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Passenger Transport Energy Use in Ten Swedish Cities: Understanding the Differences through a Comparative Review

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Received: 26 June 2020; Accepted: 14 July 2020; Published: 20 July 2020

Abstract: Energy conservation in the passenger transport sector of cities is an important policy matter. There is a long history of transport energy conservation, dating back to the first global oil crisis in 1973–1974, the importance and significance of which is explained briefly in this paper. Detailed empirical data on private and public passenger transport energy use are provided for Sweden's ten largest cities in 2015 (Stockholm, Göteborg, Malmö, Linköping, Helsingborg, Uppsala, Jönköping, Örebro, Västerås and Umeå), as well as Freiburg im Breisgau, Germany, which is a benchmark small city, well-known globally for its sustainability credentials, including mobility. These data on per capita energy use in private and public transport, as well as consumption rates per vehicle kilometer and passenger kilometer for every mode in each Swedish city and Freiburg, are compared with each other and with comprehensive earlier data on a large sample of US, Australian, Canadian, European and Asian cities. Swedish cities are found to have similar levels of per capita car use and energy use in private transport as those found in other European cities, but in the context of significantly lower densities. Possible reasons for the observed Swedish patterns are explored through detailed data on their land use, public and private transport infrastructure, and service and mobility characteristics. Relative to their comparatively low densities, Swedish cities are found to have healthy levels of public transport provision, relatively good public transport usage and very healthy levels of walking and cycling, all of which help to contribute to their moderate car use and energy use.

Keywords: Swedish cities; passenger transport energy use; urban form; transport infrastructure; mobility patterns; public transport; non-motorized modes

1. Introduction

Until the 1973–1974 Arab oil embargo from October 1973 to March 1974, (the first global oil crisis) the use of energy in transport was not seriously on any academic or policy agendas. When OPEC (the Organization of Arab Petroleum Exporting Countries) declared an embargo on oil exports to countries deemed supportive of Israel during the 1973 Yom Kippur war with Egypt, the global price of oil essentially quadrupled 'overnight', from about $US3 per barrel to $12 per barrel [1,2]. Suddenly the world realized how vulnerable it is to events in the Middle East which affect the production and export of oil and its price. This stirred a spate of interest in this topic e.g., [3,4] and led to a growing concern about how to reduce dependence on oil in transport, particularly imported oil, and especially in cities [5,6]. The 1973–1974 oil crisis played out very differently in different cities. Dutch cities (The Netherlands was included in the embargo) adapted well to the crisis, since they were compact places which relied heavily on walking and cycling anyway, while the automobile cities in the USA experienced significant societal disruption as people scrambled to fill their very gas guzzling cars [7].

The world was again rudely awakened to this issue in the subsequent Iranian oil crisis in 1979 [8] caused by the Iranian Revolution. Iran's daily oil production of 6.05 million barrels per day, of which about five million barrels were exported to supply about 10% of the non-communist world's daily needs, was thrown into chaos. This event again brought into focus the dire situation of the world in regard to its political vulnerability to oil supply and its sometimes-volatile pricing. The need to reduce petroleum consumption and its dependence on Middle Eastern sources was firmly on the table. Unlike stationary uses of oil, such as for heating homes and in industry, which can be relatively quickly swapped to other energy sources, the petrol and diesel derived from oil and used in transport is a difficult issue because these liquid fossil fuels as a source of energy are particularly suited to mobile uses due to their high-energy density and thus long range of vehicular travel on one fill, ease of distribution, and convenient, compact and safe storage inside a vehicle. Conventional oil cannot be easily substituted, as exemplified over the last years with efforts to produce oil from non-conventional sources and electric cars on a larger scale. Oil from oil shale, tar sands and coal, as well as from other fuels such as ethanol and methanol, have all proved to be difficult. They have been too expensive relative to conventional oil, have had a poor net energy return and have had large environmental impacts from mining and other problems [9].

Despite the above history and the current urgency of CO_2 reduction from carbon-based fuels, liquid fossil fuel consumption in passenger transport throughout the world has continued to rise in the relatively wealthy cities in the West and in currently less wealthy, but rapidly industrializing and motorizing cities elsewhere, such as in China, India and Brazil [10]. The sheer size of the population in such countries and others, as well as the growing environmental problems in cities from, for example, air pollution, has made it even more critical today to try to reduce transport energy use and especially dependence on oil as the major source of transport fuels. Rising living standards and incomes and increasing car ownership and use, especially in such populous countries mentioned above and the continued profligate use of transport energy in North American and Australian cities, for example, make it difficult to reduce global oil demand in the transport sector. This is especially so when there are, for the most part, still few disincentives to car ownership and use in cities and insufficient investment in alternatives to motorized private transport, such as quality public transport and good walking and cycling conditions [10].

Of course, over time there are numerous fluctuations in this general upward trend of transport demand and energy use in transport as economies fluctuate along with the demand for and price of oil. The West Texas Intermediate (WTI) or New York Mercantile Exchange (NYMEX) oil price per barrel (in US dollars) between April 2008 and August 2008 was above $US135, peaking in June 2008 at $164, but by September 2008 and the major onset of the Global Financial Crisis, the oil price dropped to $118 per barrel and proceeded rapidly downward to $50 per barrel by January 2009, as demand fell away. Oil prices did recover to some extent after this as the global economy and demand again picked up, and in December 2019, oil was $61 per barrel [11]. The global COVID-19 pandemic, however, saw passenger transport demand in cities basically collapse, and the price of oil in April 2020 had plummeted to just $19 per barrel.

Regardless of these perturbations, the issue of transport energy use in cities is still of major concern. A focus of discussion since the mid-1990s has been the geopolitical implications of oil reserves concentrated in the Middle East and the issue of "peak oil" when half the world's known oil reserves have been used and the production curve heads downward [12,13]. Although "peak oil" is disputed e.g., [14], the realities of war in the Middle East mostly focused on maintaining oil security for the United States (Gulf War in 1990–1991 and the Iraq War from 2003 to 2011) remain, as does the critical need to engage with the idea of a post-petroleum future.

Since the mid-1970s, much has been published about transport energy use in cities, and the author's own work has had a focus on growing the evidence about the best ways to reduce energy use in urban passenger transport systems through reducing automobile dependence and taking advantage of the different energy consumption rates of urban transport modes [15–17].

This paper continues in this tradition with a special focus on ten Swedish cities, plus Freiburg im Breisgau in Germany, as a benchmark small city known for its sustainable transport performance [18,19]. Sweden established a national research and education think tank on public transport called K2 (The Swedish National Centre for Research and Education on Public Transport), with the express aim of improving public transport's role throughout Sweden and shifting modal share toward public transport. As part of the author's research in K2, this paper reports on detailed comparisons of many aspects of land use, transport and other transport-related factors in ten Swedish cities, including the energy consumption of each passenger transport mode and attempts to answer the following three research questions about private passenger transport energy use in Swedish cities:

(1) How does energy use per capita in private and public transport modes compare within Sweden and with other cities in the USA, Australia, Canada, Europe and Asia?
(2) How do the modal energy-consumption rates per vehicle kilometer and passenger kilometer in Swedish cities differ from each other and other cities worldwide?
(3) Can differences in transport energy use per capita be explained through reference to a range of other important transport indicators in Swedish cities?

2. Methodology

A detailed account of the research methodologies used to obtain all the data contained in the tables in this paper can be found in [17,20,21], along with the geographies defining each city. Table 1 provides a summary of the American, Australian, Canadian, European and Asian cities used to calculate the averages for these groups of cities shown in this paper, as well as the ten Swedish cities and Freiburg. It presents their population and the year of that population, their metropolitan GDP per capita at that year (in US$1995) and the per capita annual boardings for their whole public transport systems (all modes in use in each city are included, which cover buses, minibuses, trams, light rail, metro, suburban rail and ferries). This last item gives a comparative perspective on a key transport-sustainability factor for each city. "Cities" is used here as a shorter term for metropolitan regions because the data mostly represent wider metropolitan areas, not just the "cities" lying at the heart of these areas.

Table 1. List of cities used for the international comparisons with their population, GDP per capita and annual public transport use per capita.

City	Population	Metropolitan GDP Per Capita (US$1995)	Total Annual Public Transport Use Per Capita (Boardings)
American Cities			
Atlanta 2005	3,826,866	$41,641	39
Chicago 2005	8,217,201	$40,666	73
Denver 2005	2,256,442	$45,762	38
Houston 2005	4,853,225	$44,124	19
Los Angeles 2005	9,758,886	$40,899	68
New York 2005	20,580,795	$47,206	168
Phoenix 2005	3,590,804	$32,589	17
San Diego 2005	2,824,259	$42,324	32
San Francisco 2005	4,071,751	$54,266	103
Washington 2005	4,273,361	$55,070	109
Australian Cities			
Brisbane 2006	1,819,800	$29,365	74
Melbourne 2006	3,743,000	$30,411	104
Perth 2006	1,518,700	$37,416	68
Sydney 2006	4,282,000	$31,583	136

Table 1. *Cont.*

City	Population	Metropolitan GDP Per Capita (US$1995)	Total Annual Public Transport Use Per Capita (Boardings)
Canadian Cities			
Calgary 2005	988,193	$36,713	131
Montreal 2005	3,487,520	$26,815	206
Ottawa 2005	1,130,761	$29,956	129
Toronto 2005	5,555,912	$33,103	154
Vancouver 2005	2,116,581	$29,726	134
European Cities			
Graz 2005	247,248	$33,889	411
Copenhagen 2005	1,827,239	$43,108	191
Helsinki 2005	988,347	$47,548	309
Düsseldorf 2005	577,416	$40,270	266
Oslo 2005	1,039,536	$53,941	214
Madrid 2005	5,964,143	$26,964	337
Stockholm 2005	1,889,945	$43,527	332
Bern 2005	303,202	$54,145	543
Geneva 2005	440,982	$50,918	320
London 2005	7,512,000	$33,368	483
Vienna 2005	1,651,437	$36,131	511
Manchester 2005	2,543,800	$26,611	102
Stuttgart 2005	592,028	$33,294	285
Brussels 2005	1,006,749	$39,758	328
Prague 2005	1,181,610	$20,179	1051
Berlin 2005	3,395,189	$21,027	410
Frankfurt 2005	651,583	$38,356	327
Hamburg 2005	1,743,627	$36,733	266
Munich 2005	1,288,307	$45,133	505
Zurich 2005	832,159	$48,756	536
Asian Cities			
Hong Kong 2006	6,857,100	$18,823	548
Singapore 2005	4,341,800	$23,578	353
Swedish Cities			
Stockholm 2015	2,231,439	$49,271	359
Malmö 2015	695,430	$32,709	111
Goteborg 2015	982,360	$40,808	285
Linköping 2015	152,966	$30,260	64
Helsingborg 2015	137,909	$28,917	158
Uppsala 2015	210,126	$31,998	108
Västerås 2015	145,218	$29,594	53
Örebro 2015	144,200	$29,045	39
Jönköping 2015	133,310	$29,952	60
Umeå 2015	120,777	$29,415	45
Freiburg (benchmark small city)			
Freiburg 2015	222,082	$25,782	192

In this paper, Swedish cities have been divided into five larger and five smaller cities so that differences on this basis can be seen. Averages are presented for the larger cities, smaller cities and all ten Swedish cities. The larger cities are Stockholm, Göteborg, Malmö, Linköping and Helsingborg, while the smaller cities are Uppsala, Jönköping, Örebro, Västerås and Umeå.

The value of this research on the Swedish cities, as well as the global sample, is that it uses empirical energy data from cities for private and public transport, as opposed to theoretical modeled data for different vehicular technologies e.g., [22,23]. All data are collected directly for each city from the primary sources of those data, mostly through a variety of government departments in each city or through national datasets that are available for the specific geographies used to define the metropolitan areas in this study. For example, public-transport energy use is obtained directly from every operator and mode in every city. The collection of these data is conducted by consulting published online sources in the first instance and then many emails and phone calls between many people in a plethora of transport, planning, energy, environmental and other departments in every city. Most data require this in-depth work and are not routinely published. Only primary data are collected, never the standardized indicators shown in the tables. These standardized indicators are calculated by the author by combining the relevant primary data (e.g., population and urbanized land area to get urban density). All Swedish city data and Freiburg are for 2015, while the American, Australian, Canadian, European and Asian city data are for 2005–2006, from an earlier study of these other cities e.g., see [15,19,24].

While it would be ideal to have all the comparative data for the same year, it must be pointed out that the collection of these comparative cities' data, which are much more than shown in the tables in this paper, takes many years to complete (the 2005–2006 data commenced in 2007 and was not complete until 2014). Providing 2015 data for the other cities could not have even been commenced until 2017, due to delays in data release. The comparisons, however, are still valid in relative terms, and experience over 40 years of such data collection has shown at each point that the relative differences between cities remain. This is supported by the author's publications in the reference list, including representing these other cities with 2005–2006 data at a much later date and where the 2005–2006 data have been compared to later data [25], including a paper comparing many urban indicators for the five larger Swedish cities in 2015 with the 2005–2006 data on the American, Australian, Canadian, European and Asian cities [21]. Where some variables can change quite rapidly, the discussion provides caveats on the results and cautions readers accordingly.

The point of making comparisons between the Swedish cities in 2015 with a global sample ten years earlier is to gain an insight into the general magnitude of differences, not to be absolutely precise. Over a decade, European cities are, for example, not going to become very like American cities, nor are even Canadian cities, in virtually any of the parameters. There is a basic and relatively stable difference in these fundamental metropolitan-scale indicators across such a global range of cities, which is quite resilient to change over time. The author has 1960, 1970, 1980 and 1990 data that show similar basic patterns. The exact numbers have changed, but the general relativities have not [26].

To demonstrate this, Table 2 provides the ten-year change in an earlier decade from 1995–1996 to 2005–2006 in the value for every variable that has been used in this paper for the US, Australian, Canadian, European and Asian cities. From this, it can be seen, for example, that although private transport energy use per capita has changed, European cities are still very much lower than American cities, and Asian cities are very much lower again than European cities. Australian and Canadian cities maintain their medium position in the sample. Car passenger kilometers per person did not change much in the ten years in any group of cities, so the general magnitude of differences were again stable. With respect to seat kilometers of public transport service per person, this was still worst in the American cities by a large margin, fair to middling in the Australian and Canadian cities, very much better in the European cities and better again in the Asian cities. By 2015, though values will have changed, it is highly unlikely that American cities will have reached even Australian levels of public transport service, let alone European or Asian levels. Likewise, public transport use follows the same pattern and is very similar in its relative differences, even over a decade of change. If we consider the use of non-motorized modes, American cities are the worst, Canadian cities are next and then Australian cities, and the Asian cities, while the European cities are the best. This general perspective has not changed over ten years, even though the value for each group has changed to some degree. Rather than eliminating this global perspective for the sake of 2015 data, which are not possible yet on the global sample, the 2005–2006 perspective still has utility.

Table 2. Changes in energy, land use and transport-related variables in US, Australian, Canadian, European and Asian cities from 1995–1996 to 2005–2006.

Variable	Units	USA 1995	USA 2005	AUS 1996	AUS 2006	CAN 1996	CAN 2006	EUR 1995	EUR 2005	ASIA 1995	ASIA 2005
Private passenger transport energy use per capita	MJ/person	60,034	53,441	31,044	35,972	32,519	30,804	15,324	15,795	6447	6076
Public transport energy use per capita	MJ/person	811	963	876	1036	1044	1190	1243	1532	1905	2691
Total passenger transport energy use (private plus public)	MJ/person	60,845	54,404	31,920	37,008	33,563	31,994	16,567	17,326	8352	8768
Energy use per private passenger vehicle kilometre	MJ/km	4.6	4.1	4.0	4.1	5.1	4.9	3.3	3.1	5.4	4.8
Energy use per public transport vehicle kilometre	MJ/km	26.3	24.6	15.8	17.3	22.0	23.0	13.7	14.7	15.9	19.6
** Energy use per bus vehicle kilometre*	*MJ/km*	*28.8*	*31.3*	*18.0*	*21.9*	*24.1*	*24.9*	*15.7*	*18.8*	19.2	23.5
** Energy use per minibus vehicle kilometre*	*MJ/km*	*8.5*	*13.2*	-	-	*8.1*	-	-	-	*6.9*	*9.5*
** Energy use per tram wagon kilometre*	*MJ/km*	*19.1*	*19.9*	*10.1*	*11.2*	*12.1*	*14.2*	*12.9*	*14.9*	*5.5*	*5.4*
** Energy use per light rail wagon kilometre*	*MJ/km*	*17.5*	*15.3*	-	*10.5*	*13.1*	*18.2*	*14.6*	*11.7*	*16.1*	*14.3*
** Energy use per metro wagon kilometre*	*MJ/km*	*25.3*	*16.1*	-	*22.6*	*10.6*	*13.5*	*11.0*	*9.3*	*7.8*	*18.7*
** Energy use per suburban rail wagon kilometre*	*MJ/km*	*51.8*	*50.4*	*12.7*	*11.9*	*48.8*	*43.0*	*14.3*	*15.6*	*8.9*	*14.8*
** Energy use per ferry vessel kilometre*	*MJ/km*	*846.5*	*1073.3*	*144.0*	*140.7*	*290.8*	*283.5*	*151.5*	*141.0*	*601.7*	*641.4*
Energy use per private passenger kilometre	MJ/p.km	3.26	2.85	2.55	2.87	3.82	3.79	2.46	2.30	3.46	3.31
Energy use per public transport passenger kilometre	MJ/p.km	2.13	2.09	0.99	0.97	1.14	1.18	0.74	0.76	0.59	0.70
** Energy use per bus passenger kilometre*	*MJ/p.km*	*2.85*	*2.97*	*1.77*	*1.87*	*1.50*	*1.57*	*1.10*	*1.31*	0.77	0.95
** Energy use per minibus passenger kilometre*	*MJ/p.km*	*1.02*	*7.68*	-	-	*2.34*	-	-	-	*2.66*	*1.96*
** Energy use per tram passenger kilometre*	*MJ/p.km*	*0.99*	*1.02*	*0.36*	*0.48*	*0.31*	*0.27*	*0.70*	*0.73*	*0.23*	*0.24*
** Energy use per light rail passenger kilometre*	*MJ/p.km*	*0.67*	*0.64*	-	*0.58*	*0.25*	*1.07*	*0.65*	*0.53*	*0.34*	*0.55*
** Energy use per metro passenger kilometre*	*MJ/p.km*	*1.65*	*0.69*	-	*0.75*	*0.49*	*0.64*	*0.45*	*0.42*	*0.12*	*0.34*
** Energy use per suburban rail passenger kilometre*	*MJ/p.km*	*1.38*	*1.29*	*0.55*	*0.49*	*1.31*	*1.17*	*0.69*	*0.60*	*0.16*	*0.27*
** Energy use per ferry passenger kilometre*	*MJ/p.km*	*5.41*	*6.80*	*2.97*	*2.53*	*3.62*	*1.23*	*4.01*	*4.88*	*3.64*	*4.26*
Urban density	persons/ha	14.9	15.4	13.3	14.0	26.2	25.8	49.3	47.9	215.4	217.3
Proportion of jobs in CBD	%	9.2%	8.2%	13.3%	12.7%	15.7%	15.0%	22.2%	18.3%	11.4%	9.1%
Metropolitan gross domestic product per capita	USD 1995	$31,386	$44,455	$20,226	$32,194	$20,825	$31,263	$34,673	$38,683	$23,593	$21,201
Length of freeway per person	m/ person	0.156	0.156	0.086	0.083	0.122	0.157	0.080	0.094	0.025	0.026
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	555	487	367	298	390	319	212	248	135	121
Passenger cars per 1000 persons	units/1000 persons	587	640	591	647	530	522	412	463	73	78
Average speed of the road network (24/7)	km/h	49.3	50.4	43.6	42.8	44.5	45.4	34.2	34.3	31.8	30.6
Total length of public transport lines per 1000 persons	m/1000 persons	1420	1382	2814	2609	1929	2496	2420	3183	1582	2614
Total length of reserved public transport routes per 1000 persons	m/1000 persons	49	72	170	160	56	67	231	298	18	34
Total public transport seat kilometres of service per capita	seat km/person	1566	1874	3997	4077	2290	2368	5245	6126	6882	7267
Overall average speed of public transport	km/h	27.3	27.3	32.5	*33.0*	25.1	25.7	28.0	29.8	24.0	26.3
* Average speed of buses	km/h	*21.7*	*19.9*	*23.8*	*23.4*	*22.0*	*22.4*	*21.6*	*21.9*	*19.3*	*19.4*
* Average speed of suburban rail	km/h	*54.7*	*57.3*	*46.2*	*47.6*	*49.5*	*44.7*	*49.4*	*52.1*	*40.0*	*50.8*
Total public transport boardings per capita	boardings/person	60.1	66.7	90.4	95.6	140.2	150.7	357.1	386.3	476.6	450.4
Total public transport passenger kilometres per capita	p.km/person	492	571	966	1075	917	1031	1830	2234	3169	3786

Table 2. *Cont.*

Variable	Units	USA 1995	USA 2005	AUS 1996	AUS 2006	CAN 1996	CAN 2006	EUR 1995	EUR 2005	ASIA 1995	ASIA 2005
Overall public transport vehicle occupancy	persons/unit	13.9	13.1	16.9	18.1	19.2	19.8	19.8	21.0	26.9	28.1
Overall public transport seat occupancy	%	29%	29%	25%	27%	40%	44%	38%	39%	46%	52%
Passenger car passenger kilometres per capita	p.km/person	18,155	18,703	12,114	12,447	8645	8495	6319	6817	1978	1975
Percentage of total daily trips by non motorised modes	%	8.1%	9.5%	14.9%	14.2%	10.4%	11.6%	31.7%	34.5%	25.0%	26.1%
Percentage of total daily trips by motorised public modes	%	3.4%	5.5%	5.4%	7.5%	9.1%	13.1%	21.3%	22.4%	39.3%	46.0%
Proportion of total motorised passenger kilometres on public transport	%	2.9%	3.2%	7.5%	8.0%	9.9%	11.3%	22.3%	24.5%	62.0%	62.9%
Ratio of public versus private transport speeds	ratio	0.57	0.55	0.75	0.78	0.57	0.57	0.83	0.88	0.76	0.86
Ratio of segregated public transport infrastructure versus expressways	ratio	0.41	0.56	2.18	1.98	0.55	0.56	4.17	5.51	0.93	1.42

All energy data are end-use data and do not include the energy expended for drilling, extracting, refining or distributing oil to obtain the petrol, diesel and other liquid or gaseous fossil fuels before dispensing them into vehicle fuel tanks. Renewable fuels, such as ethanol, do not include the planting, growing, harvesting and processing of crops or other energy use expended in delivering that fuel to a vehicle's fuel tank. Electrical energy does not include the power station and transmission losses or other energy expended in the production and delivery of electrical energy to its end user.

All other standardized data or indicators on cities such as urban density, which are used to help explain the observed per capita energy use and modal energy use per kilometer, were obtained by using the same methodology as for energy. All the primary data used to calculate the indicators (e.g., freeway length and population for freeway length per capita) were collected directly from the sources of those data (e.g., population data from the relevant official sources of such data, such as local or national censuses and freeway length from road inventories or other sources). All public transport operating and infrastructure data were collected from the same operators and agencies as the energy data. A little more detail is provided about methodology in the results section, when dealing with specific indicators.

3. Transport Energy Use per Capita and Modal Energy Consumption

Table 3 contains all the data on per capita levels of energy use in private and public transport in the ten Swedish cities, along with the modal energy consumption of cars and all public transport modes in each city. Also included are similar data for Freiburg, Germany, and a group of American, Australian, Canadian, European and Asian cities. These patterns are now explained.

3.1. Private Passenger Transport Energy Use per Person

Sections 3.1 and 3.2 address the first research question in the introduction. The biggest user of passenger transport energy in cities is private transport modes, mainly cars. Table 3 shows the data for the ten Swedish cities, as well as averages for the larger five cities and the smaller five cities and Freiburg as something of a benchmark by which to assess the performance of the Swedish cities, especially the smaller ones.

The annual energy use in private motorized passenger transport in Swedish cities was calculated backward from the comprehensive emissions inventories that exist in Sweden for each municipality [27]. Transport is one of the sectors in these emissions inventories, which is further broken down into its component parts and provides CO_2 equivalent emissions (as well as all other transport emissions for each municipality). CO_2 emissions were converted to energy use by using relevant conversion factors. The energy use figures here for private passenger transport are thus dependent on the integrity of CO_2 emissions accounting by the Swedish government. There was no other direct source of fuel consumption for private transport available in Swedish cities.

Figure 1 shows that the ten Swedish cities in 2015 averaged 15,601 MJ/person, which is virtually the same as the average for the other European cities in 2005 (15,795 MJ). It is close to half the global sample average of 28,301 MJ and dramatically below the American, Australian and Canadian cities (Table 3). In addition, there is hardly any difference here between the averages for the larger and smaller Swedish cities (15,886 MJ cf. 15,317 MJ, respectively). Freiburg consumes 16,488 MJ/person or 8% more than in the smaller Swedish cities (one factor could be the significantly slower average speed of traffic in the denser urban fabric of Freiburg—see later). Only the Asian cities, as a group, have lower energy use per person for private passenger transport (6076 MJ), but they are radically denser than Swedish cities (see later).

Table 3. Private and public transport energy use per capita and modal energy use in ten Swedish cities (2015), plus Freiburg im Breisgau (2015), compared to American, Australian, Canadian, European and Asian cities (2005–2006).

Variable	**Units**	**Stockholm**	**Malmö**	**Göteborg**	**Linköping**	**Helsingborg**	**SWE LARGE**	**Uppsala**	**Västerås**	**Örebro**	**Jönköping**
Private passenger transport energy use per capita	MJ/person	12,051	15,670	15,905	18,124	17,681	**15,886**	12,157	14,030	17,095	21,678
Public transport energy use per capita	MJ/person	1949	1310	2680	1179	1819	**1787**	1423	939	862	2050
Total passenger transport energy use (private plus public)	MJ/person	14,000	16,980	18,585	19,304	19,500	**17,674**	13,580	14,969	17,957	23,728
Energy use per private passenger vehicle kilometre	MJ/km	2.4	2.9	3.1	3.5	3.3	**3.1**	2.5	2.6	3.3	3.6
Energy use per public transport vehicle kilometre	MJ/km	17.1	19.9	17.8	19.3	18.4	**18.2**	12.2	17.2	16.8	25.0
* *Energy use per bus vehicle kilometre*	*MJ/km*	20.0	17.2	15.4	17.5	17.2	**17.4**	13.3	17.0	17.9	32.1
* *Energy use per minibus vehicle kilometre*	*MJ/km*	-	-	-	-	-	-	-	-	-	-
* *Energy use per tram wagon kilometre*	*MJ/km*	-	-	-	-	-	-	-	-	-	-
* *Energy use per light rail wagon kilometre*	*MJ/km*	10.5	-	14.0	11.1	-	**11.9**	-	-	-	-
* *Energy use per metro wagon kilometre*	*MJ/km*	7.8	-	-	-	-	**7.8**	-	-	-	-
* *Energy use per suburban rail wagon kilometre*	*MJ/km*	38.3	28.7	33.2	30.1	28.7	**31.8**	9.3	18.0	5.0	12.7
* *Energy use per ferry vessel kilometre*	*MJ/km*	230.4	-	243.4	-	-	**236.9**	-	-	-	-
Energy use per private passenger kilometre	MJ/p.km	1.82	2.29	2.38	2.69	2.58	**2.35**	1.98	1.99	2.32	2.74
Energy use per public transport passenger kilometre	MJ/p.km	0.76	0.90	1.09	1.34	1.14	**1.00**	0.81	1.06	2.35	2.53
* *Energy use per bus passenger kilometre*	*MJ/p.km*	1.37	1.67	1.45	1.65	1.57	**1.54**	1.33	1.40	2.64	3.43
* *Energy use per minibus passenger kilometre*	*MJ/p.km*	-	-	-	-	-	-	-	-	-	-
* *Energy use per tram passenger kilometre*	*MJ/p.km*	-	-	-	-	-	-	-	-	-	-
* *Energy use per light rail passenger kilometre*	*MJ/p.km*	0.52	-	0.47	0.80	-	**0.60**	-	-	-	-
* *Energy use per metro passenger kilometre*	*MJ/p.km*	0.39	-	-	-	-	**0.39**	-	-	-	-
* *Energy use per suburban rail passenger kilometre*	*MJ/p.km*	0.39	0.47	0.66	0.74	0.48	**0.55**	0.32	0.52	0.46	1.18
* *Energy use per ferry passenger kilometre*	*MJ/p.km*	6.88	-	8.66	-	-	**7.77**	-	-	-	-

Table 3. *Cont.*

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Private passenger transport energy use per capita	MJ/person	11,622	16,488	**15,317**	**15,601**	53,441	35,972	30,804	15,795	6076	28,301
Public transport energy use per capita	MJ/person	1132	1081	**1281**	**1534**	963	1036	1190	1532	2691	1360
Total passenger transport energy use (private plus public)	MJ/person	12,754	17,569	**16,598**	**17,136**	54,403	37,008	31,994	17,326	8768	29,661
Energy use per private passenger vehicle kilometre	MJ/km	2.3	3.1	**2.9**	**3.0**	4.1	4.1	4.9	3.1	4.8	3.8
Energy use per public transport vehicle kilometre	MJ/km	12.5	17.8	**16.2**	**17.3**	24.6	17.3	23.0	14.7	19.6	18.6
** Energy use per bus vehicle kilometre*	*MJ/km*	12.0	17.9	**18.5**	**18.0**	*31.3*	*21.9*	*24.9*	*18.8*	23.5	23.1
** Energy use per minibus vehicle kilometre*	*MJ/km*	-	-	-	-	*13.2*	*-*	*-*	*-*	*9.5*	12.9
** Energy use per tram wagon kilometre*	*MJ/km*	-	-	-	-	*19.9*	*11.2*	*14.2*	*14.9*	*5.4*	14.4
** Energy use per light rail wagon kilometre*	*MJ/km*	-	13.0	**-**	**11.9**	*15.3*	*10.5*	*18.2*	*11.7*	*14.3*	13.3
** Energy use per metro wagon kilometre*	*MJ/km*	-	-	**-**	**7.8**	*16.1*	*22.6*	*13.5*	*9.3*	*18.7*	12.7
** Energy use per suburban rail wagon kilometre*	*MJ/km*	22.4	19.0	**13.5**	**22.6**	*50.4*	*11.9*	*43.0*	*15.6*	*14.8*	23.9
** Energy use per ferry vessel kilometre*	*MJ/km*	-	-	-	**236.9**	*1073.3*	*140.7*	*283.5*	*141.0*	*641.4*	358.8
Energy use per private passenger kilometre	MJ/p.km	1.74	2.39	**2.18**	**2.27**	2.85	2.87	3.79	2.30	3.31	2.72
Energy use per public transport passenger kilometre	MJ/p.km	1.01	0.79	**1.30**	**1.10**	2.09	0.97	1.18	0.76	0.70	1.16
** Energy use per bus passenger kilometre*	*MJ/p.km*	1.06	1.66	**1.97**	**1.76**	*2.97*	*1.87*	*1.57*	*1.31*	0.95	1.78
** Energy use per minibus passenger kilometre*	*MJ/p.km*	-	-	-	-	*7.68*	*-*	*-*	*-*	*1.96*	7.16
** Energy use per tram passenger kilometre*	*MJ/p.km*	-	-	-	-	*1.02*	*0.48*	*0.27*	*0.73*	*0.24*	0.65
** Energy use per light rail passenger kilometre*	*MJ/p.km*	-	0.33	-	**0.60**	*0.64*	*0.58*	*1.07*	*0.53*	*0.55*	0.63
** Energy use per metro passenger kilometre*	*MJ/p.km*	-	-	**-**	**0.39**	*0.69*	*0.75*	*0.64*	*0.42*	*0.34*	0.52
** Energy use per suburban rail passenger kilometre*	*MJ/p.km*	0.68	0.65	**0.64**	**0.59**	*1.29*	*0.49*	*1.17*	*0.60*	*0.27*	0.76
** Energy use per ferry passenger kilometre*	*MJ/p.km*	-	-	-	**7.77**	*6.80*	*2.53*	*1.23*	*4.88*	*4.26*	4.60

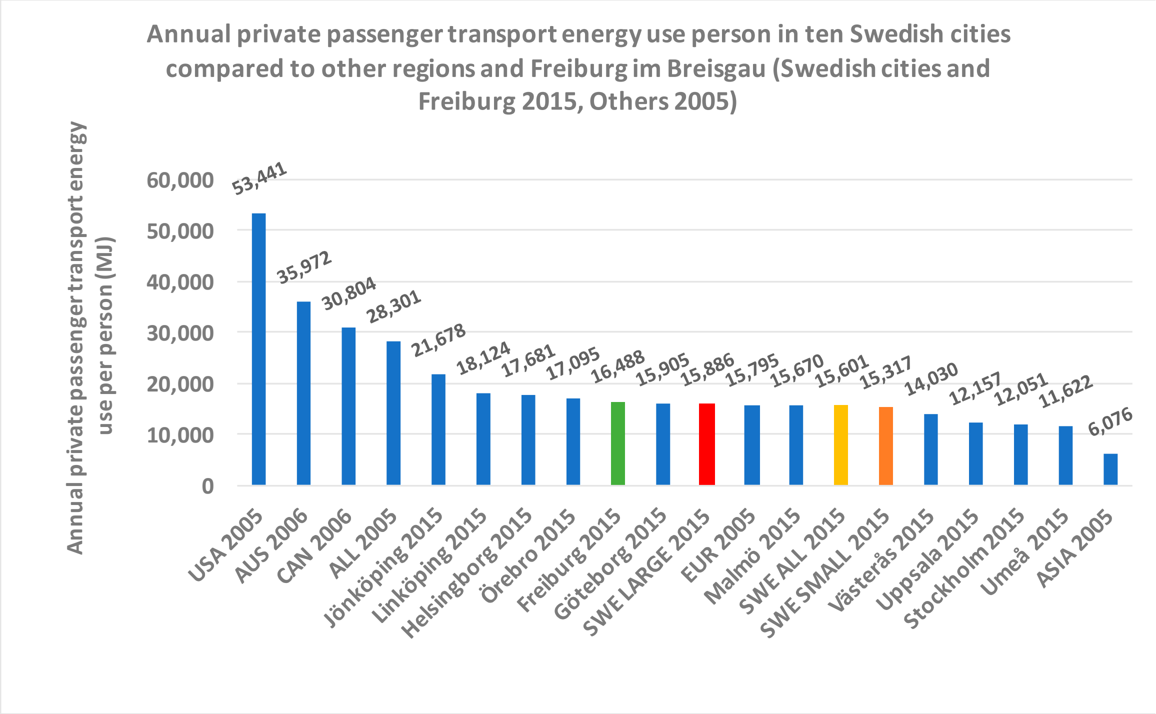

Figure 1. Annual private passenger transport energy use per person in ten Swedish cities (2015), and in American, Australian, Canadian, European and Asian cities (2005–2006).

Uppsala, Stockholm and, interestingly, Umeå consume the least energy, with 12,157, 12,051 and 11,622 MJ/person, respectively. Jönköping and Linköping, which are amongst the least-dense of the Swedish cities, consume the most private transport energy use (21,678 and 18,124 MJ, respectively), which might be expected. However, transport energy use per capita does not relate well, overall, to urban density in Swedish cities, probably due to the very small range in urban densities and other factors in these mostly small cities with short travel distances and high use of non-motorised modes (see Section 4 for these other data on Swedish cities). Overall, Swedish cities in 2015 performed comparatively well against other cities in the world, consuming only moderate quantities of energy in private passenger transport in this very energy-hungry sector. Improvements are, however, always possible through less driving and better technology.

3.2. *Public Transport Energy Use per Person*

The use of energy in public transport systems is important to understand and to compare with its private passenger transport equivalent. As already indicated, public-transport energy-use data were obtained from each of the public transport operators by mode (Figure 2). Public transport here considers every mode that exists in the city, whether it is just buses or whether it includes multiple modes (buses, trams, trams and light rail (LRT), metro, suburban rail and ferries). Even cable cars and small funiculars are included if they exist. Taxis are considered private transport. All public transport modes and operators must be included to properly and accurately represent the public transport system.

The data reported here are the average for all modes in each city. Swedish cities are identical to the other European cities in their per capita energy use by public transport, but significantly more than in the three auto-oriented groups of cities, with their lesser public transport systems. Freiburg consumes a modest 1081 MJ/person. The larger Swedish cities on average consume 1787 MJ/person, while the smaller cities consume a significantly lower 1281 MJ. Göteborg is the biggest per capita energy consumer in public transport (2680 MJ), which is surprisingly almost the same as the Asian cities. This is followed quite a bit behind by Jönköping and Stockholm, both of which are, however, still relatively high. The range of public transport energy use per person in Swedish cities is large (2680 MJ in Göteborg and 862 MJ in Örebro—Göteborg provides a vastly higher magnitude of public transport service, including a large LRT system, compared to Örebro—see Section 4).

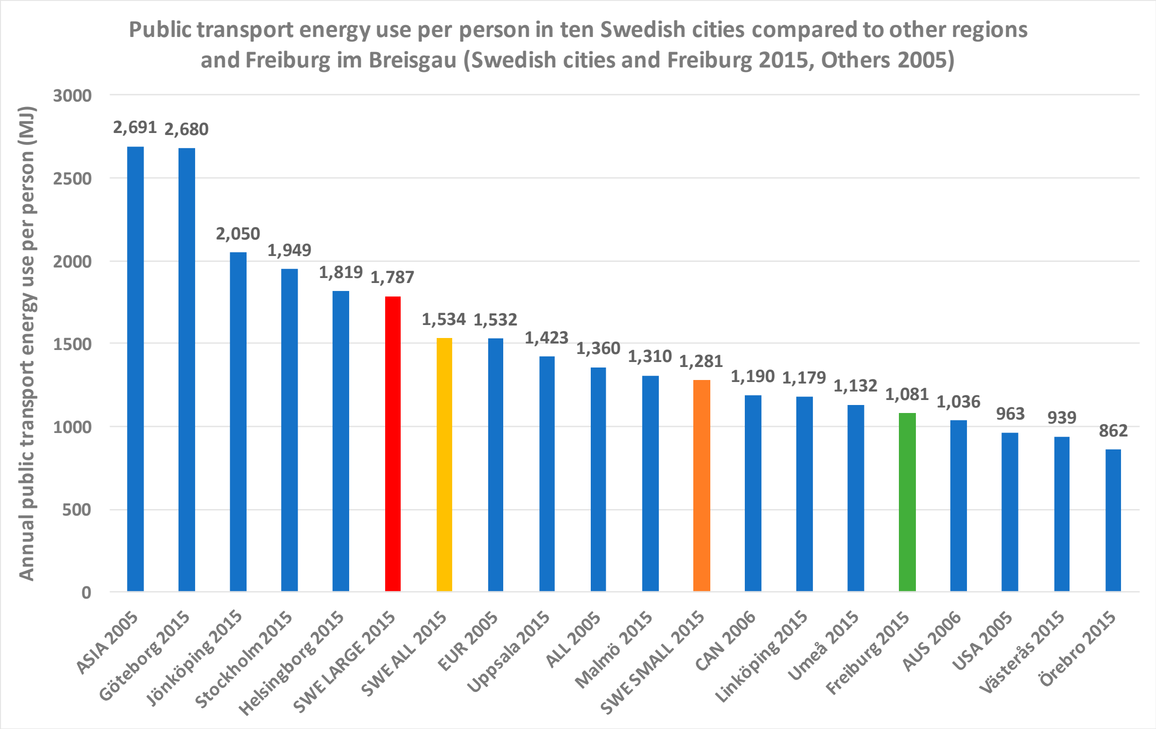

Figure 2. Annual public transport energy use per person in ten Swedish cities (2015); Freiburg (2015); and American, Australian, Canadian, European and Asian cities (2005–2006).

Figures 1 and 2 highlight the huge difference between the energy consumption by public transport systems, compared to private transport. In the case of the Swedish cities (and European cities generally), private transport consumes over ten times more per capita than that used by public transport. In the case of US cities, it is over 55 times more, while Australian and Canadian cities show less dramatic differences (35 and 26 times more, respectively). It is only in the Asian cities, with their very heavy dependence on public transport and their low levels of car use, that private and public transport energy use per capita are more equitable (private transport is a little more than twice as high). The data also suggest that there is considerable untapped energy conservation potential in public transport systems, particularly given the frequent similarity in energy use per capita in public transport in different cities, but the vast differences in levels of usage (see Section 4).

3.3. *Modal Energy Consumption in Private Transport*

This section addresses the second research question in the introduction. Energy consumption by mode can be examined in two ways—energy use per vehicle kilometer traveled (VKT), which is common for cars and something that consumers consider when purchasing a vehicle, or energy use per passenger kilometer traveled (PKT). The latter is more common for public transport, since vehicular energy consumption for higher capacity public transport vehicles is not useful to compare with cars because of the greatly different vehicle sizes and occupancy levels. Therefore, when comparing the relative energy use between modes, energy use per passenger kilometers is used.

3.3.1. Energy Use per Private Passenger Vehicle Kilometer

Table 3 shows that energy use per private passenger vehicle kilometer varies from a high of 4.9 mega-joules per km (MJ/km) in Canadian cities (4.8 MJ/km in Asian cities and 4.1 MJ/km in the American and Australian cities), down to 2.3 MJ/km in Umeå and 2.4 MJ/km in Stockholm. It must be borne in mind, however, that the data for the Swedish cities and Freiburg are from 2015, ten years later than the data for US, Australian, Canadian, European and Asian cities, over which time, technological advances and changes in the size and weight of vehicles may have yielded increases in the fuel efficiency of vehicles. It might be that 2015 data for the other cities could show lower rates of energy use per vehicle kilometer than they did in 2005, though the relativities between cities are likely to remain similar. Figure 3 summarizes these results.

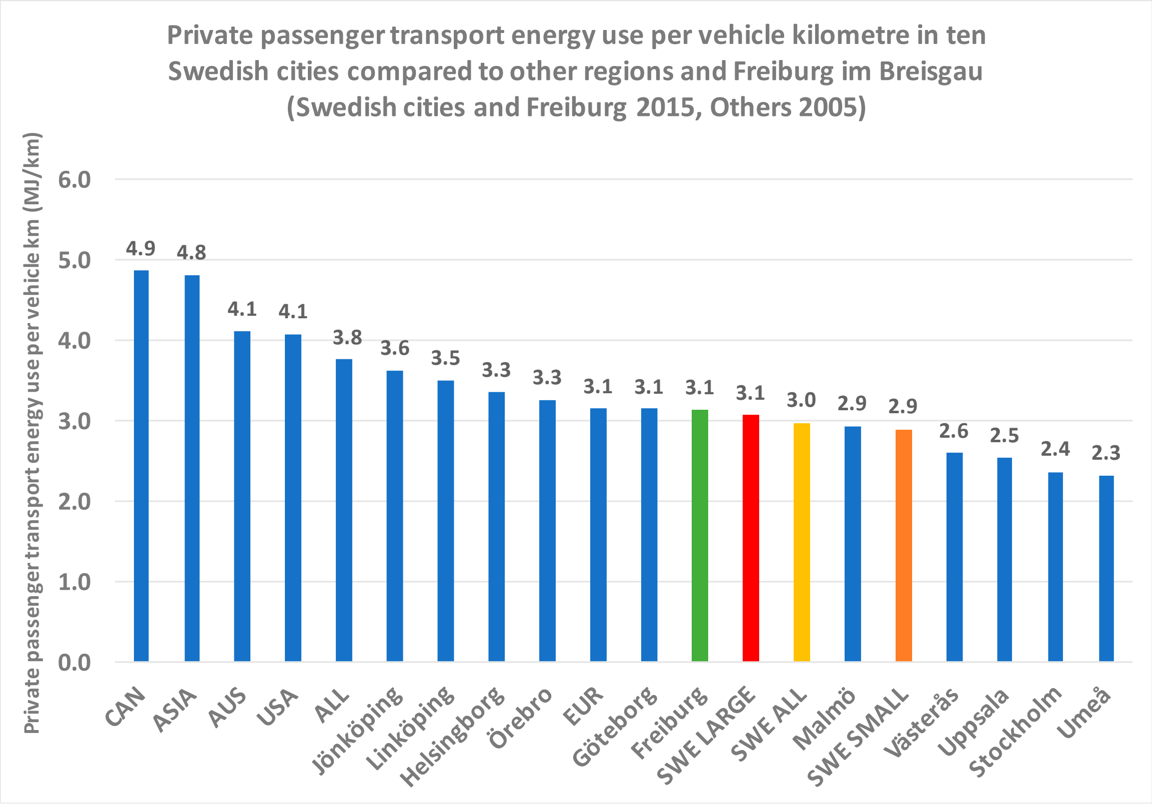

Figure 3. Energy use per vehicle kilometer in private passenger transport in ten Swedish cities (2015); Freiburg (2015); and American, Australian, Canadian, European and Asian cities (2005–2006).

The larger Swedish cities consume, on average, 3.1 MJ/km in private passenger modes, which is the same as the European cities, while the small cities consume 2.9 MJ/km (less congestion and higher vehicle operating speeds may partly explain this—see Section 4). Freiburg has the same rate of energy use as the larger Swedish cities (3.1 MJ/km). The range in energy use per VKT in private passenger transport in Swedish cities is from 2.3 MJ/km (Umeå) to 3.5 and 3.6 MJ/km in Linköping and Jönköping, respectively.

3.3.2. Energy Use per Public Transport Vehicle Kilometer

Whilst it has been explained that energy use per VKT for public transport modes is of no real use in comparing to private transport, it is interesting to compare the differences in Table 3 across cities for the same mode.

Buses: Examining buses first, we see that Jönköping and American city buses consume 32.1 and 31.3 MJ/km, respectively. At the lower end, we find Umeå and Uppsala have only 12.0 and 13.3 MJ/km, respectively, while Freiburg consumes 17.9 MJ/km, and European cities, overall, show 18.8 MJ/km, quite like the average for all Swedish cities of 18.0 MJ/km. The larger cities in Sweden consume 17.4 MJ/km, while buses in the smaller cities consume 18.5 MJ/km or quite close to the European average. In 2005–2006, the "world average" for buses, based on this large sample of global cities, was 23.1 MJ/km.

Trams and light rail (LRT): These rail modes represent very similar technologies, and their differentiation is somewhat artificial. In the Swedish cities and Freiburg, all such modes have been classed as LRT, and they only exist in Stockholm, Göteborg, Linköping and Freiburg. In the global sample from 2005, trams and LRT exist in at least some of the cities in all regional groupings. For the purposes of comparison with the Swedish cities and Freiburg, the average for the other regional groupings of tram and LRT were used (i.e., American, 17.3 MJ/km; Australian, 10.8 MJ/km; Canadian, 16.2 MJ/km; European, 13.3 MJ/km; Asian, 9.8 MJ/km; and with a global average of 13.8 MJ/km).

The data reveal the Swedish cities to be well within the normal range of energy use by these modes (11.9 MJ/km) and closest to the Australian cities, while Freiburg (13.0 MJ/km) is very close to the European average (13.3 MJ/km) and the global average from 2005–2006 (13.8 MJ/km). Swedish cities are within a relatively tight range in the three cities where LRT exists (10.5 to 14.0 MJ/km). Overall, tram/LRT systems have a range of about 10.0 to 17.0 MJ/km, depending on the age and type of system.

Metros: Metro systems are mostly underground systems and tend to operate in the denser inner parts of metro regions (e.g., the Paris metro in the Ville de Paris at the center of the Paris region known as the Île de France). In Sweden, a metro only exists in Stockholm (tunnelbana), while in the global sample, metros exist in at least some cities in all regional groupings. Stockholm's energy use per vehicle kilometer (wagon kilometer not train kilometer) is 7.8 MJ/km, which is reasonably close to the European average of 9.3 MJ/km, but significantly less than in all other groups of cities (a range of 13.5 MJ/km in Canadian cities to 22.6 MJ/km in Australian cities and a global average of 12.7 MJ/km).

Suburban rail: This rail mode covers the rail systems that operate over longer distances and include both underground sections in denser parts of cities and a lot of aboveground operations in lower-density suburban-type environments. These include the S-Bahn and regional rail systems in Germany, the RER suburban rail services throughout the Île de France and the regional rail operations that exist in all ten Swedish cities in this paper, as well as in Freiburg. Rolling stock is mostly bigger and heavier, including double-decker wagons, and train speeds are much higher than those of metro systems (see Section 4). In this mode, there is a very wide range of vehicular energy use per kilometer, depending on the type of trains, their fuel (diesel services are much higher in energy use than electric services), their age, number of wagons, their size, weight, passenger loadings and operating speeds.

All Swedish suburban train services are longer-distance regional rail lines which operate at high average speeds. Their energy use is, on average, 22.6 MJ/km, which is like the global average of 23.9 MJ/km, but with a big difference between the larger cities (31.8 MJ/km) and the smaller cities (13.5 MJ/km). Freiburg averages 19.0 MJ/km. Globally, there are also huge differences with a range of 11.9 MJ/km in the all-electric Australian cities, up to 50.4 MJ/km in the USA with a mixture of diesel and electric, mostly commuter rail style services. Canadian systems are similar, averaging a relatively high 43.0 MJ/km, whereas the European and Asian systems are virtually all electric and average only 15.6 and 14.8 MJ/km, respectively. The range in energy use per vehicle kilometer in the ten Swedish cities is from 5.0 MJ/km in Örebro up to 38.3 MJ/km in Stockholm.

Ferries: These modes only exist in Stockholm and Göteborg in the Swedish sample, but all the other regional groupings of cities have at least some ferry services. Ferries are very high in their vehicular energy use, a main factor being the very large frictional forces that must be overcome to ply through water and the speeds at which operate. Naturally, the size of vessels, which varies hugely around the world, is also a key determinant of energy use. Swedish cities average 236.9 MJ/km, with not much difference between the two cities (230.4 and 243.4 MJ/km). The global average was 358.8 MJ/km, with a massive range from 140.7 MJ/km for the ferries in Perth, Brisbane and Sydney (European cities were virtually identical at 141 MJ/km), up to 1073.3 MJ/km for ferries in US cities (only New York and San Francisco). The Asian cities (Hong Kong only) are also very high, with many large and heavily loaded double-decker ferries in operation.

3.3.3. Energy Use per Private Passenger Kilometer (PKT)

Energy use per PKT is a more meaningful measure of energy consumption in public transport, which enables genuine comparisons to be made with private passenger transport energy use. Table 3 provides the energy consumption per PKT for private transport, and Figure 4 depicts the data for the Swedish and global sample. The European cities, including Freiburg, and especially the Swedish cities, are amongst the lowest energy consumers in cars, though there is a range in Sweden from 2.74 MJ/PKT in Jönköping down to 1.74 MJ/PKT in Umeå. The larger Swedish cities (2.35 MJ/PKT) are about the same as Freiburg (2.39) and the average for the European cities (2.30), while the smaller cities are little lower at 2.18 MJ/PKT. Compared to the Canadian (3.79 MJ/PKT), Asian (3.31), Australian (2.87) and American (2.85) cities, the Swedish cities are significantly less energy hungry in cars (2.27 MJ/PKT). Of course, this sets a greater challenge for public transport to compete in energy terms, especially where loadings in public transport vehicles are low.

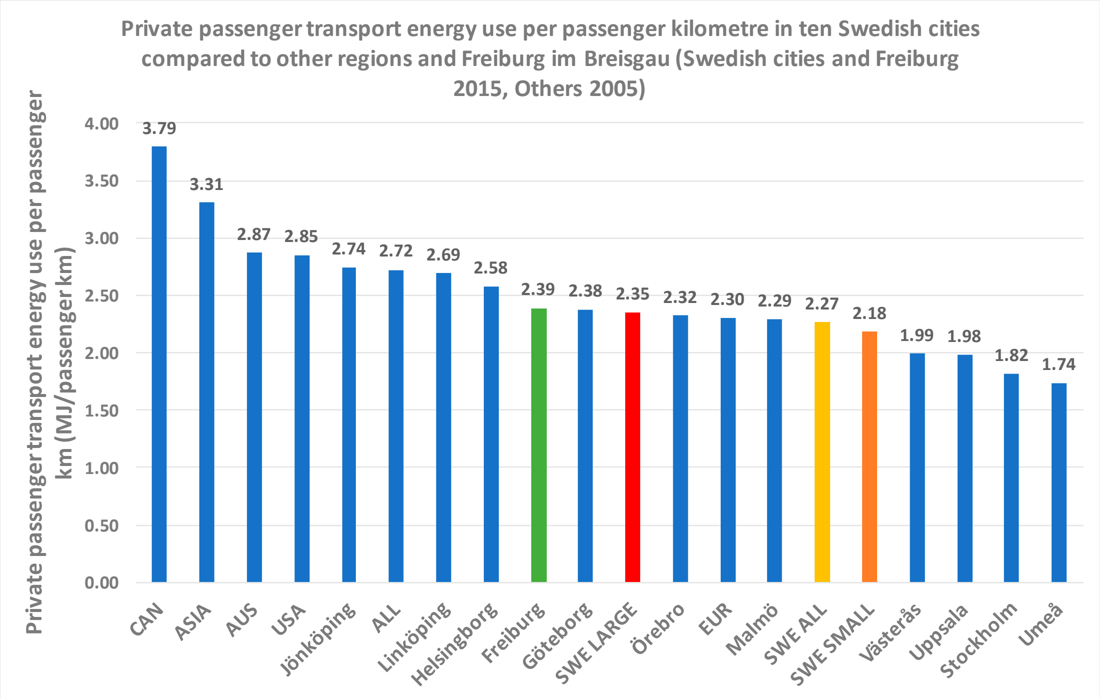

Figure 4. Energy use per passenger kilometer (PKT) in private passenger transport in ten Swedish cities (2015); Freiburg (2015); and American, Australian, Canadian, European and Asian cities (2005–2006).

3.3.4. Energy Use per Public Transport Passenger Kilometer (PKT)

Table 3 also provides the energy use per public transport PKT, and Figure 5 graphs the results. It reveals that Swedish cities have over a threefold difference in energy use per PKT, from a low in Stockholm of 0.76 MJ/PKT (identical to the European sample and almost the same as Freiburg with 0.79), up to 2.53 MJ/PKT in Jönköping, which is only 8% lower than for cars in that city. Overall, Swedish cities consume 1.10 MJ/PKT in public transport or some 45% higher than in European cities, but lower than in the American and Canadian cities. The smaller cities are more consumptive (1.30 MJ/PKT) than the larger Swedish cities (1.00 MJ/PKT). Generally, it could be said that the energy result for public transport in Swedish cities is a little disappointing, with, for example, Jönköping and Örebro exceeding US consumption levels per PKT. This is indicative of a larger public transport problem in Swedish cities related to usage levels, as discussed in Section 4.

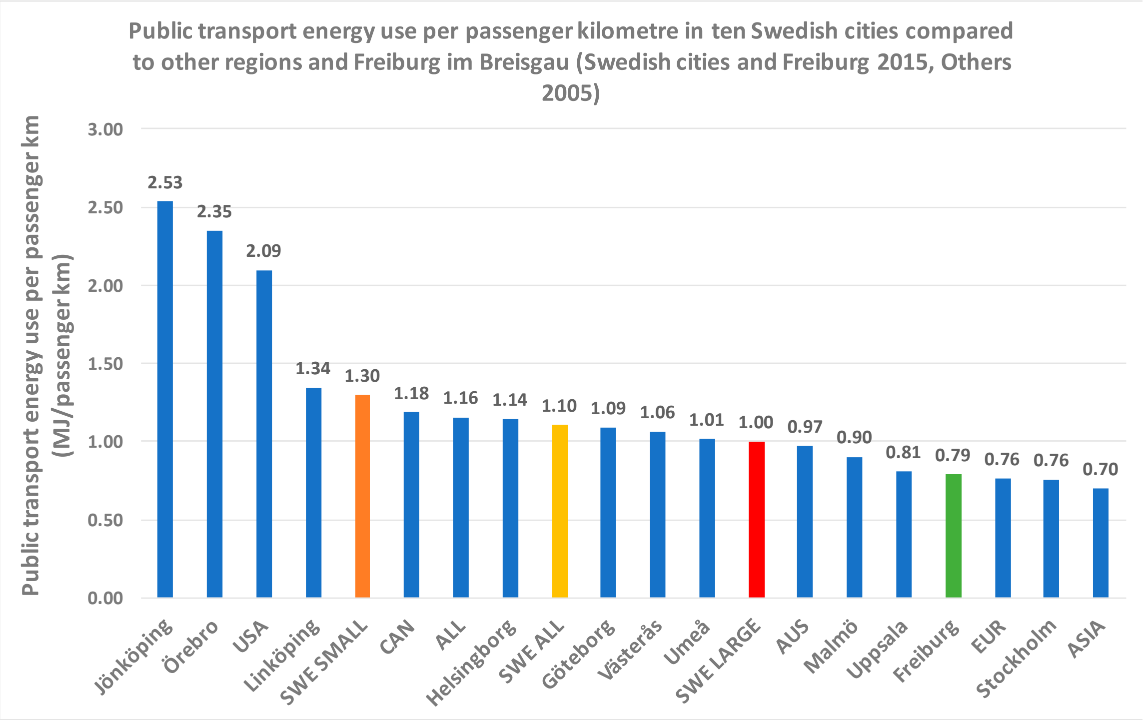

Figure 5. Energy use per PKT in public transport in ten Swedish cities (2015); Freiburg (2015); and American, Australian, Canadian, European and Asian cities (2005–2006).

3.3.5. Ratio of Private to Public Transport Energy Use per PKT

A useful way of considering the last two sets of data is to examine the ratio between private and public transport energy use per PKT. Figure 6 provides these data and shows that the Asian cities have, by far, the greatest advantage in energy consumption for public transport (cars are 4.74 times more consumptive), while in Freiburg and the other European cities, cars are three times higher in energy use per PKT. In Swedish cities, the energy advantage of public transport is significantly reduced, with cars being only a little more than twice as energy demanding per PKT, but in the larger cities, the figure is 2.36, while in the smaller cities, cars are only 1.68 times higher in energy use. Of even larger concern is that, in Örebro, public transport energy use per PKT is basically identical to that of cars and does not appear to offer any energy advantage at current levels of occupancy for cars and public transport.

3.3.6. Bus Energy Use per PKT

It is important to consider the relative energy use of the different public transport modes. Table 3 shows that buses are the second highest public transport mode for energy use after ferries. They have considerably more energy consumption than rail modes in every case, but in most cases, they are still less energy consumptive than cars (except in Örebro, where buses consume 14% more energy/PKT than cars, and in US cities, where buses are 4% higher than in cars). In the Swedish cities, buses overall consume 1.76 MJ/PKT or almost identical to the global sample at 1.78. Buses in the larger Swedish cities are a little more economical in energy (1.54 MJ/PKT) than in the smaller cities (1.97). However, clearly, the Swedish urban buses do not perform as well in energy terms as other European cities (1.31 MJ/PKT), which is likely related to their lower levels of usage (Section 4).

3.3.7. Tram/LRT Energy Use per PKT

As mentioned before, for simplicity, tram and LRT in the global sample are combined here to provide an overview perspective. These rail modes are generally the second-lowest energy-demanding modes in cities after metros (see below) and average around 0.60 MJ/PKT (e.g., the global average is 0.64 MJ/PKT, Swedish cities 0.60 and European cities 0.63). Freiburg is exceptionally good, with 0.33 MJ/PKT, and the two Asian cities quite close to this (0.40). In every case, trams and LRT are also much less energy consumptive than buses, due to their generally higher loadings, electric propulsion and the fact that they tend to operate in generally denser, more public-transport-supportive urban fabrics, especially inner areas of cities.

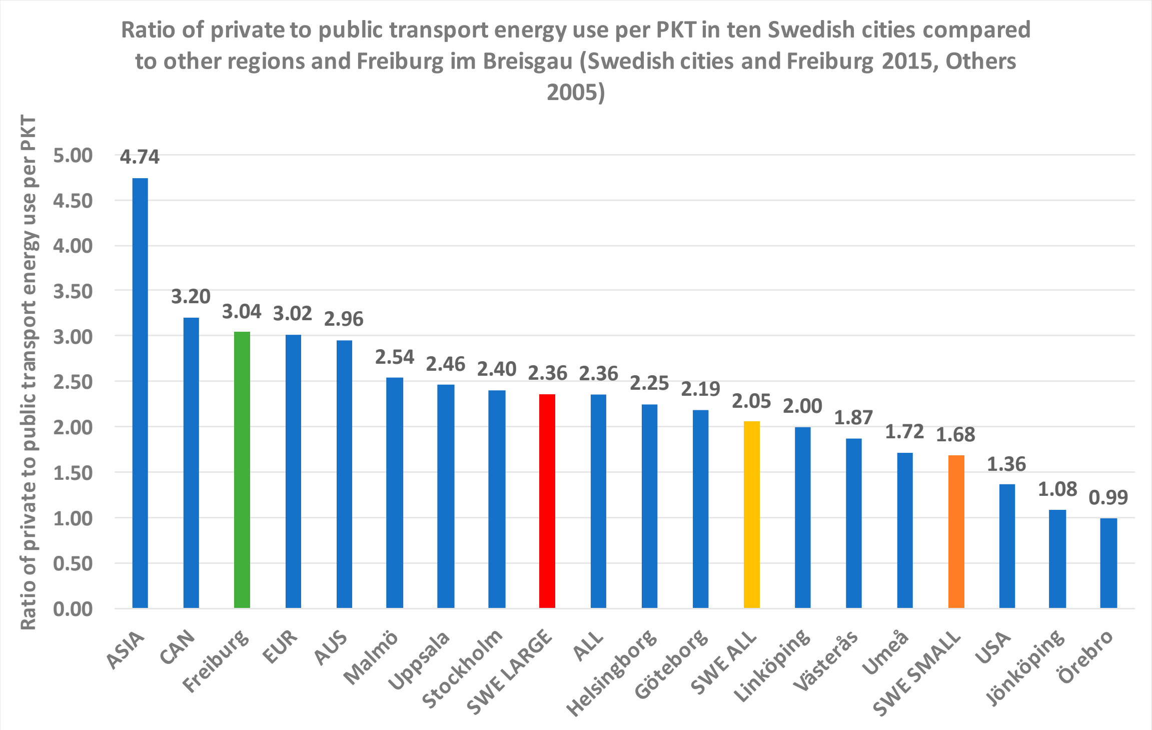

Figure 6. Ratio of private to public transport energy use per PKT in ten Swedish cities (2015); Freiburg (2015); and American, Australian, Canadian, European and Asian cities (2005–2006).

3.3.8. Metro Energy Use per PKT

Metros are very often the least-energy-consuming mode in cities. Stockholm, the only Swedish city with a metro, consumes only 0.39 MJ/PKT, even a little lower than the European average of 0.42 and only a little higher than the Asian average of 0.34 MJ/PKT. Globally, metros average 0.52 MJ/PKT, but in the auto-dependent cities in the US, Australia and Canada, they average higher energy use (0.69, 0.75 and 0.64 MJ/PKT, respectively).

3.3.9. Suburban Rail Energy Use per PKT

Suburban rail is generally the third least-energy-consumptive public-transport mode in cities, after metros and LRT. In Asian cities, however, suburban rail averages only 0.27 MJ/PKT. Swedish cities acquit themselves well here, by averaging 0.59 MJ/PKT (0.55 and 0.64 MJ/PKT in the larger and smaller cities, respectively). This is very like the other European cities (0.60) and Freiburg (0.65) and significantly better than the US and Canadian cities (1.29 and 1.17 MJ/PKT, respectively), due in no small part to the use of diesel fuel in some of their systems. In no case is suburban rail energy use more than that used in buses and is sometimes less than metros (e.g., in Linköping, Australian and Asian cities).

3.3.10. Ferry Energy Use per PKT

Ferries are the most-energy-consuming modes in cities, though they are not so common. In Swedish cities, they consume, on average, 7.77 MJ/PKT versus a global figure of 4.60 MJ/PKT. In other European cities, they consume 4.88 MJ/PKT. Although ferry systems are not generally energy-efficient anywhere, they often form critical links across water bodies where bridges for traffic are not very practicable or desirable. Therefore, their energy conservation quality is realized more in substituting for long car trips that would otherwise be needed to circumvent water obstacles in cities.

It is important to note here that Table 3 shows minibuses to also be high energy consumers per PKT (7.16 MJ/PKT), but they are a category found only in the American cities and in Hong Kong in this study. However, this is due to the high-energy-consuming-demand-responsive bus systems in American cities that drive many millions of kilometers in low-density areas, picking up very few passengers.

4. Understanding Differences in Patterns of Energy Use in Swedish Cities

This section addresses the third research question in the introduction which seeks to explain patterns of passenger transport energy use per capita in Swedish cities by reference to a set of standardized transport and land-use indicators developed for each city and compared to other global cities and Freiburg. Table 4 contains these data.

The preceding data have shown that Swedish cities have almost identical average per capita use of energy in both private and public transport systems, despite, as Table 4 shows, having densities which are significantly below those in other European cities (16.9 cf. 47.9 persons/ha) and notwithstanding that density has been shown to be the most strongly correlated variable in explaining urban energy use in private passenger transport [26,28]. This low energy use is, of course, linked to the fact that Swedish cities also have nearly identical car passenger kilometers (PKT) per capita as other European cities (6888 car PKT/person cf. 6817, respectively), which is at least partly explained by the Swedish cities' lower car occupancy of 1.31 compared to 1.38 in other European cities in 2005. Car passenger kilometers is the result of car vehicle kilometers multiplied by the average 24 h/7 days per week car occupancy, and of course includes the driver. Such low car occupancy and underutilized capacity in public transport due to low vehicle and seat occupancy (explained later) are naturally also sources of potential energy conservation if occupancies can be increased.

So, how might the relatively low car use per person and low private transport energy use per person, despite comparatively low urban densities in Swedish cities, be explained? A review of the data in Table 4 highlights some significant findings regarding Swedish cities which serve as mitigating factors in understanding the above issue. However, it is first important to highlight the metropolitan Gross Domestic Product (GDP) per capita factor in Table 4. It is common to hear that greater wealth generates more car use, but Table 4 shows that Swedish cities had a similar average GDP per capita ($30,001) in 2015 to the Australian ($32,194) and Canadian cities ($31,263) in 2006, whose car and energy use per capita are much higher than in Swedish cities (around double or more in private transport energy use). Similarly, European cities had an average GDP of $38,683/person in 2005, which was very much higher than the Australian and Canadian cities at that time, and yet all of their mobility factors are strongly oriented to public transport, walking and cycling, and they have much lower transport energy use per capita. These inconsistent relationships between wealth and transport energy use mean that wealth is generally a weak factor in predicting per capita transport energy use data at an aggregate level in cities across the globe. In the 2005–2006 data for the cities in Table 1, GDP per capita had the strongest positive relationship with private passenger transport energy use per capita, using a power function with an r^2 value of only 0.172. By contrast, urban density (persons per ha) showed a very strong negative relationship, with an r^2 value of 0.827.

Table 4. Key transport and land use indicators in ten Swedish cities (2015), plus Freiburg im Breisgau (2015), as compared to American, Australian, Canadian, European and Asian cities (2005–2006).

Variable	Units	Stockholm	Malmö	Göteborg	Linköping	Helsingborg	SWE LARGE	Uppsala	Västerås	Örebro	Jönköping
Urban density	persons/ha	23.5	20.0	19.7	13.8	21.9	**19.8**	15.3	17.1	13.7	12.6
Proportion of jobs in CBD	%	28.2%	7.8%	7.0%	18.9%	19.7%	**16.3%**	19.2%	23.3%	14.6%	20.6%
Metropolitan gross domestic product per capita	USD 1995	$49,271	$32,709	$40,808	$30,260	$28,917	**$36,393**	$31,998	$29,594	$29,045	$29,952
Length of freeway per person	m/ person	0.138	0.232	0.225	0.269	0.287	**0.230**	0.180	0.224	0.366	0.496
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	125	237	160	225	483	**246**	169	501	461	287
Passenger cars per 1000 persons	units/1000 persons	398	442	405	432	435	**423**	387	461	435	481
Average speed of the road network (24/7)	km/h	37.1	41.0	39.0	30.5	39.1	**37.3**	51.3	48.5	47.4	45.0
Total length of public transport lines per 1000 persons	m/1000 persons	4867	3109	6098	11,055	3031	**5632**	11,176	6894	9876	9024
Total length of reserved public transport routes per 1000 persons	m/1000 persons	234	222	283	378	432	**310**	584	1275	422	1457
Total public transport seat kilometres of service per capita	seat km/person	8,294	5,837	9,376	4,647	6,321	**6895**	7115	2677	3642	4,330
Overall average speed of public transport	km/h	33.6	46.8	30.9	38.6	31.5	**36.3**	64.4	38.4	33.4	40.7
* Average speed of buses	km/h	24.8	27.8	28.0	31.3	23.6	**27.1**	46.0	28.0	30.5	31.5
* Average speed of suburban rail	km/h	56.3	75.6	66.0	93.8	65.8	**71.5**	102.0	93.9	89.0	72.5
Total public transport boardings per capita	boardings/person	359	111	285	64	158	**195**	108	53	39	60
Total public transport passenger kilometres per capita	p.km/person	2579	1451	2463	877	1590	**1792**	1765	884	367	809
Overall public transport vehicle occupancy	persons/unit	22.6	22.0	16.3	14.4	16.1	**18.3**	15.2	16.2	7.2	9.9
Overall public transport seat occupancy	%	31%	25%	26%	19%	25%	**25%**	25%	33%	10%	19%
Passenger car passenger kilometres per capita	p.km/person	6630	6839	6689	6734	6862	**6751**	6131	7048	7361	7902
Percentage of total daily trips by non motorised modes	%	22.1%	31.2%	26.3%	33.0%	23.0%	**27.1%**	46.8%	32.7%	34.0%	21.2%
Percentage of total daily trips by motorised public modes	%	31.6%	17.6%	20.0%	9.7%	18.0%	**19.4%**	14.1%	6.7%	9.0%	9.6%
Proportion of total motorised passenger kilometres on public transport	%	27.8%	17.4%	26.7%	11.4%	18.7%	**20.4%**	22.2%	11.1%	4.7%	9.2%
Ratio of public versus private transport speeds	ratio	0.91	1.14	0.79	1.27	0.81	**0.98**	1.25	0.79	0.71	0.90
Ratio of segregated public transport infrastructure versus expressways	ratio	1.69	0.96	1.26	1.41	1.51	**1.36**	5.48	10.34	2.32	7.67

Table 4. *Cont.*

Variable	Units	Umeå	Freiburg	SWE SMALL	SWE ALL	USA	AUS	CAN	EUR	ASIA	ALL
Urban density	persons/ha	11.5	46.0	**14.0**	**16.9**	15.4	14.0	25.8	47.9	217.3	42.2
Proportion of jobs in CBD	%	13.7%	16.3%	**18.3%**	**17.3%**	8.2%	12.7%	15.0%	18.3%	9.1%	14.5%
Metropolitan gross domestic product per capita	USD 1995	$29,415	$25,782	**$30,001**	**$33,197**	$44,455	$32,194	$31,263	$38,683	$21,201	$37,700
Length of freeway per person	m/ person	0.000	0.063	**0.253**	**0.242**	0.156	0.083	0.157	0.094	0.026	0.112
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	240	271	**332**	**289**	487	298	319	248	121	314
Passenger cars per 1000 persons	units/1000 persons	435	393	**440**	**431**	640	647	522	463	78	512
Average speed of the road network (24/7)	km/h	46.7	29.9	**47.8**	**42.6**	50.4	42.8	45.4	34.3	30.6	40.2
Total length of public transport lines per 1000 persons	m/1000 persons	18,969	5131	**11,188**	**8410**	1382	2609	2496	3,183	2,614	2,576
Total length of reserved public transport routes per 1000 persons	m/1000 persons	1878	411	**1123**	**716**	72	160	67	298	34	188
Total public transport seat kilometres of service per capita	seat km/person	4963	3957	**4546**	**5720**	1874	4077	2368	6126	7267	4486
Overall average speed of public transport	km/h	34.0	32.1	**42.2**	**39.2**	27.3	*33.0*	25.7	29.8	26.3	28.8
* Average speed of buses	km/h	31.2	26.1	**33.4**	**30.3**	*19.9*	*23.4*	*22.4*	*21.9*	*19.4*	21.5
* Average speed of suburban rail	km/h	90.4	50.6	**89.6**	**80.5**	57.3	47.6	44.7	52.1	50.8	51.7
Total public transport boardings per capita	boardings/person	45	192	**61**	**128**	67	96	151	386	450	254
Total public transport passenger kilometres per capita	p.km/person	1117	1375	**988**	**1390**	571	1,075	1031	2234	3786	1644
Overall public transport vehicle occupancy	persons/unit	12.3	22.6	**12.1**	**15.2**	13.1	18.1	19.8	21.0	28.1	19.0
Overall public transport seat occupancy	%	23%	35%	**22%**	**24%**	29%	27%	44%	39%	52%	37%
Passenger car passenger kilometres per capita	p.km/person	6680	6899	**7024**	**6888**	18,703	12,447	8495	6817	1975	10,234
Percentage of total daily trips by non motorised modes	%	29.3%	63.0%	**32.8%**	**30.0%**	9.5%	14.2%	11.6%	34.5%	26.1%	23.2%
Percentage of total daily trips by motorised public modes	%	6.9%	16.0%	**9.3%**	**14.3%**	5.5%	7.5%	13.1%	22.4%	46.0%	16.8%
Proportion of total motorised passenger kilometres on public transport	%	14.2%	16.4%	**12.3%**	**16.3%**	3.2%	8.0%	11.3%	24.5%	62.9%	18.0%
Ratio of public versus private transport speeds	ratio	0.73	1.07	**0.88**	**0.93**	0.55	0.78	0.57	0.88	0.86	0.75
Ratio of segregated public transport infrastructure versus expressways	ratio	-	19.10	**6.45**	**3.26**	0.56	1.98	0.56	5.51	1.42	3.16

4.1. Differences and Similarities in Car-Related Factors

Firstly, Swedish cities had lower car ownership in 2015 (431/1000 people) than the European cities had in 2005 (463/1000), and the difference would have widened, since car ownership in European cities would have grown over the intervening ten years. This lower car ownership in Swedish cities will tend to reduce their energy use. However, they also have 2.5 times more linear length of freeway provision than European cities (0.242 cf. 0.094 m/person), which generally tends to increase per capita transport energy use in cities [29] because it encourages more driving over longer distances.

However, the average speed of individual vehicles is also known to be the most important single variable in explaining the fuel consumption of vehicles in traffic streams [30–32], with higher average speeds up to about 60 km/h being shown to reduce the consumption of fuel per kilometer in a vehicle. The ten Swedish cities have an average traffic speed of 42.6 km/h, compared to only 34.3 km/h in other denser European cities. Swedish average traffic speed is almost identical to the much more auto-oriented Australian cities (42.8 km/h).

While this result would tend to mitigate fuel use somewhat by reducing the fuel consumption per kilometer of vehicles in Swedish cities, it has also been shown that there is a trade-off between fuel-efficient traffic and fuel-efficient cities. Policies that try to minimize transport energy consumption by building more roads and speeding up traffic will, overall, tend to increase the amount of energy use per person through greater car-orientation of the city and more driving, and therefore should never be pursued [33].

Swedish cities also have quite similar parking spaces per 1000 Central Business District (CBD) jobs to their European cousins. European cities average 248 spaces/1000 jobs while Swedish cities average 289, though the larger Swedish cities have only 246 spaces/1000 jobs with the smaller ones being more generously supplied with parking (332/1000 jobs). Reduced parking in the CBD will greatly favor non-car modes, especially for the journey to work [34]. Overall, the similarity in Swedish cities with other European cities on this factor, and especially when compared to the very high CBD parking in US cities, will tend to reduce transport energy use. When this is combined with the relatively high centralization of jobs in their CBDs (17.3% in the Swedish cities overall and 18.3% in their smaller cities), the possibility of using public transport, walking and cycling to work is enhanced.

Table 4 shows that private transport modes constitute 55.7% of all daily trips in the ten Swedish cities, with a slightly better result in the five larger cities (53.5%). Other lower-density, auto-oriented cities in the USA, Australia and Canada have between 75% and 85% of daily trips by private modes. This is a very big factor in keeping Swedish car use and private passenger transport energy use per capita very much lower than it is in the USA, Australia and Canada.

When the fuel consumption rate in MJ/km and MJ/passenger km (PKT) is considered, as detailed earlier in the paper, it can also be seen that Sweden follows the European phenomenon of more fuel-efficient vehicles. For example, cars in the ten Swedish cities average 3.0 MJ/km, while the European cities average 3.1 MJ/km. In all other groups of cities, cars are consuming between 4.1 and 4.9 MJ/km. Likewise, considering passenger loadings, Swedish cities average 2.27 MJ/PKT, while European cities average 2.30 and the other cities average between 2.85 and 3.79 MJ/PKT. Thus smaller, more fuel-efficient cars in Swedish cities also help to suppress their transport energy use.

4.2. Public Transport and Non-Motorized Mode Factors

There are a series of other important factors that make Swedish cities a somewhat unique cohort in the global system of cities. Firstly, relative to other lower-density cities, Sweden provides a lot of public transport infrastructure. The length of all public transport lines in the ten cities averages 8410 m/1000 persons, while in other European cities, it is 3183. In American cities, it is only 1382 meters, and in Australia, in the best of the auto cities, it is 2609 m/1000 persons. The reserved route length per 1000 persons is also high in Swedish cities with 716 m/1000 persons and only 298 in other European cities (reserved routes are those that are reserved only for public transport such as bus lanes and rail lines, including segregated LRT/tram routes), so that congestion from other vehicles does not interfere with their operation. Other lower-density cities typically average only around 100 m/1000 persons. Additionally, the ratio of reserved public transport route to freeways (the two premium measures of private and public transport infrastructure) is 3.26 in the Swedish cities, only exceeded by other European cities with 5.51 times more premium public transport route than freeways.

This means that public transport systems in Swedish cities offer quite competitive average speeds. The ratio of overall public transport system speed (all modes) is 0.93 (so approaching parity with average road traffic speed), while in other European cities, it is 0.88. American and Canadian cities have public transport systems that operate at little more than half the average speed of general road traffic. The Swedish suburban rail services are especially competitive with road traffic, averaging 80.5 km/h cf. 42.6 km/h. Even Swedish urban bus systems have the best average speed of all buses in the world (30.3 km/h compared to a range in other cities from 19.4 to 23.4 km/h, with a global average of 21.5 km/h).

Furthermore, Swedish cities are blessed with relatively high levels of public transport service as measured by the annual seat kilometers of service per person. They provide on average 5720 seat km/person, with the five larger cities at 6895 km/person, which is more than other European cities (6126 seat km/person).

It could be concluded that Swedish cities do a great deal for public transport, to help compensate for what are atypically low densities for European cities and therefore quite dramatically reduced catchment densities around public transport stops. Stockholm is an exception here and has had a strong policy of transit-oriented development around stations on its tunnelbana (metro) system [35,36], thereby achieving the highest public transport use in Sweden (359 annual boardings/person), comparable to other European cities with 386/person. This suggests that even where densities are relatively modest overall (23.5 persons/ha in Stockholm), if significantly focused and denser, mixed-use urban fabrics can be developed and integrated with good public transport services, high levels of use can still be achieved.

Because of overall good infrastructure and service for public transport, the ten Swedish cities achieve what is a respectable performance in public transport use despite their lower densities. They average 128 annual boardings per capita and 195 in the larger five cities, compared to 67, 96 and 151 per capita in US, Australian and Canadian cities, respectively (and Canadian cities average 58% higher urban density than the average for the Swedish cities). Swedish cities are, however, 67% less in per capita boardings than in other European cities. Their public transport passenger kilometers are better, due most likely to longer travel distances, averaging 1390 PKT/person, compared to 571, 1075 and 1031 in US, Australian and Canadian cities, though they are still 38% below the European cities (2234/person). Swedish cities also have 16.3% of total motorized travel by public transport (20.4% in the larger cities), compared to only 3.2%, 8.0% and 11.3% in US, Australian and Canadian cities respectively. Not surprisingly, though, they lag the other European cities in this factor (24.5%).

The major public transport problem for Swedish cities is their low density. This can be seen in the vehicle and seat occupancy data. These data show how many people on average are in a public transport vehicle (for rail, a vehicle is one wagon of a train) and what percentage of the seats supplied are on average occupied. Table 4 shows that there are on average only 15 persons per public transport vehicle (23 in Stockholm), which is lower than all other groups of cities, apart from the American cities (13). In seat occupancy (24% for all Swedish cities), there are no groups of cities with lower occupancy, and the range is from 31% in Stockholm down to 10% in Örebro. Thus, there is a lot of unutilized public transport capacity in Swedish cities and therefore high energy conservation potential if occupancy of the generous services provided can be increased.

Finally, Table 4 also suggests that the strong orientation to non-motorized modes in Swedish cities, despite a cold climate for much of the year, is also contributing significantly to their moderate private passenger transport energy use per capita. Swedish cities average 30% of all daily trips by walking and cycling (and a further 14.3% by public transport), with 32.8% walking and cycling in the five smaller cities, not far behind the other European cities with 34.5%. This is in stark contrast to 9.5%

in American, 14.2% in Australian and 11.6% non-motorized-mode use in Canadian cities. Despite low overall densities, Swedish cities do have significant areas of higher density, mixed use walking city fabric which facilitates greater use of both walking and cycling [21,37].

A simple way of summarizing the collective importance of all these factors in understanding transport energy use is to look at a pair of contrasting examples from Sweden with quite different per capita energy use in private passenger transport. Table 5 contrasts these key differences and shows that Jönköping has 80% higher private transport energy use per capita than Stockholm (21,678 MJ/person cf. 12,051 MJ/person). Furthermore, despite public transport use being dramatically less than in Stockholm (60 boardings/person cf. 359 in Stockholm), even public transport energy use per capita is a fraction higher (2050 in Jönköping cf. 1949 MJ/person in Stockholm). This highlights the energy conservation potential of public transport in a simple way—despite very similar public transport energy use per capita, Stockholm carries six times more boardings. The efficiency of energy use is also very different between the two cities. Jönköping's private and public transport energy use per passenger km are very similar (2.74 versus 2.53 MJ/PKT respectively) so that public transport has only a slight advantage in energy consumption. By contrast, private transport uses 2.4 times more energy per passenger km than public transport in Stockholm.

Table 5. Key differences between Stockholm and Jönköping with low compared to high per capita energy use in private passenger transport.

Variable	Units	Stockholm	Jönköping
Private passenger transport energy use per capita	MJ/person	12,051	21,678
Public transport energy use per capita	MJ/person	1949	2050
Energy use per private passenger kilometre	MJ/p.km	1.82	2.74
Energy use per public transport passenger kilometre	MJ/p.km	0.76	2.53
Urban density	persons/ha	23.5	12.6
Proportion of jobs in CBD	%	28.2%	20.6%
Metropolitan gross domestic product per capita	USD 1995	$49,271	$29,952
Length of freeway per person	m/ person	0.138	0.496
Parking spaces per 1000 CBD jobs	spaces/1000 jobs	125	287
Passenger cars per 1000 persons	units/1000 pers.	398	481
Average speed of the road network (24/7)	km/h	37.1	45.0
Total length of public transport lines per 1000 persons	m/1000 persons	4867	9024
Total length of reserved public transport routes per 1000 persons	m/1000 persons	234	1457
Total public transport seat kilometres of service per capita	seat km/person	8294	4330
Overall average speed of public transport	km/h	33.6	40.7
* Average speed of buses	km/h	24.8	31.5
* Average speed of suburban rail	km/h	56.3	72.5
Total public transport boardings per capita	boardings/person	359	60
Total public transport passenger kilometres per capita	p.km/person	2579	809
Overall public transport vehicle occupancy	persons/unit	22.6	9.9
Overall public transport seat occupancy	%	31%	19%
Passenger car passenger kilometres per capita	p.km/person	6630	7902
Percentage of total daily trips by non motorised modes	%	22.1%	21.2%
Percentage of total daily trips by motorised public modes	%	31.6%	9.6%
Proportion of total motorised PKT on public transport	%	27.8%	9.2%
Ratio of public vs private transport speeds	ratio	0.91	0.90
Ratio of segregated public transport infrastructure vs expressways	ratio	1.69	7.67

It can also be seen how different many of the other factors are between the two cities. Urban density is 87% higher in Stockholm, the proportion of jobs in the CBD is 1.4 times more, parking spaces per 1000 jobs are 2.3 times higher in Jönköping and GDP per capita in Stockholm is 1.6 times higher than Jönköping, despite Stockholm having significantly lower car use per capita than in Jönköping (6630 PKT/person cf. 7902 PKT/person). Freeway provision per person is 3.6 times greater in Jönköping, and car ownership is 21% higher, reflecting a higher commitment to the car than in Stockholm. Average road traffic speed is 45 km/h in Jönköping versus 37.1 km/h in Stockholm, thus encouraging more car use, although the ratio between public transport system speed and road traffic speed is virtually identical in both cities due to Jönköping's average public transport speed also being higher (40.7 km/h cf. 33.6 km/h).

Although Jönköping has more public transport lines and greater reserved public transport route per person than Stockholm, this infrastructure is not as well serviced as in Stockholm (only 4330 seat km/person cf. 8294 in Stockholm). This is reflected in all the public transport usage variables in Table 5 being so much higher in Stockholm, including vehicle and seat occupancy levels. Such differences are, to a degree, expected, given the difference in density and therefore the reduced public transport catchment populations around stops/stations in Jönköping. Interestingly, in non-motorized mode use as a percentage of total daily trips, Stockholm only has a slight edge over Jönköping, and both cities are the two lowest of the ten Swedish cities in this factor.

When taken collectively, it is likely that there is a strong multiplicative effect at work in determining the differences in energy use between the two cities.

5. Conclusions

This paper has provided a detailed insight into the private and public transport energy consumption patterns in ten Swedish cities and some broad urban planning, infrastructure and mobility patterns data that help to explain that consumption, both within Sweden and in relation to other world cities. The introduction posed three research questions, and the summary answers to those questions are provided in this section.

5.1. How Does Energy Use per Capita in Private and Public Transport Modes Compare within Sweden and with Other Cities in the USA, Australia, Canada, Europe and Asia?

Swedish cities are typical European cities in both their average private and public transport energy use per capita (15,601 MJ and 1534 MJ/person, respectively), with the smaller Swedish cities being a little less than the larger cities in both. However, there is considerable variation from 11,622 to 21,678 MJ/person in Umeå and Jönköping, respectively. On average, Swedish cities have about one-half the per capita private transport energy use of Australian and Canadian cities and less than one-third that of US cities. Their public transport energy use per capita is higher than the automobile cities in the USA, Australia and Canada, about the same as in other European cities, but much lower than in the Asian cities. This public transport energy use reflects much higher levels of public transport service and therefore greater commitment to public transport in Swedish cities than in the auto-oriented cities with a similar density.

5.2. How Do the Modal Energy Consumption Rates per Vehicle Kilometer and Passenger Kilometer in Swedish Cities Differ from Each Other and Other Cities Worldwide?

5.2.1. Energy Use per Vehicle Kilometer

Private transport energy use per vehicle km in Swedish cities is on average similar in the smaller and larger cities (2.9 and 3.1 MJ/km, respectively, with an average of 3.0) and very like Freiburg (3.1), as well as the other European cities in 2005 (3.1 MJ/km). This factor is, however, much less than in all the other groups of cities, which ranged in 2005 from 4.1 to 4.9 MJ/km.

Public transport energy use per kilometer (17.3 MJ/km all modes) is lower than in the global sample (18.6 MJ/km). Swedish buses consume less energy per kilometer than all groups of cities, apart from the European cities and Freiburg, with which they are very alike. LRT energy use per wagon km is also very like European cities, but lower than the other groups of cities. Metro energy use per wagon km (Stockholm's tunnelbana) is again akin to European cities, but very much lower than metros everywhere else. Suburban rail energy use varies a lot and is higher than in European, Australian and Asian cities, but very much lower than in American and Canadian cities (which have numerous less energy-efficient diesel operations).

5.2.2. Energy Use per Passenger Kilometer

Private transport energy use per passenger km follows the same patterns as outlined above, with Swedish cities on average being almost identical to European cities, but significantly below all the other cities. On the other hand, the lower use of public transport services sees Swedish cities consuming more energy per passenger kilometer (1.10 MJ/PKT) than all groups of cities, except those in the US and Canada. This includes Freiburg and the European cities which consume 0.79 and 0.76 MJ/PKT, respectively. This pattern is mainly due to the buses, because for the rail modes (LRT, metro and suburban rail), Swedish cities are much more alike, or sometimes better than, the other groups of cities.

5.3. Can Differences in Transport Energy Use per Capita Be Explained through Reference to a Range of Other Important Transport Indicators in Swedish Cities?

An examination of a wide range of other transport-related indicators has revealed insights into why Swedish cities differ between one another in passenger transport energy use and between other cities in the world. The key point to note here is that Swedish cities have similar levels of car use to other European cities and therefore similar per capita private transport energy use. This is despite Swedish cities being significantly lower in density than other European cities. However, unlike cities of similar density in North America and Australia, Swedish cities are still more centralized in work than their more auto-oriented cousins, thus favoring walking, cycling and public transport; they have significantly lower car ownership and they provide very good levels of public transport infrastructure and service, including competitive speeds with the car. They also have respectable levels of public transport use and very healthy levels of walking and cycling, especially considering their density.

Unlike most lower-density cities in North America and Australia, Swedish cities, being much older, do retain much more significant areas of "walking city" and "transit city" urban fabric and are therefore not uniformly low in density but rather have substantially higher density mixed-land-use areas, which are very supportive of public transport, walking and cycling [37]. For a more detailed explanation of how Swedish cities distinguish themselves from other cities in these matters, readers can refer to Kenworthy [21], which also contains photographic evidence of this urban fabrics' argument.

The variation in per capita private transport energy use between Swedish cities can generally be explained by the lower energy-consuming Swedish cities having a combination of (a) more energy-efficient cars, (b) higher density, or at least more extensive areas of walking and transit city fabric, (c) more centralized jobs in the CBD, (d) less parking in their CBDs, (e) less freeway availability, (f) lower car ownership, (g) lower car use, (h) lower car speed (which makes cars somewhat less attractive), (i) higher public transport service levels and (j) better public transport use. Higher public transport energy use per capita in Swedish cities generally relates to a combination of higher service levels and how much of that service is provided by buses compared to rail—rail modes have much lower energy use per passenger kilometer.

The data in this paper can be used to explore the transport energy conservation potential of a variety of different scenarios in Swedish cities.

Funding: The research reported in this paper was funded by two small research grants from K2: Sweden's National Centre for Research and Education on Public Transport.

Acknowledgments: The author is very grateful to K2 for providing the funding to support this research and the countless individuals in each of the cities who provided the requested data. I am especially grateful to Monika Brunetti, my research assistant, and Helena Svensson in K2 for her support in locating some key data.

Conflicts of Interest: The author declares no conflict of interest.

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