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Are future renewable energy targets consistent with current planning perspectives?

Abstract

Local examples of how renewable energy targets can be fulfilled in the transport sector without compromising individual mobility will be critical as we approach peak-oil and tougher emission caps in the future. Globally, frontier cities that demonstrate best practice solutions might have an advantage when the situation becomes more acute and the urge for disseminating know-how between cities increases. The issue is complex, since sustainable traffic planning and renewable energy supply need to encompass a multi-stakeholder process, involving potential shifts in individual travel behavior, the development of future vehicle technologies, and requirements on more efficient energy supply chains. One prediction can be made: the transition to a non-carbon society will place immense pressure on the limited, solar, wind and bio energy assets.

One attempt to create a local sustainable city district with zero net contribution to fossil fuel emissions is the 'Stockholm Royal Seaport' (SRS) in Sweden. Here, many of the key elements of a sustainable transport system are being planned for, such as optimum public transport provision, optimal biking/walking conditions, condensed city planning with a mixture of dwellings and office buildings equipped with virtual meeting technologies. Given this assumed 'ideal' situation for a sustainable transport system and the long-term target of 100% renewable energy use by 2030, this study analyzes the questions: 'Is this target within reach, assuming various levels of more sustainable travel patterns?' and if not, 'What else is needed in order to meet target fulfilment?"

The analysis, which is based on a combined forecasting/backcasting approach, comes to the conclusion that even though the SRS district in many respects could be regarded as 'ideal' for target fulfilment and bio-fuel assets in Sweden are favourable, feasible strategies to actually meet the requirements for a non-fossil energy supply are lacking unless the limits on the proportion of renewable energy assets allocated to transport are exceeded. These conclusions will hopefully work as an eye-opener on current planning perspectives and feed the discussion on how to guide development towards meeting the unavoidable renewable energy targets that must be fulfilled.

Keywords: renewable, energy, target, backcasting forecasting, sustainable, planning, bio-fuel, travel behavior.
JEL Classification: Q42, Q50.

Introduction

Background. The transport sector is currently acknowledged to be one of the toughest challenges regarding sustainable development (e.g., Khöler et al., 2009; Marsden & Rye, 2010; Carlsson-Kanyama & Lindén, 1999). Today 78% of Swedish oil consumption comes from transport, and almost 90% of domestic transport is dependent on fossil-based fuels (ET, 2009, p. 28). There are many negative impacts from the current transport system, such as noise, ambient air pollution, traffic accidents and destruction of aesthetic and restorative qualities (Gärling and Schuitema, 2007). The potential socio-economic savings from mitigating these uncontrollable traffic volumes through various travel demand measures and mobility management are thus substantial (Robèrt and Jonsson, 2006). However, from a sustainability perspective, the contribution to climate change[1] and the depletion of oil[2] are the two main reasons why the transport sector needs to decouple from its strong dependence on fossil fuels. For this to be achieved, Vergragt & Brown (2006) conclude that technological, social and structural changes are needed. This view is shared by, for example, Woodcock et al. (2007), who further stress the health benefits of a shift from motorised to physically active transport. The Stockholm Royal Seaport (SRS) project, an urban development located just outside central Stockholm, addresses the question of sustainable development in an ambitious manner. The vision is to become a city area with world class environmental performance and to act as a role model for sustainable city development. This vision is formulated in terms of ambitious targets to become fossil fuel-free by 2030, and to reach a climate-positive contribution (Stockholms Stad, 2010). Consequently, there is a need to steer the projected transport system away from fossil fuel dependence and towards sustainability.

[1] Modern society's anthropogenic contribution to climate change is acknowledged to severely risk the possibility for human survival (Rockström et al., 2009). Intergovernmental Panel on Climate Change (IPCC) recommends a limitation of carbon dioxide emissions to about 450 ppm. This would possibly limit the increase of the global mean temperature to about 2 degrees, which is seen as an upper limit not to be exceeded in order to avoid severe consequences (IPCC, 2007). The probability of reaching this target with current efforts is assumed to be extremely small, and a more likely outcome is an increase in the global mean temperature of about 3 or even 4 degrees (New et al., 2010). This calls for urgent measures to reduce the anthropogenic contribution to climate change and increased efforts to reduce carbon dioxide emissions.

[2] A growing view is that peak oil (i.e., when the consumption rate exceeds the extraction rate), has already been reached or will be reached in the near future (Aleklett, 2009; JOE, 2010; Owen et al., 2010). According to World Energy Outlook for 2010, the peak for conventional oil was in 2006 (IEA, 2010). This means that the more expensive, technologically challenging and risky extraction of unconventional oil must increase for current demand to be satisfied. This can result in increased oil prices and, if dystrophic, a possible world recession (Owen et al., 2010; Rubin, 2009).

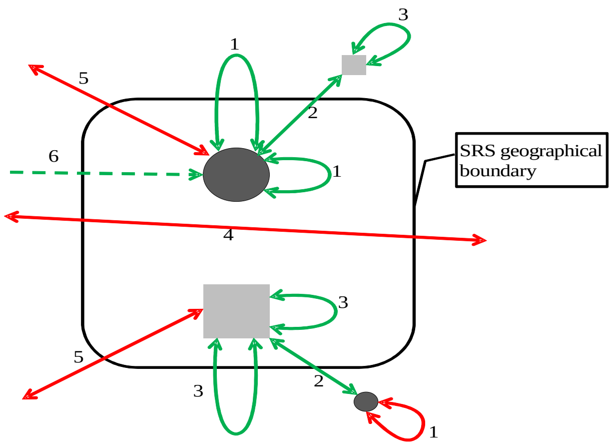
Aim and objectives. This study aims to visualize the boundaries within which such a sustainable transport system could operate. This is done by assessing the future availability of renewable energy and the future technological performance of vehicles. The transport situation of today is described, and the possibilities for some key elements of transport development are forecast. These aspects are then combined and approached from a backcasting perspective to evaluate the possibilities of matching energy use in the transport sector to the available share of renewable domestic energy.

Scope and limitations. Transportation in an urban district consists of many types of trips. In this study the focus is on land trips by residents and commuting and business trips by employees living outside but working in the urban district. Throughout this report, the latter group is referred to as 'employees'. Although this constitutes a major fraction of the transport system in an urban district, some relevant trip types are excluded. A full explanation of included and excluded trip types is given in Table 1 and Figure 1.

Table 1. Included and excluded trip types in the urban district

Trip type	Residents	Employees
1. Private trips (excl. flight/boat)	Included	Not included
2. Commuting trips	Included	Included
3. Business trips	Included	Included
4. Through trips	Not included	Not included
5. Visiting trips (by non residents/employees)	Not included	Not included
6. Road transport of goods*	Included	Not included

Note: *included as the national average per capita.



Notes: circles represent dwellings, boxes represent workplaces. Light grey arrows represent included trips, dark grey arrows represent excluded trips. The numbers by the respective arrows correspond to the trip types in Table 1.

Fig. 1. Schematic description of included and excluded trip types in this study

In SRS the estimated number of built apartments is 10000, which according to the national travel survey (SIKA, 2007) would house 23100 persons. The urban district is also planned to provide 30000 job opportunities. Of these, 4.5%[1] are assumed to be taken up by residents in the urban district. Thus, 28650 employees are assumed to commute to the urban district. The modes of transport analyzed in the present study are trips by car, train (local and long distance), bus (local and long distance) and physically active transport. Thus, trips by flight[2] and boat[3] are excluded. In addition, the impact of motorcycles and mopeds is considered to be marginal[4] and they are therefore also excluded from this study. Energy use from vehicles represents well-to-wheels (wtw) consumption. This includes collection of raw material, production of fuel, transport in the production and distribution chain and fuel consumption by vehicles. The energy use for construction of infrastructure and vehicles is not within the scope of the study.

Methodology and structure. A combination of forecasting and backcasting scenarios is used in the analysis. The forecasts are used to investigate the potential for key elements of transport development towards sustainability. In the backcasting scenarios, the results from the forecasts are combined to investigate potential paths to reach the target of a fossil fuel-free transport system for SRS in 2030. One motive for applying a backcasting approach is to highlight the 'gap' between projected future developments, and the desired target defined for the area.

This paper consists of three sections. Section 1 identifies the backcasting target constraints. This is done by assessing the domestic renewable energy available for transport in SRS in 2030, and the assumed performance of the constituents in the transport system (i.e., the different modes of transport). Together these define the boundaries within which the transport system must operate if the target is to be reached.

Section 3 presents the forecast scenarios, where the current situation and a business as usual (b.a.u.) scenario are first described. Three deviations from the b.a.u. situation are then investigated, all of which would contribute to a more sustainable transport sys-

[1] According to the CERO database (for reference, see Robèrt, 2009), 18% of employees commute less than 5 kilometres one-way (this is approximately the furthest distance in SRS). In this study it is assumed that one-quarter of these live inside the urban district.

[2] Flight is an important factor for sustainable transportation. However, it has distinctly different features compared with land-based transportation, which makes it appropriate to treat flight separately. Furthermore, the development of SRS has little direct impact on trips by flight.

[3] As with flight, trips by boat differ substantially from trips on land. In addition, trips by boat only constitute a small proportion of the average annual passenger-kilometers.

[4] Together they make up about 0.2% of all passenger-kilometers by residents in the City of Stockholm (SIKA, 2007).

tem in relation to the available share of domestic renewable energy. Here we use the word 'theoretical potential' to mean the maximum potential that could be reached under some defined considerations.

Section 4 approaches the transport system from a backcasting perspective, where alternative paths to target achievement are investigated. Here the results from the forecast scenarios are combined and the most promising are further analyzed in relation to the target of a fossil fuel-free transport system supplied by the SRS's share of domestic renewable energy.

1. Backcasting target constraints

1.1. Renewable energy potential in 2030. It is unlikely that a sustainable transport system could supply its energy demand within its local system boundaries, even in a dense urban district. A more relevant limit is, therefore, to look at the available domestic energy assets (Robèrt et al., 2007). Hence, the national renewable energy potential that can be set aside for the transport sector is assessed and discussed. This potential is then scaled to demand from residents and employees assumed to operate within the geographical boundaries of SRS. The sources of renewable energy that are assumed to be available for transport in 2030 are electricity, biogas from waste and fuels produced from renewable biomass.

1.2. Potential for renewable electricity. In Sweden the electricity demand is assumed to be relatively constant if the transport sector is excluded. The long-term forecast by the Swedish Energy Agency projects an increase of 3% from 2007 to 2030 (ET, 2011, p. 3). Electricity in Sweden is mainly produced from hydro and nuclear power, while the combustion of fossil fuels for electricity production is less than 3% (ET, 2009, p. 28). If nuclear power is replaced with renewable sources, the supply of renewable electricity available for transportation would decrease due to increased demand from other sectors. However, today nuclear power is incorporated as a constant, non-increasing part of Sweden's energy mix. This assumption is also used in this study, although nuclear power is not a renewable energy source.

Given these reasons, the increase in renewable electricity produced could reasonably be fully allocated to the transport sector. A literature review by the Swedish Energy Agency (ER, 2007, p. 21) that assessed future potential sources of renewable electricity concluded that the largest contribution to an increase in renewable electricity will come from wind, solar and biomass. In this report the increased use of biomass is assumed not to be used for production of electricity to any great extent. Rather, it is seen as a source of bio fuels and discussed later in this section. This leaves the potential to increase renewable production of electricity to wind and solar power. The governmental target regarding wind power is to reach production of 108 PJ by 2020 (ER, 2007, p. 45). In 2008 the production reached 7.2 PJ (ES, 2010, p. 3), so a reasonable assumption is that wind power could contribute 100 PJ of electricity by 2030. The current contribution of electricity from photovoltaics is marginal and only derives from some individual installations. However, photovoltaics are seen as a future component of Swedish electricity production and a reasonable potential is thought to be about 36 PJ in 10-15 years (ER, 2007, p. 21). There are studies showing future potential for photovoltaics of over 70 PJ (IEA, 2002; Kjellson, 2000), but these studies depend on questionable amounts of building surface areas for photovoltaics and are therefore not used in the present analysis. Another possible technology for electricity production is wave power, but this technology is not yet established on the market and its potential and competitiveness are difficult to estimate. Therefore, this study does not include wave power as a future contributor to Swedish electricity production, although its potential is estimated to be about 36 PJ. To summarize, the nationally produced renewable electricity available for transport in 2030 is assumed to amount to at least 136 PJ.

1.3. Potential for biogas. In 2009, 1.8 PJ of biogas was upgraded to vehicle fuel (ES, 2010, p. 5). Most of this biogas was used by buses in public transport. Studies of the biogas potential from waste products in Sweden under the current economic situation have estimated this to be roughly 38 PJ (Linné et al., 2008; Lantz & Börjesson, 2010). If the economic aspects are set aside and most of the available waste is used, the potential reaches 55 PJ. Process optimization and technical development are other aspects that could increase the biogas potential. Together they could increase the biogas yield by 33% (Linné et al., 2008). An even greater potential is available if almost all left-over products from the forest industry are collected and processed, which could increase the potential by another 210 PJ (Linné et al., 2008). However, this is unlikely to happen due to technological constraints (Linné, 2008), so the 210 PJ potential is therefore disregarded here. A combination of favourable economic conditions for biogas production and increased process efficiency could therefore increase the reasonable potential. This study assumed that 40 PJ of biogas is produced in 2030 and that all of this is available to the transport sector.

1.4. Potential for biomass. The potential increase in biomass production for energy purposes has been estimated in several different reports. Lindfeldt et al. (2011) summarize the results and estimate a reasonable potential available for transportation of 100 PJ in 2025. This potential is based on the assumption that the full ecological potential is used, due to promotion policies and economic measures. Furthermore, this potential considers the need for biomass as an energy carrier for other sectors. There is no single answer regarding the type of biomass with the best energy efficiency. According to Börjesson (2007), the production potential of bio fuels from biomass largely depends on type of crop, cultivation system, type of arable land and geographical location. This suggests that bio fuels, as today, will origin from several different types of biomass in the future. The relative contribution from different types of biomass to bio fuel production in 2030 will depend on future economic, political, social and ecological factors. The accuracy of estimating this distribution will therefore be unsatisfactory. Although this is an important question, an accurate result will not contribute much to the aim of this study. Therefore, it is assumed here that the type of biomass in the potential is unspecified. The question of energy efficiency is instead treated as a part of future vehicle technology, where various bio fuels from different sources result in differences in vehicle performance.

To evaluate the available share of renewable energy for SRS, it is assumed here that every inhabitant in Sweden is assigned an equal share. For the group of employees only, the share used by work-related trips is included. This share is assumed to be 36% of an individual's total share[1]. The number of inhabitants in Sweden in 2030 is assumed to be 10 million (Statistics Sweden, 2009, p. 1). For reasons discussed above, the full energy potential in Sweden from renewable electricity, biogas from waste and bio fuels from biomass is assumed to be 226 PJ, Table 2 presents the details of the energy potential and the corresponding share for SRS.

Table 2. Energy potential available for the transport sector in 2030

Energy source		National potential in 2030 (PJ)	SRS share of national potential in 2030 (TJ)*
Electricity		136	454
Of which:	from wind	100	334
	from photovoltaics	36	120
Biogas from waste		40	134
Biomass		50	167
Total		226	755

Notes: *Full per capita share for SRS residents (23100 individuals) and 36% of per capita share for employees (20650 individuals), which according to the national travel survey (SIKA, 2007) is the share of passenger-kilometers for work-related travel. For more details see section above.

2. Technology and fuel consumption in 2030

2.1. Electricity supply for cars and trains. The consumption of electricity in the transport sector is likely to be by cars and trains in 2030. For electric cars, a distinction can be made between full electrical vehicles (EV) and plug-in hybrid electrical vehicles (PHEV). Recent developments suggest that PHEV will dominate the market for electric vehicles, as they overcome the problem of driving range, which is seen as a major barrier to EV gaining market share. The future performance of EV and PHEV is evaluated by van Vliet et al. (2011), who suggest that the electric energy use per vehicle-kilometer with future technology is 0.34 MJ. To include the well-to-wheels (wtw) energy use, the loss in distribution needs to be considered. According to JRC (2007), this loss is 3% for electricity produced from wind turbines. In this study it is assumed that electricity from photovoltaics suffers the same loss in distribution. Thus, the wtw energy use for electric vehicles (electric mode for PHEV) reaches 0.39 MJ per vehicle-kilometer. For transport with train, a distinction is made between local and long distance trips. Today the energy use for these is 0.44 MJ (SL, 2011) and 0.29 MJ (SJ, 2009) per passenger-kilometer, respectively. Technological developments, increased occupancy rate and environmentally friendly driving techniques are all aspects that could increase the energy efficiency of transport by train (Banverket, 2006). In this study it is assumed that these aspects, excluding occupancy rate, could increase the energy efficiency in 2030 by 10%. This can be compared with the European rail energy target of 6% by 2020 (Banverket, 2006). The total, including loss in production, is an energy use of 0.41 MJ and 0.27 MJ per passenger-kilometer for local and long distance train trips, respectively.

2.1.1. Biogas potential in cars and buses. The possibilities to use biogas as fuel for passenger transport are mainly embodied in cars and buses. The energy effi-

[1] According to the national travel survey (SIKA, 2007), 36% of total passenger-kilometers in Sweden are work-related. This percentage is assumed to be unchanged in 2030.

ciency of biogas cars depends on the biogas source. In a wtw analysis (JRC, 2007) three sources are evaluated; municipal waste, dry manure and liquid manure. The range of energy efficiency for these sources varies from 2.61 to 2.74 MJ per vehicle-kilometer. For biogas buses, current tank-to-wheel (ttw) energy use per passenger-kilometer is 1.1 MJ (SL, 2010). The well-to-tank (wtt) energy loss for producing biogas ranges from 87% to 97%, depending on the source (JRC, 2007). This, together with an assumed technological development regarding energy efficiency of 16%[1], means that a biogas bus in 2030 consumes between 1.73 and 1.82 MJ per passenger-kilometer, assuming the same occupancy rate as today.

2.1.2. Bio fuels from biomass in cars and buses. Bio fuels are mainly assumed to be used in cars and buses. As discussed above, the energy efficiency of bio fuels depends on many aspects. The well-to-wheels analysis of future automotive fuels and powertrains in the European context (JRC, 2007) presents energy use and greenhouse gas emissions for a wide range of potential options. Table 3 presents the wtw energy efficiency per vehicle-kilometer by car for relevant types of biomass and fuel types falling within the scope of this study. As can be seen, the energy efficiency varies widely, with DME produced from black liquor being the most efficient and ethanol from wood the least efficient. There are also large differences within single biomass to fuel categories depending on different pathways and use of by-products. Table 3 highlights the possibilities and importance of optimising the energy efficiency in bio fuel production. For long distance bus trips, the energy use is estimated to be 0.9 MJ per passenger-kilometer (Augustinsson, 2008). The technical improvement of diesel engines by 9.5% (JRC, 2007), together with an approximate energy loss in wtw production of bio fuels of from 55% to 130%[2], gives a range in energy use of 1.26 MJ to 1.87 MJ per passenger-kilometer in 2030, assuming unchanged occupancy rate. For local bus trips with ethanol as fuel, today's energy use per passenger-kilometer is an estimated 1.1 MJ (SL, 2010). Assuming a technological improvement of 15% fuel efficiency (JRC, 2007) and a wtw production loss for ethanol of 122% to 195%[3], the wtw energy use in 2030 is assumed here to range from 2.08 to 2.76 MJ per passenger-kilometer.

[1] Due to downsizing and turbo-charging of vehicle engines and mixing of gas with air, as discussed in JRC (2007), this study assumed that these improvements are applicable for engines used in buses.

[2] The range of energy loss, depending on pathway and use of by-products, is from 0.55 MJ/MJ to 1.30 MJ/MJ, where DME produced from black liquor performs best and bio-diesel from rapeseed has the poorest energy conversion rate (JRC, 2007).

[3] The range of energy loss for production of ethanol, depending on pathway and use of by-products, is from 1.22 to 1.95 MJ/MJ, where wheat as source with straw as input energy performs best and wood as source has the poorest energy conversion rate (JRC, 2007).

Table 3. Estimated wtw energy efficiency per vehicle-kilometer of cars (with hybrid technology) with various types of biomass and fuel types

Biomass to fuel	wtw energy efficiency (MJ/vehicle-km)
Sugar beet to Ethanol	3.74-4.66*
Wheat to Ethanol	3.62-4.39*
Wheat straw to Ethanol	3.78
Rapeseed to FAME	3.19-3.35*
Wood to DME	2.92
Wood to Synthetic diesel	3.19
Wood to Ethanol	4.80
Black liquor to DME	2.19
Black liquor to Synthetic diesel	2.78

Notes: *Differs depending on alternative pathways and use of by-products.
Source: JRC (2007).

Table 4 summarizes the energy use for the respective modes of transport in 2030 as assumed in this study. The 'high' value represents the situation where the most energy-efficient source and pathway are used to produce renewable fuel. The 'low' value represents the situation where the least energy-efficient source and pathway are used.

Table 4. Summary of energy use per kilometer by transport mode in 2030

Fuel	Energy use (MJ/km)*	
	High	Low
Electricity		
Car	0.385	0.385
Long distance train	0.269	0.269
Local train	0.408	0.408
Biogas		
Car	2.61	2.74
Local bus	1.73	1.82
Bio fuel		
Car (with hybrid technology)	2.19	4.80
Long distance bus	1.26	1.87
Local bus	2.08	2.76

Notes: * Values for car are vehicle-kilometers, values for other transport modes are passenger-kilometers. For sources and explanation see section above.

2.1.3. Biomass assets for road transport of goods. Road transport of goods is a large consumer of energy and is projected to grow greatly in the future. SIKA (2005, p. 19) has projected a 21% increase in ton-kilometers over the course of 20 years (2001-2020), increasing from 32 to 39 billion ton-km in Sweden (Trafa, 2010, p. 3). Future trucks powered by electricity are unlikely due to the long distances and heavy loads involved, but hybrid technologies are feasible, which together with regenerative braking technologies could reduce fuel consumption by 20%.

Today the ttw energy use is approximately 0.65 MJ/ton-km (Lennert, 1999). Assuming that the relationship between today's diesel cars and future electric hybrid cars using renewable fuels (i.e. ethanol, biodiesel, synthetic diesel or DME) can be directly applied to diesel trucks, the future ttw energy use for trucks could vary between 0.52 MJ/ton-km (ethanol) and 0.60 MJ/ton-km (DME)[1]. In addition, the energy use in the wtw process for the fuels needs to be considered. For DME, the lowest loss during production corresponds to 55% (with black liquor as origin) giving a total wtw energy use per ton-km of 0.80 MJ. For ethanol the loss corresponds to 130%, which gives a wtw energy consumption per ton-km of 1.76 MJ. Thus, the 39 billion ton-km assumed to be transported in Sweden 2030 would result in energy use from road transport of goods of 31 to 69 PJ.

As for cars, one renewable fuel is not likely to be totally dominant for trucks. Thus it is not reasonable to believe that the lower number will be reached (which would demand that only DME produced from black liquor is used as fuel for trucks). In this study it is assumed that a reasonable energy use of biomass from road transport of goods in 2030 is 50 PJ. Consequently, the biomass potential available for passenger transport is decreased from 100 PJ to 50 PJ.

3. Forecast scenarios

This section starts by assessing today's travel behavior in the City of Stockholm and uses the results to calculate the properties of the transport system in SRS. Thereafter the b.a.u. development is described, which gives the properties of the transport system in SRS in 2030. Finally, deviations in three key elements from the b.a.u. situation are investigated.

3.1. The transport system in Stockholm Royal Seaport. *3.1.1. Data sources*. Two databases are used to assess the travel behavior. For residents and business trips, the national travel survey conducted in 2005-2006 is used (SIKA, 2007). The data are weighted to an average day and scaled to an annual value. Furthermore, the data are restricted to include trips by residents in the City of Stockholm (8697 trips by 2958 residents) and employees with their workplace in the City of Stockholm (460 trips by 2272 employees). For employee commuting trips, a specific database named CERO (Climate and Economic Research in Organizations) is used. This database is based on surveys of a number of public and private companies conducted between 2007 and 2010 (for reference, see Robèrt, 2009). For the purposes of the present study, only companies located in central Stockholm are included, resulting in information gathered from 8820 individuals.

3.1.2. Travel demand today. The annual travel demand is assessed specifically for residents and employees, as well as for the different trip types and transport modes. The results are presented in Table 5. The small difference in total annual trip distance between residents and employees is explained by the contribution from those that do not work. This group generally has less annual distance travelled. Since they are residents but not employees, the annual trip distance is affected.

Table 5. Detailed description of travel behavior for trip types included in this study

Trip type		Annual distance travelled	
		Average resident	Average employee
Private trips (exc. flight/boat)		7487 p.km	Not included
Of which with:	Car	63%	
	Local bus	5%	
	Local train	8%	
	Long distance bus	5%	
	Long distance train	13%	
	Physically active	6%	
Commuting trips		2383 p.km	7468 p.km
Of which with:	Car	41%	49%
	Local bus	8%	14%
	Local train	29%	26%
	Long distance bus	2%	1%
	Long distance train	14%	6%
	Physically active	6%	4%
Business trips		1084 p.km	2926 p.km
Of which with:	Car	82%	81%

[1] The ttw energy use is 8% better for ethanol cars with hybrid technology compared with today's diesel cars. For DME the energy use is 20% more efficient (JRC, 2007).

Table 5 (cont.). Detailed description of travel behavior for trip types included in this study

Trip type		Annual distance travelled	
		Average resident	Average employee
Business trips			
	Local bus	1%	2%
	Local train	4%	3%
	Long distance bus	0%	0%
	Long distance train	12%	13%
	Physically active	1%	2%
Total (trips*)		10954 p.km	10394 p.km
Of which with:	Car	60%	58%
	Local bus	5%	11%
	Local train	12%	19%
	Long distance bus	4%	1%
	Long distance train	13%	8%
	Physically active	6%	3%

Notes: * see Table 1 and Figure 1 for explanation of included and excluded trips.
Sources: National travel survey (SIKA, 2007) and CERO database (for reference, see Robèrt, 2009).

In the case of SRS, which is estimated to accommodate 23100 residents and 28650 employees, the total travel demand would correspond to 551 million passenger-kilometers. The relative contribution from residents, employees and different modes of transport is shown in Table 6.

Table 6. Today's travel demand in Stockholm Royal Seaport

		Residents	Employees	Total
Total annual travel demand		253 million p.km	298 million p.km	551 million p.km
Of which with:	Car	60%	58%	59%
	Local bus	5%	11%	8%
	Local train	12%	19%	16%
	Long distance bus	4%	1%	2%
	Long distance train	13%	8%	10%
	Physically active	6%	3%	4%

3.1.3. Business-as-usual scenario for passenger transport. Using a modest projection in traffic analyses made by the City of Stockholm (Stockholms Stad, 2004) and a national study (SIKA, 2005, p. 19), future travel demand can be projected. Some of the projections only include the period of 2001-2020 and the same trends are assumed here to be valid between 2020-2030. In this scenario, the total travel demand in SRS increases by 5% per capita to 578 million passenger-kilometers, see Table 7.

Table 7. Travel demand in Stockholm Royal Seaport in the business-as-usual scenario (difference from today's situation in brackets)

		Residents	Employees	Total
Total annual travel demand (million p.km)		270 (+7%)	307 (+3%)	578 (+5%)
Of which with:	Car	59%	59%	59%
	Local bus	4%	9%	7%
	Local train	10%	17%	14%
	Long distance bus	3%	1%	2%
	Long distance train	17%	11%	14%
	Physically active	6%	3%	4%

3.1.4. Market share of electric vehicles. According to the Swedish energy agency (ER, 2009, p. 20), a high-range scenario for PHEV market penetration is almost 2 million cars in 2030, which would correspond to about 40% of the total amount of cars in Sweden. Assuming that an average PHEV runs on electricity for 70% of the total vehicle-kilometers, 28% of the total annual passenger-kilometers would use electricity as energy source. In this study it is assumed that 30% of the passenger-kilometers by car use electricity as energy source. This figure could be achieved by an increased share of PHEV, an increased share of electric drive for the PEHVs, or a combination of both.

3.2. Forecasting scenarios of changed travel behavior. Three different deviations from the b.a.u. development are described below. The three aspects analyzed are intended to cover key elements of the transport system which could contribute to more sustainable development. For each element, the theoretical potential is estimated as maximum potential, which is assumed to correspond to an ideal situation for the respective aspects of travel behavior. Thus, this maximum potential is not a likely development by 2030, which is the time horizon in this study, but more a quantification of the absolute potential of the respective factors. Three more reasonable situations are presented (i.e., low, medium and high success rates). The low success rate represents quite a modest increase towards the maximum potential for the respective aspects. However it is obvious that this level will not be reached without major efforts (e.g., the projection for use of public transport points at a decrease rather than an increase). The medium success rate represents an even larger step towards a sustainable transport system, and would consequently demand larger and more ambitious measures for the respective aspect. Finally, the high success rate is believed to be possible, although challenging. Attaining the high success rate in any of the three aspects analyzed would mean the SRS district becoming one of the top performers in the world in terms of sustainable travel behavior. The results are presented as the use of biomass potential when biogas is fully used. As described above, the share of passenger-kilometers by car with electricity as fuel is assumed to be 30% throughout.

3.2.1. Increased use of physically active transport. The environmental program for SRS expresses a clear prioritisation of physically active transport. Optimal design of infrastructure within SRS as well as good connections to other traffic nodes are seen as key elements in the development of the urban district (Stockholms Stad, 2010). The use of physically active modes of transport has many benefits. It contributes to neither carbon dioxide emissions nor energy use. In addition, it has positive health effects (Woodcock et al., 2007; 2009). Promoting physically active modes of transport is also a socio-economically profitable investment, according to Lindmark (2008). From publications by Rietveld & Daniel (2004) it is evident that the Netherlands is a good role model when it comes to physically active modes of transport. In terms of passenger-kilometers by physically active modes of transport, the Dutch share is 104% higher than that in Sweden. The current trend in Stockholm is positive, however, with an approximately 50% increase in the number of trips by bicycle from 2002 to 2007 (Isaksson & Karlsson, 2010). In this study, the maximum potential for physically active modes of transport is assumed to be 10% of the total passenger-kilometers. As an example, this would correspond to all trips shorter than 7 kilometers, or half of all trips shorter than 13 kilometers (SIKA, 2007). Topographical and metrological conditions are major factors for the use of physically active modes of transport (Winters et al., 2010; Rietveld & Daniel, 2004). In Stockholm, the flat topography is beneficial for physically active transport but the metrological conditions, with cold, snowy winters, limit the chances of reaching the maximum potential. Table 8 presents the effects of different success rates in relation to the potential. The increase is specifically applied to the respective trip types as described in Table 5. Furthermore, the increase in passenger-kilometers with physically active transport is assumed to decrease the use of cars to a similar extent.

Table 8. Use of energy potential in increased use of physically active modes of transport scenario

Share of p.km. with physically active transport		B.a.u. 4.4%	Low 5%	Medium 6%	High 8%	Maximum 10%
Use of biomass potential*	170%	168%	165%	158%	151%	100%
	375%	370%	363%	348%	332%	214%

Notes: * With the biogas potential fully used and share of passenger-kilometers by car powered by electricity of 30% and 20% biomass for high and low energy efficiency, respectively.

3.2.2. Increased use of public transport. After physically active transport, the use of public transport is the next highest priority in SRS. The feeling of 'just outside the door' for public transport is thought to be important (Stockholm Stad, 2010). The use of public transportation is seen as an efficient way to reduce energy use and carbon dioxide emissions. In Stockholm today, local public transport is well established and frequently used[1]. In theory, it is possible to shift almost all trips from car to public transport. In practice, of course, this is not reasonable. In this scenario, the maximum potential for a shift of trips with car to public transport is assumed to be 50%, although lower success rates are probable. Eriksson et al. (2010) evaluated the effect of substantial push and pull measures[2] to reduce car use and promote transport with local and long distance trips by bus and train and found a possible decrease in car use of

[1] 21% of total passenger-kilometers for residents in the City of Stockholm compared with 7% for an average Swede (SIKA, 2007).

[2] The push measure includes a 50% reduction in the price of local and long distance public transportation, and increased trip frequency for local public transportation. The pull measure includes raising the tax on fossil fuels by about 50%.

28%. However, the majority of this decrease in car use was the result of a shift to local public transport. To increase the sensitivity of the scenario, a distinction is made here between short and long trips by car. These are thought to be possible to shift to trips by local or long distance public transport, respectively. The distance for a short trip is set to 40 kilometers[1]. For every trip type included as described in Table 5, the share of passenger-kilometers by car belonging to short or long trips is assessed (see Table 9).

Table 9. Share of short (< 40 km) and long (> 40 km) distance trips by car for respective trip type

	Residents		Employees	
Trip type	Short	Long	Short	Long
Private	22%	78%		
Commuting	73%	27%	57%	53%
Business	24%	76%	23%	77%

In the scenario calculations the decrease in car use is proportionally added to local and long distance trips by public transport[2]. Table 10 gives the effect for different success rates in relation to the b.a.u scenario.

Table 10. Use of biomass potential in scenario for increased use of public transport

Decrease of car use compared with b.a.u.		B.a.u. 0%	Low 5%	Medium 10%	High 20%	Maximum 50%
Use of biomass potential*	High energy efficiency	170%	163%	156%	135%	100%
	Low energy efficiency	375%	359%	343%	394%	214%

Notes: * With the biogas potential fully used.

3.2.3. Decreased demand for travel. To achieve sustainable transport, a fundamental aspect is to develop urban infrastructure in a way that promotes less and shorter travel. In SRS, an aim is that it should not be essential to travel in order to sustain everyday life (Stockholm Stad, 2010). Several different measures have been purposed to reduce travel demand (i.e., decrease annual average passenger-kilometers). Telecommuting, car-sharing and ride-matching could reduce commuting and business trips, e-commerce could reduce private trips for shopping and increased urban density could shorten the distance of trips, thus reducing passenger-kilometers.

Evaluating the effects of measures aimed at reducing travel demand is difficult and includes many factors. One example is that the freed time and economic resources resulting from avoided trips could be used to perform other trips, thus counteracting the aim of the measure (i.e., rebound effects). Another aspect is that although one trip purpose is removed, many trips include several purposes, so the avoided trip might have no effect on average passenger-kilometers. The effect of available travel reduction strategies has been evaluated by Marshall and Banister (2000), who found 'small, but in most cases significant' effects. IEA (2003) estimates that a combination of different focused and aggressive policy measures could reduce travel demand by 10%-15% in 10 years' time. The maximum potential for decreased travel demand is assumed to be 15% in this study, and in the calculations the reduction is assumed to be evenly distributed amongst trip types and modes of transport. Table 11 presents the effects on use of biomass potential for increasing success rates of decreased travel demand.

Table 11. Use of biomass potential in scenario for decreased travel demand

Decrease in p.km. compared with b.a.u.		B.a.u. 0%	Low 2.5%	Medium 7.5%	High 10%	Maximum 15%
Use of biomass potential*	High energy efficiency	170%	164%	153%	147%	135%
	Low energy efficiency	375%	362%	336%	323%	297%

Notes: * With the biogas potential fully used.

3. Backcasting scenarios for target achievement

To investigate potential paths to target achievement (i.e., a fossil fuel-free transport system supplied by domestic renewable energy), the most promising combinations of changes in travel behavior are assessed below. Because of questionable feasibility until 2030, the maximum potential of the respective aspects of changed travel behavior in the forecast scenarios is not incorporated in the analysis. There remains a total of 27 combinations (i.e., low, medium, high for the respective forecast scenario) of changed travel behavior. The most promising combinations are defined as less than 125% use of biomass potential with the highest energy efficiency. Evidently, not even high success rates in all the individual scenarios and the most energy-efficient production of renewable fuels will meet the target (see Table 12).

[1] The 95 percentile of the distance for trips by local public transportation for residents in the City of Stockholm is 38 kilometers.

[2] For example, if a resident's private trips are reduced by 100 kilometers, 22 and 78 kilometers are added to local and long distance public transportation, respectively.

Table 12. The most promising combinations of the individual scenarios of changed travel behavior

Success rate of scenario*			Use of biomass potential**	
Physically active	Public transport	Decreased travel demand	High energy efficiency	Low energy efficiency
Low	High	Medium	125%	273%
High	Medium	High	124%	272%
Medium	High	Medium	122%	268%
Low	High	High	120%	262%
Medium	High	High	117%	257%
High	High	Medium	117%	257%
High	High	High	112%	249%

Notes: * See forecast scenarios for explanation of each success rate; **with the biogas potential fully used.

As can be seen from Table 12, success in increased use of public transport has the largest effect on the performance of the transport system. All except one of the most promising combinations includes high success rate for public transport. The large effect of difference in energy efficiency suggests that high energy efficiency must be reached for target achievement to be remotely possible. The results in Table 12 further suggest that additional measures must be undertaken in order for the target to be achieved. The scope of this study encompasses three additional aspects that could contribute to decreased energy demand from the transport system. The first is increased technical development resulting in a higher degree of energy efficiency than initially assumed. The second is if the share of passenger-kilometers by electric cars were to increase even further than the 30% assumed. The third aspect is if the road transport of goods sector were to reduce its energy demand from the assumed 50 PJ.

Table 13 gives a detailed breakdown of the extent to which different additional aspects must develop for the SRS transport system to achieve the target of a fossil fuel-free urban district in 2030.

Table 13. Extent of additional aspects required to achieve a fossil free-transport system for SRS in 2030, assuming the highest energy efficiency is realized

Success rate of scenario*			Target achieved if...		
Physically active	Public transport	Decreased travel demand	...energy efficiency increases by an additional	...share of p.km by electric car increases from 30% by an additional	...road transport of goods decreases its energy demand (50 PJ) by an additional
Low	High	Medium	13%	12%	24%
High	Medium	High	13%	12%	24%
Medium	High	Medium	12%	11%	22%
Low	High	High	11%	10%	19%
Medium	High	High	10%	9%	17%
High	High	Medium	10%	9%	17%
High	High	High	7%	7%	12%

Note: * See forecast scenarios for explanation of each success rate.

Note that only one of the 'target achieved' options in Table 13 has to be used to reach the target. For example, in the case of the first row in Table 13, the target would be met by: (1) an additional 13% energy efficiency improvement in vehicles; or (2) an increase in the share of passenger-kilometers by electric cars from 30 to 42%; or (3) a decrease in the energy demand of road transport of goods in Sweden from 50 to 38 PJ. All three additional aspects are related to their respective parts in the scenario. For instance, in the first row of Table 13, the 13% increase in energy efficiency of all vehicles would then relate to the values of *X* KJ/p.km for cars, *Y* KJ/p.km for buses, etc. (see Table 4). In the case of the share of passenger-kilometers by electric cars, it relates to the scenario that 30% of all trips by car are undertaken using an electric car. The increase needed to achieve the target would then require an increase from 30% of all trips by car to 42%. Finally, the required percentage decrease in energy demand from road transport of goods corresponds to the scenario-estimated value of 50 PJ.

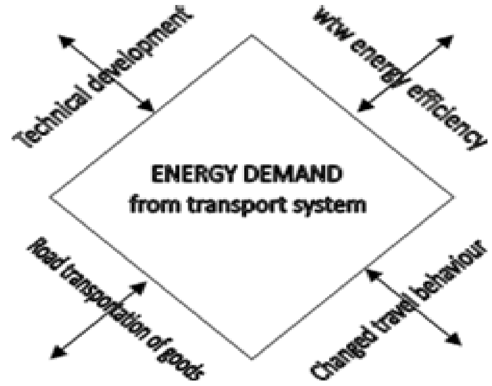
The results in Table 13 must be seen in the light of the already tough demands on the transport system. For the least favourable development in Table 13, these tough demands mean a 22% increase in physically active transport from today's level, a increase in total passenger-kilometers by public transport from 37% today to 48% in 2030, and a decrease in travel demand of 6% compared with today, thus counteracting the projected increase in travel demand. To analyze the difficulty of the additional aspects of meeting the target, the baseline of each individual option is related to the scenario value. The difference between them is then related to the additional percentages to reach the target.

4.1. Energy efficiency increase. It is possible that the estimated energy efficiency for production of fossil free-fuels and car engines could develop faster and further than assumed in the forecast scenarios. This would result in lower wtw energy use and bring the transport system closer to target achievement. For the target to be achieved for all combinations in Table 12, the wtw energy efficiency must be increased by an additional 13% for all travel modes compared with the assumed situation in the forecast scenarios. In relation, the increase in fuel efficiency from "technology-based" improvements is estimated to be 9.5% for diesel cars, 15% for petrol cars and 16% for biogas cars (JRC, 2007). Thus, an additional increase in energy efficiency of between 7% and 13% seems unlikely.

4.2. Electric car passenger-kilometers. Another aspect is if the share of passenger-kilometers by electric car could be increased compared with the business-as-usual scenario. The increase could come from a larger market share of PHEV, a larger share of vehicle-kilometers run in electric mode (e.g., due to better charging possibilities or adapted travel behaviour), or a combination of both. To reach the target for all of the combinations in Table 12, the share of passenger-kilometers by car with electricity as fuel must increase by an additional 7%-12% over the 30% assumed. As discussed in the section on market share of electrical vehicles, 30% is already a high scenario and not at all an obvious situation. Further increasing the share of electric vehicle-kilometers would therefore be a challenging task.

4.3. Reduction of the energy demand for road transport of goods. The share of renewable energy consumed by road transport of goods could be decreased by, e.g., a shift to transport by rail, increased occupancy rate and further increases in energy efficiency.

If all combinations in Table 12 were to reach the target of a fossil fuel-free transport system, the energy use from road transport of goods in Sweden would have to decrease from 50 PJ to between 37.5 and 44 PJ. Consequently, many aspects would have to develop in a greatly advantageous way for the target of a fossil fuel-free transport system to be realized, as visualized in Figure 2.



Notes: All of these need to be addressed for target achievement in SRS.

Figure 2. Relationship between the different aspects affecting the possibility for the transport system to operate within the boundaries of fossil fuel-free energy supply

Discussion and conclusions

The aim in the city district of Stockholm Royal Sea Port is to develop one of the world's leading sustainable transport role models, free from fossil fuels in 2030. In this study we use the ambitious target to analyze the prospects and requirements for such a transport system's proportion of renewable energy supply, making the study relevant also for the transport sector at large. The combined forecasting/backcasting approach highlights the challenges of planning for a target that will sooner or later be the highest priority on every city planner's agenda around the world.

The results presented here suggest that even in a city district such as this, where the circumstances in many respects are ideal, not even the improvements in sustainable travel behavior and high energy efficiency rates are sufficient to reach the target of a fossil fuel-free transport system in 2030 (Table 13). The single most important aspect for the possibility to reach such a transport system is to optimize the wtw energy efficiency for bio fuels from biomass. Poor energy efficiency leaves little hope of matching demand and supply of renewable energy for transport. To reach the target, additional aspects (i.e., energy efficiency, electric cars and road transport of goods) must also develop in a satisfactory way.

Based on the relationships between the different aspects analyzed in this study (technological development; wtw energy efficiency; changed travel behavior; road transport of goods (Figure 2)), we can draw some final conclusions. First, since the scenarios in this study show that many aspects are pushed towards their maximum potential in order to reach the target, it is important that all of them are addressed in an ambitious manner. Compromising on one aspect puts higher pressure on the others. Second, it is clearly extremely important to inform stakeholders in the planning process about the vast challenge involved in fulfilling the requirements to operate within the boundaries of a renewable energy supply. Otherwise there will be a gap between target setting and realistic and feasible strategies toward target fulfilment. Finally, there is a need for long-term actions and the introduction of incentives for innovations, new systems for technological development and new business models optimising the whole chain of renewable energy supply and demand. There is also a need for more local frontier cities such as SRS, where sustainable transport planning is considered earlier in the urban planning process, creating new relationships between workplaces and homes to change travel behavior in sustainable directions.

Regardless of the city in question, this study shows that if renewable energy targets are to be met, a long-term and rigorous planning process involving politicians on different levels, urban planners and new business developments is needed to create possibilities for all important aspects.

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