EVS24
Stavanger, Norway, May 13-16, 2009

Assessing the Ecological Footprint of Personal Mobility – a Case Study on the Benefits Generated by the Promotion of Electric Vehicles in Canton Ticino - Switzerland

Raffaele Domeniconi[1], Cecilia Matasci[1]
[1]*infovel - Center of Excellence for Sustainable Mobility, CH - 6850 Mendrisio, Switzerland, r.domeniconi@infovel.ch*

Abstract

Personal mobility carries a heavy environmental burden. This is particularly true for Switzerland, where it is responsible for 33% of energy consumption and for 34% of CO_2 emissions[1] [1]. The impact is however not equally distributed between the different means of transport. This study first addresses this problem by defining and analysing the ecological footprint of different common means of transport in Canton Ticino – Switzerland - and their evolution over time. Results for regions with similar social, geographical and economic characteristics are most likely to be comparable. The aim is to provide a guide to individuals in their choices when it comes to their personal mobility and to policy-makers when it comes to transportation policies. In the second part of the article we analyze in more detail the impact of electric vehicles. Canton Ticino was a pioneer in promoting - via incentives and consultancy - electric vehicles (and light efficient vehicles in general) to its citizens. A first project called VEL1 was launched in 1995 in the town of Mendrisio. It was then followed by a second project - VEL2 - encompassing the whole canton. The study of the outcomes generated by this political choice could be useful to politicians willing to promote sustainable personal mobility.

Keywords: mobility, emissions, passenger car, public transport, EV (electric vehicle)

[1] data refer to the total transport sector

1 Introduction

Personal mobility has a big impact on the environment, notably in terms of air quality, greenhouse gases, ozone depletion, water quality, use of natural resources, noise, and land use. This impact is however not equally distributed between the different means of transport; if the impact of common cars or planes is considerable, human powered mobility alternatives such as bicycle riding or walking are virtually nonexistent [2]. Between these two extremes there is a range of other alternatives which are more or less ecological friendly.

In this study we assess the Ecological Footprint (EF hereafter) [3] of different means of transport referring in particular to the situation in Canton Ticino – Switzerland. Similar results are likely to be found for regions with comparable social, geographic, and economic characteristics.

The main means of transport available in the canton are taken into consideration. Particular attention is given to innovative and more environmentally friendly options present on the territory. The impact is assessed using the EF method and is given in terms of square meters of land consumed per kilometre of road travelled per year per passenger. All vehicles of the retained set registered in the canton are considered. Data are mostly provided by cantonal offices and by representatives from public transportation companies. Estimates are based on different assumptions, methodologies and samples.

The ultimate goal of this study is to provide politicians and private citizens with an instrument that enables them to take better personal and collective actions when it comes to sustainable development and CO_2 reduction measures.

2 The assessment of the impact of personal mobility - The Ecological Footprint method

2.1 General overview

Ecological Footprint [3] [4] is a resource management tool that measures the human demand on the Earth's ecosystems. Said differently, it defines the amount of land and water area required by a human population to produce the resources it consumes and to absorb its wastes under prevailing technology. It is an interesting instrument when it comes to assessing a population (considered as an individual, a corporation, a city, a nation, or all of humanity) overshoot and to managing ecological assets more carefully.

2.2 The CO_2 footprint

We will hereafter focus on the CO_2 footprint, which is the impact caused by the population by emitting carbon dioxide into the atmosphere. The footprint is calculated by estimating the biologically productive area (the area that supports significant photosynthetic activity and biomass accumulation used by humans) that would be needed to sequester enough carbon emissions to avoid the increase in atmospheric CO_2 [5].

The manufacture, use, and maintenance of vehicles are considered, as are road space and the space allocated to each transport mode (e.g. rails, railway stations, parking places, etc). Dismantling is not contemplated because it is considered to carry a smaller impact in comparison. For each vehicle type, the average fuel consumption of the considered fleet is given for the use phase and the manufacture and maintenance (MM) of the vehicle and of the road space.

The method is illustrated hereafter. These figures are translated into CO_2 emissions and converted to the associated land area needed to sequester the carbon. In our case, the EF of conventional petrol engine cars therefore is:

$EF_{vehicle} = (0.083 + 0.153) * 2.36 * 1.92 * 1.17 / 1.57 = 0.800\ m^2$ per passenger-kilometer per year, where:

- 0.083 l/km is the average petrol consumption of the fleet of conventional petrol engine cars in Ticino for 2008 [6];
- 0.153 l/km is the average MM petrol consumption [7];
- 2.36 is the weight of CO_2 in kilograms produced per liter of petrol [8];
- 1.92 is the area (in m2) of average forest land required to sequester one kilogram of CO_2 per year [8];
- 1.17 is the equivalence factor for forest land [8];
- 1.57 people is the average car occupancy [8].

In addition, vehicles require built-up land. For calculating this, two data point are needed: the space allocated to the transport mode and the number of car kilometers traveled per year. This is, for conventional petrol engine cars:

$EF_{built\text{-}land}$ = 42,000,000 * 0.670/2,425,985,088 * 2.8 * 1.57 = 0.051 m^2 per passenger-kilometre per year, where:

- 420,000,000 m2 is the area covered by the road system in Ticino [9];
- 67.0 % is the share of the road that is used by conventional petrol engine cars [10] [11];
- 2,425,985,088 is the total number of Ticino car km per year [1] [12];
- 2.28 is the equivalence factor for built-upon land [8].

The total travel footprint is therefore:

$EF_{tot} = EF_{vehicle} + EF_{built\text{-}land} = 0.800 + 0.051 = 0.851$ m^2 per passenger-kilometer per year

2.3 Comparison with the Life Cycle Assessment

The method can be compared with the Life Cycle Assessment (LCA) [13]. LCA is the investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its entire existence, from cradle to grave. It generally also considers NO_x, SO_2 and PM_{10} emissions.

There are pros and cons in choosing one method or the other. From one side, LCA - if thoughtfully done - gives a far more complete and more precise picture. On the other hand, the collection of data is extremely time-consuming. It should be underscored that EF is not a scientific standard and we are fully aware of its limitations. It can - on the other hand - be useful to establish a first, rough approximation of the ecological impact of a product or a system.

3 Canton Ticino: a geographic and socio-economic overview

3.1 Geography and society

Canton Ticino lies on the southern slopes of the Alps. It is the southernmost canton of Switzerland (Figure 1). With its 2,812 km^2 and its 329,000 inhabitants [14], it possesses a density of 117 inhabitants/km^2. It is a relatively highly urbanized territory, with 67% of the population living in the four major urban centres (Lugano, Locarno, Bellinzona, and Mendrisio), and – generally - in the lower part of the valleys [14].

Almost half of the territory is covered by forests; 15% is considered agricultural area; 5% settlement and urban areas, and 32% non-productive land [14]. Canton Ticino benefits from a distinct mild Mediterranean climate.

Figure 1: Canton Ticino, located in the South of Switzerland, is characterized by relatively highly urbanized areas. The four main urban centres (Lugano, Locarno, Bellinzona, and Mendrisio) are well interlinked by a functioning road and rail system [15], modified

3.2 Economy

The most important sectors of Ticino's economy are finances, tourism, trade and commerce, logistics, and production. The average income per inhabitant in 2006 was 41,335 CHF. There is an increasing trend in the last decades (Figure 2).

3.3 Transport system

The canton possesses a well-organized transport system. A highway and a rail system link the four main urban centers to each other and with the rest of Switzerland (via the Gotthard tunnel) and with Italy. In addition, a well-structured and dense public transport network (mainly composed of buses and trains) assures a good connection within and between urban centers. More remote mountain localities, however, suffer from a less effective or nonexistent public transport system [16].

The cantonal motorization rate is 602 cars/1000 inhabitants (516 cars/1000 inhabitants for Switzerland in 2006) [18]. This rate has been steadily increasing over the last decades (Figure 2), partially boosted by the concurrently rising cantonal income. The increasing population, motorization rate and kilometres travelled per capita [16] (not shown on the graph) are responsible for the increase in CO_2 emissions in the last decades.

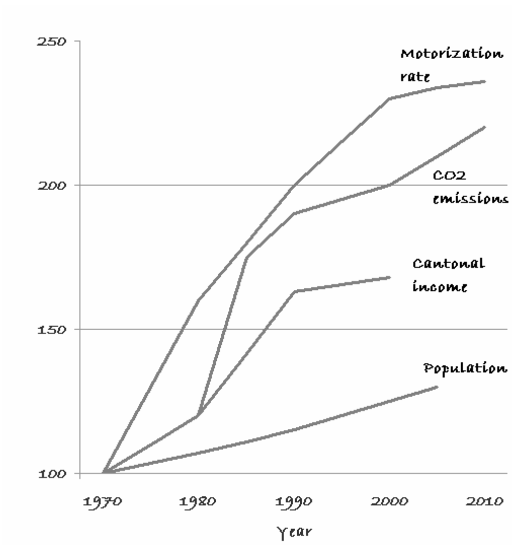


Figure 2: Evolution of the motorization rate, CO_2 emissions, cantonal income, and residential population between 1970 and 2000; index 1970 = 100. After [17], modified

Other causes include the increasing average vehicle weight due to the demand for larger cars, more safety and other features such as air-conditioning, four-wheel drive and gadgets [19]. This increase masks benefits generated by the emergence of more efficient vehicles. In particular in the Southern part of the canton, air quality is a serious concern for human health [20].

4 The current Ecological Footprint of personal mobility in Ticino

We will follow the CO_2 calculation method presented in Chapter 2.2 in order to assess the current EF for personal mobility inside the canton. Values and basis assumptions for the whole set of vehicles considered for the year 2008 are reported in Table 1. Altogether, seventeen categories have been retained. They are: bicycles, buses, car pooling, conventional petrol engine cars, E-bikes, electric cars, E-scooters, hybrid cars, light consumption diesel engine cars, light consumption petrol engine cars, motorcycles, natural gas cars, scooters, taxis, trains, and walking. Planes are not taken into account because, even if the canton is served with two airports, planes are not a common means of transport for inner displacements.

Some assumptions have been made:

- CO_2 emission during the use phase is the average one for a vehicle circulating in the canton at the given year (2008). It is therefore a mix generated by more recent and more efficient vehicles and older and more inefficient ones [6] [21] [22] [23];
- diesel produces a different quantity of CO_2 per litre than does petrol. Here we consider the weight of CO_2 emitted per litre of diesel fuel as being 2.64 kilograms (calculated after [6]);
- the equivalence of CO_2 emitted by trains is 0.131 kg/kWh [24] which reflects the Swiss electric mix;
- for walking and biking, the impact during the use phase is considered to be nonexistent;
- contrary to what is proposed by Wackernagel [8], we don't consider an uplift factor (the additional percentage of CO_2 emitted during the MM of the vehicle and of the road infrastructure), but we take data assessed in previous LCA analysis [7] [25] [26];
- in addition, in the MM phase petrol, light consumption, natural gas, taxis, and hybrid cars are assumed to have the same size and weight. It is therefore assumed that the impact during the MM phase is equivalent for the mentioned categories;
- the impact for the MM of motorcycles, scooters and E-scooters is considered to be 10% of that for a conventional car (rough weight-based assumption);
- for the assessment of the MM of trains, a lifecycle of 30 years is considered [7]. Results might vary considerably depending on the lifespan chosen;
- car road share for a particular vehicle is calculated by considering the number of exiting vehicles multiplied by the average kilometres travelled by a vehicle in a year (the car km factor), weighted by the surface occupied by the vehicle[2] and upon the totality of the (road) network surface;
- for trains, it is estimated that approximately 75% of the rail system is allocated to passenger transport and 25% to freight [27];
- for the car km factor, no difference is made between the average distance per year

[2] It has been considered that a motorcycle or a scooter occupies 1/10 of a car surface, a bike 1/15, a person 1/20 and a bus 6 times more space and that in general private cars occupy 75% of the road space.

Table 1: The considered vehicles and their characteristics for Ticino in 2008

	CO_2 emissions during use	CO_2 emissions for maintenance and manufacture	Vehicle road share	Total travelled distance	Vehicle occupancy
	[kg/km]	[kg/km]	[%]	[vehicle km]	[people]
Bicycles	0	0.005	0.088	47833104	1
Buses (50 seats)	1.062	1.476	12.409	74894770	20
Car pooling	0.196	0.363	0.094	3403000	4
Conventional petrol engine cars	0.196	0.363	66.994	2427346288	1.57
E-bikes	0.001	0.005	< 0.001	21381	1
Electric cars	0.018	0.363	0.064	2314040	1.57
E-scooters	0.004	0.036	< 0.001	8120	1
Hybrid cars	0.107	0.363	0.100	3620792	1.57
Light consumption diesel engine cars	0.120	0.363	5.585	202233484	1.57
Light consumption petrol engine cars	0.115	0.363	1.916	69366752	1.57
Motorcycles	0.129	0.036	0.020	7087935	1
Natural gas cars	0.146	0.363	0.038	1361200	1.57
Scooters	0.092	0.036	0.001	218671	1
Taxis	0.196	0.363	0.210	7595496*	2.5*
Trains (182 seats)	0.456	6.416	75.000	2384638	36.4
Walking	0	0	0.347	95666208	1

* see discussion in the text

travelled e.g. by an electric, a light consumption, a hybrid, or a conventional car (see Table 1). This choice is arguable. Data come from various sources [6] [10] [11] [12] [14] [21] [25] [28] [29] [30] [31] [32];

- car occupancy rates are taken from the literature or obtained through interviews with local transit companies [21] [22] [33] [34].

Additional assumptions are made:

- Buses are considered to be diesel 50-seat buses, with an occupation rate of 40 %. The reality is far more complex, with buses of different weight, size, and efficiency. It has to be noted that the whole fleet uses ultra low sulphur diesel fuel and that 44.2% is provided with particulate filters. This percentage is expected to increase in the coming years [22];
- for hybrid cars, the arithmetic average of the emissions of the different vehicles present in the canton is made [6]. Only the Lexus is considered as representing 1% of the fleet;
- for taxis, results are particularly critical. There are no data available on the real distance travelled by cabs and the return travel (with no occupancy). We assume the latter to correspond to half of the distance travelled by customers. The average occupancy rate during customers transport being 2.5 passengers [34], we therefore obtain an adjusted vehicle occupancy rate of 1.67 passengers and a car km value of 11,393,244 km;

Generally speaking, because of the difficulty in collecting real data specific for the region, many assumptions are made and data are gathered from different sources. Values have to be regarded more as indications than as strictly reflecting reality. In the future, the gathering of data will be improved and therefore results should become more accurate.

4.1 Results

In the following graphic (Figure 3), the EF of personal mobility is given. Error bars mark variances of results considering full vs. minimal vehicle occupancy (e.g. 1 or 50 passengers for buses). Considering that not all displacements can be done with all types of vehicles, we make a differentiation between short and long distances (e.g. respectively inside and between urban centres). Walking, biking, scooters, and taxies are dropped from the comparison for long distances, whereas train travel is dropped for short ones.

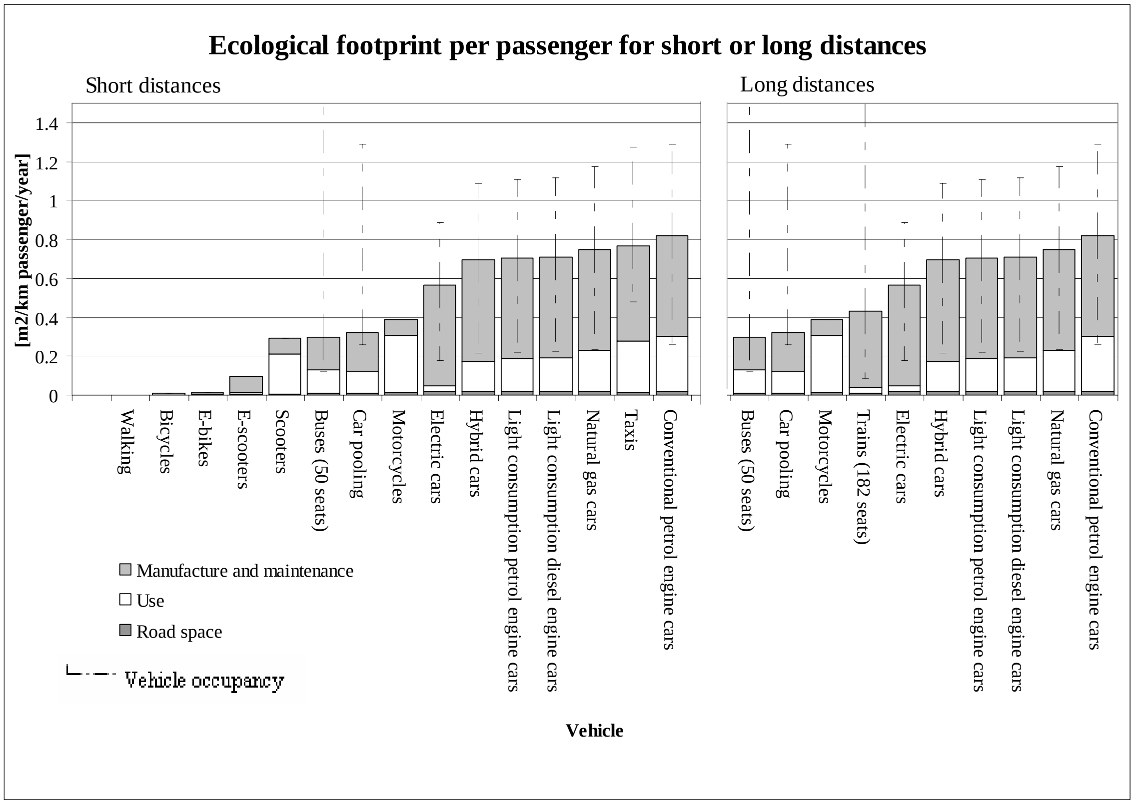


Figure 3: The ecological footprint of personal mobility in Canton Ticino in the year 2008. For each vehicle the impacts for use, manufacture and maintenance, and road space are given.

In both short and long distances, conventional petrol engine cars appear to have the worst score (0.851 m^2 per passenger-kilometer per year). For long distances, petrol engine cars are followed by natural gas cars (0.750 m^2), light consumption diesel cars (0.711 m^2), light consumption petrol cars (0.705 m^2), and hybrid cars (0.693 m^2). Electric cars come next with a smaller impact (0.565 m^2). For these vehicles, the use phase carries a particularly small impact (0.025 m^2 against 0.280 m^2 for conventional cars). Trains (0.432 m^2) are placed after electric cars and have virtually no impact during the use phase (0.028 m^2) but an important one during the MM phase (0.396 m^2). The impact varies enormously depending on the vehicle occupancy (14.118 m^2 in the case of minimal occupancy vs. 0.078 m^2 for full occupancy (182 passengers)). Motorcycles have an EF of 0.388 m^2 per passenger-kilometer per year, car pooling 0.322 m^2, and buses 0.295 m^2 (with an impact for minimal occupancy of 5.828 m^2 and for full occupancy of 0.117 m^2). It is interesting to see how generally public transport systems clearly stand out and have a smaller ecological footprint than do all sorts of private passenger vehicles.

For short distances, as it was easily foreseeable, walking obtains the best score (<0.001 m^2), followed by bicycles (0.011 m^2), E-bikes (0.014 m^2) and E-scooters (0.094 m^2). Scooters get a score of 0.291 m^2 and are placed before buses. Taxies appear to be the second worst means of transport (0.766 m^2). It could be added that for short displacements, because of cold starts and low average speed (e.g. car congestion in urban centers), cars carry an even bigger impact than that shown here. A car is 42% less efficient when traveling at a speed of 10 km/h than at a speed of 75 km/h [35]. Also air-conditioning, which is nowadays common in most brands, increases energy consumption during the use phase and therefore enlarges the EF. Consequently, the per kilometer rate of CO_2 savings from biking and walking is here significantly understated and their merits are underemphasized.

4.2 Comparison with the LCA

Life Cycle Assessment is the end-to-end analysis of the real environmental impact of a product or service. It is the broadest indicator and an internationally standardized method (ISO 14040 and ISO 14044). It not only evaluates the impact on climate change, but also other impact categories such as acidification potential, eutrophication potential, ozone depletion potential, and ground level ozone creation. It quantifies the environmental impacts over the complete life span and at every stage from raw material production, manufacture, logistics and transport, to use and disposal.

A study commissioned by Mobility CarSharing in 2002 [2], analysed the LCA of 13 different categories of vehicles in Switzerland (Figure 4). The impact in term of passenger-km is given. As we see, conventional petrol engine cars carry once again the heaviest burden on the environment, whereas bikes' impact is virtually nil. The impact of public transport is more than two times lower than that of conventional cars and it is principally generated by the infrastructure and the production, maintenance, and disposal of vehicles. It is important to note that this assessment doesn't consider only CO_2 emissions and energy consumption, but a wider range of environmental burdens. This could explain differences between the two studies for e.g. motorcycles. In the LCA, emission of particles and NO_x during the use phase worsens the impact. Also here it is interesting to observe that public transport systems carry a truly small impact during the use phase and that their impact relies almost completely on the MM phase.

5 The influence of individual behaviour in the decrease of the EF

Taking into account the microcensus for mobility carried out in Ticino in 2005 [16], on average people travel 25.5 km per day. The principal means of transport is car (20.5 km per day), followed by train and walking (both 1.7 km). Buses, motorcycles and biking come last (Table 2). The means of transport chosen depends greatly on the length of the journey (Figure 5, first graph). It appears, however, that for the majority of the means of transport, distances are relatively small. In particular:

- 50% of the walking trips do not exceed 500 m;
- 25% of the journeys made by bike do not go beyond 1.0 km;
- almost one trip out of 5 made by car doesn't go over 1.0 km and only 26% over 10 km in length;
- in contrast, 73% of the displacements made by train exceed 10 km.

Looking at these data, it appears that, on average, a person inhabiting the canton has an annual environmental footprint for mobility of 6,456 m^2 (2,832 m^2 for short journeys and 3,624 m^2 for long ones, where long journeys are considered as being longer than 5km) (Figure 5, bottom).

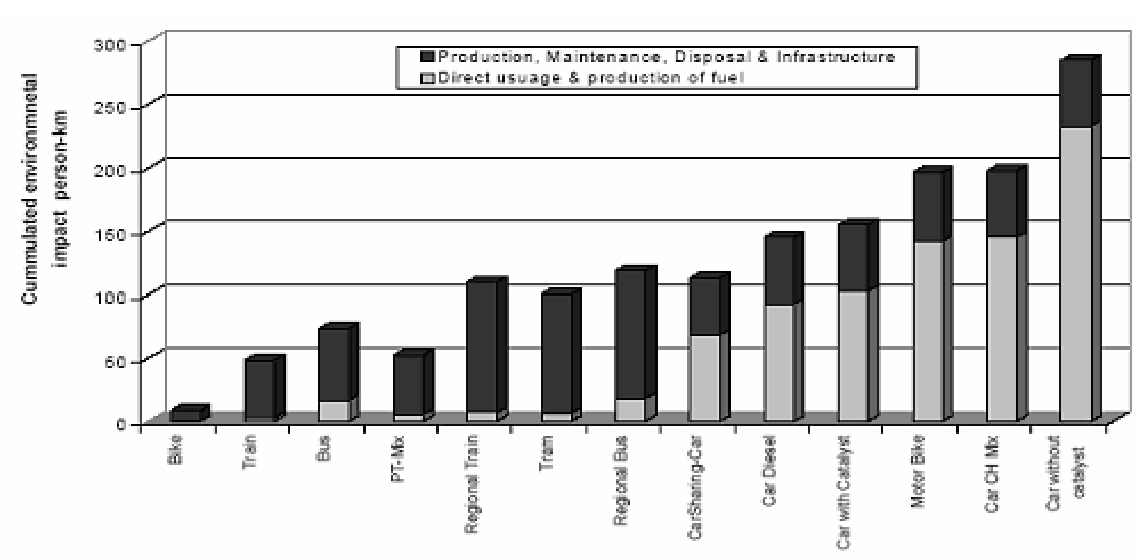


Figure 4: Comparison of the environmental impacts of the different means of transport in Switzerland [2]

There is a high potential for reduction. We will hereafter depict the possible target that could be reached by taking different mobility choices depending on the distance traveled (Table 2 and Figure 5, left).

By avoiding using cars and motorcycles and instead walking for trips shorter than 0.5 km, riding a bike or walking (50% and 50%) for trips of 0.5 - 1.0 km and choosing between bikes or buses for distances between 1.0 and 5.0 km, the impact for short trips could be more than 5 times smaller (538 instead of 2,832 m^2).

By the same principle, if for journeys longer than 5.0 km trains, buses, and cars (electric) were chosen (33% each), the impact could be 1.5 times smaller for long distances (2,111 m^2 instead of 3,624 m^2). The total reduction of the EF would be of more than 3,800 m^2 (almost 2.5 times).

We see here that by modifying personal habits only slightly, we could reduce considerably our footprint on the environment. In addition, as seen in Figure 3, by increasing the occupancy rate, personal EF could also be considerably reduced.

6 The influence of policy initiatives in the decrease of the EF

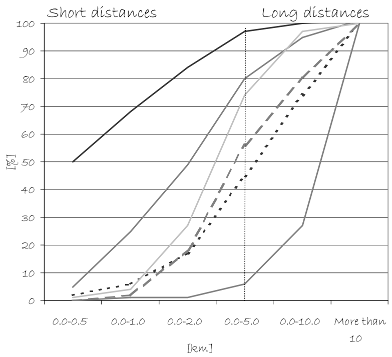
Canton Ticino is actively promoting more sustainable mobility patterns. Action consists mainly in awareness-raising and in promoting clean means of displacement. The major axes of intervention are [36] [37]:

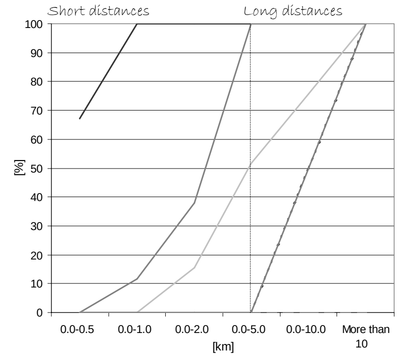
Table 2: Frequency of the length of the journey and Ecological Footprint for type of vehicle in Ticino in 2005 and as targeted [16] modified.

				Short distances			Long distances		
			0.0-0.5 km	0.0-1.0 km	0.0-2.0 km	0.0-5.0 km	0.0-10.0 km	More than 10 km	Total
2005									
Walking	Daily distance	[%]	50	18	16	13	3	1	100
		[km day]	0.85	0.31	0.27	0.22	0.05	0.02	1.70
	EF	[m2 passanger/ year]		2.57			0.11		
Biking	Daily distance	[%]	5	20	24	31	15	6	100
		[km day]	0.02	0.08	0.10	0.12	0.06	0.02	0.40
	EF	[m2 passanger/ km year]		1.26			0.33		
Car*	Daily distance	[%]	2	4	11	28	29	26	100
		[km day]	0.41	0.82	2.26	5.74	5.95	5.33	20.50
	EF	[m2 passanger/ km year]		2718.04			3322.05		
Motorcycle	Daily distance	[%]	0	2	16	38	24	20	100
		[km day]	0	0.01	0.08	0.19	0.12	0.10	0.50
	EF	[m2 passanger/ km year]		38.28			30.07		
Bus	Daily distance	[%]	1	3	23	47	23	3	100
		[km day]	0.01	0.02	0.16	0.33	0.16	0.02	0.70
	EF	[m2 passanger/ km year]		55.74			19.59		
Train	Daily distance	[%]	0	1	0	5	21	73	100
		[km day]	0	0.02	0	0.09	0.36	1.24	1.70
	EF	[m2 passanger/ km year]		16.10			252.22		
Target									
Walking	Daily distance	[%]	67	33	0	0	0	0	100
		[km day]	1.29	0.63	0	0	0	0	1.91
	EF	[m2 passanger/ year]		2.98			0		
Biking	Daily distance	[%]	0	12	27	62	0	0	100
		[km day]	0	0.63	1.43	3.34	0	0	5.40
	EF	[m2 passanger/ km year]		21.27			0		
Car*	Daily distance	[%]	0	0	0	0	50	50	100
		[km day]	0	0	0	0	2.23	2.24	4.48
	EF	[m2 passanger/ km year]		0			923.14		
Motorcycle	Daily distance	[%]	0	0	0	0	0	0	100
		[km day]	0	0	0	0	0	0	0.00
	EF	[m2 passanger/ km year]		0			0		
Bus	Daily distance	[%]	0	0	15	36	24	24	100
		[km day]	0	0	1.43	3.34	2.23	2.24	9.25
	EF	[m2 passanger/ km year]		514.02			481.65		
Train	Daily distance	[%]	0	0	0	0	50	50	100
		[km day]	0	0	0	0	2.23	2.24	4.48
	EF	[m2 passanger/ km year]		0			706.40		

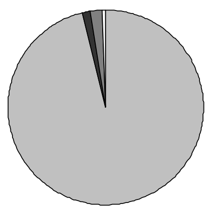
* Considering all types of cars and their relative percentage of road share (Table 2), the impact for an average car in 2005 is 0.807 m2 passenger/year km. Under the target scenario, 0.565 m^2.

2008	Target

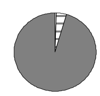




Short distances (0-5.0 km)

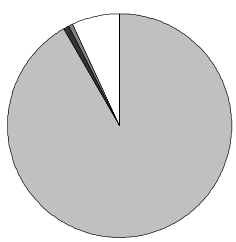


Total impact : 2,832 m^2 passenger/year

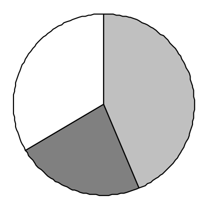


Total impact : 538 m^2 passenger/year

Long distances (>5.0 km)

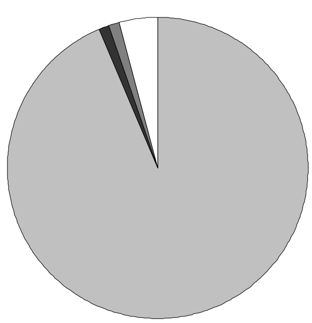


Total impact : 3,624 m^2 passenger/year

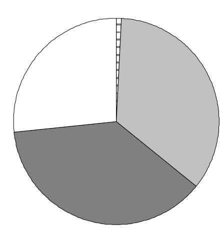


Total impact : 2111 m^2 passenger/year

Total



Total impact : 6,456 m2 passenger/year



Total impact : 2,649. m2 passenger/year

—— Walking —— Biking ---- Car* —— Motorcycle —— Bus —— Train

Walking Biking Car* Motorcycle Bus Train

Figure 5: Annual personal EF for mobility and per inhabitant of Canton Ticino in 2008 and as targeted. Graphics on the top show the cumulative frequency of length of trip for mobility pattern. In the lower part, the EF is given for short and long distances and for the total number of displacements. The area of the pie, divided per mobility patterns, illustrates the size of the impact. For more explanations refer to the text.

- Promotion of public transport between and inside urban areas;
- further development of public transportation in more rural areas;
- enhancement of complementarity between different means of transport depending on the landscape and the geological conformation (public transport inside and between urban areas; walking and cycling on a local and neighbourhood scale; coordinated management of parking places in city centres and park-and- ride/rail infrastructures).

Canton Ticino also offers ecodrive courses; promotes low consumption vehicles, car sharing solutions, and company mobility; and puts forward attractive regional public transportation subscriptions. Our study, repeated in the coming years, will show if these actions are able to successfully reduce the impact of personal mobility. Theoretically, the target is the one presented in the previous chapter (Chapter 5).

7 The VEL1 and VEL2 projects and their contribution to enhance electric and LEV vehicles

As previously depicted, one of the strategies adopted by the government to reduce the EF of personal mobility inside the canton is the promotion of low consumption vehicles.

Canton Ticino was a pioneer in promoting - via incentives and consultancy - electric vehicles to its citizens. A first project called VEL1 was launched in 1995 in the city of Mendrisio. It was then followed in 2001 by a second project - VEL2 - encompassing the whole canton. We examine the influence of this political choice on the overall impact of personal mobility.

As shown in Table 3, the political choice taken by canton Ticino allowed avoiding – during the use phase - the emission of 787 tonnes of CO_2 and the saving of up to 177 hectares of biologically productive area annually.

8 Conclusion

Generally, this study highlights the good environmental score of public transport systems and of innovative means of transport. Electric vehicles stand out significantly from other types of private vehicles, also thanks to the high percentage of hydro power in the Swiss electricity mix. Individuals attempting to reduce their environmental impact have here a choice of valuable alternatives to the use of conventional cars.

There is a huge margin for EF reduction. The biggest proportion of decrease can be obtained in short displacements. By avoiding using cars and opting instead for human powered mobility alternatives such as cycling and walking, the impact could be reduced by a factor of five. This choice also brings health benefits.

As seen in Chapter 6, policy initiatives seem to focus on long distances, whereas it could also be useful to target short displacements. An interesting approach to enhance human powered mobility was recently implemented in the town of Mendrisio (Mendrisio al Passo coi Tempi [6]).

Furthermore, political measures as incentives and consultancy emerge as effective tools to fight against environmental degradation. In addition, it

Table 3: Evolution of the cantonal Electric VEL2 fleet between 1995 and 2005 [6] [28]

Year	Total Ticino fleet	Swiss average CO2 emissions	Electric VEL2 fleet						
			Electric vehicles	Light electric vehicles	E-scooters	E-bikes	Total	Percentage of total Ticino fleet	CO2 saved
	[vehicles]	[kg/km]	[vehicles]	[vehicles]	[vehicles]	[vehicles]	[vehicles]	[%]	[t CO2/year]
1995		0.215	3	1	0	0	4		12
1996		0.213	10	6	0	4	20		46
1997		0.209	18	7	7	13	45		71
1998		0.207	34	13	24	31	102		132
1999		0.205	74	26	78	69	247		279
2000	235146	0.200	143	42	93	90	368	0.2	504
2001	240997	0.197	163	47	114	116	440	0.2	563
2002	245002	0.193	221	59	181	285	746	0.3	736
2003	246329	0.182	247	59	242	464	1012	0.4	758
2004	250967	0.176	281	59	272	628	1240	0.5	815
2005	254706	0.170	281	59	272	628	1240	0.5	787

appears necessary to take action during the production stage in order to further decrease the impact of personal mobility. This becomes apparent with EV, where manufacture and maintenance cause a big portion of the total impact of the vehicle[3].

In conclusion and as pointed out before, we are aware of the high uncertainty of our results and of the weaknesses of the EF method. We think - nonetheless - that it is a good tool for giving a first approximation of the possible actions that could be taken individually or at the governmental level to diminish our burden on the environment.

Acknowledgments

We would like to thank the many people working in cantonal offices and in public transportation companies that kindly provided us data for this analysis. We would also like to thank the reviewers for their interesting and pertinent comments.

References

[1] *BFS*, http://www.bfs.admin.ch, accessed on 2008-11-15.

[2] R. Mertens, *Eine Ökobilanz für Mobility CarSharing*, Mobility CarSharing Schweiz, Luzern, 2002.

[3] M. Wackernagel, *Ecological Footprint and Appropriated Carrying Capacity: A Tool for Planning Toward Sustainability*, Ph.D. Thesis, School of Community and Regional Planning, the University of British Columbia, 1994.

[4] W. E. Rees, *Ecological footprints and appropriated carrying capacity: what urban economics leaves out*, Environment and Urbanisation, 4 (1992), 121-130.

[5] World Wide Fund for Nature, *The Living Planet Report 2000*; WWF International, 2000.

[6] *infovel*, http://www.infovel.ch/, accessed on 2008-10-05.

[7] M. V Chester, *Life-cycle Environmental Inventory of Passenger Transportation in the United States*, Institute of Transportation Studies, University of California, Berkley, 2008.

[3] It is true, nonetheless, that we do not have real data on the impact of construction for EV vehicles and that we suppose this to be equivalent to that of common cars.

[8] M. Wackernagel and W. E. Rees, *Our Ecological Footprint* In N. Chambers, C. Simmons and M. Wackernagel, Sharing nature's interest - ecological footprints as an indicator of sustainability, Earthscan publications Ltd, 2000.

[9] M. Storni, *Mobilità nel Ticino*, Dipartimento del Territorio, Bellinzona, 2004.

[10] USTRA, *I compiti dell'USTRA*, Ufficio Federale delle Strade, 2007.

[11] OFRDU, *Comptage suisse de la circulation routière 2005*, Office Fédéral des Routes, 2006.

[12] E. Stephani, *L'impronta ecologica del traffico individuale motorizzato nel Cantone Ticino*, Università della Svizzera Italiana, 2008.

[13] ISO 14040, *Environmental management - Life cycle assessment - Principles and framework*, International Organisation for Standardisation (ISO), Genève, 2006.

[14] *USTAT*, http://www.ti.ch/DFE/USTAT/, accessed on 2008-12-06.

[15] *MagicSwitzerland*, www.magicswitzerland.com, accessed on 2008-11-15.

[16] R. Stoppa and F. Cadlini, *Mobilità: le abitudini dei ticinesi nel 2005* In Dati: Statistiche e società, Ustat, 2008.

[17] *Repubblica e Cantone Ticino*, http://www.ti.ch/, accessed on 2008-10-15.

[18] M. Storni, *Mobilità nel Ticino*, Dipartimento del territorio, 2004.

[19] M. E. Bouwman and H. C. Moll, *Energy use reduction potential of passenger transport in Europe*, Transport Reviews, 20(2), 191-203, 2000.

[20] UPA, *Analisi della qualità dell'Aria 2000*, Ufficio Protezione dell'Aria, Cantone Ticino, 2007.

[21] A. Aletti (TILO), personal communication.

[22] M. Nocker and F. Tadini (AutoPostale Svizzera), personal communication.

[23] R Widmer and M. Gauch, *Umweltnutzen von E-Scooter*, EMPA Materials Science & Technology, 2008.

[24] *BFE INFRAS*; http://www.bfe.admin.ch/ accessed on 2008-10-05.

[25] C. von Rozycki, H. Koeser and H. Schwarz, *Ecology Profile of the German High-speed*

Rail Passenger Transport System, ICE, lnt J LCA 8 (2) 83-91, 2003.

[26] D. Stead, *Relationships between transport emissions and travel patterns in Britain Transport Policy,* 6, pp. 247-258, 1992.

[27] R. de Gottardi, *Traffico merci: la ferrovia allunga il passo In* Trasportiamoci nel futuro, Repubblica e Cantone del Ticino - Divisione dello Sviluppo Territoriale e della Mobilità, 2007.

[28] G. Moreni, U. Haefeli, and M. Oetterli, *Veicoli efficienti leggeri - l'impatto del progetto VEL2 sul mercato delle automobili efficienti in Ticino*, Repubblica e Cantone Ticino, 2006.

[29] *RTSI*, http://retetre.rtsi.ch, accessed on 2008-10-05.

[30] E. D'Alessandri (Sezione della Circolazione, Cantone Ticino), personal communication.

[31] *TSR*; http://www.tsr.ch/tsr, accessed on 2008-10-05.

[32] BFS, *Mobilität in der Schweiz - Ergebnisse des Mikrozensus 2005 zum Verkehrsverhalten*, Bundesamt für Statistik, 2007.

[33] UFS, *Mobilità in Svizzera - Risultati del microcensimento sul comportamento del traffico,* Ufficio Federale di Statistica, 2007.

[34] Associazione Tassametristi Ticinesi, personal communication, 2008.

[35] J. Barret and A. Scott; *The application of the Ecological Footprint: a case of passenger transport in Merseyside*; Local Environment, 8(2): 167-183, 2003.

[36] *Cantone Ticino*, http://www.ti.ch/dt/dstm/sm/Temi/ Mobilita_aziendale/, accessed on 2008-10-05.

[37] *Cantone Ticino,* http://www.ti.ch/dt/dstm/temi/Mobter/doc/ Dati_0607/27_30_Citta_Ticino.pdf, accessed on 2008-10-05.

Authors

Raffaele Domeniconi obtained his title of Electronics Engineer at the Swiss Federal Institute of Technologies in Zurich. Since 2001 he has been the director of AssoVEL2, managing first the evolution of the EV pilot project of Mendrisio, followed by the VEL2 project, and then the Center of Excellence for Sustainable Mobility - infovel. He is vice-president of e'mobile, the Swiss association promoting electric and efficient vehicles and is President of Citelec, the European association of cities promoting electric vehicles.

Cecilia Matasci obtained a Master's Degree in Natural Sciences of the Environment at the University of Geneva in 2006. After various job experiences in Switzerland and abroad, she is now writing a PhD thesis at the Economics and Environmental Management Laboratory at the Swiss Federal Institute of Technology in Lausanne and collaborating with infovel in the assessment of the cantonal Ecological Footprint for mobility.