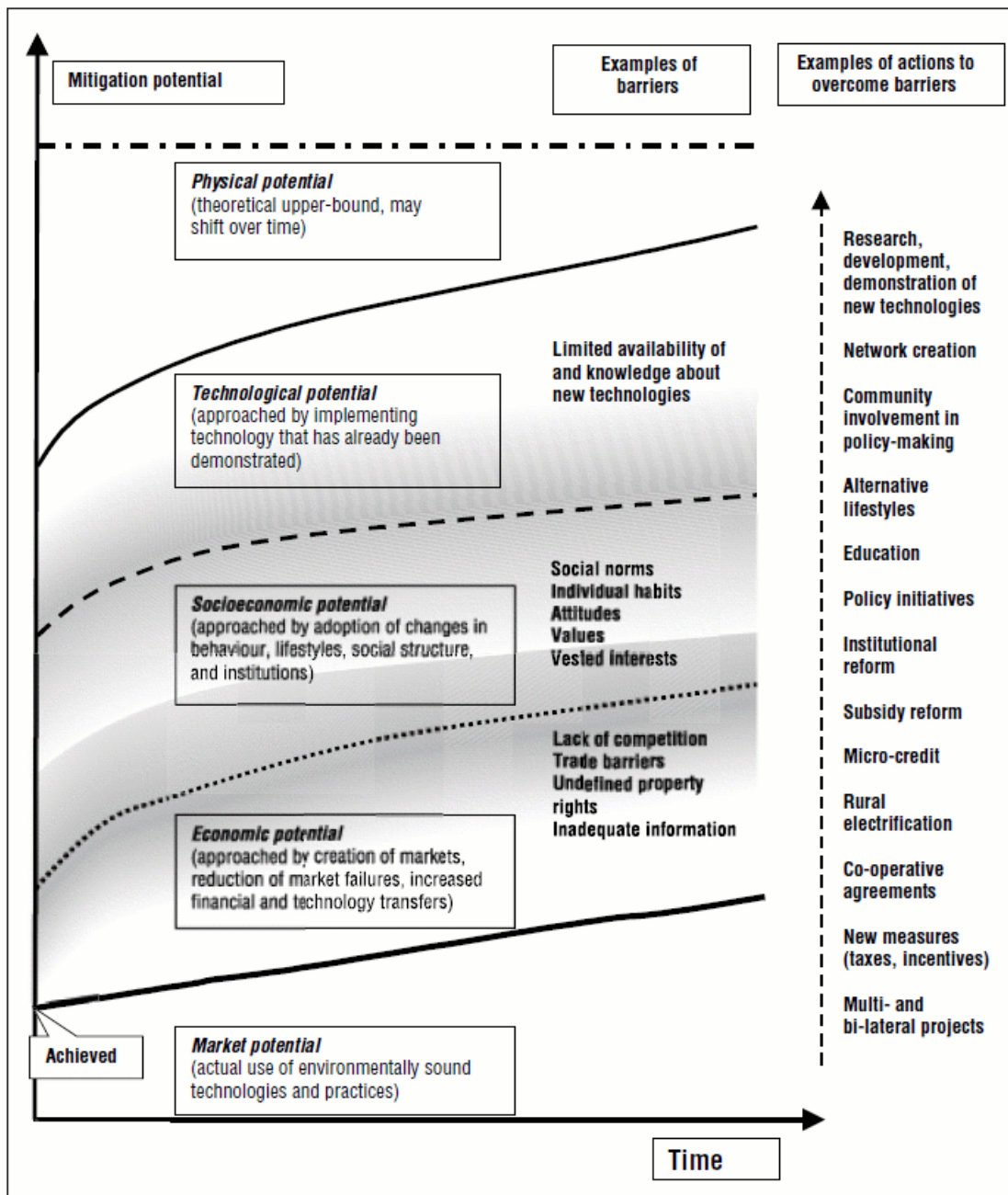


Figure 2.3 Penetration of environmentally sound technologies: conceptual framework<sup>Y</sup>

## Practical theories

### System and technological models

There are two well used methods of assessing transportation technology potential, based on the second conceptual theory. They can be classified as bottom-up (technology focussed) models and top-down (system) models.

"In the first approach, each technology is assessed independently via and accounting of its costs and savings. Once these elements have been estimated, a unit cost can be calculated for each action, and each action ranked according to its costs."<sup>vi</sup> The second approach considers a range of options and typically tries to account for some of their interactions with predicted patterns. The top down approach tends to incorporate the measures which move people away from their cars, while typical bottom-up studies tend to focus on improving the performance of cars.

The two methods and the measures they each focus on are complementary, and though there are difficulties directly comparing costs across different studies, it is possible. Of particular interest in looking at velomobiles are the benefits that top-down approaches tend to illuminate, of moving people away from automobile trips. While a technology focussed approach is the obvious choice given the subject and available resources.

### **Transportation technology**

"Reducing Congestion by Introducing New concepts of Transport" (RECONNECT) is a study performed in the EU to "identify, analyse and assess new means of transport in generic categories with particular respect to their potential to ease congestion and promote sustainable mobility." It introduces a conceptual theory as well as a practical methodology and accounting techniques for definition, focus and a resource for future studies.

### **Estimating behaviour change**

The concept of a travel emissions profile has used to estimate the potential of emissions to be altered without new technology, entirely through behavioral change. Its essence is a survey and calculation of individual emissions together with a self assessed estimate of potential change. As the velomobile is both a new technology and a behavioural change, this method is used in conjunction with technology detailed methods and systems derived values for in this study.

## **Practical Methodologies**

### **Emissions Profiling**

The emissions factor calculations incorporate a penalty for short trips along with several variables that reflect driver habits, engine, fuel, and vehicle size. Overall the emissions factor method compares well, and one of the conclusions of the study validates the ability of individuals to self estimate their current travel with fair accuracy.

## **Reconnect**

The Reconnect study introduced earlier included a methodology for future studies. In order to be able to integrate and accurately compare technology specific costs and benefits, the study draws on systems type analysis in the form of the ExternE computer model to arrive at estimates for unit pollution costs. These can then be compared to the discounted capital and operating costs over its lifetime<sup>3</sup>. Comparisons among technologies with different economic lives in the Reconnect study is accomplished by converting all the cash flows accruing over the life of an option into an annual cost.

## **Niche market analysis**

A method similar to that used by the RECONNECT study was used to assess effective technology options and market prospects of technologies in the UK by Ben Lane in his PhD on the potential and cost effectiveness of hydrogen fuel cells. Two types of analysis are employed in his study, the qualitative niche market analysis focuses the study then a quantitative analysis follows, and uses a computer model to compare the costs and emissions of a variety of new technologies. The methodology is similar in many ways to the Reconnect study, yet tailored to costs in the U.K.. It also uses lifetime costs with specific definitions, which are integrated into a computer model. In chapter 5 a copy of this model is modified to reflect the velomobile and the calculations used by the model are approximated by a spreadsheet tailored to the velomobile.

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<sup>3</sup> The reader unfamiliar with economic concepts such as discounting are referred to the appendix of the full thesis for a brief explanation along with the equations described in this section relating to the models utilized.

### **3. Existing studies**

The first chapter of the full thesis introduced two conceptual theories, and several practical theories with methodologies. From the same study as the second conceptual theory, this chapter of the full thesis begins by reviewing the prospects of the transportation sector as a whole to be a competitive emissions reduction option in comparison to other sectors of the economy. These costs then form a reference for comparisons to results obtained through this research project.

The second section of this chapter in the full thesis estimates the current velomobile market from a variety of sources. None of these are particularly authoritative, but they do tend to agree on its current small size. The last two sections of review two vehicles drawn from among a large study of transportation options performed using one of the methodologies described. One of these vehicles is a type of velomobile and their potential impact on a variety of aspects of the economy, society and the environment are reviewed. These categories are used to conceptualize the costs and benefits of the velomobiles more specifically considered by this study.

In the final study, the velomobile is explored for its future market prospects in sustainable and less sustainable scenarios, which are reported to be significant and the highest of any concept explored. This projection indicates a large technical potential in the future, and together with cost effectiveness values calculated in later chapters, shows the velomobile to be significantly different than the usual transportation projects described in the first section of this upcoming chapter.

As our conceptual theories suggest, there are a variety of barriers that could have an effect on whether the technical potential is approached. Some of these barriers are initially approached in the next chapter (4) while describing the survey of public attitudes performed, and later chapters describe others in more detail.

The reader is referred to the full thesis at the web link on the cover for the studies covered by this chapter, which have been excluded from this paper from space constraints.

## 4. Research Project

The goal of this project was an estimate of the potential environmental impact of velomobiles, particularly their emissions reduction potential through replacing automobile trips. There were several related stages to gathering original data for an estimate of the potential use of a velomobile. First hand experience and interviews began the process, followed by real estimates from U.K. residents collected in several small centres.

In order to prepare the investigation of the velomobile's socioeconomic potential and barriers, the full thesis introduced emissions profiling. This technique was developed to easily gather information and estimate the environmental potential of behavioural change to travel habits. Used and validated by an earlier Oxford based study was the process of using a self completed survey to gather existing patterns and potential, and this serves as a rough model for this project . A novel addition to the technique was two real velomobiles for participants to sit in and experience before answering the questions.

### Survey design

A survey was planned in the UK and the vehicles were brought from Denmark and the Netherlands specifically for this purpose. The survey was designed to be completed fairly fast, so that as many opinions as possible could be sampled. It was printed as a single A4 sheet in landscape orientation, in two columns and on both sides, shown reduced in size by Figure 4.1 and Figure 4.2 . The twenty seven questions collected travel estimates of several modes and required a fair bit of recollection by some participants. Multiple choice was used in the final version<sup>4</sup> to simplify the responses, but during the process it was felt that much more could have been done in this respect.

The first page of questions asked about current weekly travel patterns and an estimated percentage of trips less than five miles each way. Additional questions on the first page asked about regular exercise and demographic information. The first column of the second page asked whether the participant could use a velomobile 'if cost was NOT a barrier', for their weekly trips, and if so, what percentage of trips and which current form of travel it would replace. If not, they were asked to select from a list the reasons why not. Other questions asked about willingness to pay to own a velomobile, roads participants would feel comfortable on, and incentives. The questions posed and some responses gathered are detailed in the full thesis.

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<sup>4</sup> A pilot version used long answer and is shown in the Appendix

Can you estimate how many miles you typically travel in one week using each of the following modes of transport?

Your own car as the only occupant						
None	under 50	50-150	150-300	300-600	over 600	
Your own car carrying other passengers (includes motorcycles)						
None	under 50	50-150	150-300	300-600	over 600	
A ride in someone else's car (includes Taxi's)						
None	under 50	50-150	150-300	300-600	over 600	
By Bus or Train						
None	under 50	50-150	150-300	300-600	over 600	
Using a Bicycle or Tricycle						
None	under 5	5-10	10-30	30-60	over 60	
Walking or Running						
None	under 5	5-10	10-30	30-60	over 60	
Other (please specify)						

What percentage of your weekly journeys by each mode are less than 5 miles one-way?

Your own car as the only occupant					
None	Under 25%	25-50%	50-75%	75-100%	
Your own car carrying other passengers (includes motorcycles)					
None	Under 25%	25-50%	50-75%	75-100%	
A ride in someone else's car (includes Taxi's)					
None	Under 25%	25-50%	50-75%	75-100%	
By Bus or Train					
None	Under 25%	25-50%	50-75%	75-100%	
Using a Bicycle or Tricycle					
None	Under 25%	25-50%	50-75%	75-100%	
Walking or Running					
None	Under 25%	25-50%	50-75%	75-100%	
Other (please specify)					

Can you estimate how often you exercise?

Never      less than 1 day/ week      2-4 days/ week  
                  4-6 days/ week      every day of the week

And how long you spend exercising each time?

Less than 1 hour      2-3 hours      3- 4 hours      over 4 hours

Please tell us about yourself (optional)

Age:      25 or under      25-60      60 +

Sex:      Male      Female

Household Income:      under 15K      15K- 45K      45K+

Have children:      Yes      No

Own a bicycle:      Yes      No

Please Turn Over

Figure 4.1 Survey final version front page

If cost was NOT a barrier, could you use a Velomobile, to make some of your usual weekly trips?

Yes

What percentage of your weekly journeys can you envisage using it for?

Under 25%      25-50%      50-75%      75-100%

Which form of travel do you think the Velomobile would be most likely to replace?

Own Car      Getting Rides      Bus      Train  
 Motorcycle      Bicycle      Walking      Other:

No

Can you select the reason(s) why not?

- Too much exercise
- Roads Unsafe
- Vehicle Unsafe
- Vehicle Appearance
- Not enough luggage space
- Other (please specify):

Considering the costs of other forms of transport, can you estimate the maximum amount you would be willing to pay to purchase a new Velomobile?

Up to 2000£      3000£      4000 £  
 5000£      6000£      7000£ or more

Can you indicate which type of roads you would feel comfortable using a Velomobile on

- Separate Bicycle Paths
- Roads with marked Bicycle Lanes
- Roads without marked Bicycle Lanes and with a hard shoulder (non motorway)
- Roads without a marked bicycle lane and without a hard shoulders
- Narrow Country Lanes
- Urban areas and Town Centres
- Would not feel safe on any road or bicycle path
- Others

Would you consider committing to use a Velomobile for a minimum distance each week, if that reduced the price?

Yes      No

Would you consider using a vehicle with advertising on the outside, if that reduced the price?

Yes      No

Can you select the incentives that would encourage you to purchase and use a Velomobile:

- Trying one for a week
- Easy availability (a UK dealer)
- Monthly payments
- Showers at work
- A rental or sharing scheme (like car clubs)
- Better infrastructure (wider roads or bike paths)
- Other (please specify):

Figure 4.2 Survey final version second (back) page

## Limitations

The initial response to the question of whether they could replace some of their journeys with a velomobiles was surprisingly positive, perhaps owing to a bias in asking mostly people who expressed an interest to complete a survey. It was frankly hard to get someone who was not even a little interested, to take the time required.

The approach was felt to be imperfect. The sample was self-selecting owing largely to the visibility of the vehicle in an unusual location, and measures to compensate were not effective<sup>5</sup>. The effect was occasionally compensated for in the larger centres by the coupling effect, where only one of a couple or group was actually interested but all members completed the survey.

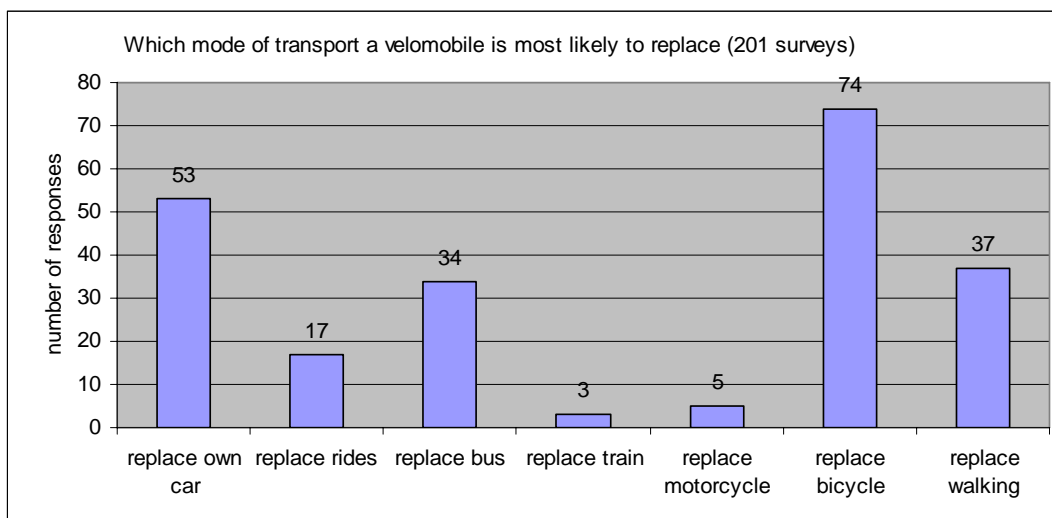


Figure 4.3 Surveyed mode of transport velomobile could replace

### *Interpreting the results*

Of those who did self-select to participate in the survey, we can identify at least three overlapping groups, based on our criteria for emissions reduction potential.

#### **Just curious/non-user**

These are those who answered no to using a velomobile.

#### **Potential user**

People who indicated they could use a velomobile in place of an existing form of travel, but they either do not currently use a car or they do not feel that the velomobile is a suitable replacement for their current car trips. This group is somewhat larger than the group who would replace car travel with a velomobile

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<sup>5</sup> See the case of Barcombe and the letter distributed to some residents of, both in the Appendix of the full thesis.

and referred to in this study by the acronym YV for Yes Velomobile. Weekly mileage estimates (examined later) are not inconsiderable by this group, and because several of the respondents do not currently drive their own car, a velomobile might be considered to provide increased mobility in a rural area, without a consequent rise in emissions.

### **Potential users who could replace car travel**

This group is given the acronym YVROC to represent answers to the questions: Yes Velomobile to Replace my Own Car. In the next chapter, estimates of their potential emissions reductions are performed. They are the segment of all those 'just curious' persons who could reduce their car trips with a velomobile, if provided with appropriate incentive, or at least they would be willing to try. They are the focus of the emissions reductions calculations in later chapter and their characteristics are analysed in terms of the demographics in later sections and the appendix. They make up approximately one quarter of the respondents to the survey, neither the largest nor the smallest group.

## 5. Benefits and emissions

Based on questions about how people currently travel and whether they imagined a velomobile could replace some of their journeys, some rough estimates about their current travel and potential for change are made. Then, a conceptual outline of the potential costs and benefits of new users is attempted. The paper then focuses on the emissions, of existing trips which form the base case, and the potential modal changes as a result of the velomobile.

Lastly, the conceptual cost benefit outline is used to assign referenced monetary estimates, which are then employed in economic approximations. This is done by first creating a spreadsheet based on the conceptual costs and benefits of the velomobile, and then comparing the results thus obtained to an established computer simulation. The velomobile is compared to several different types of petrol-hybrid, battery powered, and hydrogen fuel cell powered vehicles. It far outperforms them all, before its unique health and congestion related benefits are included.

### ***Existing and potential mileage***

Calculations used the survey results to estimate reductions and are first described in terms of the acronyms used:

Ldshmpwk (Lone Driver Short Miles Per Week)  
= % trips less than 5 miles one way X weekly estimated distance driven alone

YVROC (Yes Velomobile to Replace my Own Car)  
= % of trips a velomobile could replace X estimated weekly car mileage

veloreplace = sum of % of trips a velomobile could replace, by mode  
X weekly mileage, by mode

Estimated distance travelled per week by each person surveyed is tallied as 'all modes' and shown in brown in Figure 5.1. Mileage driven with and without passengers is "total driven", and distances driven alone are described as 'lone driver,' both are in blue while Ldshmpwk are considered more polluting trips and are seen in red. The green columns are approximations of the percentage of trips a velomobile could replace: the dark green column represents potential velomobile trips which may replace car trips, light green are potential velomobile trips replacing all modes. Summarized for the entire group in Figure 5.1, this data is also discussed based on individual locations in the Appendix of the full thesis.

### surveyed weekly mileage and potential reductions

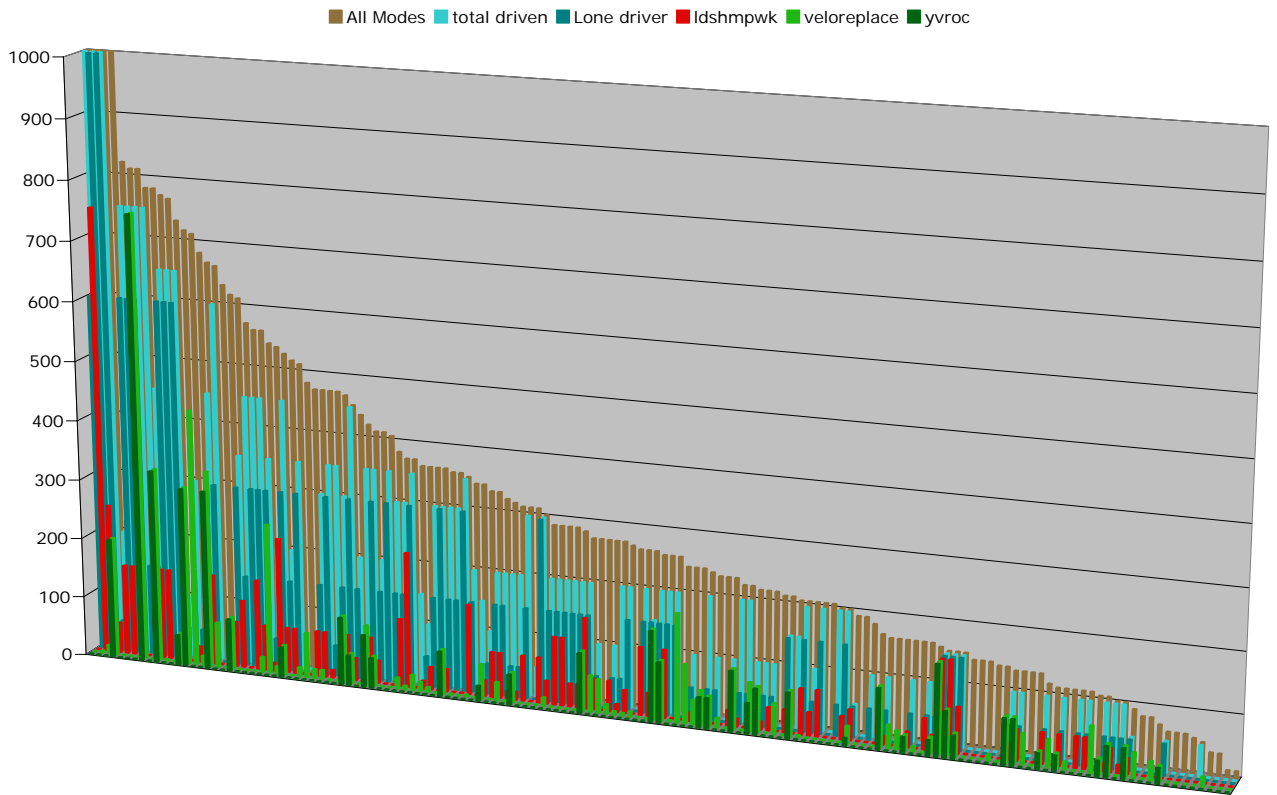


Figure 5.1 Surveyed mileage and potential reductions overall

Those surveyed who indicated that a velomobile could reduce their car travel are focussed on in Figure 5.2. There is not a distinct correlation visible between potential velomobile use and either more current short trips or distance of trips alone. This unexpected result seems to disagree with some literature on the potential for change which tends to suggest that short single travellers have less of a need for a large vehicle and would be mostly likely to consider an alternative.

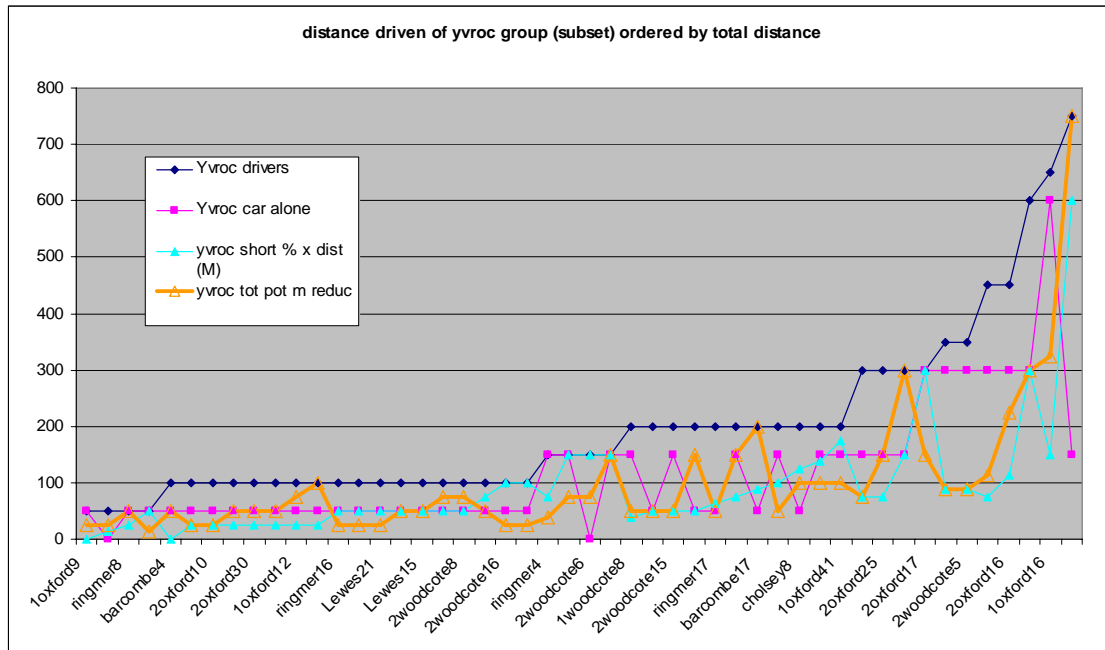


Figure 5.2 Surveyed distances driven and YVROC potential mileage reductions ordered by distance driven

### ***Identifying the costs and benefits***

In order to assess changes in terms of the methods discussed, this section first describes the base case for the surveyed group, and then lists aspects which have so far become apparent as potential aspects which could change.

#### **Base case and change**

The scaled yearly mileage averaged per person indicates 9847 miles (16,093km) travelled as the driver and is consistent with the RECONNECT base case mileage of 17000 km per year, which was used for the annual cost calculations.

#### **Conceptual costs and benefits**

There are likely to be different costs and benefits associated with the portion of trips which replace car trips and those which replace other modes. The most benefits are assumed to be from those trips which replace car trips, and they are thus the focus of the cost and benefit discussion.

#### **Primary costs**

The primary costs of the velomobile are borne by the user in the form of the vehicle purchase and the energy input, both human and electric.

## **Purchase and maintenance**

For this study the cost of the velomobile is typically treated in addition to existing capital costs, though marginal (operating and fuel) costs are considered in more depth for those which are projected to replace car trips. Bus and train marginal costs are not considered and no maintenance costs are included for the velomobile as they are expected to be minimal and seldom require expert attention.

### ***Energy***

The vast majority of the energy required for the velomobiles considered is provided by the human it transports. Emissions are therefore near negligible though some electricity related emissions at grid values could be included, they are not in this study.

## **Primary benefits**

### ***Energy and pollution***

For those trips which are expected to replace car trips, fuel and consequently several atmospheric pollutants are avoided for each of these miles moved. The fuel costs of trips replaced by the velomobile can be considered a cost savings, thus a benefit. Fuel use in automobiles is generally responsible for the release of atmospheric pollutants including CO<sub>2</sub>, PM, CH<sub>4</sub>, NO<sub>x</sub> and SO<sub>x</sub><sup>6</sup>. Emissions thus avoided add to the benefits.

### ***Maintenance***

There are potential maintenance related benefits through reduction in automobile trips which can also be considered cost savings and thus a benefit.

## **Other benefits**

### ***Health***

The user could feel health benefits from the increase in exercise. These benefits would be felt more by those who do relatively little exercise, but are likely to be felt by all. They could result in reduced medical bills, which would affect individuals and society in a variety of ways. Existing monetary estimates of the value of these benefits are sourced but used without an inquiry into the methods from which they are derived.

### ***Reduced roadway costs***

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<sup>6</sup> Carbon Dioxide, Particulates (10), Methane and Sulphur Dioxides are examples among pollutants and greenhouse gasses emitted.

Like non-motorised transport users, velomobiles inflict few damages on the roads that they use. In as much as a velomobile trip replaces a car trip and they use the same infrastructure there is the potential for cost savings through increased longevity or more efficient use of resources. If a velomobile made the same trip as a car but on a parallel cycle path, which may have had lower per mile construction and/or maintenance costs and/or be underused, this could also be a cost savings. There is more work to be done in specifying these costs for the velomobile in particular, values derived from other studies of primarily human powered transport are used and adjusted where possible.

### ***Equity***

The velomobile is thought to have the potential to provide active, ongoing-cost-free and dignified form of transportation for many individuals who do not drive or would prefer to drive less<sup>vii</sup>. This is generally not quantified by this study, but is mentioned frequently to highlight its importance.

### ***Increased Safety for other users***

Especially on narrow rural roads, the experiences gained indicate that the velomobile would make the road safer for other non-motorized users, by limiting the speeds of the automobiles on the road. The velomobile on many rural roads in the south is narrow enough to fit next to a car down many lanes. The fit is however too tight for many drivers to feel comfortable with and they are liable to wait until told to pass by a stationary vehicle. It is a nice sensation to have human power in control of the road, but one that is difficult to quantify as well and is generally not attempted.

## **Other Costs**

### ***Production***

Environmental costs associated with production and disposal of the vehicle at the end of its life. These may be minimal compared with its alternative of a car, and slightly larger than a bicycle<sup>viii</sup> but are not calculated in detail.

### ***Congestion***

The velomobile does take up some room on the road, especially in rural areas and on narrow roads. It is also slower than automobile traffic and to the extent that it slows traffic down can be considered a cost to other users of the road. This point should be considered together with the benefit of safety for other non-motorised users and is treated as such by monetary estimates in this study.

### ***Group emissions***

### Emissions base case

Emissions levels for the survey participants who indicated that they drove weekly were first calculated. The initial calculations used an emissions factor of .2478 kg/mile CO2 equivalent and the entire vehicle's emissions were assigned to the participant in cases where they indicated they were driving alone, half if they were carrying passengers<sup>ix</sup>.

### Potential Reductions

YVROC is an acronym that stands for Yes Velomobile Replace Own Car. It refers to the small group of respondents who said they could use a velomobile to replace some of their own car trips. It is this group of individuals who do use a car in their currently weekly travel, who make up the most promising potential for velomobiles to reduce emissions through modal changes away from cars. Figure 5.3 shows how they appear in the emissions profile spectrum: scattered and with little correlation to making short trips. Very few are already high mileage drivers, who seem least likely to consider a velomobile.

The YVROC group is 25% of the population and together they drive about 9,600 miles per week, accounting for about 25% of all the miles driven by all participants. A slightly higher percentage of their trips are short (43% vs. 39%), and they estimate they could use a velomobile for a greater percentage of those journeys (50% vs. 32%).

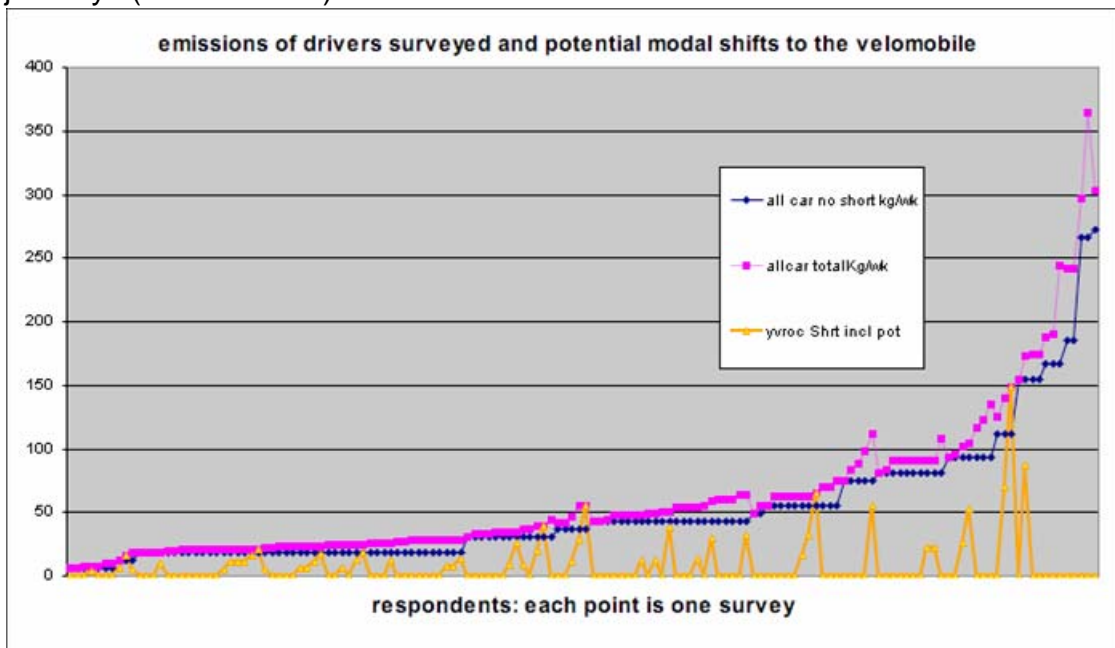


Figure 5.3 Surveyed emissions with and without short journeys (CO2 kg/wk) and reductions,

Using surveyed estimates of the percentage of trips a velomobile could replace, applied to the fraction of their choices an automobile accounted for<sup>7</sup>, the group could reduce 1,167 kg/ wk or 61 tons per year.

### **A cost benefit analysis**

In order to allow the costs and benefits of potential users with different expected weekly mileage to be easily calculated, as many of the potential costs and benefits outlined in the previous section were agglomerated into a single spreadsheet calculation. Shown is a spreadsheet that uses the formulas discussed for deriving annual costs, provided by RECONNECT, along with methods outlined by the LEAF2 process in defining and calculating public and private costs.

#### **Input**

The spreadsheet returns a variety of output based on a single user input: projected weekly mileage, entered in the dark pink area at the top. All other inputs are optional and can be used to improve the accuracy of the estimate or particular circumstances.

If desired, it is possible to adjust the purchase price of the velomobile, in the second row. The first figure will affect both the social and individual costs calculated, while the post-tax rebate input box will only lower the individual cost by the amount entered. This calculation is in line with the treatment of the Power Shift Grant input into the LEAF2 model, yet with a different name.

Current fuel efficiency can be modified as can the cost, which must be input without VAT (value added tax). The fuel costs are treated differently by the LEAF2 public and private costs definitions, and this spreadsheet attempts to mimic the calculation of an underlying fuel rate by first deriving a taxation factor from the values in the LEAF2 model. The underlying fuel rate is used to calculate the social scenario while the fuel price with VAT added is used for the individual scenario.

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<sup>7</sup> For example if the bike and automobile were both selected as modes which could be replaced, then half of the reductions were assigned to each mode.

**Table 1 Velomobile cost benefit analysis at 62 miles per week**

velomobile potential - all trips replace car trips			
	<b>primary input:</b>	<b>projected weekly mileage</b>	<b>62</b>
optional input:	pre-tax purchase price	£ 5,000	post-tax rebate
	current fuel efficiency (miles/L)	8.5	£ 0
	current fuel cost incl VAT (/L)	£ 0.75	number
	maintenance VAT excl (p/mile)	4.03	1
		individual:	social:
	VAT	15%	0%
	discount	20%	6%
<b>output:</b>	present value of future fuel	£ 1,192.64	£ 501.10
	reduced maintenance estimate	£ 626.42	£ 956.28
velomobile, future fuel & maintenance saved:			
present value cost		<b>-£ 3,930.94</b>	<b>-£ 3,542.63</b>
	<b>total annual cost</b>	<b>-£ 937.62</b>	<b>-£ 481.33</b>
lifetime emissions cost effectiveness			
	NOx g/£ spent	1.85	2.05
	CO2 kg/£ spent	2.76	3.06
	CO2 (fcm) kg/£	2.34	2.59
other benefits: lifetime present value			
	road costs and noise reduction	£ 3,514.30	£ 6,169.52
	health improvement estimate	£ 2,536.45	£ 4,452.85
	market value CO2 reduction	£ 91.79	
	emission damages reduced estimate		£ 252.95
subtotal of other benefits		£ 6,142.53	£ 10,875.32
	annual benefits value	£1,465.13	£1,477.61
<b>Lifetime Cost Benefit</b>		<b>£ 2,211.59</b>	<b>£ 7,332.69</b>
	<b>Overall Total Annual</b>	<b>£527.51</b>	<b>£996.28</b>

A number input will multiply mileage and appropriate costs in order to approximate multiple vehicles. This was done in order to quickly be able to use this spreadsheet to enable it to calculate an approximate value for the modal or average mileage for our entire surveyed population, as well as individuals. Maintenance rates, again without VAT can be changed and these costs are again used without taxes in the social scenario.

Two different sets of costs are returned, each defined according to public and private costs in the LEAF2 model, and are adjusted by default to reflect the same discount rates used in the model. The aspiration is a close enough approximation to enable valid comparisons. The VAT and discount rates for each of the two cost scenarios can be changed if desired. They affect all costs but not emissions, which have a separate discount rate set by default to 0.

## Output

The first value returned by the spreadsheet is the present value of the fuel that could potentially be saved, calculated based on the number of miles, current fuel efficiency and fuel cost. The calculations are discounted at the appropriate rates.

Accounting for the current purchase price with Value Added Tax (VAT) against the cost savings thus calculated results in the third output row: the present value cost of the velomobile at individual and social rates. Using this value and a capital recovery factor the total annual cost is calculated. Lifetime emissions are reported for NO<sub>x</sub>, PM, CH<sub>4</sub>, and CO<sub>2</sub>, not shown in the main window<sup>8</sup>. Two methods are used to calculate CO<sub>2</sub> emissions, the first based on the emissions profile, and the second based on fuel consumption figures and a separate emissions figure. All of the emissions factors can be modified individually and the discount rate for all emissions as one. Lifetime cost effectiveness is calculated using the formula from LEAF2 for NO<sub>x</sub> and CO<sub>2</sub> using both CO<sub>2</sub> methods, shown in the main window.

Assessing the other benefits a velomobile may be responsible, a per mile estimate of the damages due to traffic safety and noise reduction which a velomobile could bring about is used. Referenced example values for this assessment range from 0.26 GBP in a rural part of Canada<sup>x</sup>, to 3.06 GBP estimated in the central of London<sup>xi</sup>. For the default we have used the lowest figure our estimates indicated, with appropriate discounts applied to these benefits.

The health improvement benefit estimate example is on a scale from zero to 1206 GBP estimated benefit from increased cycling, on a scale of diminishing returns, meaning that a less fit person would benefit relatively more than a more fit person. The default value is the mid range of this scale at 605 GBP, again discounted at different rates for each scenario but otherwise treated the same<sup>xii</sup>. This roughly corresponds to the surveyed exercise estimates covered in the next chapter and to impressions from current owners.

A current saleable rate for CO<sub>2</sub> on a consumer focused website was used to calculate the equivalent cash value those emissions have and accounted on the individual side<sup>xiii</sup>. The social benefits subtotal estimates damages from emissions and these are accounted for three of the four values calculated (PM excluded)<sup>xiv</sup>.

The subtotal sums up the other benefits estimates, before they are added to the costs of the first section. The lifetime costs benefit analysis provides two figures that represent the public and private potential costs or benefits at the end of a ten year lifespan of a velomobile. The overall total annual value again uses the appropriate capital recovery factor to return an annual cost for public and private scenarios.

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<sup>8</sup> See the appendix for an image of all the results and references used in these calculations

In our example, calculated for an average potential user in our survey, it can be seen that the individual scenario results in net benefits which are equivalent to the initial purchase price. The public scenario report even larger return of more than twice the original purchase price in benefits by the end of its life. The lifetime cost effectiveness of emissions reductions for the velomobile can be compared to existing studies, in particular to the LEAF2 model; and in the full thesis modifications to the LEAF2 model are shown to have a reasonable correlation to the results of the spreadsheet presented.

The comparative emissions cost effectiveness is shown by the results page of the LEAF2 model below. The other vehicles modelled beside the velomobile, from the left: a petrol internal combustion engine, a petrol hybrid-electric vehicle, a grid powered battery electric vehicle, the velomobile, renewably generated hydrogen fuel cell, grid generated hydrogen fuel cell, petrol refined hydrogen fuel cell, methane refined hydrogen fuel cell, liquefied petroleum gas refined hydrogen fuel cell, and one last fuel refined into for use in hydrogen fuel cell. The velomobile replaces naturally generated hydrogen used in a fuel cell in this set of results, so it is not shown.

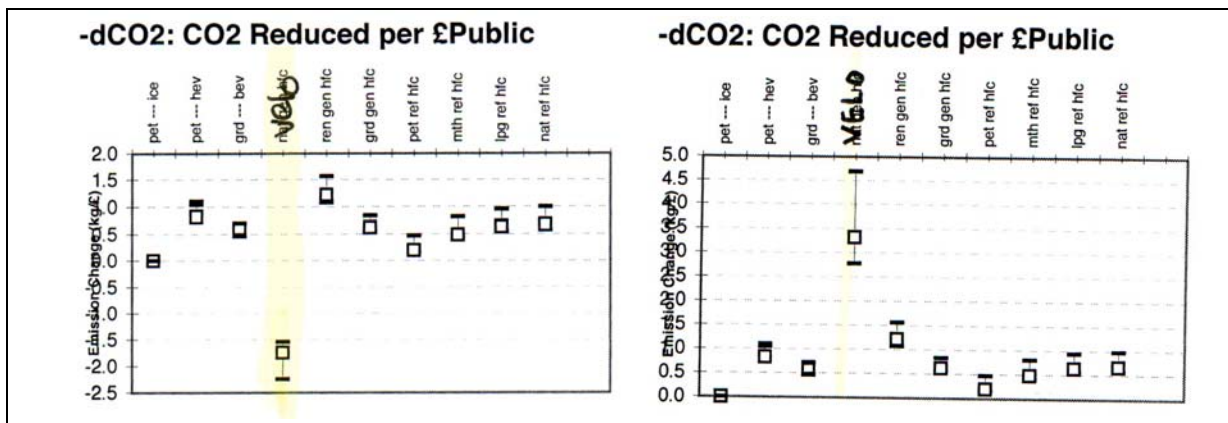


Figure 5.4 Results from the first two modified LEAF2 scenarios: the velomobile is fourth from the left

## 6. Other Questions and comments

Having estimated the relative costs and benefits of potential velomobile trips by surveyed residents of the south east UK, the first section of this chapter now addresses other questions posed. Many of these related to barriers to using a velomobile: the first asks specifically why not? Some of the questions are quite subjective, such as which roads a new rider would feel comfortable on, while others ask for estimates about current behaviours, such as those about frequency and time spent exercising. Overall these questions paint an interesting picture of likely velomobile users. This picture is in many ways different from the cycling enthusiast who, within the evoliner framework introduced by the first theory, would be considered its usual users. The survey results thus far seem to confirm the validity of the new matrix sociotechnical frame in chapter 2.

The second section of this chapter relates comments which arose from the process of having the surveys completed, as well as from the experiences of a new velomobile driver in an unfamiliar country. The qualitative results in this section are considered to have a major potential to change the impact that the velomobile could have in the U.K.. The narrow rural road network in particular is assessed to be conducive to the velomobile becoming an activist's tool, by forcing drivers to become aware of alternatives and make accommodations for other road users. Many slow users of the roads are sustainable users, however their space requirements tend not to reflect the priorities their movement should be afforded in a sustainable society. By using more space than the typical non-motorized user, the velomobile could make the roads safer for those users. It would thus take space for sustainable transportation.

The reader interested in these results and a detailed discussion is referred to the full thesis from the link on the cover page, as excerpts from this chapter have not been included for space reasons.

## 7. Cost effectiveness

The cost effectiveness chapter of the full thesis is divided into four sections, each building upon the last. In the first, the emissions cost effectiveness of the velomobile is plotted for weekly mileages from zero to four hundred. The results provide a use rate at which the velomobile is within the usual costs of transportation related studies. In the second section the same range of mileage is used to examine the variety of other values output by the velomobile cost-benefit spreadsheet, with particular reference to consumer cost effectiveness.

The last two sections of the chapter attempt to make an economic case for social (government) support of the velomobile in order to improve its consumer cost effectiveness and use, and thereby achieve potential benefits estimated earlier. The argument is modelled on the study from which the computer model employed in that chapter was drawn. Having demonstrated the potential social benefits and using original survey data as a reference, the case is as follows.

Manufacturing efficiencies, which could lower the price based on current technology require larger orders, and these tend not to arrive until the cost falls. By temporarily intervening in the market to have consumer costs reflect public values, it is possible to optimize emissions reductions. The subsidy approximations in the final section demonstrate the minimal costs possible through such a program. Potential benefits are shown in the full view of the velomobile cost-benefit spreadsheet, adjusted to reflect the initial year of this case and followed by graphs of the cases described, in the Appendix.

### ***Cost and distance***

Our analysis has shown the velomobile to be cost competitive when considered with the average mileage of surveyed respondents, next to existing technologies modelled in LEAF2. Our spreadsheet calculation was assessed to be within a reasonable range of similarity to the LEAF2 results, but much easier to modify for our circumstances. Our survey results indicate that there is significant variation in the amount that individuals expect to be able to use a velomobile. The result of this is that the cost effectiveness used for comparison to the LEAF2 model will only be accurate for a very small number of current or potential users. A fair number of the costs and benefits are dependant on the potential distance travelled, and our spreadsheet shows that the lifetime cost effectiveness of the velomobile depends heavily on the average weekly mileage.

For a better idea of the relationship between mileage and the costs and benefits estimated, results were gathered at intervals of 25 miles per week from 0 to 400. Figure 7.1 shows the public and private emissions cost effectiveness of the velomobile, from 0 to 400 miles per week as an amount of each pollutant per GBP spent. Reviewing the definition from LEAF2: negative value indicates that

the measure is cost effective and is likely to be pursued in the absence of other barriers. Using a purchase price of £ 5000 the velomobile is cost effective with a weekly mileage above 200 at public rates, above 175 with private costs. The values for CO2 public emissions cost effectiveness are from 100 (120) kg/£ to -120 (-140) kg/£, NOx values are from +75 to -90 gms/£.

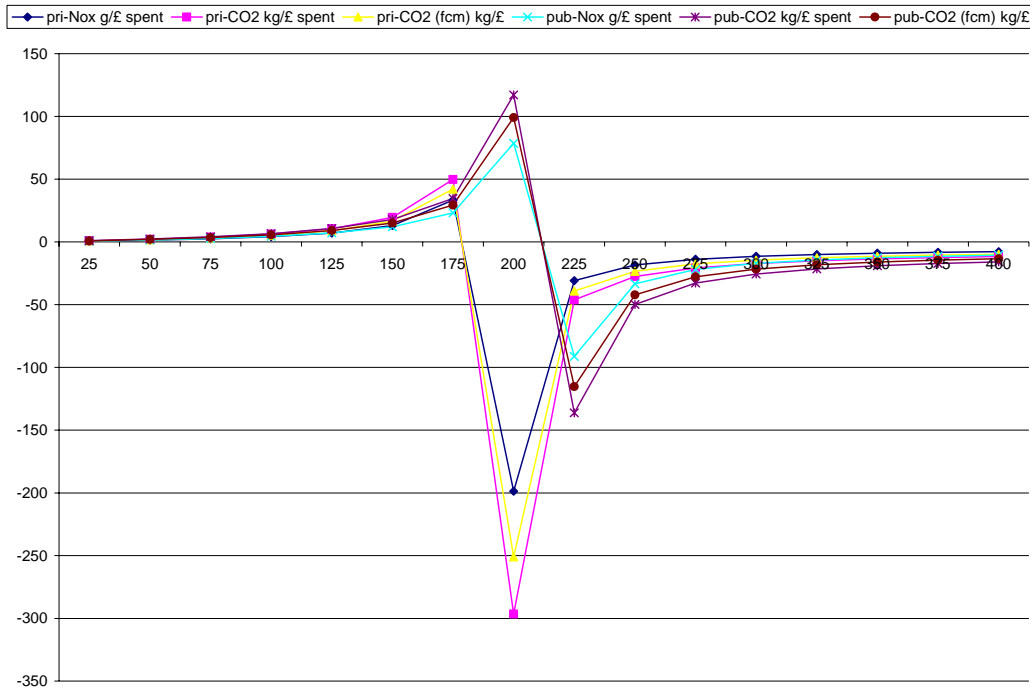


Figure 7.1 Emissions cost effectiveness from 0 - 400 miles per week

A cost reference of - US\$ 200 to + US\$ 200 / tC for transportation projects is high compared to other sectors. Figure 7.2 shows the cost of the pollutants estimated by the velomobile cost-benefit spreadsheet converted to US \$ per kg or ton for easy comparison. For weekly mileages at or over 125 miles per week the velomobile is considered within the usual costs of transportation emissions reductions projects. Ancillary benefits such as health, noise reduction and congestion relief are not included and add to the benefits.

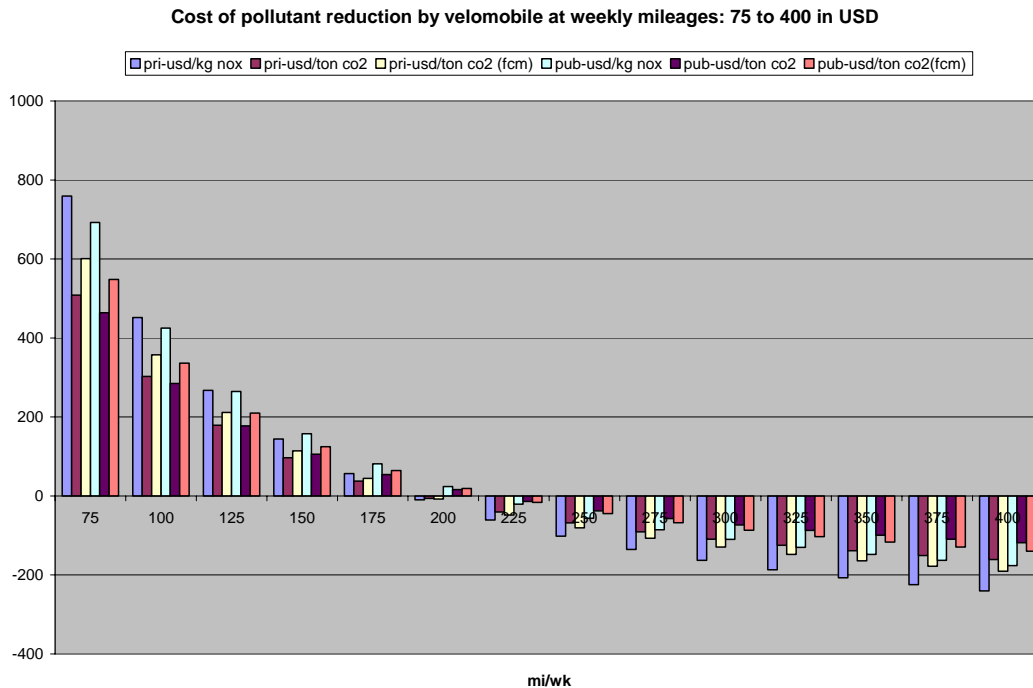


Figure 7.2 US \$ cost of pollutant reduction by velomobile weekly mileage

### ***Mileage and benefits***

The results for all output at the individual rates are seen in Figure 7.3: the majority of the results are linear relationships with the weekly mileage. The point at which the present value cost becomes a positive value is around 190 miles per week. On a five day work-week commute this is approximately 20 miles each way and is consistent with impressions gathered through interviews with current owners<sup>xv</sup>.

The non-linear output, all emissions lifetime cost effectiveness values, change around this same weekly mileage value because they are related. Different discount rates used to calculate private and public cost effectiveness result in the different slopes in Figure 7.3 and Figure 7.4. Notice especially the different cost scales on the y-axis, and the location at which the lifetime cost-benefit function crosses the x-axis. There is no mileage at which the cost benefit analysis is negative from the public perspective; it is negative from the individual perspective a weekly mileages below around 40 miles. Lifetime social benefits as a result of the individual who uses a velomobile for 40 miles per week are close to the current pre-tax purchase price. This is largely attributable to the health benefit estimate, and for the commuter is beneficial above 3.6 miles per day one way (7.2 miles return) on a five day work week.

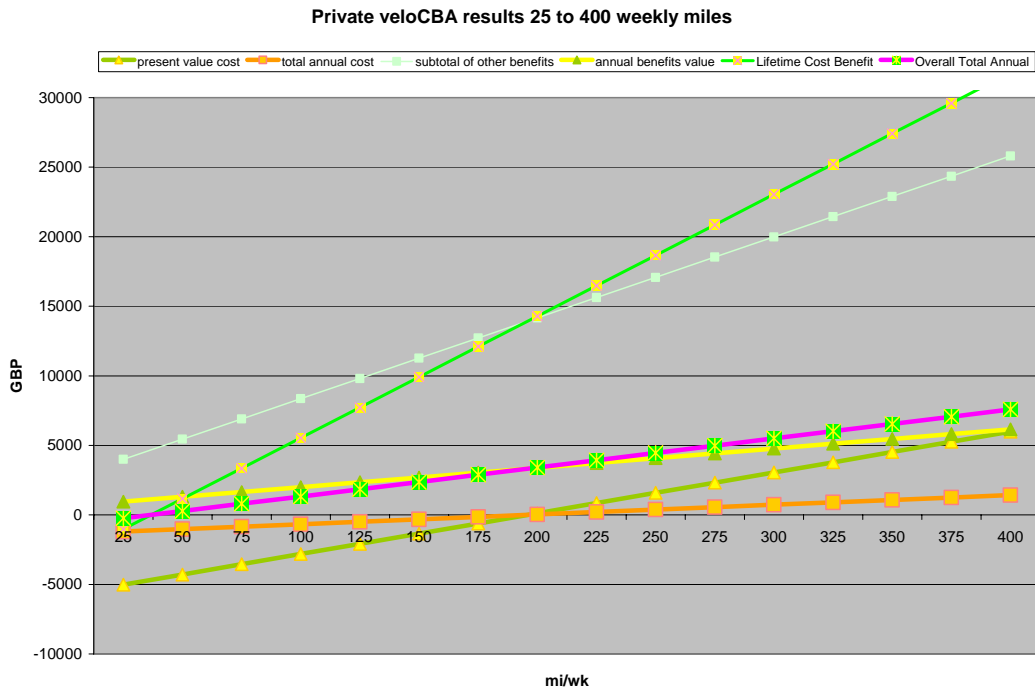


Figure 7.3 Graph of velomobile cost-benefit output (individual) from 0 - 400 miles per week

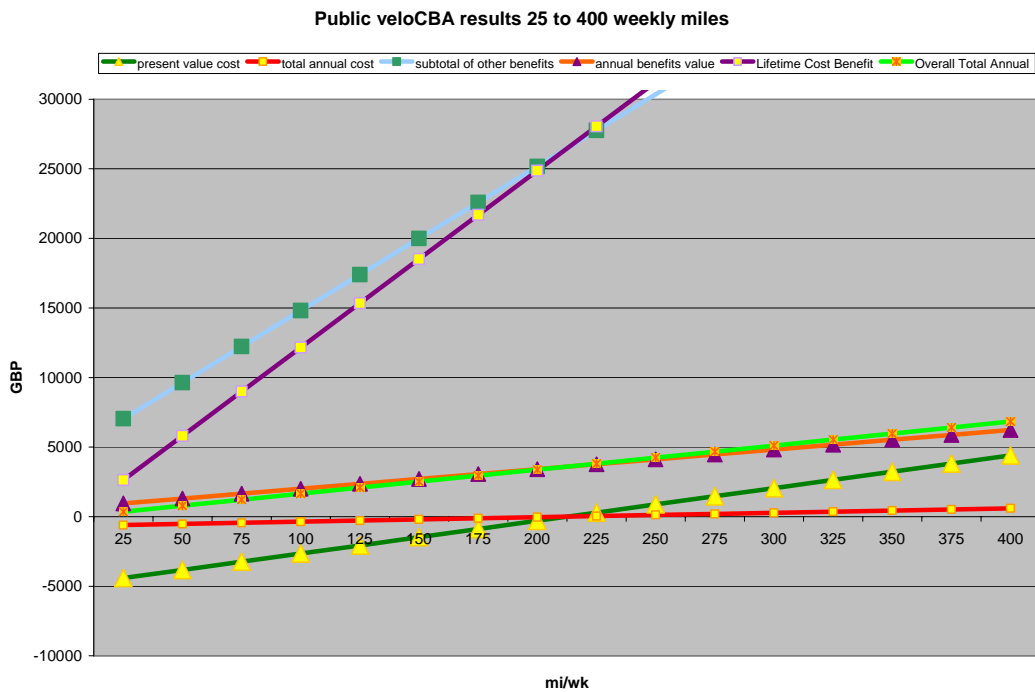


Figure 7.4 Graph of velomobile cost-benefit output (social) from 0 - 400 miles per week

## Consumer cost

Survey results from UK residents show that the velomobile's value to the consumer is low, particularly compared to its current cost. The IPCC framework would suggest that the technology's value would be close to the marginal costs saved from its alternative. Figure 7.5 showed the responses of those who indicated potential velomobile use, the amount they could replace against the amount they might pay showed little correlation.

For automobile owners we might expect a stronger correlation between expected mileage and willingness to pay, considering the marginal costs of driving a vehicle. There appears to be an equal number of low and high mileage drivers willing to pay above GBP 2000. A very weak, if any correlation is also seen for the mileage of potential automobile replaces.

The only response above the real price of GBP 5000 is a person who would not replace car trips, and there are several individuals at various mileages that would pay the current price. This indicates that there is an untapped potential for emissions reductions available simply through resolving market imperfections, information and learning. Overall from these two graphs, the somewhat counterintuitive impression is that those willing to pay more are not necessarily more likely to be higher mileage drivers of velomobiles.

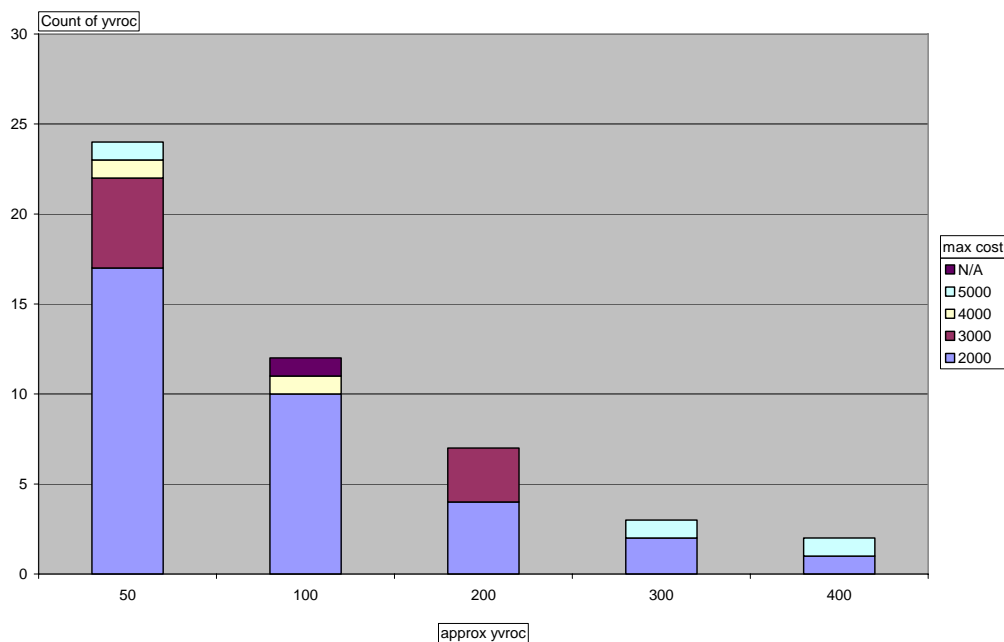


Figure 7.5 YVROC distances (replace car) and maximum price

Trying to estimate the value of any object to any given person is difficult. The LEAF2 model and much economic theory attempts to approximate how those decisions are made by using a heavily discounted private lifetime cost. Our representation of the velomobile did the same and showed that if the marginal

costs of its replacement are considered, consumer cost effectiveness prevents realization of most benefits. Our survey does not quite agree and demonstrates that there are many reasons why a vehicle is or is not worth a certain amount to any given person, not all captured by existing theories.

Still, economic theory and our survey results both indicate that there will be more people interested when the consumer cost of the velomobile decreases. Often considered the easiest to realize, are savings that occur as a result of building more, described in chapter two as the learning rate. Expressed as a progress ratio it approximates the percentage that costs will decrease as production increases and the amount of investment needed to bring a technology to cost effectiveness<sup>xvi</sup>. Based on available literature and private conversations with various manufacturers, a progress ratio for the velomobile has been estimated at 75%. Using an initial cost of GBP 5000, results are shown in Figure 7.6 to illustrate the number of new orders potentially required to bring the consumer purchase cost closer to that expected by survey respondents.

For many technologies including the velomobile, a significant barrier is that reductions in manufactured costs tend to first require more orders, which tend not to arrive until costs drop. This barrier was discussed by the IPCC conceptual theory to be among those which prevent achieving the technical potential. General strategies were outline and some are explored in the following section, using a previous study as an example.

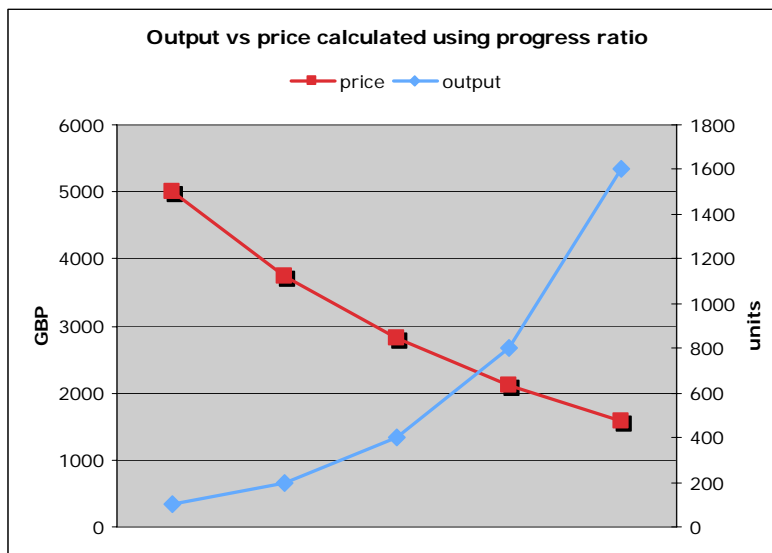


Figure 7.6 Progress ratio: price to output of the velomobile at 75%

### ***Purchase subsidies***

At the time of Lane's thesis it was considered reasonable to subsidize the capital purchase costs of a private owner's transportation vehicle, particularly when the vehicle reduced comparative public costs. Without discussing the likelihood of

such a program returning to existence or being applied to the velomobile, it is still felt appropriate to discuss the potential costs it might have. In imitation, several copies of the velomobile cost benefit spreadsheet were used to plot the effect of a temporary market intervention. The results, included in the Appendix of the full thesis, are summarized and discussed here.

The intention is to consider how a subsidy could impact consumer price, as it is reduced by ongoing manufacturing efficiencies, to realize potential benefits. The reduction in rates implied to be over time mimics the rational implementation strategy recommendations of Lane. These relate well to the learning curves discussed by, among others, the Prime Minister’s office in a study which proposes a similar strategy for introducing and removing support for renewable energy niche markets<sup>xvii</sup>.

Approximating efficiencies based on the velomobile progress ratio estimate, and using the same subsidy rate Lane recommended, brings the consumer price in line with our surveyed maximum low value. The cases plotted are summarized in Table 2 and the results can be compared to the base case at existing costs which were presented by Figure 7.3 and Figure 7.4.

**Table 2 Cases considered**

Cases plotted	Pre-tax Cost	Subsidy	Purchase price
A1	5000	75%	2000
A2	3000	50%	1500
A3	2000	25%	1800
A4	1500	0%	1725

Perceived in relation to the modal expected mileage of 50 and a high average of 100, the improved cost effectiveness of the velomobile from the consumer perspective is obvious. A 75% purchase subsidy to the current price would reduce the consumer price to £ 2000. The velomobile driver traveling around 75 miles per week would have no net annual costs (equivalent to over 175 miles per week without a subsidy) if their trips all replaced car trips and the marginal car costs were considered saved. Once manufacturing efficiencies affected the price it would be cost effective even for the very low mileage traveler, under 50 miles per week.

As orders for velomobiles increased the subsidy could be expected to maintain consumer cost effectiveness for the modal or average traveler. Summing up expected costs, at a current price of £ 5000 per vehicle, even with a 75% subsidy, only several hundred are expected to be sold. Initial yearly cost would be less than £ 500 000, and would remain so for the entirety of the program. As the number of orders increases, manufacturing efficiencies will maintain the subsidy costs at a reasonable rate while the number of vehicles (and consequent benefits) would rise. Reducing the subsidy rate as the price drops would support

an emerging technology in a niche market where it was already cost effective, and induce improved learning to achieve environmental and social benefits. Table 3 demonstrates the minimal costs a program such as this could have.

Table 3 Example subsidy costs 2005 - 2011

	2005-2006	2007-2008	2009-2010	2011-
UK velos	100	300	1000	1600+
Pretax cost	5000	3000	2000	1500
Subsidy	75%	50%	25%	0%
Value GBP/yr	375 000	450 000	500 000	0

## 8. Conclusion

Our exploration of the velomobile began with a discussion of social aspects inherent in the use of technology –socio-technology - and its implications on the sustainability of the velomobile. We then explored broad concepts commonly used to frame this interaction between technology and society, captured in the ideas of the market, socioeconomic, and technical potential of a technology to achieve environmental and social goals.

Using the example of existing studies, a survey of two hundred self selected individuals in the smaller centres in the south of England was performed, which resulted in first hand travel profiles, modal change estimates, and data on potential barriers. These were then analysed, initially the emissions results were compared to existing transportation technologies at current costs.

Costs and benefits were then explored in more depth and monetized where possible, proving how the scope of the velomobile's benefits meant that, even for low mileage users, lifetime social benefit were at least equal to the current purchase price. This was followed by a discussion of several barriers to realizing these benefits and, assessed as most pressing, the consumer cost barrier was the subject of the last chapter. It concluded with a case for a temporary subsidy to bring consumer costs in line with surveyed expectations and the sizeable potential social benefits.

The conclusion will first look back on the question initially posed by the study then briefly highlight the only the most pressing of the variety of answers which emerged from this investigation.

### ***A viable alternative***

Our initial question sought to discover whether the velomobile was considered a viable alternative mode of transportation by residents of the U.K. The short answer is yes, not to everyone but to a broad segment of people from all age, gender and economic groups.

To many of those surveyed the velomobile was thought to have the potential to significantly change individual emissions: the average for those who drove and would consider replacing their car was a 50% reduction.

In addition to emissions potentially reduced, the velomobile also has a number of less tangible benefits, like improved health and noise reduction. Not unaccountable, moderate monetary estimates of these benefits could more than equal the current cost.

Economic models of the costs and benefits show a sizeable social benefit accruing over each velomobile's lifetime, even from low mileage users who would currently tend to bear a larger share of the costs.

Rectifying this imbalance could result in a large scope for cost effective emissions reductions to be realized, with minimal costs compared to the alternatives.

In this the velomobile is nearly unique among transportation alternatives, also true of its benefits which avoid the usual 'rebound effect' by accruing as more miles are travelled.

### ***The UK scene***

The reality of attempts to introduce any new technology in the UK is likely to be subject to the unique circumstances of the country and even local areas. Disaggregating some results by location shows that the potential use value of the velomobile is dependant on location.

Compared to other European countries the UK has few dedicated bicycle paths, which the velomobile would typically be in a position to utilize. The alternative in rural areas is the narrow system of shared use lanes, less used by motorists because major road alternatives reach the same destinations. The realities of rural road priorities observed in the UK indicate that motorists are often given priority by non-motorized users, as a result of safety concerns or other reasons.

By using more space on a crowded road system, the velomobile appropriates space for non-motorized users. Its presence causes motorized users to react and thereby acknowledge the legitimacy of alternative users of the road.

To the extent that the velomobile is slower than other users of the road, it can cause congestion. By causing other users of the road to travel slower, especially on roads which are shared by many types of users, the congestion is considered a safety benefit.

### ***Open door***

Those who were potential users of the velomobile came from many different groups in society. Significant numbers had individual requirements which could require a diversity of features and improved information about current models and availability. Information, even in the supposed age of it remains a significant barrier to new technologies, to a large extent due to ours being a tactile culture. Learning and experience are needed.

The challenge of private cost also remains a significant barrier. Though being actively approached by several manufacturers, the scope of potential benefits not limited to emissions reduction, and any price reduction is in the U.K. public's interest. There is ample potential for learning about this new technology to have a snowball effect in attracting new users.

### ***Step in***

Electricity is a particularly strong psychological symbol of modernity. As participants of the survey were told the vehicles had electric engines<sup>9</sup>, a spark was clearly visible in many eyes at that moment, when it passed from plaything to potential tool.

With this knowledge more than half responded positively to using a velomobile and fewer than half considered it an alternative for the bicycle alone. This bodes well for hope that an unfortunately common and often unacknowledged mental link between evolution and automobiles, depicted by Figure 2.1, can be bent into the more sustainable matrix of Figure 2.2.

Like other things in the world, entering the matrix is likely to be helped out by a spark and of course a good slogan. If this project was successful, the velomobile can now at least be promoted as 'travel for free' and ought, more accurately, to be thought of as beneficial travel. Over its lifetime a velomobile at least pays for itself; the benefits are felt by the individual and society, while the costs are borne by the individual.

Ample justification to change this imbalance exists and precedents set by other transportation technologies prove it could work. The single largest barrier may remain social perceptions, which seem intent on describing this technology as something it really is not, a bicycle.

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<sup>9</sup> The reality that one did not being completely immaterial.

## 9. Appendix

### Velomobile cost benefit spreadsheet

The full detailed view of the velomobile cost benefit spreadsheet is shown in Figure 9.1, Figure 9.2 and Figure 9.3. The excel file is available as a part of this thesis to interested parties<sup>10</sup>. Subsidies discussed in the last chapter of the body are shown in the final section of this, the final part of the appendix.

legend		primary input	primary cba output
		secondary inputs	secondary cost output
		discount/interest rates	emissions output
		emission/impact factors	other benefit estimates

velomobile potential - all trips replace car trips				lifetime emissions:	
primary input: projected weekly mileage				0% discount rate	
optional input: pre-tax purchase price £ 5,000				nox	
current fuel efficiency (miles/L) 8.5				0.14 g/km	
current fuel cost incl VAT (/L) £ 0.75				58580.12 g/yr	
maintenance VAT excl (p/mile) 4.03				-585,801.22 g Nox	
				- 585.80 kg Nox	
		individual:	social:	pm	
		VAT 15%	0%	0.02 g/km	
		discount 20%	6%	8368.59 g/yr	
output: present value of future fuel		£ 96,180.24	£ 40,411.21	-83,685.89 g pm	
reduced maintenance estimate		£ 505.18	£ 771.19	- 83.69 kg pm	
velomobile, future fuel & maintenance saved:				ch4	
present value cost		-£ 103,314.58	-£ 458,817.60	0.04 g/km	
total annual cost		-£ 24,642.88	-£ 62,338.61	16737.18 g/yr	
lifetime emissions cost effectiveness				-167,371.78 g ch4	
Nox g/£ spent 5.67				- 167.37 kg ch4	
CO2 kg/£ spent 8.46				co2	
CO2 (fcm) kg/£ 7.16				209.00 g/km	
other benefits: lifetime present value				87451.75 kg/yr	
road costs and noise reduction		£ 283,411.11	£ 497,541.88	-874,517.53 kg CO2	
health improvement estimate		£ 253,644.56	£ 445,285.27	-874.52 ton CO2	
market value CO2 reduction		£ 7,402.35		co2- fuel consumption (fcm)	
emission damages reduced estimate			£ 20,398.94	588.24 L/wk	
subtotal of other benefits		£ 544,458.03	£ 963,226.09	2.42 kg CO2/L	
annual benefits value		£129,865.63	£130,871.56	74023.53 kg/yr	
Lifetime Cost Benefit		£441,143.45	£504,408.49	-740,235.29 kg CO2	
Overall Total Annual		£105,222.75	£68,532.95	-740.24 ton CO2	

reduced noise and congestion (car costs)		health benefit	
£ 0.26 to	£ 3.08 /mile reference	£ 0 to	£1210 max /year pp health benefit from cycling
£ 0.26 /mile figure used		£ 605 avg of figure w/ dim returns	
£ 67,600.00	£ 67,600.00 £ /yr	£ 605.00	yearly per capita benefit figure used
£ 283,411.11	£ 497,541.88 present value	£ 60,500.00	£ 60,500.00 £ /year (group)
		£ 253,644.56	£ 445,285.27 present value

Figure 9.1 Velomobile cost benefit analysis spreadsheet view of main results, adjusted to the modal surveyed mileage and 100 participants, illustrating the potential benefits those surveyed by this project could realize, with public support

<sup>10</sup> Many thanks to Dr Lane for the example to follow in the model and providing LEAF2 for other researchers.

	individual	social		
yearly fuel estimate	£22,941.18	£5,490.59		
full cost/effic*miles*number*52		ul cost/eff*#*mi		
yearly maintenance	£120.50	£104.78		
wklymiles*(cost incl tax)*52				
annual avoided cost subtotal	£23,061.67	£5,595.37		
rebate value	£375,000.00			
total investment expenditure	£200,000.00	£500,000.00		
#*purchase + tax - rebate%*price		#*purchase + tax		
year discount (1/r)^y		discount		
0	1.00	-£200,000.00	-£500,000.00	1.00
1	0.83	£19,218.06	£5,278.65	0.94
2	0.69	£16,015.05	£4,979.86	0.89
3	0.58	£13,345.88	£4,697.98	0.84
4	0.48	£11,121.56	£4,432.06	0.79
5	0.40	£9,267.97	£4,181.18	0.75
6	0.33	£7,723.31	£3,944.51	0.70
7	0.28	£6,436.09	£3,721.24	0.67
8	0.23	£5,363.41	£3,510.60	0.63
9	0.19	£4,469.51	£3,311.89	0.59
10	0.16	£3,724.59	£3,124.42	0.56
lifetime cost avoided	£96,685.42	£41,182.40		
present value cost	-£103,314.58	-£458,817.60		
capital recovery factor 10 years				
$r(1+r)^n/1+r^n-1$	0.24	0.14		
total annual cost	-£24,642.88	-£62,338.61		

	individual	social
fuel	£1,764.71	£422.35
	8.82	2.11
	5.48	1.31
monthly		
maintenance	£9.27	£8.06
	4.63	4.03
	2.88	2.50
monthly		
subtotal	£1,773.97	£430.41
	13.46	6.14
	8.36	3.82
monthly		
fuel	£ 96,180.24	£ 40,411.21
present value		
maintenance	£ 505.18	£ 771.19
present value		
lane 2000 (LEAF2 fuel data.xls ULSP)		
price £ incl VAT		0.75
fuel duty		0.458
underlying price		0.18
calculated factor		0.71843137
factored tax /L		£ 0.46
remaining/underlying fuel rat		£ 0.18

Figure 9.2 Velomobile cost benefits spreadsheet view of calculations and results, adjusted to the modal surveyed mileage and 100 participants, with a post-tax subsidy of 75% shown

Default figures and estimates:						
lane fueldata.xls 2002 data	median cars.xls	nox	pm	ch4	co2	0.188235
mid 2002 fuel use	2.7 MJ/km	g/km	g/km	g/km	g/km	5.3125
maintenance	2.5 p/km	0.28	0.01	0.04	208.81	13.67942
Anable Root & Boardman		fuel	nox	pm	ch4	co2
petrol aver:	2.42	kg co2 /L	g/km	g/km	g/km	g/km
<40 mph medium petrol + cat		8.5379	0.27	0.01	0.22	195
45-85 mph medium petrol+cat		6.5399	0.14	0.01	0.05	153
		8.99				
						converted economy
						7.28 miles/L
						9.50 miles/L
						8.91

Active (individual) and public discount rates based on Lane 2000 LEAF2 model 20% and 6% respectively  
 0% discount for emissions is also Lane Leaf2 model (factor of 1 is I think no discount)  
 Saelendeminde is credited at www.bikezone.org.uk with health estimates of £605 and seem reasonable compared to Litman 2004 (not shown)  
 6% discount is recommended by the Bank of England, sourced from RECONNECT study 2000, also used by Lane for public discount rate

Litman Estimated benefits of non-motorized transport Canadian dollars 2000/4?			
	urban: pea / off-peak		rural
Congestion Reduction	0.2	0.2	0
Roadway cost Savings	0.05	0.05	0.03
Vehicle Cost Savings	0.25	0.2	0.15
Parking costs (per trip)	2	1	0.5
Air pollution reduction	0.1	0.05	0.01
Noise pollution reduction	0.03	0.02	0.01
energy conservation	0.05	0.04	0.03
traffic safety benefits	0.05	4	0.03
total per mile	> \$ 2.73	> \$ 1.42	> \$0.76

European Scrutiny Committee (2003) at bikezone.co.uk	\$0.50	\$0.44	\$0.18
		\$0.30	\$0.24
noise and congestion (high) cost estimate in London	£ 1.08	£ 0.48	£ 0.26
£ 3.08 /mile	£ 1.18	£ 0.57	£ 0.26
high figure low ->>	£ 1.33	£ 0.89	£ 0.37

converted \ \$Can 1.00 = £ 0.49

energy, vehicle & congestion excluded  
 vehicle and energy subtotal  
 converted total (vehicle, energy and congestion excl)  
 converted total (vehicle and energy removed)  
 converted original estimates (minimum ie. > each)

vv very high  
 \*shifts to non-motorized modes often leverage additional motorized travel reductions...  
 If seven motorized motor vehicle miles are reduced for each increased mile of non motorized travel  
 ...as the data suggest.\* (Litman 2004:19)

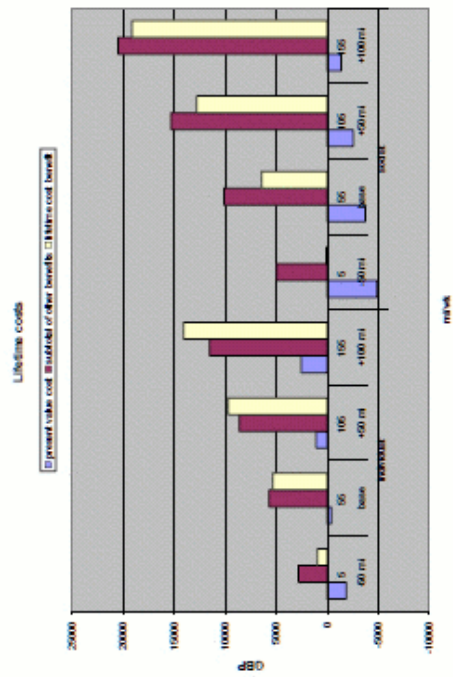
... estimate with benefits multiplier of			7
£ 7.59	£ 3.33	£ 1.84	- V E & C
£ 8.27	£ 4.02	£ 1.84	- V E
£ 9.29	£ 4.83	£ 2.59	ALL total per mile

Figure 9.3 Suggested damage and pollution estimates used in the cost benefit spreadsheet

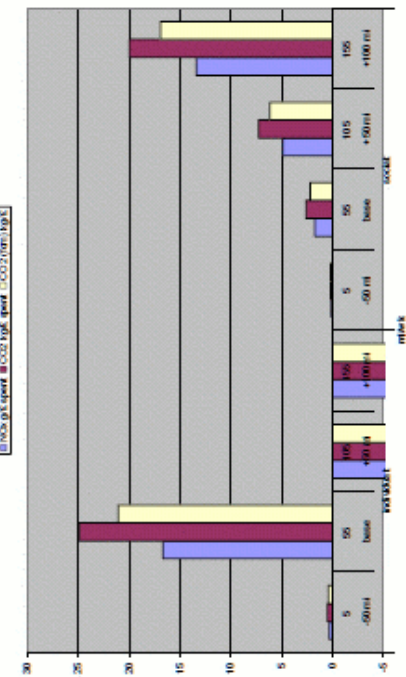
### Subsidies modeled

The subsidies discussed in chapter 7 are presented on the following two pages in eight graphs. They show a diminishing level of post-tax rebate which moves the consumer cost to a fairly constant price of around 2000 GBP. Social benefits remain substantial while public costs of the subsidy and project as a whole are level and not substantial. Consumer cost effectiveness is immediately improved and should begin a process of learning which could accelerate the production efficiencies faster than modeled. For this reason the results are all presented as if they were equally available subsidy options for the present even though they are discussed in the text (and would actually be) occurring in subsequent years.

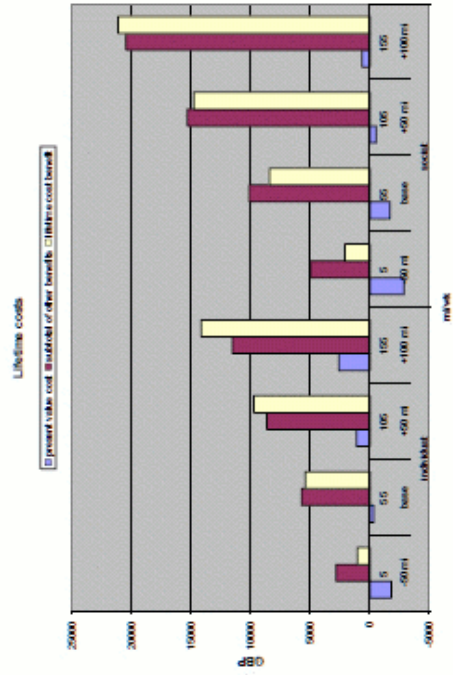
Case A1 GBP 5000, 75%



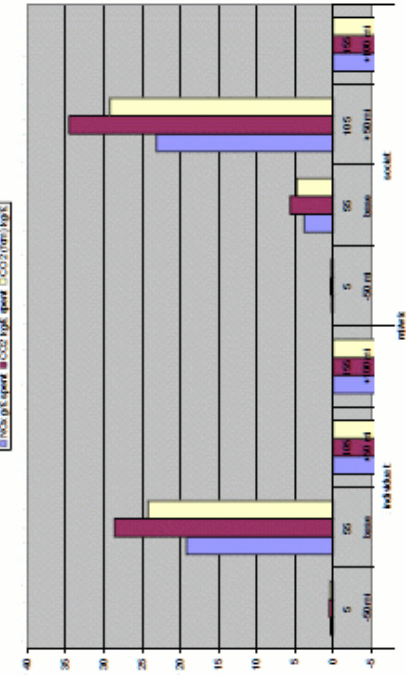
Emissions cost effectiveness



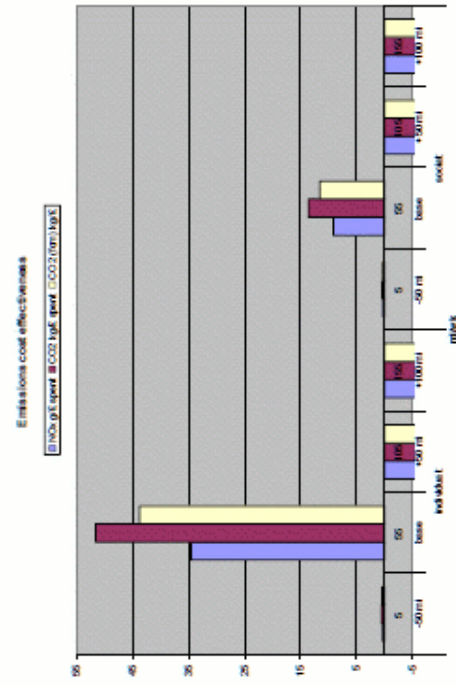
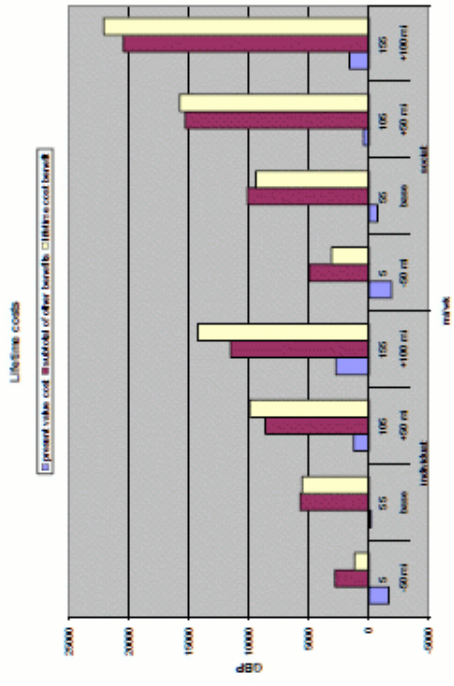
Case A2 GBP 3000, 50%



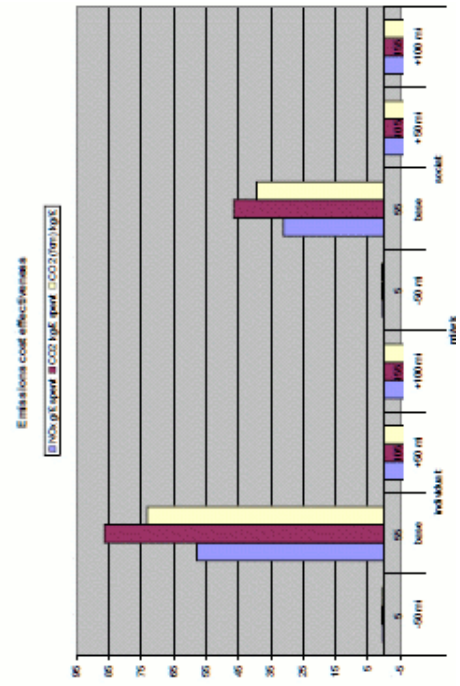
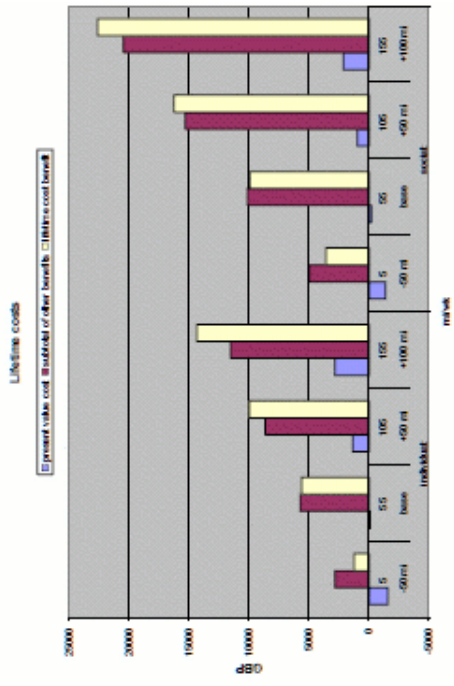
Emissions cost effectiveness



Case A3 GBP 2000, 25%



Case A4 GBP 1500 0%



## References

### Endnotes

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- <sup>i</sup> Bercicci: 97
- <sup>ii</sup> see Boardman 1998.
- <sup>iii</sup> Walle: 77
- <sup>iv</sup> Walle: 78
- <sup>v</sup> Pachauri TS.7: 45
- <sup>vi</sup> IPCC WGIII 2001: 40
- <sup>vii</sup> Several sources contributed to this list, Litman in particular has been invaluable.
- <sup>viii</sup> Velomobiel in the Netherlands is reported to have already incorporated recyclability into many of their products.
- <sup>ix</sup> Derived from the mid value of Anable for the average light passenger vehicle
- <sup>x</sup> Litman 2004
- <sup>xi</sup> European Scrutiny Committee report (cited in spreadsheet references)
- <sup>xii</sup> ESC also
- <sup>xiii</sup> Carbon trading .com. au
- <sup>xiv</sup> Based on several example values from the RECONNECT study
- <sup>xv</sup> Especially one with Halfdan Grimstead in Denmark, where he explained that though he knew of the Leitra he did not make a purchase until his commute increased as a result of new locations, raising the marginal commute costs to make the velomobile cost competitive.
- <sup>xvi</sup> Chapman and Gross
- <sup>xvii</sup> Chapman

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