REPORT

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FUEL OPTIONS FOR PUBLIC BUS FLEETS IN SWEDEN

Report from an f3 project

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report brings results from a project developed by the Energy and Climate Studies (ECS) group at the Department of Energy Technology, KTH. ECS is involved in research, education and outreach in four thematic areas: bioenergy systems, energy systems efficiency, energy and development, and urban sustainability. Energy and climate policy relevance is aimed for in all four thematic areas (www.ecs.kth.se). The project received funds from the Swedish Knowledge Centre for Renewable Transportation Fuels (f3).

Sweden has the ambition to reduce emissions from transport drastically in the coming decades. As part of the efforts being made in this direction, public transport needs to become more attractive while also adopting new fuels and technologies. This study focuses on the adoption of renewable fuels in public buses across Sweden, and the efforts being made by municipalities to contribute to the national goal of a fossil free society. It is a unique analysis of the efforts being made and the results achieved in various regions. The study highlights both achievements and shortcomings across the country, and pulls together valuable lessons for continued efforts towards a low-carbon society.

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ACKNOWLEDGEMENTS

This report is the result of a collaborative project within the Swedish Knowledge Centre for Renewable Transportation Fuels (f3). f3 is a networking organization, which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities,
- Carries through system oriented research related to the entire renewable fuels value chain,
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners, the Swedish Energy Agency and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industrieknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

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HIGHLIGHTS

- Adoption of renewable fuels in bus fleets has increased rapidly in line with the goal of having 90% renewable fuels in public transport by 2020 – the percentage achieved until 2014 is close to 60% in Sweden as a whole. Still 71% of the busses are diesel busses and can run on both fossil and renewable fuel.
- Emissions per vehicle kilometer for public buses have decreased by 43% on average between 2007 and 2014.
- There is no strong correlation between population densities or bus transport volume and the share of renewable fuels achieved in the bus fleet of Swedish municipalities – political will, strategic planning and policies to promote public transport are key factors affecting renewable fuel deployment.
- Cost is the highest barrier to increasing renewable fuel deployment in public bus fleets. Characteristics of engines such as range and fuel type can also pose a barrier in sparsely populated areas with long travel distances and/or very cold climate.
- Efforts need to be intensified if the goals for increased energy efficiency and public transport volume are to be achieved – energy efficiency has practically remained stable at national level since 2007. Less fuel consumption and higher passenger rates can help reduce costs of public transport per trip and improve energy efficiency.
- Electricity is likely to receive increasing attention in the future in line with the EU road map but also because of the energy efficiency potential, reduction of emissions and noise as well as other social benefits.

EXECUTIVE SUMMARY

Sweden has set the ambitious goal of acquiring a fossil-free vehicle fleet in 2030. This is a key step towards the country's CO_2-emissions neutral target to be achieved by 2050. The public transport sector, and bus service in particular, plays an important role in achieving this goal. Bus transport services are offered in all municipalities in Sweden and accounted for 52% of passenger boarding in public transport in 2013. This study focuses on the adoption of renewable fuels in public buses across Sweden. The fuel alternatives considered are biodiesel, biogas, ethanol and electricity.

The Swedish public transport sector has defined two major targets: (i) to run 90% of the total vehicle kilometers of the fleet on non-fossil fuels by 2020, and (ii) to increase the share of public transport in relation to the total personal transport in the country, and double the volume of travel via public transport by 2020. Our analysis highlights the challenges and solutions encountered, particularly when it comes to the adoption of renewable fuels in the regional bus fleets. As a result of the efforts made in the last few years, renewables respond for 60% of the fuels used in bus transport in Sweden compared to approximately 10% in 2009.

There is no strong correlation between population density or bus transport volume and the share of renewable fuels in the bus fleet, as shown in our mapping of renewable fuel deployment at regional level. This indicates political will, strategic planning and policies to promote public transport as very important factors affecting renewable fuel deployment. Political will to promote decarbonization of public transport has speeded up the shift towards renewables in bus fleets, while fuel tax exemptions have made deployment feasible. Procurement requirements for public transport services are adjusted regionally, and the regional Public Transport Authorities (PTAs) have freedom to cooperate with transport operators in designing strategies.

Biodiesel has been the preferred fuel while increasing deployment of renewable fuels in buses, especially in scarcely populated regions. In addition, the compatibility with traditional diesel engines has favored this option among service providers. The use of biogas is increasing in line with incentives at local and national level. The deployment of electricity in buses is only found in city traffic, while the major choice for regional routes is usually biodiesel. A survey among experts in public transport indicated that electricity is likely to receive increasing attention and become more attractive. Environmental aspects such as emission reduction potential and energy efficiency are a priority when choosing fuels, together with infrastructure needs and fuel availability. The respondents to our survey indicated cost as the highest barrier to increasing renewable fuel deployment in public bus fleets. Engine technologies are also a barrier, mainly in sparsely populated areas with long travel distances and/or colder climates.

While the adoption of renewable fuels has been rapid and impressive, efforts need to be intensified if reduced energy intensity and increased public transport volume are to be met. Emissions per vehicle kilometer for public buses have decreased 43% on average between 2007 and 2014. However, energy efficiency has remained constant since 2007. Lower fuel consumption and higher passenger rates are necessary to reduce trip costs with public transport and guarantee its attractiveness to the public. Yet, energy cost is only one part of the total cost structure for public transport. In the near future, other factors are likely to become more challenging such as the provision of related infrastructure and salary costs in the sector. Enhancing the role of public transport is subject to solutions for these problems. However, these issues have not been part of deeper analysis in the scope of this study.

Various knowledge transfer initiatives already in place show that decentralizing implementation efforts and sharing experiences serves well to promote innovative solutions and avoid mistakes. Devising a successful strategy for renewable fuels and low emissions in public bus fleets requires long-term engagement of decision-makers and broad collaboration with stakeholders. Every region has a different starting point but, with a multitude of concrete actions at local level, Sweden is showing that the transition to a fossil-free bus transport is indeed possible. These experiences provide lessons that should be shared internationally, and shall contribute to the transformation of transport systems towards sustainability.

SAMMANFATTNING

Sverige har satt det ambitiösa målet att införa en fossilfri fordonsflotta år 2030, vilket är ett viktigt steg mot målet om ett koldioxidneutralt samhälle som ska uppnås år 2050. Kollektivtrafiken, och särskilt busstrafiken, spelar en viktig roll för att uppnå detta mål. Busstrafik erbjuds i alla kommuner i Sverige och motsvarar 52 % av det totala antalet påstigningar i kollektivtrafiken under 2013. Denna studie fokuserar på användandet av förnybara drivmedel i bussar runt om i Sverige. De bränslealternativ som omfattas är biodiesel, biogas, etanol och el.

Svensk Kollektivtrafik har satt två mål: (i) att köra 90 % av det totala antalet fordonskilometer på icke-fossila bränslen år 2020 och (ii) att öka andelen kollektivtrafik för de totala persontransporterna i landet och dubbla volymen resor med kollektivtrafik till år 2020. Vår analys belyser de utmaningar och lösningar som uppkommer i den snabba förändring som regionala bussflottor genomgår för att införa förnybara bränslen och minska utsläppen. Tack vare insatserna under de senaste åren, representerar förnybara bränslen 60 % av de bränslen som används i busstrafiken i Sverige, jämfört med cirka 10 % år 2009.

Det finns inget starkt samband mellan befolkningstäthet eller busstransportvolym och andelen förnybara bränslen i flottan, vilket kartläggningen, som genomförts på regional nivå, visar. Detta pekar ut politisk vilja och strategisk planering inom kollektivtrafiken som mycket viktiga faktorer för att påverka användningen av förnybara bränslen. Politisk vilja att främja fossilfrihet har snabbat upp takten vad gäller skiftet till förnybara bränslen i kollektivtrafiken, medan skattebefrielser på bränsleområdet har underlättat införandet. Upphandlingskraven för kollektivtrafik justeras regionalt, och därmed har de regionala trafikhuvudmännen flexibilitet att samarbeta med trafikoperatörer för att utforma strategier.

Biodiesel har varit viktigt för att öka användningen av förnybara bränslen, särskilt i glest befolkade områden. Dessutom har kompatibilitet med traditionella dieselmotorer gynnat detta alternativ bland trafikoperatörer. Användningen av biogas ökar i linje med incitament på lokal och nationell nivå. Elbussar finns bara i stadstrafik, medan det huvudsakliga valet för regionala linjer oftast är biodiesel. En undersökning bland experter inom kollektivtrafiken indikerade att el sannolikt kommer att få allt större uppmärksamhet och bli mer attraktivt. Miljöaspekter, såsom potential att minska utsläppen och energieffektivitet, prioriteras vid val av bränslen, likaså infrastrukturbehov och bränsletillgång. De tillfrågade i vår undersökning pekade på kostnad som det högsta hindret för att öka användningen av förnybara bränslen i bussflottor. Motortekniken är också ett hinder, särskilt i glest befolkade områden med långa avstånd och/eller kallare klimat.

Medan det varit en snabb och betydande ökning vad gäller användandet av förnybara bränslen måste insatserna intensifieras för att målet för ökad energieffektivisering och transportvolym ska uppfyllas. Utsläppen per fordonskilometer för bussar har minskat 43 % i genomsnitt mellan 2007 och 2014, men energieffektivitet har varit nästan densamma sedan 2007. Lägre bränsleförbrukning och högre beläggning är nödvändigt för att minska kostnaderna för kollektivtrafikresor och garantera attraktivitet för allmänheten. Ändå är energikostnaden endast en del av den totala kostnadsstrukturen för kollektivtrafiken. Snart kommer sannolikt andra faktorer att få större betydelse, såsom utbyggnad av angränsande infrastruktur och lönekostnaderna inom sektorn. Att stärka kollektivtrafikens roll skulle kunna bli en del av lösningen på dessa problem. Emellertid har dessa frågor inte djupare analyserats inom ramen för denna studie.

Olika initiativ för kunskapsöverföring som redan är på plats visar att decentralisering av genomförande och erfarenhetsutbyte bidrar till att främja innovativa lösningar och undvika misstag. Att utforma en framgångsrik strategi när det gäller förnybara bränslen i offentliga bussflottor kräver långsiktigt engagemang hos beslutsfattare och brett samarbete med berörda parter. Varje region har en unik utgångspunkt, men med en mängd konkreta åtgärder på lokal nivå visar Sverige att övergången till en fossilfri busstrafik faktiskt är möjlig. Dessa erfarenheter ger lärdomar som bör delas internationellt och bidra till förändringen mot hållbara transportsystem.

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LIST OF ACRONYMS

BR	Svenska Bussbranschens Riksförbund (Swedish Bus and Coach Federation)
FAME	Fatty acid methyl ester
FQD	Fuel Quality Directive
GWP	Global Warming Potential
HVO	Hydrogenated Vegetable Oil
MDE	Methane Diesel Engine
PTA	Public Transport Authority (kollektivtrafikmyndighet)
RED	Renewable Energy Directive
RME	Rapeseed Methyl Ester (Rapsmetylester)
RVU	National transport survey (resvaneundersökning)
SK	Svensk Kollektivtrafik (Swedish Public Transport Association)
SKL	Sveriges Kommuner och Landsting (Swedish Association of Local Authorities and Regions)
SL	Storstockholms Lokaltrafik

USEFUL DEFINITIONS

energy efficiency	energy consumption per transport volume (measured in kWh per pkm (passenger km) or vkm (vehicle km)
fuel consumption	distance travelled per unit of fuel volume used (measured in kilometers/liter)
fuel efficiency	relationship between the distance travelled and the amount of consumed by the vehicle (measured in liters/kilometer)
occupancy rate	the ratio between transport performance (passenger-kilometers) and transport volume (vehicle kilometer). Expressed as a percentage, which indicates the ratio of seats occupied.
passenger kilometers (pkm)	distance (in kilometers) travelled by passengers of vehicles; determined by multiplying the number of passenger trips (otherwise known as passenger boardings) by the average trip length
plug-in hybrid bus	bus technology that utilizes the combination of electric batteries with an internal combustion engine
Public Transport Authorities (PTAs)	the regional organizations set by Swedish counties for developing public transport services
transport service operators	private companies offering contracted transport services assigned from PTAs after procurement
transport volume	the total amount of trips travelled by passengers, usually on annual basis (measured in passenger kilometers)
vehicle kilometers (vkm)	a measure of traffic flow, determined by multiplying the number of vehicles on a given road or traffic network by the average length of their trips

1. AIMING AT SUSTAINABLE PUBLIC BUS FLEETS

Sweden has the ambitious goal of acquiring a fossil-free vehicle fleet in 2030. This is a key step towards the country's CO_2-emissions neutral target to be achieved by 2050 (Regeringskansliet, 2013). The public transport sector plays an important role in achieving the 2030 fossil-free vehicle fleet goal (SKL, 2014b). The Swedish Public Transport Association (Svensk Kollektivtrafik - SK thereof) has set the target to run 90% of the total vehicle kilometers of the fleet on non-fossil fuels by 2020 (SKL, 2014b). Bus transport services are offered in all municipalities in Sweden and accounted for 52% of passenger boarding in public transport in 2013. This study focuses on the adoption of renewable fuels in public buses across Sweden. The fuel alternatives considered are biodiesel, biogas, ethanol and electricity.

The public transport sector is subject to a combination of EU and Swedish regulations. According to the Renewable Energy Directive-RED[1] (2009), at least 10% of the energy for transport should originate from renewable sources by 2020. In addition to targets and policy instruments, RED provides the framework for sustainability criteria, which determines which fuels will be eligible and counted towards the 10% target and, therefore, can receive tax exemptions. The Fuel Quality Directive-FQD of 2003 sets the limits on renewable fuel blending in diesel and gasoline, and also sets targets to reduce emissions on the fuel supply side. In 2013, the share of renewable fuels in the whole Swedish transport sector was 9.7%, indicating that Sweden will be able to reach the EU 2020 goal of 10% share of renewable fuels in transport (Swedish Energy Agency, 2014b). However, this share also shows that there is a long way to go to reach the ambitious target of a fossil fuel independent vehicle fleet in 2030.

The Swedish public transport sector has defined two major targets: (i) to run 90% of the total vehicle kilometers of the fleet on non-fossil fuels by 2020, and (ii) to increase the share of public transport in relation to the total personal transport in the country, and double the volume of travel via public transport by 2020. The analysis in this report highlights the challenges and solutions encountered, particularly when it comes to the adoption of renewable fuels in the regional bus fleets. As a result of the efforts made in the last few years, renewables respond for 60% of the fuels used in bus transport in Sweden compared to approximately 10% in 2009.

In line with the energy and climate policies of the Swedish government, and the objectives set by the Swedish Public Transport Association, major efforts are being made to make public bus transport a renewables-based, climate neutral and attractive option throughout the country. The purpose of this project was to perform a comparative analysis of renewable fuel policies and initiatives being pursued in relation to public bus fleets in Sweden, and to evaluate their results when it comes to the adoption of a carbon neutral public bus fleet. Ultimately, we aimed at analyzing the key factors affecting the promotion of renewable fuels in the Swedish regional public bus fleets and identifying options that can be showcased and serve to speed up the shift towards a fossil-free public transport in Sweden and elsewhere.

[1] RED text available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

1.1 AIM AND STRUCTURE OF THE REPORT

The focus of this study is the adoption of carbon neutral fuels in public buses in Swedish municipalities and regions (referred to as renewable fuels in this study). Bus is the most common means of public transport in Sweden. Passenger boardings on buses comprised 52% of the total number of boardings in public transport in 2013, and bus transport services are offered by all counties of Sweden (Trafikanalys, 2014). Therefore, public transport by bus has an important role to play in a future scenario involving a modal shift from private transport to public transport.

In this study, quantitative and qualitative methods are combined to provide a comprehensive picture of the performance of regional bus fleets. First, primary data are analyzed in order to (i) map regional performance characteristics, progress and fuel mixes, and (ii) classify all regions of Sweden according to renewable deployment status and other variables. For the qualitative part of the study, we performed a survey and personal interviews to identify and analyze successful practices in regions/municipalities, and understand the factors leading to higher deployment rates of renewable fuels in bus fleets in certain regions. Finally, we compiled the experiences that have served to promote the expansion of renewable fuels for buses in Sweden and the lessons learnt.

This study has focused exclusively on busses as a means of public transport. In Sweden, data on public transport are collected and published by state agencies, as well as various stakeholders in the sector. However, the relevant reports do not focus bus transport only. A deeper analyses of bus fleets is justified in face of the peculiarities of this transport mode, and its importance in the country. Train transport is mostly run on electricity, which is most carbon-free, while a significant part of the bus transport still depends on fossil fuels. The report contributes to highlighting important lessons, especially when it comes to the performance of bus fleets at regional level, and in the context of national targets. The survey insights serve to bridge information gaps between experts and decision makers, and also as a starting point for a discussion on the challenges still to be faced.

The report is structured to reflect the combination of quantitative and qualitative analysis in the study. Section 2 provides important background on the organization of public transport in Sweden, with particular focus on public bus transport. Section 3 focuses on the statistics analysis. Section 4 discusses the survey results and compiles best practices. The final section presents the main conclusions obtained of the project.

The results are useful as a benchmark and decision support for Swedish authorities, municipalities, and transport companies. Sharing knowledge acquired in successful cases serves to highlight specific actions and instruments, and further develop strategies for providing sustainable transport services. The project showcases the Swedish public transport experiences and, therefore, serves also to display Swedish sustainable public transport experiences abroad.

2. PUBLIC TRANSPORT IN SWEDEN

The EU has a goal to reduce 20% of greenhouse gas (GHG) emissions in 2020. Sweden is well on-track to making its contributions, and the EU as a whole will meet the target despite the shortcomings of many member states. However, when it comes to sectors not covered by the EU Emissions Trading Scheme (EU ETS), the Swedish national goal is 40% reduction by 2020, as opposed to the agreed 17% in the EU agreement related to 2005 levels. Transport as a non-EU ETS sector receives particular attention not least due to its dependence on fossil fuels.

Two key instruments are normally used for promoting renewable fuels in transport: tax exemption to biofuels, and mandatory blending (Holmgren, 2012). Exemptions have been previously applied to non-blended biofuels, and Sweden would like to combine that with quotas for biofuel blending in diesel and gasoline. However, according to the EU State Aid rules, both tax exemption and compulsory quota count as government support. Dual state aid is not allowed as this is considered overcompensation. Moreover, tax exemptions should not result in the supported option becoming cheaper than the conventional option, as this distorts competition.

Under the new Public Transport Act (Lag 2010:1065 om kollektivtrafik) that came into force on January 1st 2012, new regional public transport authorities (PTAs thereof) were created in Sweden. The PTAs are organized either as a federation or a committee of local authorities (municipality and county administration) together with the County Council (landsting). In some cases, the County Council is the PTA. These authorities are responsible for the development of public transport systems in their respective regions. One of the reasons for re-structuring the organization of public transport was to better coordinate actions towards public transport with other aspects of planning, and thus facilitate regional strategic decisions.

The responsibilities of PTAs are in line with the EU regulation 1370/2007 which is also included in the 2012 Public Transport Act. Regional PTAs and county transport companies are organized under the SK. SK represents the interests of its members nationally and internationally, develops guidelines on how public transport services should be offered, and helps strengthen the image of public transport through knowledge dissemination. A list of the PTAs that are member of SK is provided in Appendix I.

The long-term goals of regional public transport are defined by the PTAs, which also develop programs for provision of regional transport (trafikförsörjningsprogram). These programs set the basis for public service obligations (allmän trafikplikt), also in regions where public transport services are not of commercial interest. In this way, the provision of transport services is guaranteed to all citizens. Another very important dimension of the Public Transport Act (Lag 2010:1065 om kollektivtrafik) is to divide the roles between state and commercial actors more effectively. All in all, the focus is on building a dynamic market with high customer focus. Hence, commercial companies are free to offer public transport services anywhere in Sweden, but have the obligation to submit information about the range of services offered (SKL, 2014b; Svensk Kollektivtrafik, 2014c).

Public transport services are commonly supplied via procurement. According to the Swedish Public Transport Association (Svensk Kollektivtrafik – SK thereof), 95% of local and regional public transport services are supplied through procurement. SK has issued a common sector standard for procurement of public bus services, named “Bus 2014-common sector functional requirements for buses”[2]. The standard includes requirements for safety, passenger comfort, information, communication etc. The environmental requirements are set in more detail in a separate sector standard, titled “Environmental requirements in connection with transport procurement”[3]. All key stakeholders are involved in the development of these standards.

The procurement of transport services has been an instrument for reducing costs and fulfilling important goals, such as improving environmental quality, road safety and accessibility. After the procurement, the contracts are classified as gross or net. The main difference is that, in the net contracts, operators are given the right to receive the ticket revenues while, in gross contracts, all revenue is transferred to the PTA. Hence, the payment to operators under a gross contract is larger than to operators under a net contract (Svensk Kollektivtrafik, 2014a).

As previously mentioned, the transition to non-fossil fuels in the public transport sector is connected to another Swedish target, that is, to increase the share of public transport and thus curb private passenger transport. The Partnership for doubling public transport (Partnersamverkan för en fördubblad kollektivtrafik) started in 2008 aiming at doubling the share of public transport until 2030. If accompanied by deployment of non-fossil fuels in transport, a significant reduction of greenhouse gas emissions can be achieved. The partners who launched the partnership are the Swedish Public Transport Association, the Swedish Bus and Coach Federation (Svenska Bussbranschens Riksförbund - BR), the Swedish Taxi Association (Svenska Taxiförbundet), the Association of Swedish Train Operating Companies (Tågoperatörerna), the Swedish Association of Local Authorities and Regions (Sveriges Kommuner och Landsting - SKL) and the Swedish Transport Administration (Samtrafiken) (Bergström, 2013; Partnersamverkan för en fördubblad kollektivtrafik, 2013).

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[2] http://www.svenskkollektivtrafik.se/Global/2014%20Dokument/Buss_2014_eng.pdf

[3] http://www.svenskkollektivtrafik.se/Global/fordubbling.se/dokument/NY-Avtalsprocessen/Milj%C3%B6krav_buss_20131218sv.pdf (In Swedish)

3. ENVIRONMENTAL PERFORMANCE OF REGIONAL PUBLIC BUS FLEETS

Information regarding environmental performance and other bus fleet characteristics is found in the FRIDA database (FRIDA miljö- och fordonsdatabas - Svensk Kollektivtrafik, 2015), which gathers official statistics for public buses in all 21 counties of Sweden. The web-based database was developed by Nordic Port. The transport service operators report the information to the PTA, which are responsible for making the information available in FRIDA. The amount and quality of statistics gathered in FRIDA offer a rich source of information for analysis. We collected the raw statistical data and processed them in order to better understand the patterns of bus fleets in each region. This included not only the total renewable fuel use in buses per region analyzed, but also the size of the bus fleet, types of renewable fuels preferred, and the trends in efficiency of non-fossil fuels used in relation to the total amount of services provided. The aim of this mapping process is to classify all regions of Sweden according to biofuel deployment status and other relevant variables, and verify how the regions are performing. Data about public bus fleets are collected in FRIDA since 2007.

The statistics for public transport in Sweden indicate biodiesel, biogas, ethanol and electricity as non-fossil or renewable fuels (as seen for example in SKL, 2014 and Svensk Kollektivtrafik, 2015). Electrified public transport is seen as key for increasing the sustainability of the vehicle fleet, and this is why renewable electricity is included in this “extended” classification of non-fossil fuels in the databases. We follow the same categorization in this study. The types of renewable fuels used in Sweden and their characteristics are listed in Table 1.

Table 1: Types of renewable fuels used by Swedish bus fleets and their characteristics 2013

Fuel type	Energy content (MJ/lit)	Lifecycle emissions ($grCO_2/MJ$)	Feedstock
Biodiesel (FAME)	33.2	47.6	Rapeseed oil (RME)
Biogas	34.9*	22.5	Organic residues from wastewater treatment and other waste types
Ethanol	21.1	28.7	Sugarcane, maize, wheat etc.
HVO	34.3	15.9	Vegetable oils and animal fats

*in MJ/Nm^3

Source: Swedish Energy Agency, 2014a)

3.1 NATIONAL STATISTICS

At present, 71% of the buses operating in Sweden run on diesel and/or biodiesel. The share of diesel technology buses has decreased since 2007 as shown in Figure 1, while gas technology engines have increased from 9% to 23%. Ethanol engines respond for a smaller share, which increased from 1 to 6% between 2007 and 2014. Electric buses are only operated at demo stage (7 electric buses reported in FRIDA in 2014). Also MDE (Methane Diesel Engine) have only been used to a small extent (only 11 MDE buses reported at national level in 2014).

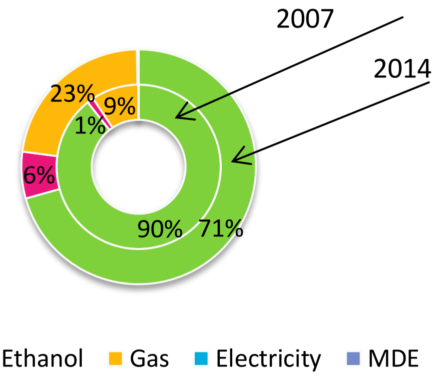


Figure 1: Buses in public transport operating in Sweden, by engine technology
Data source: Svensk Kollektivtrafik, 2015

Regarding Environmental Class Performance (miljöklassprestanda in Swedish), the Euro 5 standard buses dominate, as shown in Figure 2. Euro 5 buses comprise almost 70% of the bus fleet currently, with most of the other buses being under the Euro 3 and 4 standards. Euro 1 and 2 have an almost negligible share at this point. Here, it is interesting to highlight the rapid increase of Euro 6 buses which have reached a share of almost 8% since their introduction by the EU in 2013. The Euro standards are used to set the maximum emission levels for new buses and heavy-duty trucks (European Commission, 2015).

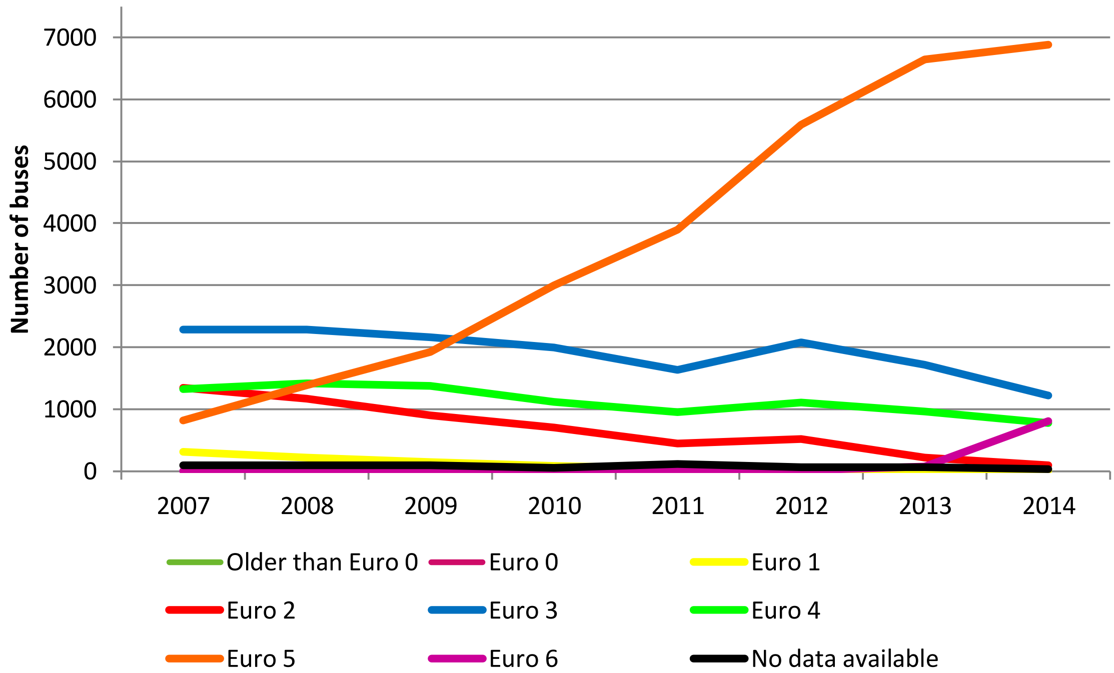


Figure 2: Environmental class performance of the Swedish public bus fleets, 2007-2014
Data source: Svensk Kollektivtrafik, 2015

Table 2 shows some basic characteristics of the regional bus fleets for public transport in different regions of Sweden. Naturally, the three most populous regions of Sweden (Stockholm, Västra Götaland and Skåne) have the largest fleets and the largest amount of passenger kilometers on bus. Together, they control 51% of the total number of buses operating public transport services, and 58% of the total passenger kilometers on bus. This highlights the impact that the use of renewable fuels in buses operating in those regions may have in the total emissions reductions. Smaller regions have small fleets with larger average trip lengths because of the lower population density but, together, control almost half of the Swedish bus fleet.

The statistics also show that the average age of the fleet has decreased between 2007 and 2014, from 6.96 to 5.59 years. In general, the lower the bus age, the better its environmental performance as technologies are being continuously improved. In counties such as Kronoberg, Västernorrland and Blekinge, the average fleet age has decreased rapidly in 2013 and 2014 as a result of new initiatives promoting the renewal of the fleets, new environmental standards and more stringent emissions targets. The bus fleets of the populous regions of Stockholm and Skåne are close to the average age at national level, while Västra Götaland has a much lower than average bus fleet age at 4.44 years. Notably, Västra Götaland's PTA, Västtrafik, sets a maximum limit of 6 years for the average bus fleet age within the city of Gothenburg in its contracts with transport service operators (Björk, 2015).

Table 2: Characteristics of bus fleets in 21 regions in Sweden

	Bus fleet size (no. of buses, 2014)	**Average bus age (in years, 2014)**	**Average trip length (in km, 2013)**	**Passenger kilometers with bus (in thousands km, 2013)**
Blekinge	175	4,78	8	51 032
Dalarna	354	7,10	35	329 300
Gotland	37	6,70	14	12 976
Gävleborg	209	4,00	12	160 869
Halland	272	5,27	17	167 337
Jämtland	188	5,94	15	79 598
Jönköping	287	4,31	9	145 092
Kalmar	255	6,07	20	137 737
Kronoberg	302	2,38	19	111 486
Norrbotten	284	7,66	15	123 521
Skåne	989	5,42	7	786 289
Stockholm	2 230	5,79	6	1 842 000
Södermanland	236	5,94	20	189 156
Uppsala	466	4,72	12	317 000
Värmland	418	7,30	18	198 098
Västerbotten	333	6,16	18	195 355
Västernorrland	371	5,97	10	103 847
Västmanland	185	6,45	13	117 234
Västra Götaland	1 906	4,44	8	1 159 982
Örebro	271	6,45	8	97 000
Östergötland	385	4,61	12	239 554
Total	10 112	5,59	9	6 564 463

Data source: Svensk Kollektivtrafik, 2015a; Trafikanalys, 2015
Note: Data for bus fleet size and average bus age is for 2014. Average trip length and passenger kilometers is from 2013 because data for 2014 was not released at the time of the report's publication.

The increase of vehicle kilometers run on renewable fuels has been impressive in the past few years, rising from a total share of 8% in 2007 to 58.4% in 2014 (see Figure 3). Biodiesel is currently leading among renewable fuels (33.7%), followed by biogas (17.2%), and ethanol (7.2%). Electricity has currently a very small share (0.3%). A significant increase in the use of renewable fuels can be observed particularly after 2010 when the first common sector standard was introduced. The even higher rates after 2012 can be credited to the boost given to procurement with the creation of PTAs in 2012, as well as the dissemination of new bus technologies.

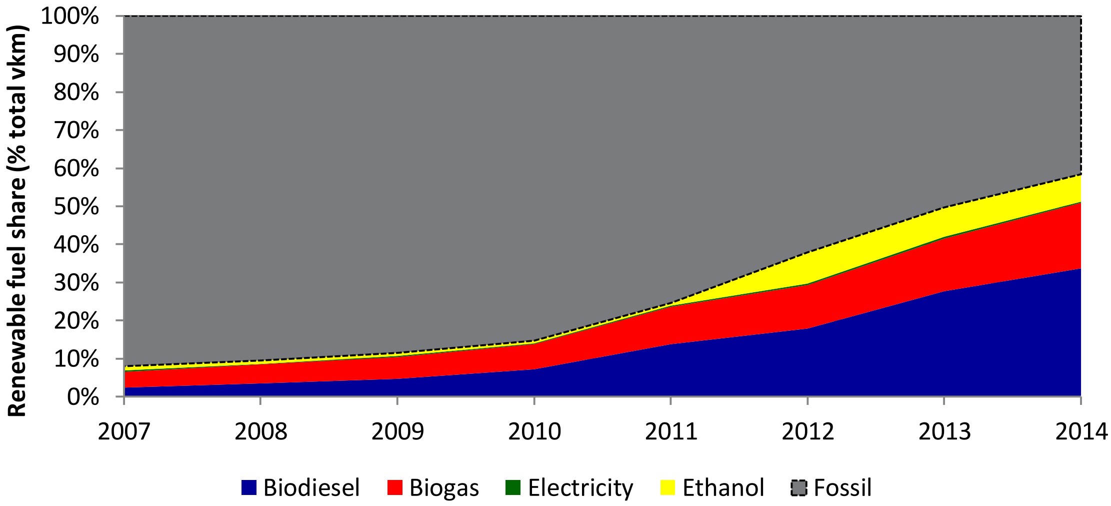


Figure 3: Fuel share in Swedish public bus fleets 2007-2014, as percentage of total vehicle-kilometers run by buses
Data Source: Svensk Kollektivtrafik, 2015a

Analyzing the environmental data on bus fleets, a steady decrease on CO_2 emissions per vehicle kilometer can be observed at national level between 2007 and 2013 (see Figure 4). However, this is not the case for energy efficiency, as energy efficiency values have remained relatively stable. Moreover, when counting CO_2 emissions and energy efficiency per passenger kilometer, emission levels are increasing and energy efficiency seems to be decreasing (see Figure 5). The end year of this analysis is 2013, since at the time of writing this report the data on passenger kilometers for 2014 were not yet available. The values in Figure 4 are extracted from FRIDA, where statistics are provided per vehicle kilometer, meaning the amount of kilometers driven by the bus fleets of each region.

For Figure 5, the values of emissions and energy efficiency were calculated by dividing the total CO_2 emissions and energy use of the bus fleets (in ton CO_2 and MWh respectively) by the occupancy rates reported for each regional PTA. This gives results in grCO_2 or kWh per passenger km (emissions per pkm and energy efficiency respectively). Occupancy rate is defined as the number of passengers occupying a vehicle, and is calculated by dividing passenger kilometers by vehicle kilometers. The higher the occupancy rate of a bus, the more positive the environmental impact of a passenger's travel via bus is, if compared with the use of a private car. Figure 5 shows that: (i) the total energy use is increasing because of the increase of bus transport volume (amount of offered vehicle km) and, (ii) occupancy rates are not increasing, therefore leading to decreased energy efficiency and also limited changes in CO_2 emissions levels.

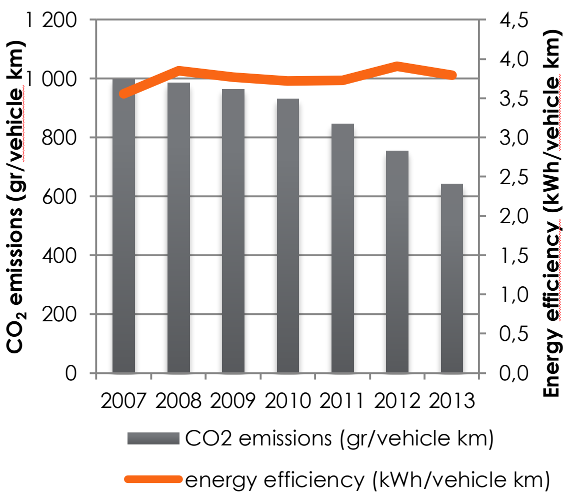
The primary source for occupancy rates is the national transport survey (resvaneundersökning-RVU). Therefore, to calculate passenger kilometers, the PTAs can use two methods, as indicated by Trafikanalys, the government agency responsible for collecting statistics for transport in Sweden.

These two methods are the following (Trafikanalys, 2012):

i. Multiplication of the average trip length per boarding (påstigning) for each region/county with the total amount of passenger boardings. The average trip length is calculated by Trafikanalys to help PTAs in statistics reporting, and is derived from the information collected in the RVU.

ii. Multiplication of the average occupancy rates for buses per region with the total amount of vehicle kilometers driven by bus.

Both methods include uncertainties. Average trip lengths, for example, are not regularly updated, or include both bus and train transport. Average trip lengths obviously differ between city and regional buses. Data used in this study for passenger kilometers, vehicle kilometers and number of trips for all regions from 2007 to 2013 were provided from Trafikanalys upon request. The occupancy rates calculated from these data can be found in the Appendix II.



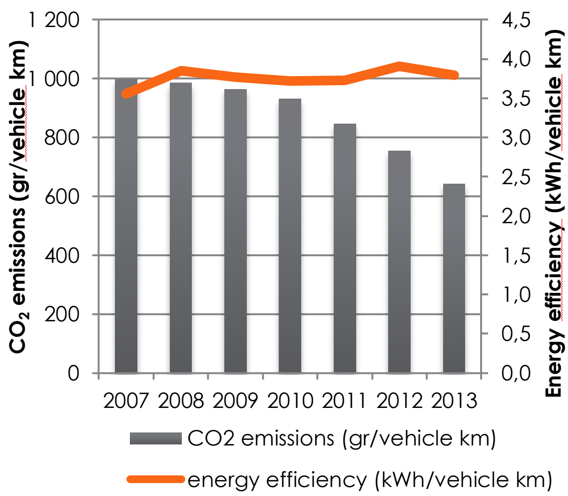


Figure 4 (left): CO_2 emissions and energy use per vehicle kilometer (national data, 2007-2013)
Data source: Svensk Kollektivtrafik, 2015
Figure 5 (right): CO_2 emissions and energy use per passenger kilometer (national data, 2007-2013)
Data source: Svensk Kollektivtrafik, 2015a; Trafikanalys, 2015

The data on passenger kilometers, occupancy rates and trip lengths should be used with caution, but nonetheless they should not be excluded from the analysis, as they provide a very useful basis for discussion. It should be noted here that data on vehicle kilometers, although certainly more precise, also include uncertainties as they are self-reported by transport service operators.

3.2 REGIONAL MAPPING

At regional level, a rapid increase in the share of vehicle kilometers reported to run on renewable fuels is observed in most Swedish counties. Figure 6 shows the changes comparing values in the years 2010, 2012 and 2014. Exceptions to this trend are found in Dalarna, Gotland, Norbotten and

Västerbotten. Kalmar has also had a slow growth in the use of renewables lately but, on the other hand, the share of renewable fuels was already quite high by 2010 (around 55%). It is useful to include the values for 2012 in this figure to show an intermediate step in the process of renewable fuel deployment as well as to observe eventual impacts after the creation of the PTAs (2012). Indeed, only four regions had surpassed 50% in 2012, while in 2014 this number had increased to nine. It should be noted that Stockholm was not using FRIDA for reporting this information on the bus fleets before 2012. However, the official reports of the county council (Stockholm Läns Landsting, 2011) provide this information, as per shown in Figure 6.

The first common sector standards for sustainability were released in 2010, but regional PTAs had been already testing strategies and implementing the use of alternative fuels. Therefore, quite a few regions already had considerable shares of renewable fuels before 2010. Such examples are Stockholm, Västmanland, Östergötland and Kalmar, among others. This is a result of prior independent strategies of these regions pursuing sustainable public transport. For example, Östergötland has invested in the use of locally produced biogas in the city of Eskilstuna since 2002 (Dädeby, 2015). The same has been the case with biogas production in Västerås in Västmanland, as well as Stockholm's early adoption of ethanol in buses (established at 2007).

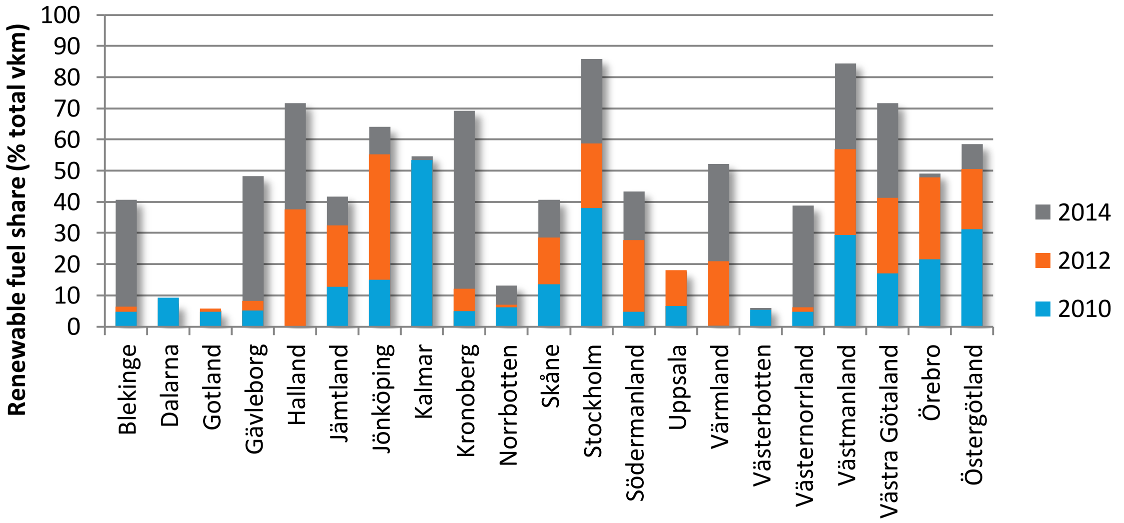


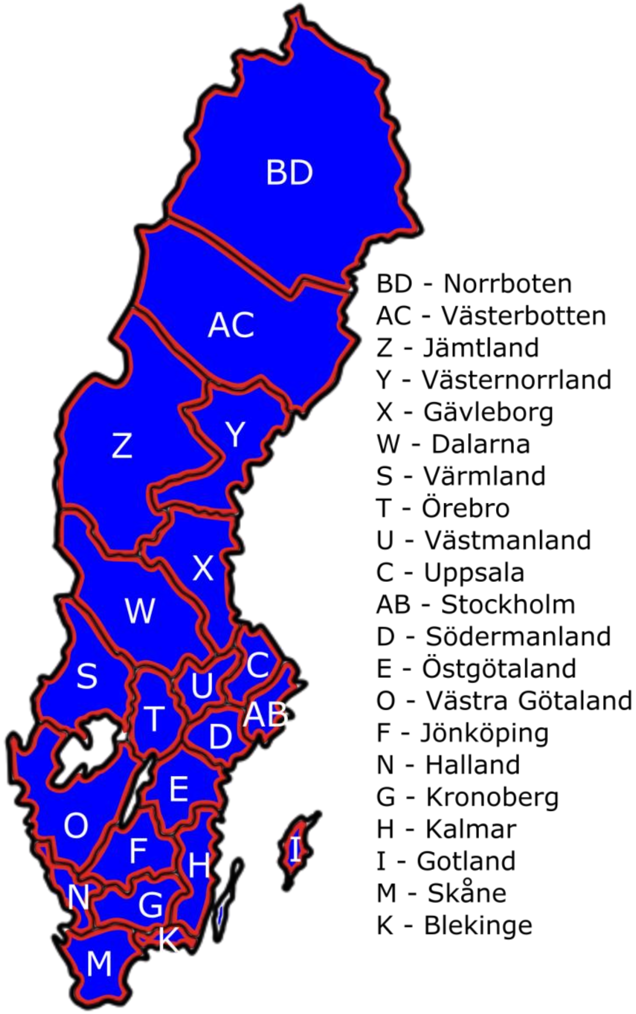
Figure 6: Renewable fuels share (%) in Swedish public bus fleets at regional level, 2010, 2012 and 2014
Data source: Stockholm Läns Landsting, 2011; Svensk Kollektivtrafik, 2015

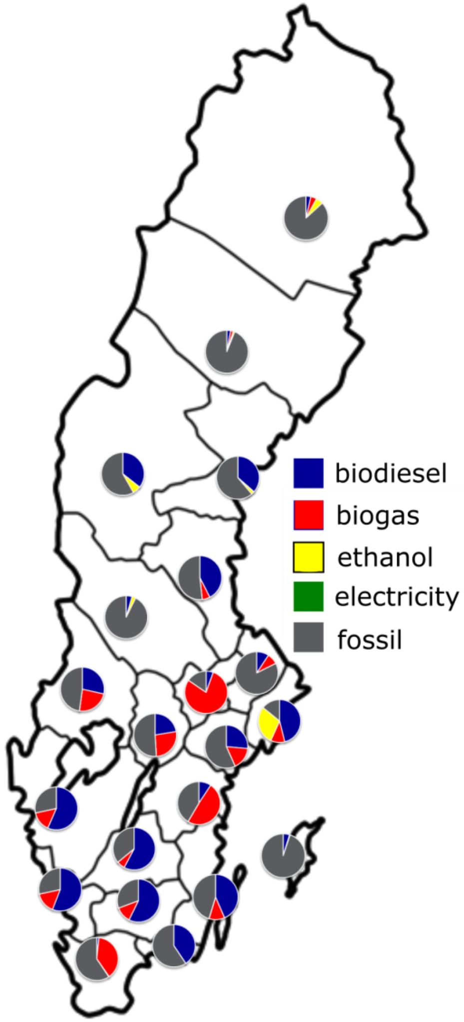
In Figure 8, the fuel mixes for regional bus fleets are mapped for Swedish regions. A contrast in the north-to-south axis in terms of increase of renewable fuels use can be noticed both in Figure 8 and Figure 9. This contrast can be partly attributed to climatic conditions which may limit the use of renewable fuel, for example due to fuel freezing or other engine and/or vehicle requirements. Another reason could be the low population densities that lead to longer trip lengths which cannot always be covered using renewable fuels.

However, not only densely populated regions with large bus transport volume perform well in terms of renewable fuel deployment. This is shown in Figure 10, where renewable fuel shares are plotted against population density and amount of vehicle kilometers with bus for each region. This places political will and strategic planning in public transport as important factors affecting renewable fuel deployment. Regions such as Västmanland, Halland and Kronoberg have small transport volume but are placed high in terms of renewable fuel deployment in buses. Among the densely populated regions, Stockholm and Västra Götaland perform better than Skåne.

Figure 11 plots CO_2 emissions and energy efficiency in a similar style as Figure 10. Not surprising, the five regions with the lowest renewable fuel share have the highest CO_2 emission level as a result of 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 considerably lower fuel efficiency than, for example, biodiesel. Therefore, in regions where biogas is the dominating fuel, lower energy efficiency is observed (e.g. Skåne, Västmanland).

Densely populated regions with large transport volume such as Stockholm and Västra Götaland have achieved relatively low emission levels, but they seem to have lower energy efficiency. This can be attributed to driving conditions, as in densely populated urban environments, buses stop more frequently and, therefore, more fuel is consumed, thus resulting in lower fuel efficiency. Detailed information on renewable fuel shares, CO_2 emissions and energy efficiency for each region are listed in Table 3 at the end of this section.





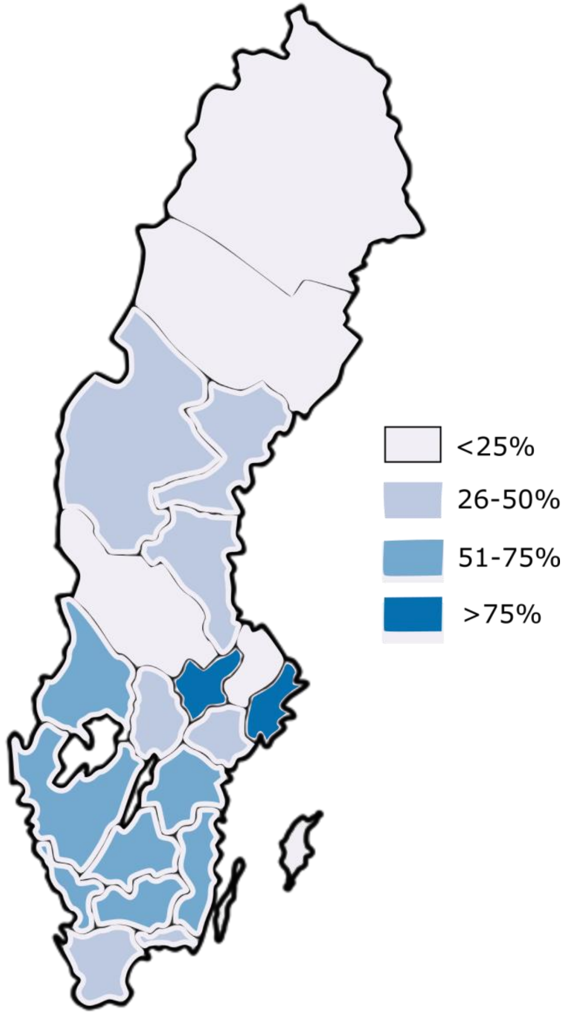


Figure 7 (left): Map of Sweden divided in its 21 counties (län)
Figure 8 (middle): Bus fleet fuel mix per region - 2014 (constructed by authors with data from Svensk Kollektivtrafik, 2015)
Figure 9 (right): Map of regions grouped by renewable fuel share – 2014 (constructed by authors with data from Svensk Kollektivtrafik, 2015)

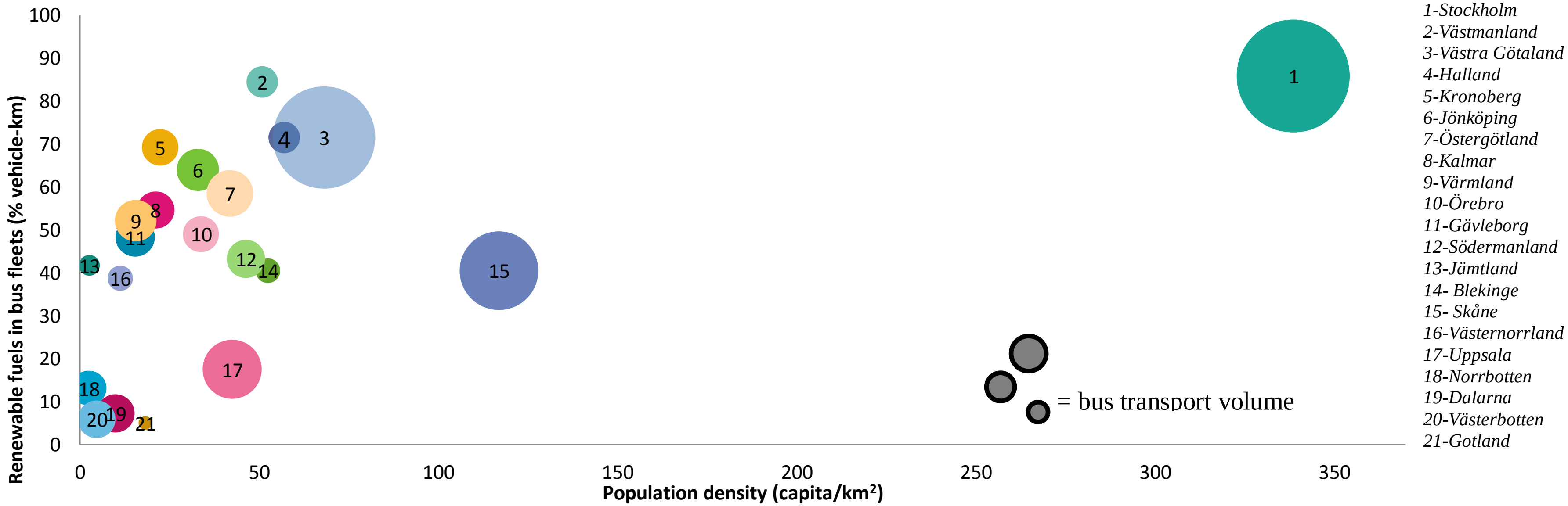


Figure 10: Renewable fuel share for public bus fleets in relation to population density and vehicle kilometers -2014 (constructed by authors with data from Svensk Kollektivtrafik, 2015)

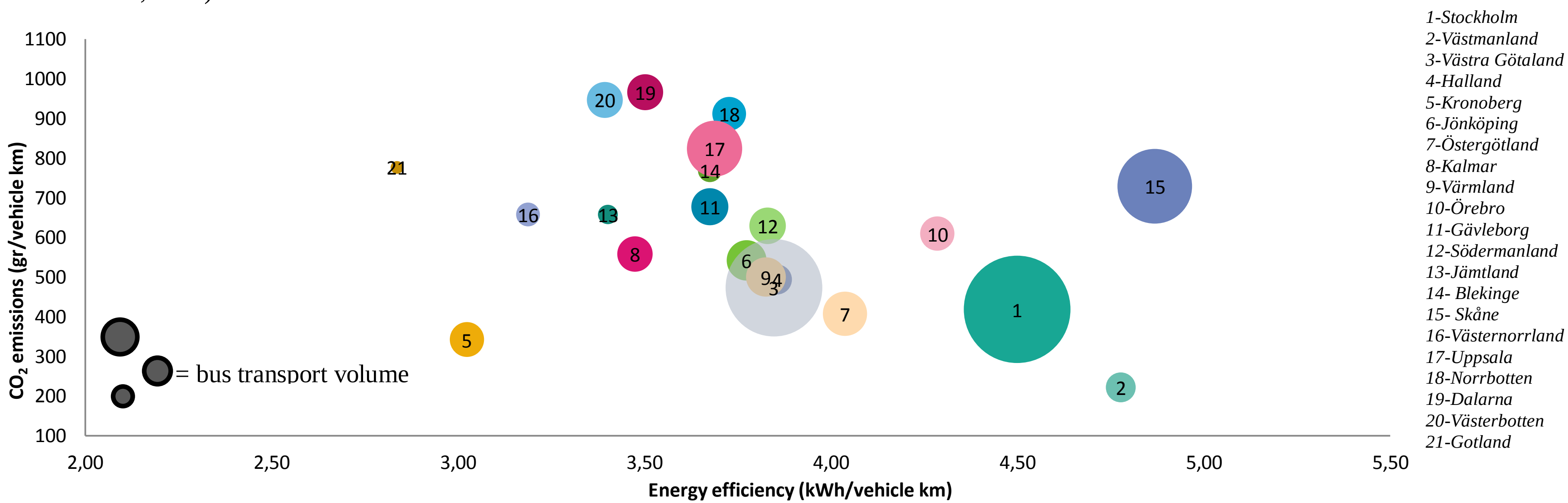


Figure 11: CO_2 emissions for public bus fleets in relation to energy efficiency and vehicle kilometers-2014 (constructed by authors with data from Svensk Kollektivtrafik, 2015) (Note: the area of each bubble represents the vehicle kilometers performed with bus and each bubble corresponds to a region as shown in the legend)

Table 3: Ranking of Swedish regions by population density and bus fleet renewable fuel shares, CO_2 emissions and energy use - data for 2014

Rank	Population density (capita/km^2)		Renewable fuel share (% vkm)		CO_2 emissions (gr CO_2/vkm)		Energy efficiency (kWh/vkm)	
1	Stockholm	338,7	Stockholm	85,9	Dalarna	966	Skåne	4,87
2	Skåne	116,9	Västmanland	84,5	Västerbotten	947	Västmanland	4,78
3	Västra Götaland	68,2	Västra Götaland	71,6	Norrbotten	912	Stockholm	4,50
4	Halland	57	Halland	71,6	Uppsala	824	Örebro	4,29
5	Blekinge	52,4	Kronoberg	69,3	Gotland	777	Östergötland	4,04
6	Västmanland	50,9	Jönköping	64	Blekinge	769	Halland	3,86
7	Södermanland	46,3	Östergötland	58,5	Skåne	729	Västra Götaland	3,85
8	Uppsala	42,5	Kalmar	54,7	Gävleborg	677	Södermanland	3,83
9	Östergötland	41,9	Värmland	52,2	Jämtland	658	Värmland	3,83
10	Örebro	33,8	Örebro	49,1	Västernorrland	658	Jönköping	3,77
11	Jönköping	32,9	Gävleborg	48,3	Södermanland	629	Norrbotten	3,70
12	Kronoberg	22,4	Södermanland	43,3	Örebro	609	Uppsala	3,69
13	Kalmar	21,1	Jämtland	41,8	Kalmar	558	Blekinge	3,68
14	Gotland	18,2	Skåne	40,6	Jönköping	542	Gävleborg	3,67
15	Värmland	15,6	Blekinge	40,6	Värmland	500	Dalarna	3,50
16	Gävleborg	15,4	Västernorrland	38,8	Halland	494	Kalmar	3,47
17	Västernorrland	11,2	Uppsala	17,6	Västra Götaland	473	Kronoberg	3,45
18	Dalarna	9,9	Norrbotten	13,2	Stockholm	418	Jämtland	3,40
19	Västerbotten	4,7	Dalarna	7,3	Östergötland	407	Västerbotten	3,39
20	Jämtland	2,6	Västerbotten	6	Kronoberg	342	Västernorrland	3,19
21	Norrbotten	2,5	Gotland	5,1	Västmanland	222	Gotland	2,84

Data source: Statistiska Centralbyrån, 2015; Svensk Kollektivtrafik, 2015

4. SURVEY RESULTS

4.1 SURVEY DESIGN

Once the condition and performance of the regional bus fleets in public transport are mapped, the next step is to find out (i) why specific fuel choices are made, (ii) which is the outlook for future fuel and technology choices, and (iii) which measures and policies can assist in reaching the targets on renewable fuel deployment. For this, the input from the public transport sector was sought. Survey research methods, with an anonymous electronic questionnaire and personal interviews with straightforward note-taking were used. The questionnaire survey was carried out in the period from January to February 2015.

The sampling pool was environmental managers or persons working with strategy and planning at each one of the regional PTAs. The respondents were asked also to distribute the questionnaire to other colleagues. We estimate that the final sample was around 35 persons, that is, those who actually received the questionnaire. In total, 19 persons responded to the survey, thus the response rate can be estimated to be around 55%. In addition to the survey, three personal interviews were scheduled and five persons responded to a set of additional questions through email correspondence. The central questions covered in the questionnaire where the following:

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

Supporting these main questions, a number of additional questions were asked that facilitated sorting out the data collected, as well as offered a better overview of the conditions of regional public transport bus fleets. These questions were related to the current status of bus fleets, current and future technology demonstration projects, strategies and organization of the regional PTAs, as well as assessment of current policy initiatives for the public transport sector.

The questionnaire was in Swedish and comprised three categories of questions: (i) General questions (ii) Fuel choice questions (iii) Instruments for increasing renewable fuel share questions. In total, the questionnaire comprised 16 questions. A text box was provided for additional comments from the respondents, in case they had any. The survey was anonymous, unless the respondent specified otherwise at the end of the questionnaire. In the cases when the respondent chose not to be anonymous, a follow-up interview was scheduled. From the 16 questions, 11 of them were closed format questions, but a few of them were followed by open format questions for elaboration. We chose to use a mix of closed and open questions in order to give freedom to the respondents in case they wanted to provide more information. We aimed at unbiased, uncategorized answers, especially related to the fuel choices and successful policy instruments. The questionnaire's design was adjusted after comments resulting from a testing session and a personal interview with the first respondent.

4.2 HOW ARE FUEL CHOICES MADE?

The results from the survey show that public transport authorities are strongly interested on electricity as a fuel option for buses. In the question about which is the most attractive fuel alternative in the foreseeable future, the respondents placed electricity first (see Figure 12). Biodiesel from rapeseed oil (RME), which is the most common type of biodiesel currently in use in Sweden, came second, together with biogas. Finally, some replied that HVO (Hydrogenated Vegetable Oil) is the most attractive fuel option. The performance of HVO is similar to conventional biodiesel, but the fuel has significantly lower lifecycle GWP (Arvidsson, Persson, Fröling, & Svanström, 2011).

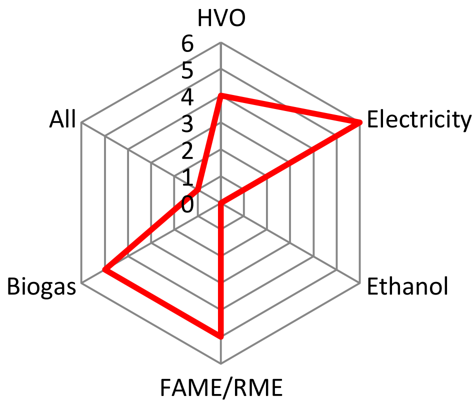


Figure 12: The most attractive fuel alternative in the future as per perceived by survey respondents
Note: the numbers in the chart indicate the number of respondents for each survey answer

The survey shows the importance of biodiesel, especially in scarcely populated regions, where infrastructure for electricity or biogas may not be profitable. Biodiesel is quite flexible a fuel, and can be used in ordinary diesel motors without modifications. It must be noted that, at the moment, electricity can only be seen as an alternative for city traffic, and the choice for regional routes is usually biodiesel. Currently transport service operators tend to choose biodiesel, unless another fuel is specifically procured from the PTAs. For regions that have already invested in a specific fuel, either biodiesel or biogas, the survey shows that the majority of PTAs wish to continue investing in the same fuel, combined with electricity.

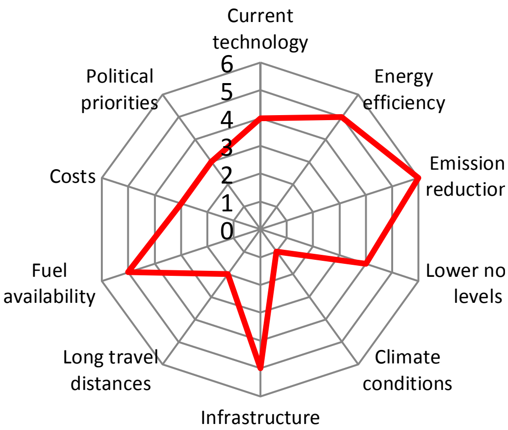
One of the respondents identifies biodiesel "*as the only alternative until electric buses become a good alternative*". One of the respondents from a small region with more than 55% share of renewable fuels in buses bases the choice of biodiesel on the fact that it is "*Available. We are too small to dare try anything else*". For regions with larger population, e.g. Stockholm, more investment opportunities are available which can be directed toward more than only one fuel alternative. In some cases, although biogas is currently the main fuel used, electricity or biodiesel are identified as more attractive in the future. The reason for this is the lower fuel efficiency of gas-driven vehicles compared to diesel and the difficulties in securing the biogas supply.

Electricity rises as a very promising fuel alternative in the opinion of the respondents, provided that it comes from renewable sources. One big advantage of electric buses according to the survey is the lower noise levels compared to buses with internal combustion engines. Low or no noise from the bus engine can lead to substantial improvements in the urban environments. However, the investments needed for infrastructure for electric bus charging stations are a big challenge for the PTAs. This needs to be addressed in a cost-effective way and, perhaps, new business models have to be developed to operationalize it. A period of 10 to 15 years will be needed for building the infrastructure at the scale required for city traffic, as per stated by the respondents.

Figure 13 summarizes the responses obtained on the main factors affecting fuel choices for bus fleets. Environmental aspects such as emission reduction potential and energy efficiency are given as priority, as well as infrastructure needs and fuel availability. Lower noise was also a factor mentioned, as well as investments currently being made in specific vehicle technologies which may delay the switch to certain fuels. Political priorities influence the pace of development as long-term support from the local political authorities is essential for allocation of resources and investments in renewable fuels for public transport. Finally, climate conditions affect fuel choices, especially in the colder Northern part of Sweden, where some fuels are not an option due to freezing.

Costs are what most of the respondents classify as the highest barrier to increasing renewable fuel deployment in public bus fleets (see Figure 14). Connected to the overall cost issue, there is also the requirement for new infrastructure, which implies large investments. Engine technologies and bus design can also 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 (låggolvsbussar in Swedish). The latter are usually the bus models that use renewable fuels.

Fuel supply is also an important factor affecting choices and investments. Uncertain policy conditions are placed high in the response list, because the policy framework related to renewable fuel taxation and incentives is unclear at the moment. That hinders new investments. Other political priorities may also affect public transport 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. Stockholm's PTA is expecting that when a few public service contracts expire, they will be able to use more stringent procurement requirements to achieve the city's goals toward a fossil fuel independent public transport. Thus environmental performance is being systematically pursued but ambitious roles have to be constant balanced in relation to technology and fuel availability, costs, character of the service among other factors.



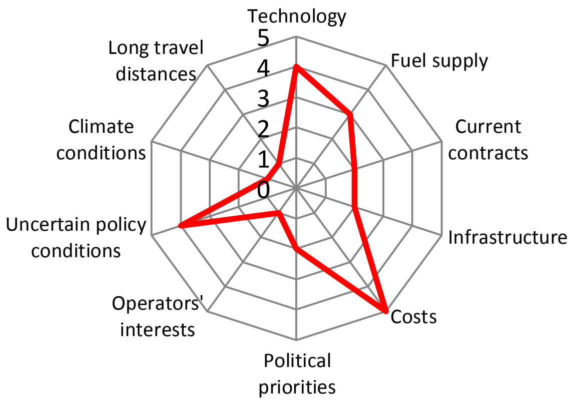


Figure 13 (left): Survey results on factors that affect fuel choices for Swedish public buses
Figure 14 (right): Survey results on perceived barriers to higher renewable fuel deployment for Swedish public buses

4.3 EXAMPLES OF BEST PRACTICE

Most of the respondents indicated that the sector standards for procurement are followed by the PTAs in their region (59%). In the most populous regions of Sweden, e.g. Stockholm and Västra Götaland, the PTAs set even higher requirements than the sector standards. SK's standard already has different levels of ambition for the requirements on procured bus services, thus giving flexibility to each PTA to design strategies that are realistic in different regional contexts or in line with ambitious political visions. For example, the requirements on emissions reduction and energy efficiency set by Västra Götaland are beyond the average and will most likely result in transport operators opting for hybrid buses to improve the fleet's environmental performance (Björk, 2015).

In the survey, 78% of the respondents indicate that there is a specific environmental strategy for public transport 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 public transport. A very good example of a structured strategy for increased renewable fuel deployment 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.

The respondents of the survey as well as the interviewees were asked to indicate if there are any ongoing demonstration projects for innovative bus technologies supported by the PTAs in their region. Eight responded that there are such projects and most of them are related to demonstration of electric bus technologies. For reference, the demo projects mentioned in the survey are the following:

- Demonstration project of 8 plug-in hybrid buses in Stockholm (line 73) under the EU program ZeEUS (Zero Emission Urban Bus System) led by SL in collaboration with Volvo and Vattenfall. The plug-in hybrid buses are performing 80% of the route on electricity and the remaining 20% on HVO. The project entered its full operation phase in the beginning of March 2015 (Vattenfall, 2014). Stockholm region is planning for a demo project of plug-in hybrid buses with inductive charging for 2016 in collaboration with Scania (Böhlin, 2015).

- Demonstration project Electricity (starting operation in summer 2015) and Hyperbusprojekt in Västra Götaland region (Björk, 2015). The Electricity project is a collaboration of the City of Gothenburg, Västra Götalands Regionen, Volvo, Chalmers, Göteborg Energi, Västtrafik and the Swedish Energy Agency among others.

- Demonstration project for 2 electric buses in Eskilstuna in Södermanland (Dädeby, 2015).

- SlideIn project for demonstration of 5 trolleybuses in Landskrona in Skåne region which has operated since 2003 (Skånetrafiken, 2013). The project is a collaboration of Skånetrafiken, Lund University, ÅF, Volvo and E-On among others (Skånetrafiken, 2013).

- A project for the construction of an HVO depot in the region of Gävleborg (Forsberg, 2015).

In addition to these projects mentioned in the survey, there are more ongoing projects for demonstration of electric bus technologies in Umeå, Borås, Kalmar, and Jönköping, among others. Skåne's PTA (Skånetafiken) recently published a report investigating the opportunities for pilot implementation of electric buses in smaller communities, using the municipality of Ängelholm as a case (Skånetrafiken, 2014).

Municipalities are important in disseminating best practices, being free to develop ambitious strategies and invest in new technologies independently. For example, the Skellefteå and Umeå municipalities in Västerbotten invest in biogas and electricity respectively, and have achieved much higher renewable fuel deployment than the overall renewable fuel share in buses for Västerbotten, which only reaches 6% of the total in the region (Byring, 2015). Similarly, the municipality of Eskilstuna has set a requirement for biogas deployment in procurement for city traffic since 2002 (Dädeby, 2015).

The performance in relation to emissions and energy efficiency vary significantly among regions, as shown in Section 2. Fuel consumption also varies. An example with data provided from the Västra Götaland region (see Table 4), shows that gas buses consume 36% more fuel per km than diesel buses (Västtrafik, 2015). In Västra Götaland, 81% of buses have a diesel engine and 18% of buses have a gas engine. Therefore, the average fuel consumption for buses in the region is closer to the fuel consumption of diesel engines. There can be conflict of targets for renewable fuel deployment and energy efficiency when biogas is used for driving the buses. Biogas' lifecycle Global Warming Potential (GWP) is lower than biodiesel (Hallberg et al., 2013). As discussed in Section 2, since biogas driven buses consume more energy than biodiesel driven buses, the effect on emissions of these two engine technologies becomes approximately the same, despite the biodiesel's higher GWP (Västra Götalandsregionen, 2013).

Table 4: Fuel consumption per engine technology for buses in Västra Götaland region – data for 2014

Transport mode	Engine technology			Average
	Diesel	Gas	MDE	
Bus	3,72 lt/mil[4]	5,85 lt/mil	3,56 lt/mil	3,99 lt/mil

Source: Västtrafik, 2015

Note: Fuel consumption for gas and MDE (Methane Diesel Engine) is expressed in diesel fuel equivalent

Fuel consumption is also affected by the type of route the bus operates, i.e. city route or regional route. In Gävleborg, a medium-size region with 277 970 inhabitants in 2014, data was provided for the 193 diesel buses in use (see Table 4). Fuel consumption was 14% higher in city routes than in regional routes, which is equal to around 6 deciliters more fuel consumed per driven Swedish mile[2] (Region Gävleborg, 2015). The majority of buses in service are of diesel technology, except from 15 biogas buses operating in the city of Gävle.

[4] 1 mil (svensk mil) = 10 km

Table 5: Fuel consumption per transport service type for buses in Gävleborg region – data for 2014

Transport mode	**Transport service type**		**Average**
	Regional	**City**	
Bus (diesel engine)	3,6 lt/mil	4,2 lt/mil	3,86 lt/mil

Source: Region Gävleborg, 2015

Stockholm has adopted comprehensive strategies for decarbonizing public transport and is a showcase of policy success for promoting renewable fuels in bus fleets. As much as 85% of bus kilometers in the city already run on renewable fuels. The three main documents comprising Stockholm's strategy on renewable fuels is the transport provision program, the environmental strategy program (Miljöutmaning 2016) and the internal sustainability strategy (Johan Böhlin, personal communication, 4 February 2015). The goals and strategy of Stockholm for full decarbonization of vehicular transport by 2050 are presented in the "Urban Mobility Strategy" report, published in 2012 (The City of Stockholm Traffic Administration, 2012). The city of Stockholm is constantly growing, so the demand for space, resources and transport services will increase dramatically in the future. It is very important that public transport market shares increase to balance the city's growth (Ericsson, 2015).

Figure 15 shows how Stockholm has invested broadly in different types of renewable fuels and how rapidly the deployment of these fuels has increased in just a few years. Fossil diesel (with 5% RME blend) is decreasing and being replaced by RME. Biogas use has increased, but is less than the use of RME. This can be explained by larger number of diesel-engine buses in Stockholm than gas-engine buses (1251 diesel and biodiesel buses to 308 gas and biogas buses). Ethanol use has slightly decreased, and only a very small share of natural gas is used as a complement when biogas is not available. Ethanol shares have been decreasing for various reasons, including controversies related to ethanol production and higher service and maintenance costs for ethanol buses compared to other fuels (Böhlin, 2015). From Figure 15, one can also notice the slight decrease of energy efficiency. This might be a result of the changes in the fuel mix, but also of the fact that the amount of passenger kilometers is not increasing as expected. Supporting data for fuel efficiency provided by Stockholm's County Council can be found in Appendix III.

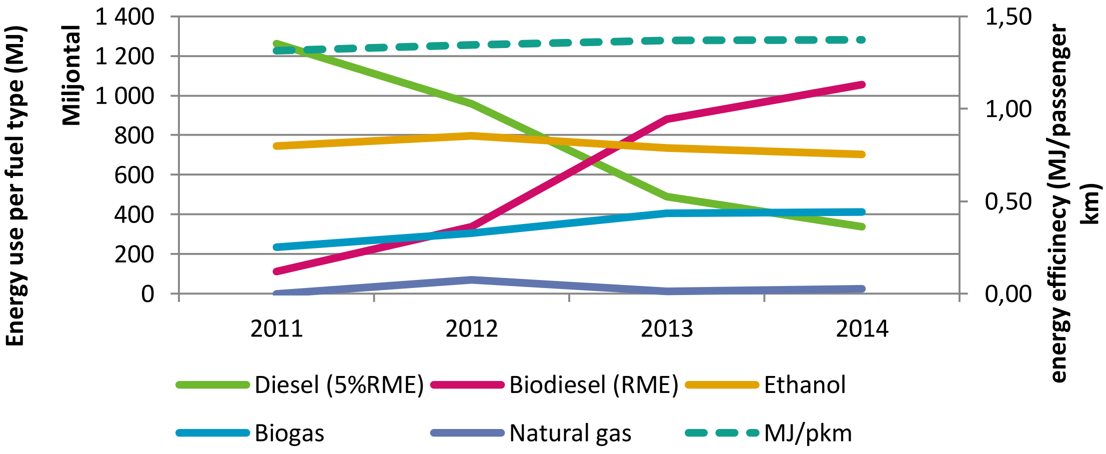


Figure 15: Energy use and energy efficiency per fuel type for Stockholm county 2011-2014
Source: SLL, 2015

According to the data provided by the Stockholm county, public bus transport volume has risen from 1 792 000 000 passenger-kilometers to 1 844 841 742 passenger kilometers from 2011 to 2014, that is, around 3%. As mentioned previously, a combination of decreasing energy use and increasing occupancy rates needs to be aimed for, if the goals on energy efficiency are to be achieved.

It is expected that with the adoption of electricity in transport, Stockholm will be able to reduce its total energy use at absolute terms. Energy use is also expected to decrease when older transport service provision contracts expire around 2025 and are replaced with contracts guided by more ambitious environmental requirements (Böhlin, 2015). Whether this will lead to increased energy efficiency depends on whether the occupancy rates and passenger kilometers with bus increase accordingly.

4.4 KEY POINTS OF STRATEGIES FOR RENEWABLES IN BUS FLEETS: LESSONS FROM SWEDEN

i. Success drivers: Long-term vision and active stakeholder cooperation

Political will and strategic planning for public transport provision have been important drivers of renewable fuel deployment in successful municipalities in Sweden. Thus once technical limitations are overcome and specific regional differences are understood, policies and actions are key to the promotion of alternative fuel choices and improved technologies. In particular, the survey respondents and interviewees agree on the success of transport service procurement as the most important instrument to promote increased renewable fuel deployment in bus fleets. Among others and as an example, strategic decisions for promoting local biogas production and use in bus fleets have been pursued through procurement (e.g. in Southern Sweden).

It is important to highlight stakeholder cooperation in this process. The procurement standards are set after careful consideration, as explained in Section 2. Fuel choices are important long-term strategic decisions, which are made after stakeholder dialogues are carried out, possible alternatives are identified, and goals commonly understood. Knowledge transfer and effects of economies of scale while introducing renewable fuels and new bus technologies can curb barriers, as has been observed in the case of Stockholm (Böhlin, 2015). PTAs and other stakeholders collaborate in new projects (e.g. line 73 in Stockholm). Political decisions for new legislation (e.g. taxation) are also subject to stakeholder consultation.

Key points for strategy design: Decision making for public transport occurs at political level and implementation strategies are on the PTAs , but for developing a sustainable public transport strategy a wider participatory approach is needed. A stakeholder dialogue prior to each new procurement process ensures that the goals and requirements are clear to all involved parties. It is of particular importance for PTAs to communicate information and collaborate with all stakeholders involved in public transport provision.

ii. Future challenges: Costs and infrastructure needs

Costs have been identified in our survey as a very strong factor affecting fuel choices and public transport strategies. Upgrading the bus fleets with newer and more environmentally friendly technologies requires large investments. A comparison of the information provided in Table 2 and Table 3 indicates that, when the average bus fleet age is lower, the renewable fuel shares tend to be higher. Not only do newer types of buses allow multiple fuel choices, but the procurement of new contracts promotes the renewable choice particularly in communities where there are clear targets in that direction.

Stakeholders have previously indicated that environmental bus premiums could be offered as an incentive for improving vehicle technology (Svensk Kollektivtrafik, 2014b; Volvo, 2014; Västra Götalandsregionen, 2014). This premium, as suggested, should cover part of the investment required for purchasing buses with the highest environmental standards and minimal emissions. A premium would assist in a faster adoption rate of new bus technologies such as electric hybrids and fully electric buses, which are now considered as an emerging alternative with large potential.

Despite all efforts made and the significant progress already achieved, the goal to double public transport will most likely not be reached under the current trajectory (Nilsson, Pyddoke, & Anderson, 2013). The amount of passenger kilometers has increased by 7% between 2007 and 2013 (from 6 100 527 to 6 564 463 thousand kilometers - Trafikanalys, 2015). However, the costs have increased more rapidly, reaching 27% in the same period (SKL, 2014a). The reasons behind these cost increases are manifold, including fuel prices and more ambitious environmental targets. Still fuel prices or vehicle costs do not respond for the largest share of the cost increase. According to SKL's breakdown of the total cost increases observed for public bus transport in recent years, fuel costs represent 20% of the increase and vehicle costs 10%, while the majority of the increase is the result of increased salary costs. The latter is closely related to the increase in the amount of services being offered in line with the overall goal to make public transport more attractive. Certainly, the knowledge of this fact may push for new solutions in the future such as the introduction of driverless vehicles. Exploring the implications of this scenario is, however, outside the scope of this study.

Another issue raised by the survey respondents is how state funds are utilized in promoting renewable fuels. In many cases, state support of public transport is utilized to cover net losses in public transport income balances, instead of transport service operation investments. A survey respondent indicates that demo projects for innovative technologies and fuels, and public transport planning should receive more support.

Infrastructure issues will be challenging to address in the future, especially for the case of full-scale introduction of electric buses. Issues of infrastructure ownership or stakeholder competition will be a question that municipalities and regional authorities will have to face, as well as large needs of recharging (Ericsson, 2015). Increasing the number of filling stations is also important, especially for increasing deployment of renewable fuels in longer travel distances. In this context, increasing renewables in long routes that may cross one or multiple regions is very important and requires coordination.

Key points for strategy design: The costs of promoting renewable fuel penetration in bus fleets are likely to increase after the low hanging fruits have been picket. Therefore, cost issues need to be addressed in a comprehensive way considering not only fuel prices, bus operations or investments in new infrastructure, but also considering the attractiveness of public transport and the new business models that will be needed to make the segment more sustainable.

iii. Strategy replication and knowledge transfer

It is important to learn from the various experiences and their outcomes. This does not mean simply replicating strategies, for example from larger to smaller regions. It is necessary to contextualize the character and volume of demand in each region, and evaluate opportunities and challenges. With the exception of the three most populous regions (Stockholm, Västra Götaland, Skåne), the vast majority of Swedish regions have an average fleet size of 200-250 vehicles, which is about 10 times smaller than Stockholm's bus fleet. A larger fleet serving densely populated regions has a demand characterized by large transport volume often in urban environments. This is not the case in scarcely populated regions with large distances to cover. Climate conditions may also play a role as certain technologies may pose limitations in the very cold climate of the North. Therefore, a strategy that was successful in one region may not be suitable or cost-effective in another as conditions for transport service delivery and profitability vary.

Nevertheless, there are significant lessons to be learnt from successful regions, such as the importance of setting clear goals, allocating investments for new infrastructure and demos for testing new technologies, running campaigns to promote and increase the use of public transport, collecting comprehensive documentation for monitoring costs and achievements, etc.

The organization of cooperation initiatives is very important in the development of public transport strategies for renewable fuels. The Swedish Public Transport Association (SK) is a hub that provides support to regional PTAs and is a "*powerful voice for public transport, spreading know-how on and increasing the insight into its advantages among decision-makers, nationally and internationally*" (Svensk Kollektivtrafik, 2015b). SK develops common sector standards and organizes dialogue with transport stakeholders across Sweden.

In addition to SK's activities, other important networks for public transport exist, such as the closer collaboration of the three PTAs representing the most populous regions of Sweden, i.e. Storstockholms Lokaltrafik (SL), Västtrafik, and Skånetrafiken. Representatives meet often, discuss options and common concerns, and have a close cooperation. Stockholm's County Council has initiated a debate on the use of biogas in public transport services with the participation of actors in biogas production (e.g. Biogas Öst) and municipalities (e.g. the City of Stockholm), as well as an international network of knowledge transfer about ethanol buses with the participation of several countries (e.g. India, Poland) (Böhlin, 2015). Another example is the cooperation of the City of Stockholm in a consortium with 50 European cities, where experiences with public transport are shared and common application for EU grants are submitted (Ericsson, 2015).

Key points for strategy design: The types of technologies to be promoted depend not only on technology and fuel availability, but also on regional characteristics and the type of service to be provided (e.g. city traffic or low-density areas). Knowledge transfer is pivotal and a first step in replicating successful strategies, while also taking into account the case-specific characteristics of each region. Organization of national and international consortia is helpful particularly when it comes to municipalities with low economic or expertise capability. Close cooperation between cities facing similar challenges may be useful in addressing transaction costs.

5. CONCLUSIONS

Our analysis highlights the challenges implied in the shift towards renewable fuels in various Swedish regions. The rapid increase achieved in the use of renewables in buses has been impressive. However, efforts need to be intensified in order to achieve the goals for increased energy efficiency and public transport volume. Energy efficiency has not received the same attention as climate goals and emissions reduction. Energy efficiency can be improved through newer vehicle technologies that reduce energy use and fuel consumption, and/or by increasing the occupancy rates. Lower fuel consumption and higher passenger rates can help reduce the costs of public transport per trip.

By mapping the available data, significant differences could be observed in the deployment of renewable fuels in bus fleets of various regions in the country. Southern regions have reached higher penetration of renewables. Nevertheless, there is no strong correlation between population density or bus transport volume and the share of renewable fuels observed in the fleets.

Political will to promote the decarbonization of public transport has pushed the goals high in the agenda of some regions, taking advantage of fuel tax exemptions that made deployment economically feasible. Procurement requirements for public transport services have been instrumental in promoting the shift towards renewable fleets. The PTAs have freedom to adjust requirements regionally and cooperate with transport operators in designing strategies. This flexibility in procurement design has allowed for consideration of regional capacities and constraints, and local priorities and preferences. Municipalities have become important for innovating and disseminating best practices, as they can develop ambitious strategies and invest in new technologies independently.

The survey conducted among PTA representatives, shows that environmental factors seem to be prioritized when fuel choices are made. There is a strong indication for the interest to switch city routes to electricity as a way to lower emissions, improve energy efficiency, and obtain other benefits such as lower noise and overall improvement of the urban environment. An important future challenge for PTAs and municipalities will be to provide infrastructure, and secure increased supply of electricity from renewable sources for their buses. Biogas contributes to emissions reductions and can be used in suburban routes where less stops are required so that closer to optimal fuel efficiency is achieved. For regional routes where longer fuel range is needed, biodiesel and HVO seem to be a preferred choice so far.

Barriers to increasing renewable fuel penetration are mainly economic and political. A combination of ambitious procurement requirements with economic instruments can help alleviate these barriers. Fuel costs still represent a significant part of the total cost of bus transport and, therefore, the uncertainty surrounding the fuel taxation system beyond December 2015 can potentially slow down the adoption of renewable fuels in public bus fleets in Swedish municipalities. Long-term tax exemption policies may still be needed, especially in the case of HVO. The introduction of environmental bus premiums could have effects, especially for fully electric and hybrid buses.

Swedish public transport strategies have been an international example, and various knowledge transfer initiatives show that sharing experiences is an important aspect of promoting innovative solutions and avoiding shortcomings. The attention given to public transport adds social components to sustainable transport policies, and raises the bar while pushing for innovative technologies. Long-term political vision is important, but the complexity of issues related to transport and mobility should not be underestimated. Sustainable fuel choices for public transport can be recommended or even strongly pursued at expert level, but it is at the political level that stringent targets and design of strategies and instruments take place. Strong policies, together with clear instruments for policy implementation dealing with technological capacity, fuel supply security and costs, and funding for infrastructure development remain important to promote renewable fuels and energy efficiency of regional public bus fleets so that the ambitious national goals can be also achieved.

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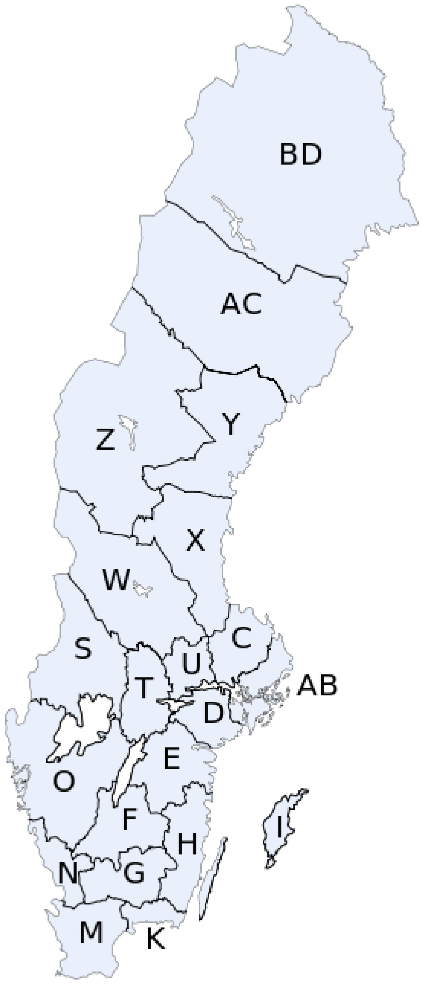
APPENDIX I

List of members of The Swedish Public Transport Association

County / Region	Public Transport Authority (PTA)
Blekinge län (K)	Blekingetrafiken
Dalarnas län (W)	Dalatrafik AB
Gotlands län (I)	Region Gotland, Enhet Kollektivtrafik
Gävleborgs län (X)	Kollektivtrafikförvaltningen X-trafik
Hallands län (N)	Hallandstrafiken AB
Jämtlands län (Z)	Länstrafiken i Jämtlands Län AB
Jönköpings län (F)	Jönköpings Länstrafik
Kalmar län (H)	Kalmar Länstrafik
Kronobergs län (G)	Länstrafiken Kronoberg
Norrbottens län (BD)	Länstrafiken i Norrbotten AB Luleå Lokaltrafik AB
Skåne län (M)	Skånetrafiken
Stockholms län(AB)	SLL, Tillväxt, miljö och regionplanering SLL, Trafikförvaltningen SLL, Waxholms Ångfartygs AB
Södermanlands län(D)	Kommunalförbundet Sörmlands Kollektivtrafikmyndighet
Uppsala län (C)	Kollektivtrafikförvaltningen UL
Värmlands län (S)	Värmlandstrafik AB Karlstads Kommun, Karlstadsbuss
Västerbottens län (AC)	Länstrafiken i Västerbotten AB
Västernorrlands län (Y)	Kollektivtrafikmyndigheten i Västernorrlands län
Västmanlands län (U)	Kollektivtrafikmyndigheten i Västmanland
Västra Götalands län (O)	Västtrafik AB
Örebro län (T)	Länstrafiken Örebro läns landsting
Östergötlands län (E)	Östgötatrafiken, AB



Source: Svensk Kollektivtrafik, 2014a

APPENDIX II

Occupancy rate – bus

County/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

APPENDIX III

Supporting data on fuel emissions and energy content – Data for Stockholm county

Fuel type	Emissions ($gr\ CO_2$/ liter)	Energy content (MJ/liter)	
		Total	**From fossil fuel**
Diesel MK1	2 600	35,28	35,28
Biodiesel (RME)	194	33,09	2,01
Diesel/RME[5]	2 504	35,19	33,95
Ethanol, ED95	140	21,00	2,40
	($gr\ CO_2$ /Nm^3)	(MJ/Nm^3)	
		Total	**From fossil fuel**
Biogas	0	37	0
Natural gas	2 253	42	42

Source: SLL, 2015

[5] Blend of 96 %MK1 and 4 %RME

APPENDIX IV

Questionnaire

Bränsle-alternativ för bussar i kollektivtrafik i Sverige

Denna undersökning genomförs som en del av ett forskningsprojekt vid Kungliga Tekniska Högskolan. Respondenter är intressenter i kollektivtrafiksektorn, dvs. regionala kollektivtrafikmyndigheter, statliga myndigheter och trafikföretag. Syftet med denna undersökning är att samla in uppgifter om faktorer som påverkar andelen förnybara drivmedel i bussar i kollektivtrafiken, samt identifiera "best practice" på regional nivå och politik på nationell nivå som hjälper till att främja användningen av förnybara bränslen för bussar i kollektivtrafiken. Det tar cirka 15 minuter att fylla i enkäten. Obs: Denna undersökning är anonym, om du inte anger något annat.

I. Allmänna frågor

1.Hur stor är befolkningen i din region?
upp till 200 000 invånare
200 001 till 500 000 invånare
500 001 till 1 000 000 invånare
mer än 1 000 000 invånare

2.Hur bedömer du sannolikheten för att Sverige lyckas nå målet 90% förnybara drivmedel i kollektivtrafiken till år 2020?

1 2 3 4 5

1- Inte sannolikt att lyckas … 5-Mycket sannolikt att lyckas

3.Anser du att de nuvarande styrmedel för kollektivtrafiken är tillräckliga för att nå 90% förnybara drivmedel i kollektivtrafiken 2020?

1 2 3 4 5

1-Inte tillräckligt för att nå målet … 5-Helt tillräckligt för att nå målet

II.Bränsle-alternativ

4.Vad är andelen fordonskilometer som körs med förnybara drivmedel i bussar i din region idag?

<10%
<35%
<55%
>55%
Jag vet inte

5.Vilket förnybart bränsle har störst andelen i bussarna i din region?

Biodiesel
Etanol
Biogas
El
Jag vet inte

6.Vad är målet för andelen förnybara bränslen för bussar i din region? Om det inte finns något mål, skriv "Inget mål" i textrutan.

7.Vilket bränsle-alternativ är mest attraktivt inom överskådlig framtid för bussar i din region?

Biodiesel
Etanol
Biogas
El
Other:

8.Varför?

9.Den svenska energipolitiken bygger på tre pelare: ekologisk hållbarhet, konkurrenskraft och försörjningstrygghet. I jämförelse av bränslealternativ, vilket bränsle uppfyller bäst de olika pelare? Du kan välja endast ett alternativ per rad.

	Ekologisk hållbarhet	Konkurrenskraft	Försörjningstryghet
Biodiesel			
Etanol			
Biogas			
El			
Kan inte säga			

10.Om du har ytterligare kommentarer, vänligen skriv dem i textrutan nedan.

11.Vad är det största hindret för att öka andelen förnybara drivmedel i bussar i din region?

Styrmedel för att främja förnybara bränslen för bussar i kollektivtrafiken

12.Följer ni Svensk Kollektivtrafiks branschgemensamma Avtalsrekommendationerna när det gäller om förnybara bränslen i bussar?

Ja
Nej
Jag vet inte
Other

13.Har ni en miljöstrategi dokumentation för kollektivtrafik i din region? Om ja, hur ofta uppdateras den?

Ja, den uppdateras varje år
Ja, den uppdateras varje 2-3 år
Ja, den uppdateras varje 4-5 år
Nej
Jag vet inte
Other:

14.Vilka styrmedel bör införas för att främja förnybara bränslen i bussar i kollektivtrafiken?Välj att beskriva det som du tycker är mest nödvändigt att införa.

15.Finns det någon demonstrationsprojekt för hållbara bussteknik som stöds av eran organisation? Beskriv kortfattat och ange om det är vid planering eller i genomförandefasen.

16.Vilka åtgärder har varit mest framgångsrika för att främja förnybara bränslen i eran region? Beskriv kortfattat.

17.Har ni några ytterligare synpunkter på denna enkät?

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