On the road to fossil-free public transport: the case of Swedish bus fleets

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Abstract

Public transport is important for Sweden to acquire a fossil-fuel independent vehicle fleet by 2030. The aim of this paper is to assess the status of Swedish public bus fleets towards decarbonization, and explore factors affecting regional performance variations and fuel choices. Environmental performance indicators such as renewable fuel shares, CO_2 emissions, and energy efficiency are analyzed nationally and regionally. Fuel preferences and best practices are investigated through a survey and interviews with experts working with strategic planning at Public Transport Authorities. Almost 60% of the bus transport volume ran on renewables in 2014 compared to 8% in 2007, but regional variations are significant, partly due to factors such as driving conditions, bus and fuel types, typical trip lengths, and climatic conditions. However, there is no strong correlation between population densities or bus transport volume and the share of renewables achieved. This places political will, strategic planning and policies to promote public transport as key factors affecting renewable fuel deployment. Environmental factors are a priority when choosing fuels, while barriers to renewable fuels are mainly economic and political. Meanwhile, despite the overall progress, achievements in energy efficiency improvement are falling short in comparison to emissions reduction and adoption of renewable fuels, thus requiring further attention.

Highlights

- The penetration of renewables in Swedish public bus fleets reached ca. 60% in 2014.
- Public bus emissions per vehicle-km have decreased by 43% between 2007 and 2014.
- Efforts are needed to improve energy efficiency in bus transport.
- Electricity is likely to receive increased attention according to expert survey.

1. Introduction

Sweden has set the ambitious goal of acquiring a fossil-fuel independent vehicle fleet in 2030. This goal implies reducing significantly the share of fossil fuels in the transport sector so that the vehicle fleet won't be highly dependent on fossil fuels for its operation in the future as is the case today (Regeringskansliet, 2013). This is a key step towards the country's target to achieve CO_2-emissions neutrality by 2050 (Regeringskansliet, 2013). The public transport (PT thereof) sector plays an important role in this context, as it represented 27% of the total amount of passenger-kilometers in road transport in 2014. PT responds for only 2.7% of domestic road transport emissions in Sweden (Naturvårdsverket, 2015; Svensk Kollektivtrafik, 2015a; Trafikanalys, 2015a). An ambitious target has been set to run 90% of the total vehicle-kilometers of PT on renewable fuels by 2020 while at the same time increasing the share of PT (SKL, 2014a). Renewable fuels are defined as fuels produced from renewable sources, such as biofuels, hydrogen fuel or electricity originating from renewable energy sources.

In line with the energy and climate policies of the Swedish government, and the objectives set by the Swedish Public Transport Association (Svensk Kollektivtrafik – SK thereof), major efforts are being made to make public bus transport a renewables-based, climate neutral and attractive option throughout the country. So far, this transition to renewables has been driven to a great extent by effective strategic planning from regional public transport authorities (PTAs thereof) as well as fuel taxation that make renewable fuels a competitive choice. As a result of the efforts made in the last few years, renewables accounted for almost 60% of the fuels used in the whole public bus fleet in 2014 compared to approximately 10% in 2009. This is a much higher share than the 23% renewables for all Swedish buses in traffic (Trafikanalys, 2015b) and the 12% of renewables in Swedish road transport overall (Swedish Energy Agency, 2015). However, strong regional variations can be observed when it comes to the share of renewables in public buses.

In this context, it is worth evaluating what has been achieved so far and how it was achieved, and addressing the challenges that lie ahead so that successful policies can be designed to reach the 90% goal. The aim of this paper is to make a regional assessment regarding the target towards fossil-free bus fleets in PT, and explore which factors influence performance variations and fuel choices. We highlight challenges and fill information gaps through a closer examination of the performance of regional bus fleets. We are interested in how the penetration of renewables in buses has varied in different regions in Sweden. *What types of fuels are preferred and why? What challenges are still to be addressed and what are the lessons learnt?* By following the narrative of the transition of public bus fleets to renewable fuels, we identify the actors involved, the sustainability choices they face, and what is missing from the current policy landscape to promote the transition further. We identify patterns established in past years as well as best practices worth disseminating.

1.1. LITERATURE REVIEW AND ANALYTICAL APPROACH

There is a gap in energy policy research related to public transport in Sweden. The role of biofuels in Swedish road transport has been analyzed from a policy perspective in various studies, e.g. Börjesson et al. (2014), Sanches-Pereira and Gómez (2014), Holmgren (2012) and Stelling (2014). However, these studies don't focus on the particular role of PT in transport. An analysis of the role of PT in a fossil-fuel independent vehicle fleet is explored by Nilsson et al. (2013), where the need for more systematic policy analyses in Swedish PT is pointed out.

Although the Official Report SOU 2013:84 *Fossil-freedom on the way* (Regeringskansliet, 2013) highlighted the importance of PT for realizing the goal of fossil fuel independence, it failed to propose concrete measures to foster further technology and fuel transition in the sector. In fact, various stakeholders have criticized the lack of incentives for the PT sector in their inputs to the official consultation process. SK suggests that more instruments for urban development in combination with PT planning should be defined to favor a transition towards renewables (Goldmann and Persson, 2014).

Looking at existing international literature, Xu et al. (2015) discuss the factors influencing decisions on bus technologies and fuels, and conclude that the optimal combination of technology and fuel for minimizing emissions depends on the location in relation to complex factors such as weather, terrain and duty cycle. Energy efficiency in buses is discussed by de Abreu e Silva et al. (2015), where factors affecting the energy efficiency in buses operating in Lisbon are explored using regression models. The authors conclude that the main factors affecting energy efficiency are vehicle types, speed and driving conditions (terrain and routes). The impact of different fuels on energy efficiency isn't discussed because all buses examined were operating on diesel.

Ou et al. (2010) suggest that integrated policies are needed to promote various electric bus technologies as a future PT option and indicate that further research is needed for improving vehicle fuel efficiency. The focus is on the emissions, while the role of various stakeholders in promoting alternative fuels isn't discussed in detail. R. Wang et al. (2015) simulate emissions, energy efficiency and fuel consumption for bus fleets in the three most developed Chinese regions. Their study points out the importance of diversifying the fuel mix at regional level for achieving simultaneous energy savings and emissions reduction.

In Turcksin et al. (2011), Multi-Actor Multi-Criteria Analysis (MAMCA) is applied for assessing biofuel options for Belgian transport in relation to the binding targets of the Renewable Energy Directive (RED) for 10% renewables in transport. The authors identify the options preferred by stakeholder groups, indicating that government actors seem to strongly prefer renewable alternatives. The study contributed to better understanding of stakeholders' positions regarding fuel choices, which in turn can serve to better design policy instruments aimed at decarbonizing the transport sector.

Hung (2006) investigated the impact of policy instruments such as fossil fuel taxation and subsidies on non-fossil fuel deployment on private transport. The author concluded that costs are the *"single most important factor"* for switching fuels. However, we argue that for PT other factors such as social and environmental goals may come into play and affect fuel and policy instrument choices. Indeed, Faivre d'Arcier (2014) argues that the increased ambition towards sustainable mobility is increasing operation costs and putting pressure on urban PT. At the same time, the author highlighted the lack of reliable and/or comprehensive PT statistics.

There are no studies mapping emissions and efficiency indicators for regional public bus fleets, and connecting those to fuel choices and policy implications, which also motivates this study. The use of secondary data from a national database gives the opportunity to extend the scope of empirical data from local bus lines or theoretical data from meta-analyses to real data for larger regional fleets. We have identified relatively few studies using real driving conditions for bus emissions and energy efficiency. FRIDA, the Swedish database for bus fleets, is unique and provides a rich data source for analysis not found elsewhere.

We also explore the role of stakeholders involved in policy implementation for achieving environmental goals set for PT, improving bus technologies and choosing alternative fuels. In this study, input from a PT stakeholder survey adds value to the discussion on challenges and information gaps in policy-making among decision-makers and technical experts. Drivers and barriers to renewable fuel adoption connected to fuel choices are discussed in the survey. In this way, we explore whether factors other than the purely technological ones identified in previous studies affect fuel consumption and technology choices.

The Swedish case is remarkable in an international context because of the highly ambitious goals for alternative fuels in PT, and the fast deployment achieved for these fuels in buses. Through a regional comparison we are able to highlight differences and extract valuable lessons and best practices, which offer insights that are useful both domestically and internationally.

In this paper, the focus is exclusively on bus as a means of PT (the term “public transport” is used here interchangeably with the term “public transport by bus”). This separation is important since addressing all PT modes together wouldn’t provide insight into the particular features of bus transport. The majority of vehicle-kilometers of the other means of PT (i.e. train and tram) are driven on electricity, which is mostly supplied from renewables or carbon-free sources in Sweden. In 2013, 87.1% of the transport volume on train and 100% of trams run on electricity (Svensk Kollektivtrafik, 2015a). PT via bus accounts for 90% of the total volume of bus transport in Sweden (Trafikanalys, 2015c). Hence, studying the buses operating in Swedish PT has high relevance to bus transport overall. The data presented refer only to buses operating in PT.

Following this section, public bus transport in Sweden is presented in more detail in Section 2, and the analysis methods are described in Section 3. In Section 4, we map the bus fleets’ performance when it comes to environmental indicators, such as renewable fuels deployment, CO_2 emissions, and energy efficiency. In Section 5, the priorities and challenges when making fuel choices are discussed, as well as their impact on strategic planning for fossil-free PT. Conclusions and lessons learnt from the case of Swedish bus fleets finalize the study with Section 6.

2. Public Bus Transport in Sweden

Among PT modes, bus is the most common in Sweden, representing 52% of the total passenger trips in 2014. Bus transport is offered by all regions (Trafikanalys, 2014). In the past ten years (2004-2014), the number of passenger boardings has increased by almost 23%, from 609 million to 747 million. In the same period, the bus transport volume offered to the public increased by 19%, from 506 to 590 million vehicle-km; and passenger-km by bus increased by 21%, from 5 456 to 6 604 million (Trafikanalys, 2015d). PT via bus holds 73% of PT’s market share (Sveriges Bussföretag, 2015). In 2014, emissions from buses represented almost 83% of the total emissions from PT, or 374 327 tons CO_2 out of a total of 451 850 tons CO_2 (Svensk Kollektivtrafik, 2015a).

The shift of buses towards renewables had to be accompanied by investments for purchasing new vehicles. The national public bus fleet increased by almost 60% since 2007 and included in total 9 808 vehicles in 2014 (Svensk Kollektivtrafik, 2015a). Naturally, the majority of trips occur in the three most populous regions of Sweden (Stockholm, Västra Götaland and Skåne). Together, they control 51% of the total number of buses operating PT services, and 58% of the total passenger-kilometers on bus. The average age of the fleet has decreased between 2007 and 2014, from almost 7 to less than 6 years (see

Appendix Table A.1). For example, Västra Götaland's PTA, Västtrafik, sets a maximum limit of 6 years for the average bus fleet age within the city of Gothenburg (Björk, 2015).

Biodiesel, biogas, ethanol and electricity from renewable sources are the renewable fuels that are used in Swedish PT (see Table 1). Hydrotreated Vegetable Oil (HVO) is similar to conventional biodiesel, but has significantly lower lifecycle emissions (Arvidsson et al., 2011). Electricity being used in buses is certified and comes from renewable sources.

Table 1: Fuels used in the Swedish transport sector and their characteristics

Fuel type	Energy density (MJ/lit)	Emissions (grCO2/MJ)	Feedstock
Biodiesel (FAME – fatty acid methyl ether)	33.2	47.6	Rapeseed oil (RME)
Biogas	34.9*	22.5	Sewage sludge (39%), MSW (19%) and waste from food industry (19%)
Ethanol	21.1	28.7	Sugarcane, maize, wheat etc.
HVO	34.3	15.9	Vegetable oils and animal fats
Electricity	*Not applicable*[1]	0	Certified electricity from renewable sources
Fossil diesel	35.13	86.4	Diesel low-blended with RME(5%)
Natural gas	39.96[2]	69.2	100% natural gas (EU data)

Source: Swedish Energy Agency, 2014a, 2014b

[1] Energy density is defined as the amount of energy stored per unit of volume. Therefore, the energy density concept is not applicable in the case of electricity that does not have volume.

[2] in MJ/Nm^3

Tax exemption to biofuels and mandatory blending are well-known instruments for promoting renewables in transport (Holmgren, 2012). Sweden has previously applied exemptions to non-blended biofuels, in combination with quotas for biofuel blending in diesel and gasoline. However, this implies overcompensation according to the EU State Aid rules. The Swedish Government has applied to the EU Commision for extending the State Aid approval for biofuel tax exemptions, which was granted by the Commission in December 2015. Tax exemptions for all biofuels except biogas will remain until 2018, and tax exemptions for biogas will continue until 2020 (Regeringskansliet, 2015). Differences between Swedish and EU views have created significant uncertainty which have been heavily criticized by bus companies and the industry. Eliminating tax exemptions for biofuels may lead to large increases in the costs of alternative fuels such as HVO and affect the rate of adoption of renewable fuels (Sveriges Bussföretag, 2015).

The PTAs play an important role in the planning and implementation of strategies that promote renewable fuels in bus fleets. In the late 70s, PTAs were established for coordinating PT at either regional or municipal level and provide transport services themselves or through concessions. In the late 80s, competitive tendering of PT transport services was introduced and became increasingly spread (Vigren, 2015). In 2013, 96% of PT volume was subsidized by the PTAs in350 tendered contracts comprising 92 commercial operators (Trafikanalys, 2015e).

Under the new PT Act (*Lag 2010:1065 om kollektivtrafik*) that came into force on 1st January 2012, PTAs were organized into regional agencies, in line with the EU Regulation (EC) 1370/2007, which also opened the market to commercial operations. Moreover, the PTAs were made responsible for regularly updating "regional transport provision programs" that specify long-term goals for PT at regional level, and guarantee PT services to the citizens (Partnersamverkan för en förbättrad Kollektivtrafik, 2015).

Although the PTAs make the ultimate decisions when it comes to strategic planning, they are not alone when working with strategies. In line with the importance of PT for improving urban environments, the key stakeholders of the sector formed a cooperation (named "Partnership for improved public transport") in 2008. The partnership set the goals to (i) double the market share of PT and (ii) increase the share of renewables in PT up to 90% (Partnersamverkan för en förbättrad Kollektivtrafik, 2015). The stakeholders participating are the Swedish Public Transport Association (SK), the Swedish Bus and Coach Federation, the Swedish Taxi Association, the Association of Swedish Train Operating Companies, the Swedish Association of Local Authorities and Regions (SKL), the Swedish Transport Administration (Trafikverket) and the state owned train infrastructure company Jernhusen (see Figure 1).

Figure 1: Stakeholders in the Swedish PT sector categorized at local and regional, national and international level of governance and as per type of involvement (stakeholders involved in the "Partnership for improved public transport" shown in bold type)

In addition to setting the goals for increased market shares and use of renewables, the partnership help develop support tools. This includes the standards for guiding the procurement process of buses using renewable fuels. SK adopted the Partnership's recommendations and set detailed environmental requirements for bus transport procurement in a separate sector standard[1], first issued in 2010 and updated in 2014.

The standard has different levels of ambition. This gives flexibility to each PTA to choose between increased, basic or minimum requirements for bus emissions and energy use (see Table 2). The emission standard is fuel-neutral, and is expressed by varying levels of emissions reductions compared to 100% fossil diesel use. PTAs that aim at higher environmental performance can push even further than the maximum requirements of the standards, leading bus operators to newest technologies or specific fuels that the PTAs wish to promote.

Table 2: The Swedish Public Transport Association's (SK) common sector standard for SORT requirements for energy efficiency. The different requirements are expressed in kWh/10v-km

	SORT 2 (class 1 buses)[1]			SORT 3 (other buses)		
Bus type	**Minimum requirement**	**Basic requirement**	**Extended requirement**	**Minimum requirement**	**Basic requirement**	**Extended requirement**
2-axle	58	44	32	52	40	29
Boggie	70	53	39	63	48	35
Articulated	78	60	44	70	54	40
Bi-articulated	88	66	49	79	59	44

Source: ***Partnersamverkan för en fördubblad kollektivtrafik, 2013a***

[1] The requirements are sorted in different driving conditions, as per the SORT standard (Standardized On-Road Test Cycles, used by the UITP (International Public Transport Association). The three SORT standards represent bus driving conditions with low and normal speed in urban traffic and slightly faster speed in suburban and rural traffic (Anderson, 2014).

3. METHODS AND DEFINITIONS

The *policy research* framework used in this study is characterized by a multidimensional focus and empirico-inductive approach, whereby quantitative and qualitative approaches are combined. For the quantitative part of the study, *secondary data analysis* is applied. Secondary data analysis is by far the most cost- and time-efficient method for answering policy research questions (Majchrzak, 1984). For the qualitative part of the study, a *survey* and *in-depth interviews* were carried out with individuals in organizations that play an important role among the key stakeholders. A survey may involve a small number of respondents or be quite extensive. However, in policy research, fairly small and purposefully sampled surveys may produce relevant results (Majchrzak, 1984).

This paper includes data collected for all 21 Swedish counties, since PT is administered at county/regional level (see Figure 2). The information regarding environmental performance and other bus fleet characteristics is found in the FRIDA database (FRIDA miljö- och fordonsdatabas - Svensk Kollektivtrafik, 2015). The web-based database was developed by Nordic Port in cooperation with SK, and the transport service operators report the information to the PTAs. Relevant stakeholder organizations publish statistics and analyses on PT in Sweden, which have also been sources of

[1] http://www.svenskkollektivtrafik.se/globalassets/partnersamverkan/dokument/mallavtal-och-kravbilagor/miljokrav/miljokrav_buss_20131218sv.pdf (In Swedish)

information for this study. This includes the annual publications of key indicators by Transport Analysis (Trafikanalys), a government agency engaged in policy analysis and statistics production for the Swedish transport sector (Trafikanalys, 2014).

Figure 2: Map of Sweden, as divided in 21 regions

The indicators used to track environmental performance in this paper are the following:

i. Renewable fuel deployment (%): measured as vehicle-kilometers run by buses on renewables in relation to total vehicle-kilometers.
ii. CO_2 emissions: counted as gr CO_{2eq} per vehicle-kilometer. CO_{2eq} per passenger kilometer is also considered. Passenger-kilometers determine the distance traveled by the passengers of a vehicle.
iii. Energy efficiency: energy consumption per transport volume (measured in kWh per v-km (vehicle-kilometer) or p-km (passenger-kilometer).

Vehicle-kilometers for bus fleets are reported in FRIDA by transport service operators. Data reliability for vehicle-kilometers has improved since FRIDA first started, and now all regional PTAs use it for reporting data on their bus fleets. There is more uncertainty when calculating passenger-kilometers, since there is currently no way of recording data of the actual trip length of passengers using PT modes. The PTAs estimate passenger-kilometers either by multiplying the average trip length per boarding with the total passenger trips (passenger-boardings), or by multiplying the average bus occupancy rates with the total vehicle-kilometers driven by buses. The average trip length is estimated at regional level by Trafikanalys or the PTAs from the national transport survey (resvaneundersökning-RVU), which is the primary source of occupancy rates at regional level (Trafikanalys, 2015f, 2012a).

Occupancy rate is defined as the number of passengers occupying a vehicle. The higher the occupancy rate of a bus, the more positive the environmental impact of a passenger's travel by bus if compared with the use of a private car. Both methods include uncertainties. Average trip lengths, for example, aren't regularly updated, or include both bus and train transport. Data used in this study for passenger-kilometers, vehicle-kilometers and number of trips for all regions from 2007 to 2013 were provided by Trafikanalys upon request (see Appendix Table A.4). Additional information for goal achievements, strategic planning and policy-making in PT was gathered through *document analysis* of published material from the PTAs, regional authorities, transport stakeholder associations, research institutes and the Swedish government.

The expert survey was carried out in the period from January to February 2015, with an anonymous electronic questionnaire. Personal interviews were carried out with straightforward note-taking. The respondents are sampled among experts working with strategic planning at PTAs.The questionnaire was sent to 35 persons. In total, 19 persons responded the survey, thus the response rate was 55%. The aim of the survey was to answer the following questions:

- *Which is the most attractive fuel alternative in the foreseeable future for PT buses and why?*
- *Which are the main barriers to increasing the share of renewable fuels for PT bus fleets?*
- *Which instruments should be implemented to encourage increased shares of renewable fuels in PT bus fleets?*
- *Which measures have been the most successful for encouraging renewable fuel deployment at regional level?*

The survey was anonymous, unless the respondent specified otherwise. In the cases when the respondent chose not to be anonymous, a follow-up interview was scheduled. From 16 questions in total, 11 of them were closed format questions, but a few were followed by open format questions for elaboration. We chose to use a mix of close and open questions in order to give the respondents freedom to provide more information. The questionnaire's design was adjusted after comments resulting from a testing session and a personal interview with the first respondent. Here, we include only the questions that are relevant to the scope of the paper.

4. ENVIRONMENTAL PERFORMANCE AND FUEL MIXES FOR BUS FLEETS

4.1 NATIONAL AND REGIONAL INDICATORS OF ENVIRONMENTAL PERFORMANCE

The increase of the share of vehicle-kilometers on renewables has been impressive in the past few years for the Swedish public bus fleet, rising from a total of 8% in 2007 to 58% in 2014 (see Figure 3). At the same time, the amount of vehicle-kilometers via bus at national level increased by 17%, from 506 to 590 million v-km(Trafikanalys, 2015d). Figure 3 illustrates how the use of renewables has increased in line with the increase of bus transport volume.

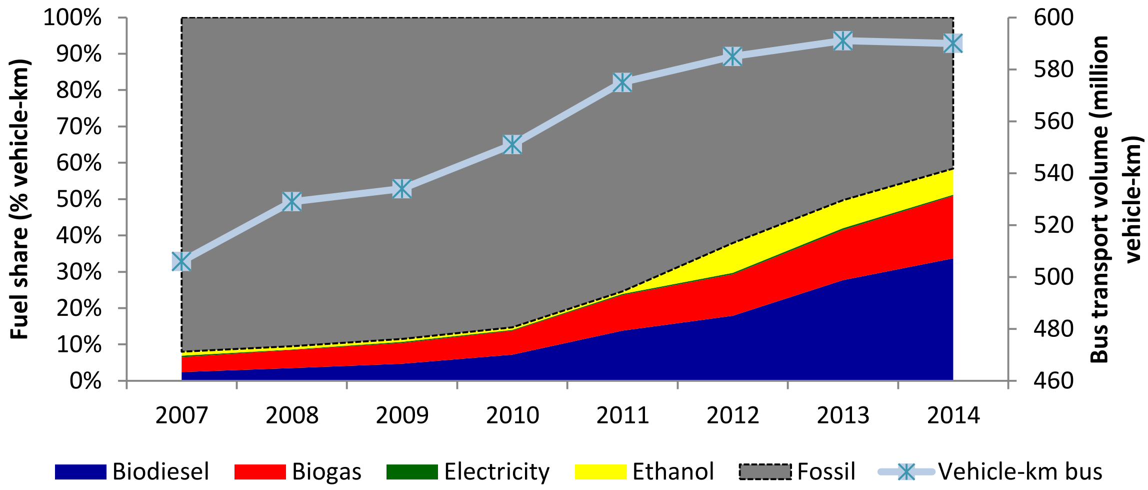


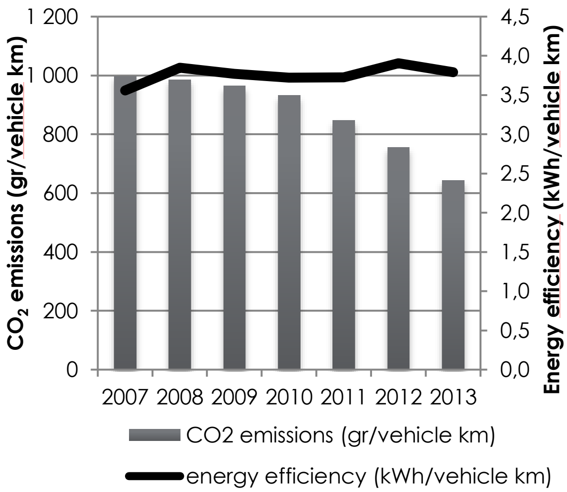
Figure 3: Fuel mix as share of total transport volume and transport volume for the Swedish public bus fleet 2007-2014)

Source: Svensk Kollektivtrafik, 2015a; Trafikanalys, 2015a

Biodiesel is currently leading among renewables (33.7%), followed by biogas (17.2%) and ethanol (7.2%). Electricity has currently a very small share (0.3%), since few pure electric or electric hybrid buses are in operation (only 71 in 2014, from a total number of 13,992 registered buses in PT - Trafikanalys 2015a). The growth curve becomes steeper after 2010, which was the year when the first common sector standard was introduced. The even higher growth rates after 2012 could be credited to the boost given to procurement with the creation of PTAs in 2012, effects from the mobilization of stakeholders within the "Partnership for improved public transport", as well as the dissemination of improved bus technologies.

A steady decrease in CO_2 emissions per vehicle-kilometer is observed at national level from 2007 to 2013 due to the shift towards renewables (see Figure 4). Emissions per vehicle-kilometer decreased by 43% at a national average level, from 998 grCO_2/vehicle-km to 564 gr CO_2/vehicle-km, while energy efficiency values have remained relatively stable in average for the whole fleet (3.7 to 3.9 kWh/vehicle-km). Emission levels per passenger-km have been also stable. However, energy efficiency measured in terms of energy unit per passenger-km has been increasing and has only stabilized in the past two years.

For Figure 5, the values of emissions and energy efficiency were calculated by dividing the total CO_2 emissions and energy efficiency (in gr CO_2 and kWh per vehicle-kilometer respectively) with the *occupancy rate* reported for each regional PTA. This gives results in grCO_2 or kWh per passenger-km. Since data on occupancy rates were only available up to 2013, the comparison of values is up to 2013 in both figures.



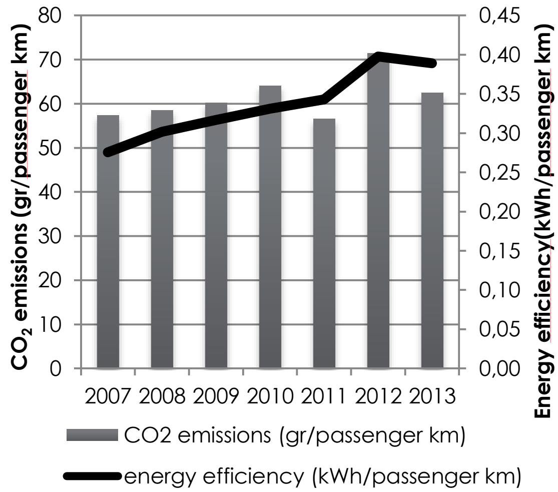


Figure 4 (left): CO_2 emissions and energy efficiency (national data, from 2007 to 2013)
Figure 5 (right): CO_2 emissions and energy efficiency (national data, from 2007 to 2013)
Source: Svensk Kollektivtrafik, 2015a; Trafikanalys, 2015

Energy efficiency when expressed per passenger-km is the important indicator showing the effect of PT in energy savings through modal shifts. An increase of this value, as in Figure 5, indicates an increase of total energy use for bus transport, and this increase isn't balanced with an equal or higher increase of occupancy rates or passenger-kilometers. The statistics show rather stagnant numbers for occupancy rates in Swedish regions (see Appendix Table A.4). This also affects the CO_2 emissions per passenger-km. As discussed in Section 3, these numbers must be used and interpreted with caution, but they serve as an indication of how the situation is evolving, which deserves attention. A deeper investigation and collection of data on occupancy rates and trip lengths is necessary to draw final conclusions.

To explore what these national indicators really mean, we move from national to regional level. That will help understand how much and why regions differ in the way they are shifting towards more sustainable bus fleets. The aim is to investigate possible patterns in renewable fuel deployment both in volume increases and renewable fuel type. Through data visualization, fuel choices and deployment trends can be highlighted and causality can be further explored.

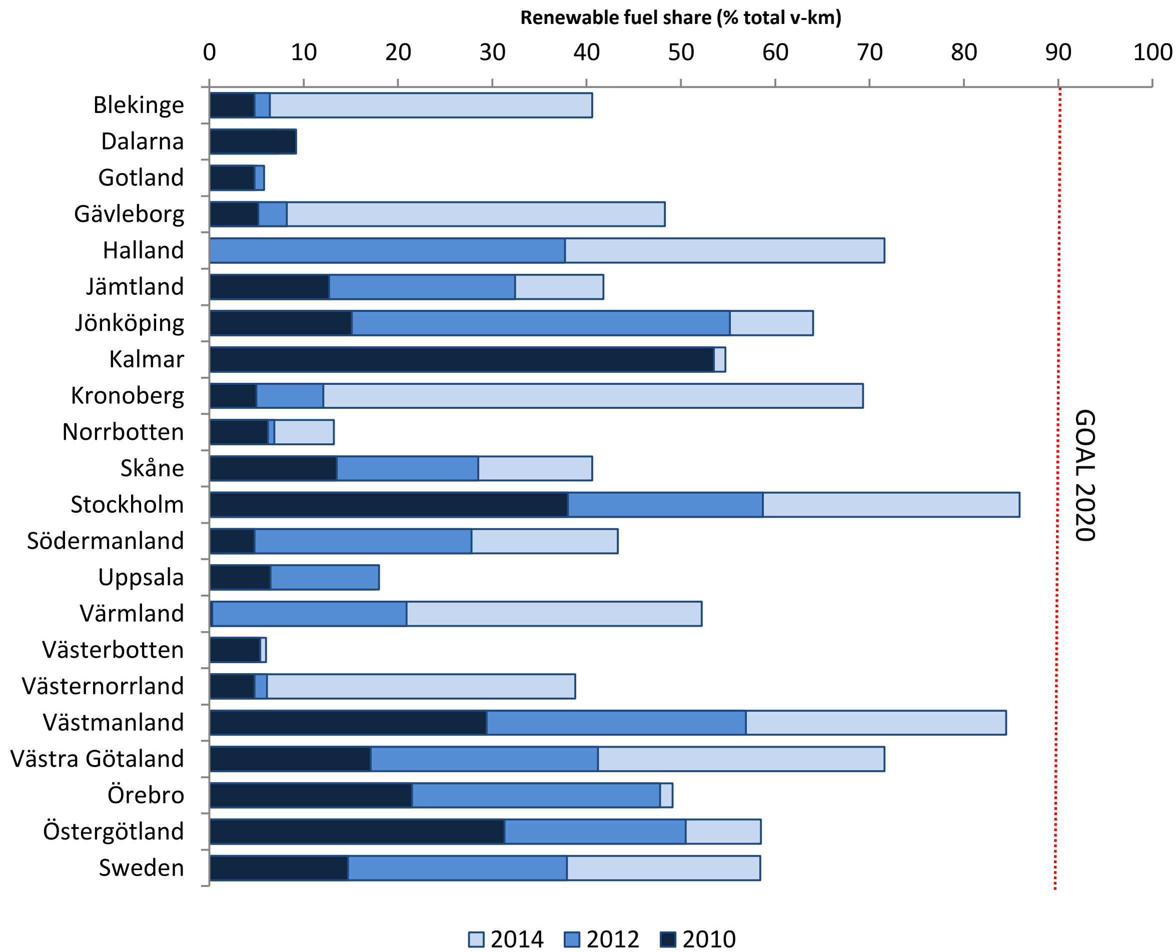


Figure 6: Renewable fuels share as percentage of total vehicle-kilometers (%) in Swedish public bus fleets at regional level, 2010, 2012 and 2014

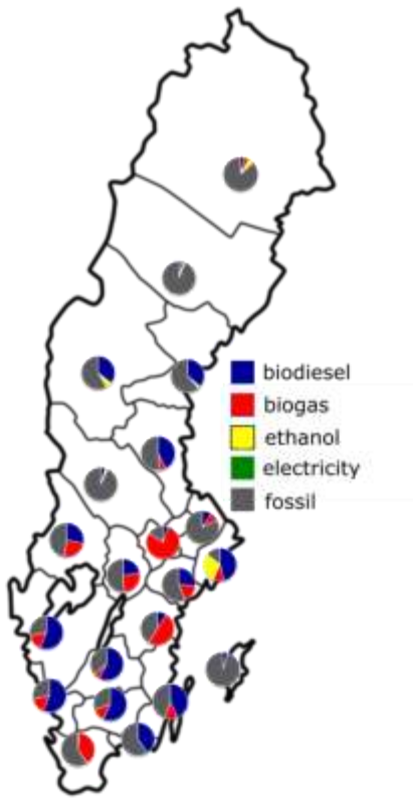
Source: Stockholm Läns Landsting, 2011; Svensk Kollektivtrafik, 2015

Figure 6 shows the changes in renewable fuel deployment comparing values in the years 2010, 2012 and 2014. The values for 2012 are included in the figure to highlight intermediate progress in renewable fuel deployment as well as to observe eventual impacts after the creation of the PTAs in 2012. Indeed, only four regions had surpassed 50% renewables in 2012, while in 2014 this number had increased to nine. Exceptions to the rapid increases observed in most regions are found in regions such as Dalarna, Gotland, Norbotten and Västerbotten. It should be noted that Stockholm wasn't using FRIDA for reporting bus fleet information before 2012. However, information missing from FRIDA can be found in the official reports of the county council (Stockholm Läns Landsting, 2011).

As previously mentioned, the first common sector standards for sustainable PT were published in 2010, but this was not the beginning of measures in the sector. The "Partnership for improving public transport" started in 2008, and various PTAs had been promoting the use of renewables in buses even before that. As a result, few regions had already achieved significant shares of renewable use in buses by 2010 such as Stockholm, Västmanland, Östergötland and Kalmar, among others. The region of

Östergötland has invested in locally produced biogas in the city of Eskilstuna since 2002 (Dädeby, 2015). Local biogas production has been also promoted in Västerås in Västmanland, and Stockholm was an early adopter of ethanol in buses (already established at 2007).

Further insights can be gathered by investigating the specific fuel mixes in each regional fleet and the implications of fuel choices on environmental performance. In **Error! Reference source not found.** and **Error! Reference source not found.**, a contrast in the north-to-south axis in terms of increase of renewables use can be noticed. The vast, low-populated northern regions and the island of Gotland have less than 25% renewable fuel deployment for buses. The main fuel used in these regions is biodiesel, and to a smaller extent ethanol. This contrast can be partly attributed to: (i) climatic conditions which may limit the use of renewables, for example due to fuel freezing or other engine vehicle requirements, (ii) low population densities that leads to longer trip lengths which cannot always be covered on renewables, and (iii) low revenues from PT in these regions which delays investments in new vehicle technologies.



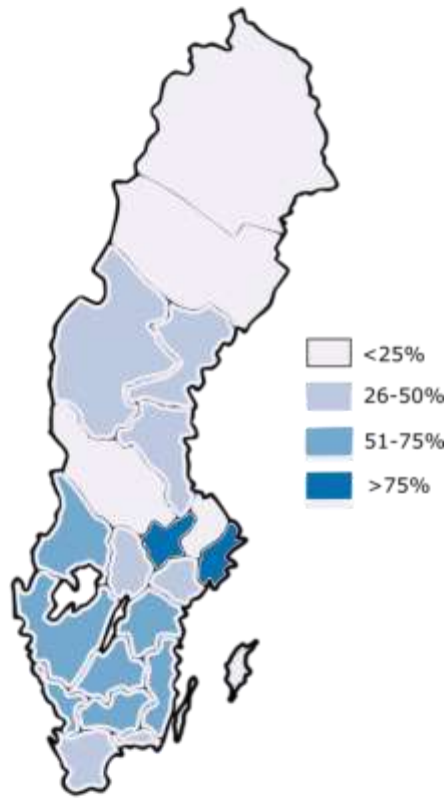


Figure 7 (left): Bus fleet fuel mix per region - 2014
Figure 8 (right): Map of regions grouped by renewable fuel share – 2014
Source: cconstructed by authors with data from Svensk Kollektivtrafik, 2015

Indeed, in the Northern regions of Norrbotten and Västerbotten, average trips are considerably longer than in densely populated regions such as Stockholm (14 and 20 km respectively, in contrast to 6 km – see Appendix Table A.1). Moreover, the average costs per boarding in Norrbotten and Västerbotten are almost 70% higher than in Stockholm (Trafikanalys, 2015d). This cost difference between larger urban centers and low-density areas is one of the main reasons delaying the transition to renewables and new technologies in the latter.

Figure 9 compares the change in levels of emissions per vehicle kilometer and energy efficiency per vehicle-km from 2007 to 2014. Certainly, the sharp increase of renewable shares in a few years has led to significant emissions reduction from buses in the majority of Swedish regions (see Appendix Table A.2). Yet, energy efficiency isn't following the same trend as emissions reductions. The bus fleets are getting "younger", old vehicles are being replaced to support the use of renewables, and new technologies come with improved engine efficiency. However, this does not come across in the efficiency indicators.

One reason why energy efficiency improvements are falling short in comparison to emissions reduction could be the lack of equally strict requirements for energy efficiency in standards in comparison to requirements for emissions reduction. Another reason could be the unmatched increase of transport volume and occupancy rates. Energy efficiency requirements defined in the sector standard range from 3.2 to 8.8 kWh/vehicle-km (Partnersamverkan för en förbättrad kollektivtrafik, 2014). At national level, energy efficiency ranges between 3.5 and 4 kWh/vehicle-km between 2007 and 2014. This means that energy efficiency achievements are within the lower limits of the procurement standard. Also regionally, energy efficiency doesn't surpass 5 kWh/vehicle-km in any Swedish region in 2014 (see Appendix Table A.3). Yet another reason could be that the energy density of the chosen renewable alternatives is lower than for the conventional fossil fuels they replace. This applies to biogas and to a lesser extent biodiesel and ethanol (see Table 1). In the next section, we investigate reasons behind regional variations in environmental performance further.

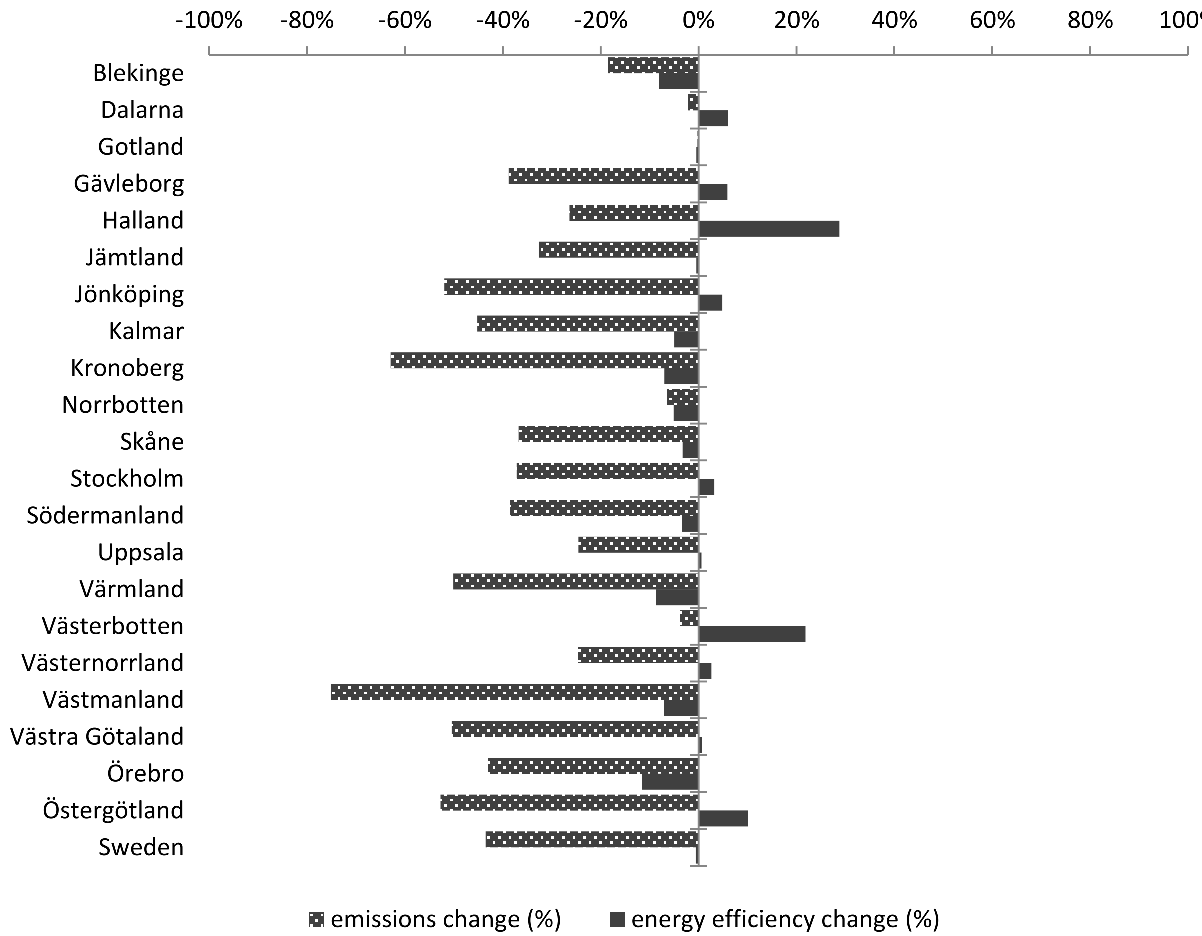


Figure 9: Change in CO2 emissions (% gr CO2/v-km) and energy efficiency (% kWh/v-km) in public bus fleets per region, 2007-2014 (secondary data from Svensk Kollektivtrafik, 2015b) (note that a positive energy efficiency change indicates a decrease in the energy use in kWh/vehicle-km)

4.2 Factors causing regional variations in environmental performance

In Figure 10, renewable fuel shares are plotted against population density and bus transport volume for each Swedish region. The figure shows that not only densely populated regions with large bus transport volume perform well in terms of renewable fuel deployment. Regions such as Västmanland, Halland and Kronoberg have small transport volume but have high shares of renewables in buses. Among the densely populated regions, Stockholm and Västra Götaland perform better than Skåne. This observation places political will and strategic planning in PT as very important factors affecting renewable fuel deployment.

Also, the overall environmental impact of the fuel choices made depends on both fuel density and transport volume. Figure 11 plots CO_2 emissions and energy efficiency per vehicle-km in a similar style as Figure 10. Not surprisingly, the five regions with the lowest renewable fuel share have the highest CO_2 emission level due to high fossil fuel use. The regions with high shares of biogas (e.g. Skåne, Västmanland, Örebro, Värmland, Kronoberg, Östergötland, Stockholm, Västa Götaland) show low levels of CO_2 emissions per vehicle-kilometer, as biogas has a low emissions factor. However, biogas has lower energy density than, e.g. biodiesel. Therefore, in regions where biogas is the dominating fuel, lower energy efficiency is observed, as more fuel is consumed per vehicle-kilometer offered. Data provided for the Västra Götaland region shows that gas buses consume 36% more fuel than diesel buses. More specifically, diesel engine buses consume 0.37 lt/vehicle-km, while gas engine buses consume 0.58 lt/vehicle-km (Västtrafik, 2015).

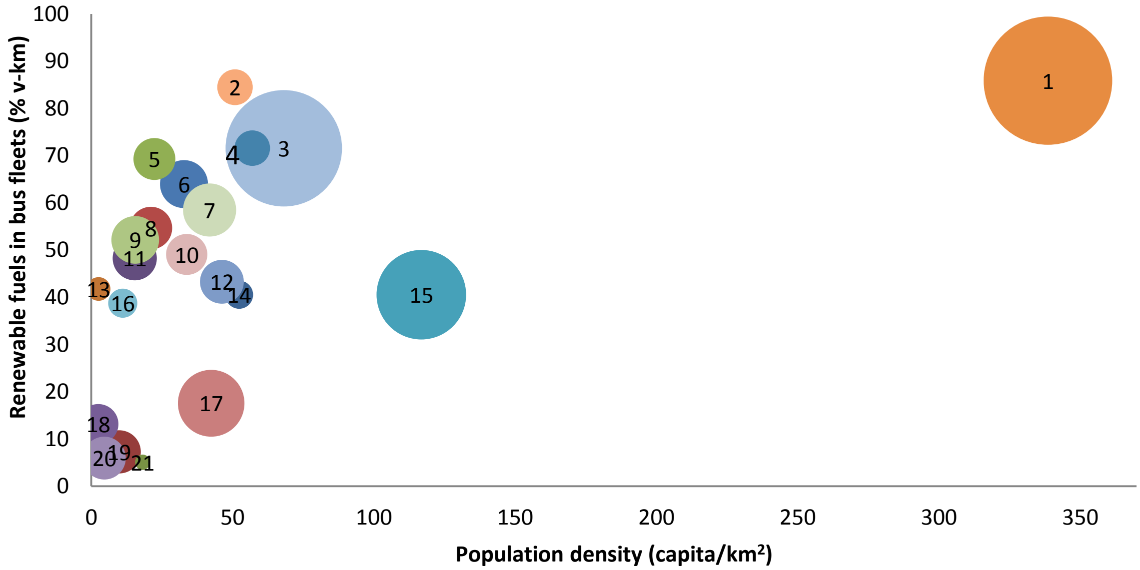


Figure 10: Renewable fuel share for public bus fleets in relation to population density and vehicle-kilometers -2014
Source: constructed by authors with data from Svensk Kollektivtrafik, 2015

Note: the area of each bubble represents the offered transport volume (in thousand vehicle-kilometers) and each bubble corresponds to a region, as numbered in the list of regions below:
1-Stockholm2-Västmanland 3-Västra Götaland 4-Halland 5-Kronoberg 6-Jönköping 7-Östergötland 8-Kalmar 9-Värmland 10-Örebro
11-Gävleborg 12-Södermanland 13-Jämtland 14- Blekinge 15- Skåne 16-Västernorrland 17-Uppsala 18-Norrbotten 19-Dalarna 20-Västerbotten 21-Gotland

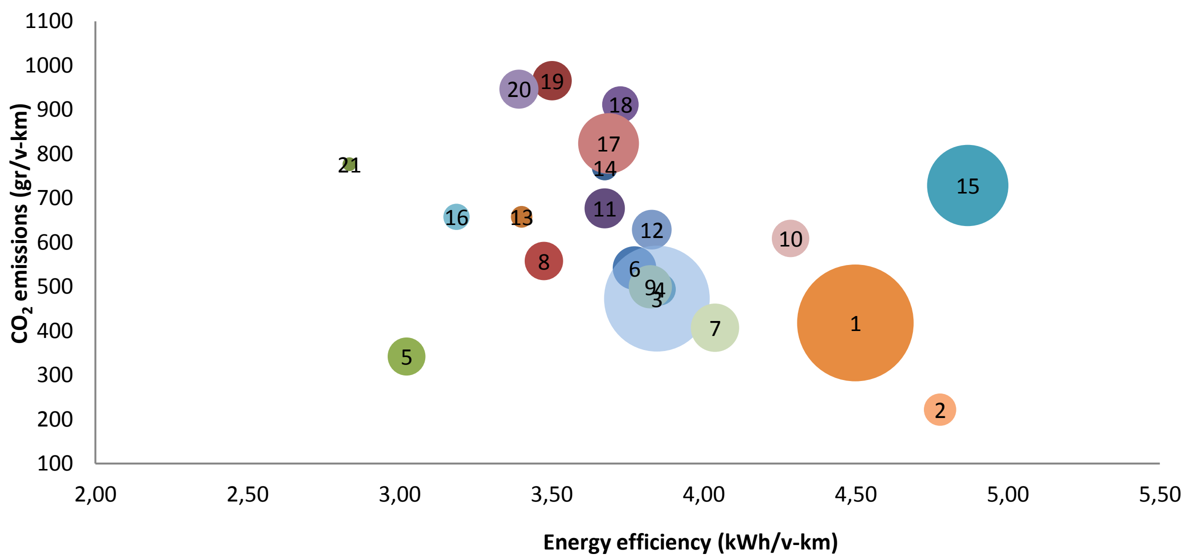


Figure 11: CO_2 emissions in 2014 for public bus fleets in relation to energy efficiency and transport volume - 2014
Source: constructed by authors with data from Svensk Kollektivtrafik, 2015
Note: the area of each bubble represents the offered transport volume (in thousand vehicle-kilometers) and each bubble corresponds to a region, as numbered in the list of regions below:
1-Stockholm2-Västmanland 3-Västra Götaland 4-Halland 5-Kronoberg 6-Jönköping 7-Östergötland 8-Kalmar 9-Värmland 10-Örebro

11-Gävleborg 12-Södermanland 13-Jämtland 14- Blekinge 15- Skåne 16-Västernorrland 17-Uppsala 18-Norrbotten 19-Dalarna 20-Västerbotten 21-Gotland

The issue of energy efficiency of gas-driven buses has lately gained attention, leading to in-depth comparisons between biogas and other fuels for buses, as well as exploration of more efficient alternative uses for biogas (Anderson, 2014; Skånetrafiken, 2014; Västra Götalandsregionen, 2013). Volvo Buses, for example, has explored the option of utilizing biogas for producing electricity to drive more efficient electric buses (Anderson, 2014). The possibility of this alternative biogas use is also explored by Stockholm's PTA, as confirmed in our interviews.

Densely populated regions with large transport volume have reduced emission levels significantly, but seem to have low energy efficiency in general. This can be attributed to real-life driving conditions. In densely populated urban environments, for example, buses stop more frequently and, therefore, consume more fuel. For Gävleborg, a medium-size region with 277 970 inhabitants, data for the 193 diesel buses in use in 2014 show that fuel consumption was 14% higher in city traffic (0.42 lt/vehicle-km) than in regional traffic (0.36 lt/km) (Region Gävleborg, 2015).

Also external temperatures may have an impact on fuel deployment and efficiency as previously mentioned. But low temperatures in the North cannot explain shortcomings in the efforts to deploy renewables. Municipalities have an important role in the dissemination of best practices. The municipalities of Skellefteå and Umeå in the region of Västerbotten invest in biogas and electricity respectively, and have achieved much higher renewable fuel deployment than the regional average for renewables in buses, which only reaches 6%. In Skellefteå, the share of renewables in the bus fleet is 18.5% (most biogas) or 3 times higher than the average for Västerbotten (Svensk Kollektivtrafik, 2015a).

Thus fuel choices have strong impact on environmental performance indicators, but aren't the only factors influencing performance. In line with previous studies (e.g. de Abreu e Silva et al., 2015 and Xu et al., 2015), technology-related factors (e.g. type of bus), driving conditions (e.g. city vs. regional traffic), trip lengths and climatic conditions influence environmental performance in Swedish bus fleets. Additionally, other external factors may affect what can actually be achieved such as population densities, and political will and ambition. In the next section, we bring insights from a stakeholder survey and interviews to identify what factors are being prioritized, and what challenges lay ahead as Sweden aims at fossil-free PT.

5. STRATEGIES FOR FOSSIL-FREE PUBLIC TRANSPORT

5.1 PRIORITIES AND BARRIERS TO PROMOTING RENEWABLE FUELS

In the previous sections, we have shown diversity in the achievements of Swedish regions when it comes to adoption of renewables and new bus technologies. In this section, we provide the results of a survey and interviews aimed at better understanding the main reasons affecting attractiveness of different renewable fuels.

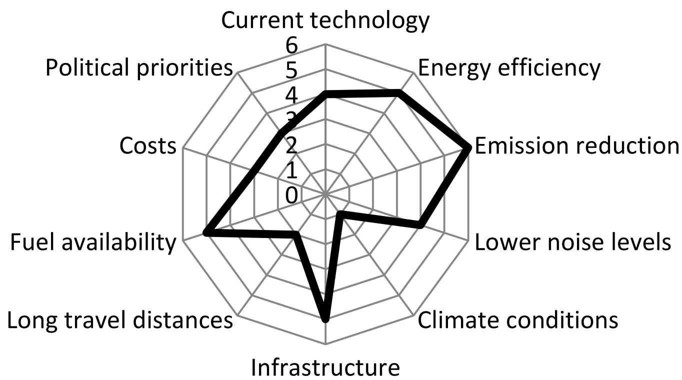


Figure 12: Survey results on factors that affect fuel choices for Swedish public buses (the numbers in the chart indicate the number of respondents for each survey answer)

Figure 12 shows what the planning experts at the PTAs perceive as important factors affecting fuel choices for buses. Environmental aspects such as emission reduction potential and energy efficiency are first priority when choosing new fuels by most of the respondents, followed by infrastructure needs and fuel availability. Lower noise was also a factor mentioned. Political priorities for the use of specific fuels are also a factor mentioned. For example, the choice of biogas has been politically driven in some regions of Sweden, and thus supported by significant allocation of resources and investments. Finally, climate conditions were placed as priority by one respondent. This is because in the colder Northern parts of Sweden, some fuels are not an option due to freezing. The survey results obtained share some similarities to the ones found in Turcksin et al. (2011), indicating that government actors tend to prioritize environmental factors such as emission reduction and air quality when choosing alternative fuels.

Despite the progress achieved, barriers exist in pursuing higher renewable fuel shares. These barriers stay in contrast to the drivers for fuel choices shown in Figure 12. Costs are what most of the respondents classify as the highest barrier to increasing renewable fuel deployment in public buses (see Figure 13). Connected to the overall cost issue, there is the requirement for new infrastructure, which implies large investments. Engine technologies and bus design appears also to be a barrier to a broader use of renewables, especially in sparsely populated areas with long travel distances, cold climate or road conditions that do not allow the use of low-floor bus models, which usually the bus models designed to use renewables.

Transport costs are probably the biggest challenge that Sweden has to face when it comes to PT. In the past 5 years, the ratio of revenues to cost per passenger-boarding has decreased. The costs per boarding have increased almost double as fast as the revenues per boarding, by 9.5% and 5.5% respectively (Trafikanalys, 2015a, 2014, 2013, 2012b, 2011). These developments require rising levels of subsidies from the PTAs to operators to complement ticket revenues.

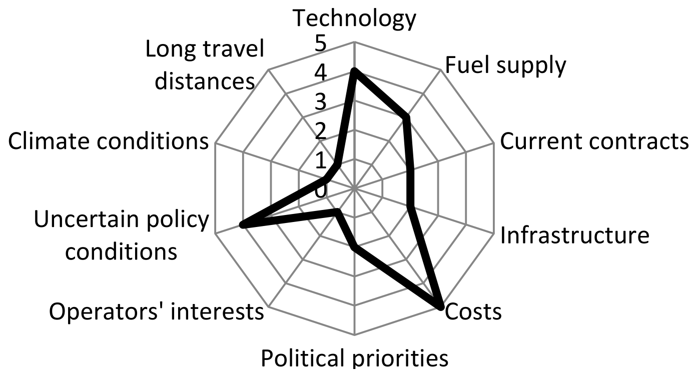


Figure 13: Survey results on perceived barriers to higher renewable fuel deployment for Swedish public buses (the numbers in the chart indicate the number of respondents for each survey answer)

But where does this cost increase come from? In a recent report prepared by the Swedish Association of Local Authorities and Regions (SKL), a price index is constructed to understand better the recent cost increases. The price index is distributed among the following factors: salary costs, fuel costs, vehicle acquisition costs and the CPI (Consumer Price Index), the latter being an indicator related to inflation (SKL, 2014b). The increasing bus transport volume together with the price index increases respond to almost 90% of the total cost increase in the years 2007-2012. Only around 10% of the cost increase is attributed to other factors, such as the stringency of environmental and safety requirements in the new transport service contracts (SKL, 2014b). Still there can be impact on renewable fuel strategies if investments are not promoted or competition among fuels change.

Another challenge for the sector is the infrastructure provision needed to implement new technologies, and guarantee alternative fuel supply and use. Fuel supply is an important factor affecting choices and investments. For example, the expansion in the use of biogas has been hampered by biogas availability, opening for penetration of natural gas. Also the expansion of electro-mobility will require major infrastructure deployment. Finally, to achieve sustainable urban mobility, further integration of transport and urban planning is desirable. While transport planning is a responsibility of the PTAs at regional level, municipalities usually own transport infrastructure, such as bus stations, and control urban planning. Issues of governance may, therefore, have to be resolved in order to attract investments, optimize the benefits and achieve the national overarching goals.

PTAs make a very low contribution to infrastructure costs, with Stockholm region being an exception. Infrastructure costs in Stockholm represent 20.6% of all PT costs (Trafikanalys, 2015c). This happens because the Stockholm PTA, SL, invests and owns the infrastructure, in contrast with other PTAs where infrastructure costs are less than 5% of the total PT costs. In the cases where PTAs do not control the infrastructure, they can only try and steer other stakeholders towards a given direction. Given the achievements so far, this governance model seems to have worked in terms of promoting a shift towards renewables. The question is whether it provides the institutional basis necessary to achieve the ultimate goals of a fossil-free transport, and to improve energy efficiency significantly.

Clarification of the policy frameworks is much needed. Uncertain policy conditions are placed high in our survey among identified barriers to deployment of renewables in buses. This uncertainty imposes risks that halt investments or lead to higher costs for deployment. Table 3 shows some of the suggestions and potential instruments that can be introduced according to the respondents to our survey and interviews. Other political priorities may also affect PT development, for example when private car transportation is indirectly encouraged through various measures to guarantee consumption, jobs or economic growth. Current contracts with transport operators tie PTAs to specific fuels but, with clearer policy guidelines in place, new contracts can push further as they come into the pipeline.

Table 3: Policy instruments to increase renewable fuel deployment in bus fleets (alternative policy instruments as per suggested by survey respondents)

Suggested policy instrument	Reasoning
Long-term tax exemptions on the use of biofuels	The frequent changes of taxation policies are causing uncertainty to transport operators and the PTAs over fuel choices.
Better follow-up processes on the goals for renewables and stricter procurements standards	With stricter procurement standards, the PTAs can steer bus technology and fuel choices towards more efficient and carbon-neutral alternatives. For example, the strict requirements set by the PTA of Västra Götaland could result in transport operators opting for hybrid buses (Björk, 2015).
Investment on new vehicles that will be owned by the municipalities/regional authorities regardless of which company operates the service	With the current structure of the PT sector (see Section 2) transport service operators own the buses.
Investment support for the introduction of renewables in longer distances, such as inter-urban and cross-regional routes	An example is the introduction of more filling stations along longer routes.
Stronger state support for testing of new vehicles and other demonstration projects that can increase the use of renewables	There are concerns on how state funds are utilized in promoting renewables. In many cases, a survey respondent says, state support of PT is utilized to cover net losses in income balances through the supporting funding mechanisms, instead of investments on new technologies.
Introduction of a technology-neutral environmental bus premium to encourage purchase of environmentally advanced vehicles	Although discussed in stakeholder networks, this measure was not a part of the proposed legislation for fulfilling the fossil-fuel independent vehicle fleet goal.

5.2 Renewable fuel preferences

To the question on the most attractive fuel alternative in the foreseeable future, the survey respondents placed electricity first (see Figure 14). Biodiesel and biogas follow closely, with an equal amount of respondents supporting these two options. An interesting thing to note is that ethanol is not at all considered as an attractive option, despite the infrastructure built in the whole country and the established use of ethanol blended with gasoline in private transport. According to Böhlin (2015), one of the reasons for this is the high maintenance costs for engines that run on ethanol blends. Other reasons may be related to the policies and interests pursued in reference to ethanol (Silveira and Johnson, 2016).

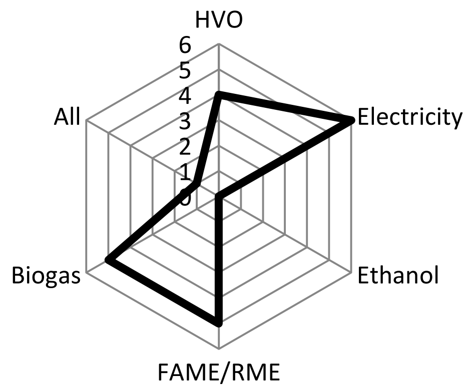


Figure 14: The most attractive fuel alternative in the future as per perceived by survey respondents (the numbers in the chart indicate the number of respondents for each survey answer)

The respondents had several arguments to justify their choice of electric buses as the most attractive future option, despite the fact that the technology is only at demo stage in Sweden. Electric buses combine increased energy efficiency with very low (or even zero) emissions. Another advantage of electric buses according to the survey is the lower noise levels compared to bus with internal combustion engines, which can lead to substantial improvements in urban environments, and connect to sustainable urban planning strategies in several cities of Sweden. For full-scale implementation of electric buses, issues of infrastructure ownership such as charging stations, logistics or stakeholder competition will be a question that municipalities and regional authorities will have to face (Ericsson, 2015). The stakeholders interviewed estimated that full scale implementation of electric bus technologies will take at least ten years.

Biodiesel has played a very important role in the transition to renewables in buses so far, especially in scarcely populated regions, where infrastructure for electricity or biogas may not be profitable. Biodiesel is quite flexible a fuel, which is used in ordinary diesel motors without modifications. The importance of these characteristics is also highlighted in the survey. One of the respondents identifies biodiesel "*as the only alternative until electric buses become a good alternative*". Another respondent from a small region with more than 55% share of renewables in buses bases the choice of biodiesel on the fact that it is "*Available. We are too small to dare try anything else*".

A share of 70% of the buses in Swedish PT have diesel engines (6 895 buses out of 9 898 in total for 2014) (Svensk Kollektivtrafik, 2015a). The role of biodiesel in the increasing shares or renewables is also highlighted by SK. SK warns that since a large portion of buses are operating with diesel engines rather than gas, and there has been a trend towards biodiesel, there are serious risks that the transition to fossil-free bus fleets will be delayed, should changes to the fuel taxation system happen (Svensk Kollektivtrafik, 2015b). HVO could be a good alternative in the long-term to replace both fossil diesel and biodiesel, but its availability in larger volumes still needs to be secured through infrastructure and supply chains.

Other survey respondents justify the use of biogas based on infrastructure investments made for local production or political guidelines for procurement processes. Three of the respondents from regions with high biogas shares mentioned that the most successful measure for promoting the renewable transition was investment on locally produced biogas. However, the amount produced is not always sufficient to cover the needs, and natural gas is used as a complement.

5.3 Key Components of Strategies for fossil-free bus fleets in Sweden

There are common components in regions where renewables in buses have shown impressive growth rates in the past few years. In our analysis, we identify these common components and show best practice examples that can assist in the design of successful strategies for fossil-free bus fleets both nationally and internationally.

Key decision making for development of PT occurs at political level and implementation strategies are a responsibility of the PTAs. *Political will* to pursue sustainable choices in PT has been a strong driving force in Sweden. From the organization of the “Partnership for improved public transport” to the investments by regional authorities in biogas infrastructure, many initiatives show that renewable fuel deployment in buses has been pursued politically at various levels, and has delivered results. Therefore, political uncertainties, such as the one regarding biofuel taxation or infrastructure ownership, can be a serious threat now that the low hanging fruits have already been picked, and efforts need to be revamped.

The definition and follow up of short and mid-term *environmental strategies for PT* is another important instrument for pursuing ambitious goals. In our survey, 78% of the respondents indicate that there is a specific environmental strategy for PT in their region, which is updated at least every 4 to 5 years, while 18% indicate that their strategy is updated every year. These environmental strategies are very important for the development of PT. A good example of a structured strategy for sustainable fuel choices is the one in Västra Götaland, with clear follow-up and documentation of the goals, and monitoring of progress, as well as evaluation of fuel alternatives and cost assessment of proposed actions (Västra Götalandsregionen, 2013). Nevertheless, even regions that have not developed separate documentation specifically aimed at monitoring environmental performance usually cover some of these aspects within their respective transport provision programs. In our review of the existing documentation, we were able to trace these documents for all PTAs.

Another very positive component in the Swedish model is the *flexibility* that PTAs have in designing requirements for transport service procurement. Four of the survey respondents indicated the environmental requirements in procurement as the most successful action taken for promoting renewables. Most of the respondents (59%) also indicated that the common sector standards for procurement are followed by the PTAs of their region. In the most populous regions of Sweden, e.g. Stockholm and Västra Götaland, the PTAs have set even higher requirements than the common sector standards, which shows that these regions have explored the advantage of scale that they have. Other regions have explored internal connections, for example, linking fuel substitution with investments in waste management and local fuel production and job generation. Thus flexibility in the institutional and legal framework has allowed for different models when dealing with local advantages or barriers in the implementation of the overarching goals.

Finally, it is also particularly important for PTAs to communicate and collaborate with all stakeholders involved in PT provision, as well with other PTAs. *Knowledge transfer* is pivotal for replicating successful strategies, while flexibility allows for regional adaptation. Close cooperation between cities facing similar challenges may be useful too. An example provided by an interviewee and worth mentioning is the close cooperation between the three most populous regions of Sweden (Stockholm, Västra Götaland and Skåne) regarding environmental issues in PT (Böhlin, 2015). At the same time that PT can develop demos and/or serve as an early adopter of new technologies which can later be up-scaled, information sharing may help push investments and/or safeguard from shortcomings. A closer cooperation aimed at knowledge transfer between regions more experienced in using renewables for buses and regions that are lagging behind can be helpful for disseminating good practices.

6. CONCLUSIONS

In this paper, we assessed the status of regional bus fleets regarding the target towards fossil-free PT, and explored the factors influencing performance variations as well as fuel choices. At national level, the progress in the adoption of renewables has been fast and noteworthy. In 2014, almost 60% of the Swedish bus fleets were running on renewables compared to only 8% in 2007. However, by mapping environmental indicators at regional level, we could observe significant regional variations. Some of the variations may be traced to population density, technology-related factors, driving conditions (city vs. regional traffic), length of trips or climatic conditions (fuel freezing in colder climates).

Yet, none of these factors alone can explain the shortcomings of certain regions. For example, this study shows that there is no strong correlation of population density or bus transport volume to the share of renewables in the fleet. This places political will and strategic planning in PT as very important factors affecting renewable fuel deployment. In this context, higher ambition at local (municipal) level has proved to be an important success factor. The flexibility allowed to PTAs has been instrumental, and led to multiple choices and alternatives for policy implementation among the various regions of Sweden based on their particular conditions and preferences.

An important issue of concern is that achievements in emissions reduction are not being equally followed by improvements in energy efficiency measured in unit of energy per passenger-km. This could be the result of lax requirements for energy efficiency in procurement standards in comparison to emissions requirements. Unequal increase of transport volume in relation to occupancy rates and passenger-kilometers has also been observed, and this has a direct effect on efficiency. Energy efficiency is linked to costs because less fuel consumption and higher passenger rates will result in lower costs for PT per trip. Given that costs for PT are rising fast and requiring increasing subsidies, there is urgent need to address these issues if the goal to have a fossil fuel bus transport is to be achieved at reasonable costs for Swedish tax payers.

The survey we conducted among environmental strategy experts at the Public Transport Authorities (PTAs) shows that environmental factors are prioritized when choosing fuels. Biodiesel is the leading fuel in Swedish buses because of its flexibility and compatibility with existing diesel technology buses, while biogas has also been promoted in regions where local production takes place. Electricity raises as a promising fuel alternative in the opinion of the survey respondents, provided that it comes from renewable sources. Electric buses combine increased energy efficiency with low emissions and low noise levels, therefore offering significant advantages for deployment in urban environments.

Barriers to increasing renewable fuel penetration are mainly economic and political. Fuel costs account for a significant share of bus transport costs and, therefore, the uncertainties regarding fuel taxation and infrastructure ownership can be a potential threat to the adoption of renewables in the future. A closer connection of PT planning at regional level with urban planning at municipal level is desirable so that issues of governance can be properly addressed opening up for new business models. It is important that policy instruments that promote sustainability of PT are technology and fuel-neutral, so that each region chooses the strategic path that can be best adapted to overcome specific barriers while building upon local comparative advantages.

Sweden has shown significant achievements from its efforts to introduce renewables in PT. Important components of the Swedish model includes strong political will, clear programs, goals and strategies for sustainable public bus transport which are constantly monitored, and flexibility for regions to explore multiple fuels and technological options. The best practices developed offer inspiration to other regions and countries. Knowledge transfer can speed up the adoption of new fuels and bus technologies in Europe and elsewhere. Meanwhile, challenges related to policy frameworks at EU versus national levels, energy efficiency and PT cost increases remain to be addressed if the goal of a fossil-free fleet is to be achieved in 2030.

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APPENDIX

A.1 Bus fleet characteristics for the 21 Swedish regions

Region	Bus fleet size (no. of buses, 2014)	Average bus age (in years, 2014)	Average trip length (in km, 2014)	Vehicle kilometers with bus (in km, 2014)	Costs – bus transport (in SEK/boarding, 2014)
Blekinge	116	4.78	11	7 488 020	40.44
Dalarna	321	7.10	38	17 844 488	57.86
Gotland	37	6.70	14	2 213 275	40.67
Gävleborg	206	4.00	11	18 580 982	67.91
Halland	273	5.27	17	12 021 088	45.54
Jämtland	184	5.94	14	5 322 128	50.26
Jönköping	283	4.31	9	21 869 822	41.07
Kalmar	254	6.07	20	17 167 020	78.52
Kronoberg	301	2.38	19	16 547 581	52.12
Norrbotten	286	7.66	14	15 300 361	49.80
Skåne	978	5.42	7	76 300 208	42.22
Stockholm	2 209	5.79	6	156 805 636	33.61
Södermanland	232	5.94	12	18 207 437	26.81
Uppsala	458	4.72	10	42 334 396	46.38
Värmland	400	7.30	18	21 500 736	16.78
Västerbotten	372	6.16	20	17 494 275	41.02
Västernorrland	320	5.97	11	7 966 988	51.00
Västmanland	168	6.45	12	12 092 042	43.33
Västra Götaland	1 860	4.44	9	128 745 054	39.48
Örebro	263	6.45	8	16 046 483	40.77
Östergötland	385	4.61	12	26 856 614	22.57
National	**9 898**	**5.59**	**9**	**658 704 634**	**23.42**

Source: **Svensk Kollektivtrafik. 2015a; Trafikanalys. 2015a**

A.2 CO2 emissions (gr CO_2/v-km) buses per region 2007-2014

Region	2007	2008	2009	2010	2011	2012	2013	2014	2007-2014 (%)
Blekinge	944	1 024	1 048	1 041	1 032	1 028	1 024	769	-19%
Dalarna	988	950	962	960	959	918	950	966	-2%
Gotland	N/A[1]	N/A	N/A	779	775	837	774	777	0%
Gävleborg	1 106	1 098	1 099	1 072	1 026	1 015	879	677	-39%
Halland	N/A	N/A	N/A	N/A	N/A	671	602	494	-26%
Jämtland	977	905	897	890	779	725	699	658	-33%
Jönköping	1 128	1 123	1 072	1 013	788	660	520	542	-52%
Kalmar	1 019	941	652	587	585	570	563	558	-45%
Kronoberg	923	985	942	845	846	768	563	342	-63%
Norrbotten	975	978	977	966	946	983	957	912	-6%
Skåne	1 153	1 057	1 030	1 032	923	914	851	729	-37%

Stockholm	N/A	N/A	N/A	N/A	N/A	665	468	418	-37%
Södermanland	1 022	1 041	1 045	1 033	951	739	694	629	-38%
Uppsala	1 092	1 105	1 067	965	1 003	882	868	824	-25%
Värmland	1 002	1 016	1 049	1 057	1 024	851	590	500	-50%
Västerbotten	985	1 042	N/A	1 131	1 164	1 117	991	947	-4%
Västernorrland	874	898	894	917	923	934	939	658	-25%
Västmanland	893	814	817	805	654	515	309	222	-75%
Västra Götaland	955	954	953	892	782	714	593	473	-50%
Örebro	1 069	1 071	1 058	845	710	626	608	609	-43%
Östergötland	861	862	838	781	575	485	431	407	-53%
National average	**998**	**986**	**965**	**932**	**847**	**755**	**643**	**564**	**-43%**

Source: secondary data from Svensk Kollektivtrafik, 2015b

[1] Where no data was available for 2007, the first year where values have been reported were used for calculating the difference to 2014

A.3 Energy efficiency (kWh/v-km) buses per region 2007-2014

Region	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2007-2014 (%)**
Blekinge	3.4	3.7	3.8	3.8	3.8	3.8	3.7	3.7	8%
Dalarna	3.7	3.6	3.7	3.7	3.7	3.5	3.7	3.5	-6%
Gotland	N/A[1]	N/A	N/A	2.8	2.9	2.8	2.8	2.8	0%
Gävleborg	3.9	4.0	4.0	3.9	3.9	3.8	3.8	3.7	-6%
Halland	N/A	N/A	N/A	N/A	N/A	5.4	3.6	3.9	-29%
Jämtland	3.4	3.3	3.3	3.4	3.0	3.2	3.3	3.4	0%
Jönköping	4.0	4.1	4.1	4.0	3.9	4.0	N/A	3.8	-5%
Kalmar	3.3	3.4	3.8	3.5	3.5	3.4	3.5	3.5	5%
Kronoberg	3.2	3.5	3.3	3.1	3.2	3.0	3.0	3.4	7%
Norrbotten	3.5	3.5	3.6	3.6	3.5	3.7	3.7	3.7	5%
Skåne	4.7	4.6	4.6	4.6	4.5	4.7	4.9	4.9	3%
Stockholm	N/A	N/A	N/A	N/A	N/A	4.6	4.5	4.5	-3%
Södermanland	3.7	3.8	3.8	3.7	3.7	4.1	4.0	3.8	3%
Uppsala	3.7	3.8	3.9	3.5	3.5	4.0	3.9	3.7	-1%
Värmland	3.5	3.6	3.7	3.7	3.6	3.5	3.3	3.8	9%
Västerbotten	N/A	4.3	2.4	2.9	3.1	3.7	3.5	3.4	-9%
Västernorrland	3.3	3.3	3.3	3.4	3.4	3.5	3.5	3.2	-3%
Västmanland	4.5	4.6	4.5	4.6	4.7	4.5	4.8	4.8	7%
Västra Götaland	3.9	3.8	3.8	3.8	3.9	3.8	3.8	3.8	-1%
Örebro	3.8	3.9	3.8	3.9	4.5	4.5	4.4	4.3	12%
Östergötland	4.5	4.5	4.5	4.7	4.6	4.5	4.2	4.0	-10%
National average	**3.8**	**3.8**	**3.8**	**3.7**	**3.7**	**3.9**	**3.8**	**3.8**	**1%**

Source: secondary data from Svensk Kollektivtrafik, 2015b

[1] Where no data was available for 2007, the first year where values have been reported were used for calculating the difference to 2014

A.4 Occupancy rates of buses per region 2007-2013

Region	2007	2008	2009	2010	2011	2012	2013
Blekinge	13.3	11.4	6.7	6.8	6.6	5.8	6.1
Dalarna	22.0	20.6	20.5	20.6	20.7	20.8	20.7
Gotland	10.4	10.2	11.2	11.6	12.4	10.4	5.1
Gävleborg	10.5	10.6	10.0	10.4	8.0	8.1	9.1
Halland	9.8	9.8	9.4	12.0	12.8	11.6	11.4
Jämtland	7.3	8.2	8.0	8.9	8.0	6.9	7.4
Jönköping	9.6	9.9	9.0	8.6	7.8	8.6	8.2
Kalmar	13.0	12.7	12.0	12.1	12.5	9.9	8.6
Kronoberg	10.6	10.3	9.3	9.5	11.0	10.6	9.7
Norrbotten	9.4	9.4	8.7	8.9	8.6	7.9	7.5
Skåne	12.6	11.5	11.4	10.1	10.1	10.6	11.2
Stockholm	15.3	14.7	15.5	15.7	15.3	15.1	14.5
Södermanland	14.3	14.2	14.2	14.1	14.0	13.4	11.9
Uppsala	10.9	10.2	8.4	9.4	8.2	8.5	7.7
Värmland	12.7	13.9	16.5	15.4	14.7	14.1	10.5
Västerbotten	10.3	9.5	9.1	9.9	9.4	10.4	10.5
Västernorrland	10.4	10.0	11.4	10.5	8.7	8.3	7.6
Västmanland	13.7	13.8	13.2	14.5	14.3	14.0	12.8
Västra Götaland	9.6	9.6	9.3	8.8	10.0	10.0	10.9
Örebro	8.2	9.1	8.6	7.7	7.6	7.8	7.4
Östergötland	10.8	10.8	9.8	9.1	9.4	9.2	9.7

Source: Trafikanalys, 2015