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Business case for electric road

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Abstract

Electrified roads have the potential to reduce carbon dioxide emissions from the transport sector. Where long-distance heavy traffic is concerned, there is actually no cheaper alternative which is equally energy-efficient, has such low carbon dioxide emissions and for which the energy supply is assured in Sweden and the rest of Europe. Many questions nevertheless remain.

In this preliminary study we have focussed on the business ecosystem likely to be built up alongside an electrified road. This has been done by means of interviewing interested parties and a thorough review of previous publications. On the basis of this background information, a computation model has been developed to be able to analyse the influence of various parameters. The stretch of 120 kilometre long road between Gävle and Borlänge has been used as a case study but an attempt to find other applicable stretches has also been undertaken. The model has a solid footing with the parties involved in the project and with people who have good insight into financial computations previously undertaken in relation to electrified roads.

The computation model that has been developed is primarily thought of as a model for overall surpluses or deficits for all stakeholders in the business ecosystem. It is not, therefore, a complete socio-economic model, which would include considerably more consequences for society at large, such as the influence on local and national businesses, increased employment and so forth. The model has been developed on the assumption that all prices and values are given for a point in time when the solution is in an 'early commercialisation phase'.

In comparison with diesel routes, it generally applies for electrified roads that every kilometre of road and every vehicle adds extra costs and that every kilometre driven creates savings. Thus for an electrified road system to be profitable, the stretch of electrified road must comprise a significant percentage of the overall distance driven by a truck. Nor must the stretch of road be too short, for then too much time is spent loading/unloading and too few kilometres (where the savings occur) are driven. Following familiarisation with various scenarios, a coherent, highly qualitative judgment, based on the electrified road computation model, would suggest that the suitable characteristics for such roads would be:

- A distance of at least twenty kilometres
- Annual average daily traffic (AADT) for electrified road trucks should be around two times as many as the number of electrified kilometres
- The electrified stretch should comprise 60% percent or more of the trucks' overall distance driven each year.

For the case of Gävle-Borlänge (120 km), it appears that the stretch will be able to pay for itself, for example, when 190 electrified trucks complete the stretch an average of 4 times per day throughout the year (back and forth twice a day 365 days a year), amounting to 92% of the vehicles' overall distance being driven on electrified road.

Keywords: Electric Road System; ERS; Dynamic power transfer; Sustainable transport; Electric vehicles;

Nomenclature

ERS Electric Road System

1. Introduction

The basic technologies for dynamic power transfer from the road to vehicles in motion has been developed through various research projects across the globe. Electric road systems (ERS) is today tested on public roads, but is still a long way from constituting a large-scale commercial system. At the beginning of ERS deployment, when the systems are still immature, the systems will be more suitable for closed transportation systems (Sundelin et al. 2016). Examples of closed systems are bus loops or mining transportation applications where the routes are predictable and relatively easy to service and maintain. In closed systems, system integration is easier because only a single operator is involved. When ERS has been proven to operate in closed systems at the same level of quality as traditional systems and when the market uncertainties have decreased, commercial ERS operations could evolve into an open system operating on the highway (Tongur & Sundelin 2016). Open systems, such as transportation corridors and highways, carry large transport volumes and are important nodes in the transportation system. Such open systems are also regarded as the main challenge when it comes to mitigating environmental impacts. This paper aims at analysing the business ecosystem needed for a successful commercial ERS.

2. Methodology

In order to evaluate the economic feasibility of electrified roads for trucks, we prepare alternatives for comparison (e.g. road systems based on diesel) and estimate all costs that differ between the systems. The alternatives for comparison we have looked at are partly diesel and partly bio-synthetic diesel (HVO) as energy sources by means of internal combustion engines. In the short term, diesel is often the most relevant comparison alternative for private actors since that is what is mostly used today. But from a societal perspective, biofuels are possibly a more relevant alternative considering the Swedish government's stated objective of achieving a fossil-independent vehicle fleet by 2030

Our calculation is primarily intended to serve as a calculation of the total profit or deficit for all actors involved in the business ecosystem. It is thus not a complete macroeconomic calculation which would include significantly more consequences for society as a whole, such as the risk of accidents and their costs, local impact and domestic industry and commerce, employment, etc.

2.1. *Cost components*

The cost components we have examined are:

- Road costs, in particular the electricity transmission infrastructure in/on the roads
- Grid costs, electricity grid infrastructure for transporting electricity up to the electrified road.
- Vehicle costs, in particular the higher costs per vehicle in order to be able to receive and use electric propulsion while driving.
- Energy costs, i.e. costs for diesel, HVO and electricity for the propulsion of trucks.

We have focused exclusively on the electric propulsion of trucks weighing more than 3.5 tonnes, which is the definition given in the Swedish Transport Administration's ASEK 6.0 (2016) – Analysis method and macroeconomic calculation values for the transport sector.

In addition to the four cost sources above, we have also included two potential costs in the calculation, but with reservations:

- Environmental costs, based on ASEK estimates for the year 2040.
- Taxes, i.e. fuel taxes and electricity taxes.

Environmental costs may be relevant to include as they are proposed to be included in macroeconomic calculations for the transport sector according to the Swedish Transport Administration, and when the environmental consequences of today's system are the major driving force for developing electrified roads. The inclusion of environmental costs has a relatively strong impact on the competitiveness of electrified roads. Taking into consideration what today's CO2- limiting institutions look like, it is however possible that a better environmental cost value for a private and closed electrified road can be the current market value of CO2 emission rights according to EU ETS. In spring 2016, this value was so low that it would not have any significant effects on an economic calculation for electrified roads.

Taxes should generally not be included in the calculation if it is done from a macroeconomic perspective. However, this may be of interest if a private actor wants to set up an electrified road for trucks in the short term, as the tax system for road transport and fuel will likely take several years to change.

A seventh potential cost source is also worth mentioning:

- Invoicing and administration of the system.

We have not included any figures for administration and invoicing of the electrified road system in our calculation. A partial reason for this is that it was difficult to find credible figures. But the main reason is that a rough calculation based on public figures from the Swedish Transport Agency concerning the cost for Stockholm's and Gothenburg's congestion charges (2 SEK per passage) showed that the impact in our case would likely be negligible in most contexts.

The equation which describes the relative attractiveness of electrified roads is thus the differences in costs of the following terms:
Δcosts= Δroad costs+ Δgreat costs+ Δvehicle costs+ Δenergy costs+ (Δenvironmental costs) + (Δtaxes).
The differences thus refer to the difference in the respective cost type between electrified road systems and diesel and biofuel road systems. Generally, the first three terms are much higher for electrified road systems, while the remaining terms are lower for electrified road systems than for the two alternative road systems.
A calculation sheet was prepared based on the assumption that all prices and values are stated for a point in time when the solution is in an "early phase of commercialisation". This means the following for different values:

- Cost electrified road: Cost for the 101st kilometre.
- Cost electricity grid: We assume costs will remain unchanged (as this is a mature technology)
- Cost vehicles: Cost for the 101st vehicle
- Fuel prices (diesel, biofuels and electricity): We assume that the year 2025 corresponds to early commercialisation.
- Environmental costs: We assume that the year 2025 corresponds to early commercialisation.
- Taxes: We assume taxes will remain unchanged.

2.2. *Sources for cost estimates*

We have chosen to estimate the costs for an electrified road system's components from scratch. A large number of reports have been written presenting such figures, mostly based on statements or estimates from companies hoping to supply such components in the future. This means that all figures included in our analysis come from such sources.
We tried to get hold of figures related to costs from an actual pilot project – i.e. real, historic costs which had already arisen during installation of an electrified road. These figures could then form a credible ceiling – highest value – for the cost estimates. But we were not able to get hold of any such figures. The closest we got were estimates related to a short section (2 km) at Sandviken, between Gävle and Borlänge (E16) in Sweden. A pilot section for electrified roads has been built there, in cooperation between the Region Gävleborg, Swedish Transport Administration, Siemens and Scania. However, we have not used those figures for the initial, short section there in any of our cost scenarios as we did not get access to sufficiently detailed calculations in order to be able to properly separate the different cost sources in this case. Based on an oral source familiar with the in-company calculations, we assessed that the overall cost was not applicable to our purposes, seeing that so much would be done manually (for example monitoring).
A method for selecting reports to examine was an ad hoc search which was successively expanded using a so-called snowballing search – meaning that one source lead us to other sources. A ad hoc search seemed justifiable as several of the project's members had been doing research on electrified roads for many years and were very well-versed with the literature and phenomenon.
In total we have reviewed estimates and argumentations on the costs for electrified road components in some 30 different reports. Many of these overlap in their underlying sources and assumptions. Ultimately, we elected to use figures from 16 sources. Furthermore, we have been in contact with a number of experts in the project group and at Vattenfall, Circle K, SPBI, Volvo and Scania by mail and phone in order to get input for best assumptions concerning the costs for electricity grids, price strategy and efficiency for biofuels, or the price for current collectors, respectively.

3. **Analysis**

As the spread of the cost estimates is so wide and actually implemented road sections so few, the costs for electrified roads are still extremely uncertain. Our best estimate which is described below, is the one we ourselves consider as being the most likely of the previously reported cost estimates and which we take as a basis in analysis. This estimates was reviewed at a workshop with experts from Scania, Siemens, KTH, Region Gävleborg and Stockholm School of Economics in August 2016. Although, we would like to emphasise that the uncertainty is significant.
Note that the costs per km in this section refer to electrified road distances in km. All figures are for both directions.

3.1. *Road costs*

General assumptions:

- Lifespan 40 years.
- Distribution of costs over the lifespan using the annuity method. This means that the investment is indexed by the assumed interest rate for calculation purposes and distributed over the lifespan by an equal amount each year.
- Assumed interest rate for calculation purposes 3.5%.

Our best estimate: The values here are based on the study of an electrified road between Mertainen and Svappavaara. The costs including maintenance amount to 0.75 MSEK per km and year. Electricity transfer here is based on Siemens technology, where power is transferred from a mesh above the roadway. The report was written in cooperation between KTH, LKAB, Scania, Siemens, Svemin, Sweco and the Swedish Transport Administration year 2015. Our interpretation of the report is based on an interview with one of the authors.

3.2. *Electricity grid cost*

General assumptions:

- Lifespan 40 years.
- Distribution of costs over the lifespan using the annuity method. This means that the investment is indexed by the assumed interest rate for calculation purposes and distributed over the lifespan by an equal amount each year.
- Assumed interest rate for calculation purposes 3.5%.

Our best estimate: The values are based on the study of an electrified road between Mertainen and Svappavaara (KTH 2015). The costs including maintenance amount to 0.28 MSEK per km and year. Electricity transfer is based on Siemens technology, where power is transferred from an overhead line above the roadway. The report was written in cooperation between KTH, LKAB, Scania, Siemens, Svemin, Sweco and the Swedish Transport Administration year 2015. Our interpretation of the report is based on an interview with one of the authors.

3.3. *Vehicle cost*

General assumptions: Additional costs for vehicles include current collectors and the additions that need to be done to the vehicle in order to receive electric power from the grid. Lifespan 7 years. Distribution of costs over the lifespan as an annuity loan. Assumed interest rate for calculation purposes 3.5%. The value for vehicle maintenance has not been stated separately in any of the reports, and is assumed to be included in the figures below. It is adjusted from 5 years (according to Gävle-Borlänge-report) to 7 years in the project group, allowing for the "early commercialisation-principle".

Our best estimate: The value 0.11 MSEK per vehicle and year is based on information in the report about the electrified road between Gävle and Borlänge from 2015, written by Region Gävleborg (2015), Siemens and Scania. The figure is reported as being the actual additional cost for the trucks used on the section that is already in operation.

In summary, an overview is provided of investment and annual costs (annuity cost for investment + maintenance) for the various components in the table below.

Cost component	**Investment**	**Annual cost**
Electrified road (MSEK/km)	13,7	0,75
Electricity grid (MSEK/km)	3,85	0,28
Additional vehicle costs (MSEK/km)	0,5	0,11

3.4. *Energy costs*

General assumptions: Here the same prices are used for all scenarios.
Diesel cost: The diesel price per litre is stated excluding VAT and other taxes. According to the Swedish petroleum and biofuel institute, the average price in the year 2014 (latest available statistics) was 4.58 SEK. The prize has been indexed by 3.5 percent (annual indexation according to the Swedish Energy Agency) to 4.7. The

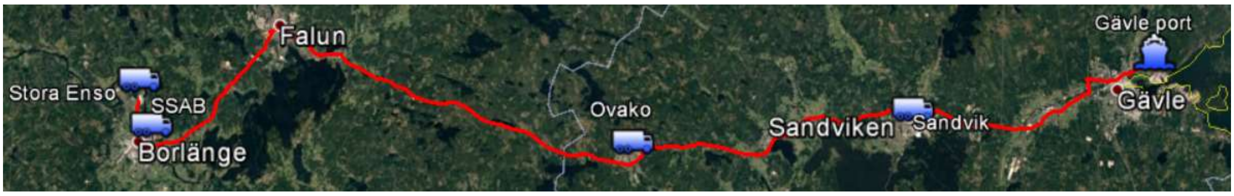
price per km was then calculated using the conversion factor 0.43, which comes from Grontmij's report about electrification of the section Södertälje Helsingborg, author Mattias Haraldsson (2010). The price per km is then 1.97 SEK.
Electricity cost: The electricity price is calculated as a sum of the spot price and the cost for the backbone and regional grid. The spot price is approx. 0.25 SEK per kWh, according to information from Svensk Energi (2015). The cost for the backbone and regional grid is calculated to be 0.07 SEK per kWh, which is based on information from Vattenfall that 20% of the cost for the electricity grid is for the backbone and regional grids. The electricity price excluding taxes and local grids is then 0.32 SEK per kWh. The electricity consumption is 50% of that of diesel thanks to the higher degree of efficiency according to Arctic electrified road (2015) and the electricity cost per km is then 0.69 SEK.
Biofuel cost: In Sweden, the synthetic diesel HVO100 is currently used mainly as a biofuel for heavy vehicles. The price per litre at the end of May 2016 was 13.35, according to statistics from Circle K (2016), which makes 11.05 SEK per litre excluding VAT. HVO100 is not subject to other. The cost per km is calculated using the conversion factor 0.96, i.e. HVO is 4 % more efficient than diesel (according to contact with Circle K), and the cost per km is then 4.56 SEK.

3.5. *Environmental costs*

General assumptions: Here the same costs are used for all scenarios.
CO2-price: CO2-price, 1.34 SEK per kg CO2, comes from the Swedish Transport Administration's ASEK-calculations (2016) for the year 2040. 1.34 is estimated for the year 2025, in accordance with the "early commercialisation-principle".
Cost/km - CO2: The cost per km is calculated as the product of the price per kg and the number of kg of CO2-emissions per km which a heavy truck with trailer causes on country roads (also from ASEK). This becomes 1.15 SEK per km for the year 2025.
Cost/km - other emissions: The cost for other emissions includes NOx, VOC and SO2 and is calculated using ASEK's prices and emission volumes for the year 2014. The emission volumes are based on heavy trucks with trailers on country roads, and the cost is 0.35 SEK per km, for the year 2025.

3.6. *Case study*

Electrified road systems today generally require higher investments than combustion engine road systems. This is driven by investments in roads, electricity grids and vehicles. On the other hand, electrified road systems have lower variable costs, as electricity costs less per driven kilometre than using a combustion engines. In order to compare the total cost for an electrified road system with a combustion engine road system, assumptions must be made concerning the stretch of road to be driven on. In particular regarding distance, number of vehicles and how much the vehicles frequent the section (AADT).
As a sample section we have used the section Gävle-Borlänge (120km), 273 electric trucks and AADT=600. These values for distance, number of electric trucks and traffic density are based on the forecast for pilot projects which are currently set to begin on the section. We also assessed the section as interesting to take as a starting point, as it is quite typical of what we have assessed as suitable properties for electrified road sections (further down).



3.6.1. *Sensitivity analysis of the Gävle Borlänge-case*

The original calculation for the Gävle Borlänge-case is thus based on an electrified road section of 120 km, and an assumption of 273 cars. We have made a general assumption that only 60% of the section needs to be actively electrified (depending on the road topography, etc.). We have included environmental costs and excluded taxes. We have chosen to compare with a diesel-fuelled system. The congestion limits is set at 10 trucks/km and the max km driven per vehicle and year are 192,000 (i.e. 526 km per day 365 days a year). The 273 cars must then drive 70% of their annual distance on the electrified road for the system to pay off. This corresponds to an AADT figure (round trip) of 1.5 per truck.

In order to get a picture of how different assumptions affect the breakeven-levels in the calculation, a sensitivity calculation for five different factors is done here.

- Number of vehicles and proportion on electrified road

If instead of 297 trucks we assume that 400 trucks frequent the section, the proportion of km to be driven on the electrified road section in order to reach breakeven is 54%. This means an AADT figure per truck of 1.2 round trips between Gävle and Borlänge. 54% of the annual distance can be considered as being a realistic proportion of the vehicles entire driving distance, but we can still elaborate further by changing the max number of km driven per vehicle and year. If we change this from 192,000 to 250,000, the proportion of km driven on electrified roads would fall from 54% to 42%. However, 250,000 km per vehicle and year equals 680 km per day every day of the year.

The lower limit for when the number of trucks would be sufficient to make the electrified road section profitable (constantly assuming a max of 192,000 km per truck and year) is 170 trucks. In this case, all trucks would have to drive 100% of their time on the electrified road in order for this scenario to break even.

If instead the number of vehicles is increased to 550, each vehicle would only need to drive 45% of its time on the electrified road for the scenario to become profitable, which corresponds to one round trip on the section every day.

- Energy prices

An important factor in the calculation is the energy price. It is the saving between the electricity cost per km and diesel (or biofuel) cost per km that makes up the "revenue side" in the calculation. If we assume a doubling of the electricity price (spot price + grid charges for backbone and regional grid) from 0.32 SEK to 0.64 SEK per kWh, we immediately see a big difference in the breakeven level. Instead of the 273 trucks having to drive 70% of their time on the electrified road, this figure is now 93%, or another way of seeing it.

With an electricity price of 1.20 SEK/kWh, it doesn't look as if it is possible to reach breakeven on any of the sample sections. If we instead assume that the diesel price goes up from 4.7 SEK/litre to 8 SEK/litre, this would change the numbers for the Gävle Borlänge-case to the 273 trucks only needing to drive 47% of their time - or 1 round-trip per day - on the electrified road for the scenario to reach breakeven. It would also be enough if 105 trucks frequented the section in order to reach breakeven, if 100% drive on the electrified road section.

In such a scenario with strongly increased diesel prices, a route such as Stockholm - Gothenburg could also be profitable with 410 electrified trucks frequenting the section 100% of their time.

- Electrified road installation

Electrified road investment, incl. road and electricity grid components, is the largest item on the "cost side" in the calculation In "Our best estimate" we have calculated using an annuity cost of 1,020 kSEK per year. If we select our optimistic estimate here instead (based mainly on figures from Elways), the annuity cost remains at approx. 380 kSEK. For the Gävle Borlänge-scenario, this means that the 273 trucks need to drive 33% of their time on the electrified road, or 0.7 round trips per day. Another way of seeing this is that it would be enough with 59 trucks driving 100% on the electrified road section to reach breakeven.

- Environmental cost

In our original scenario, the price for CO2 was assumed at 1.34 SEK/kg, in accordance with ASEK's calculation model for environmental costs. ASEK itself states that 3.50 SEK/kg is a reasonable level for a sensitivity analysis. If you choose this cost, the breakeven level for the 273 trucks on the Gävle Borlänge-section changes to 42% driving on the electrified road section or 0.9 round trips per day. At an elementary level, 94 trucks could be enough for the system to be profitable.

If on the other hand, we completely remove the environmental costs from the calculation, 520 trucks would be needed on the section Gävle Borlänge to reach profitability even with a hypothetical 100% of driving on the electrified road section.

- Life-span

In the calculation we assume a lifespan electrified road and electricity grid installation of 40 years, following consultation with the Swedish Transport Administration. A sensitivity analysis that changes the lifespan to 20 years results in the following difference: The breakeven point for the 273 tracks changes from 70% to 90% with regard to the time on the electrified road. And AADT per day changes from 1.5 to 2.0. This means that the minimum number of trucks required to reach breakeven (with 100% of driving on the electrified road section changes from 172 to 241).

If we, on the other hand, increase the lifespan to 30 years, then the 273 trucks would need to drive 77% of their annual distance on the electrified road to reach breakeven assuming an AADT of 1.7 round trips per day per truck.

- Assumed interest rate for calculation purposes

The assumed interest rate for calculation purposes of 3.5% is based on the macroeconomic discount rate in ASEK 6.0. From a private investment perspective this is low. We have thus carried out a sensitivity analysis with interest rates of 5 and 10%, respectively. With an interest rate of 5% the annuity cost for the electrified road and electricity grid part changes from 1,020 SEK to 1,230 SEK, and for the section Gävle-Borlänge the number of

trucks required to reach breakeven changes from 172 to 208. With an interest rate of 10%, the annuity cost for the infrastructure is 1,990 kSEK and the breakeven level in the Gävle-Borlänge-case becomes 351 trucks.
Note that the regulation does not, however, discount the savings (which are in the future) by the assumed interest rate for calculation purposes. It is not a capital investment appraisal. Instead the interest rate is used only to calculate the annual cost for the hardware including interest expenses.

3.6.2. *Our collective assessment regarding costs*

Electrified road systems require major investments. It is relatively difficult to reach breakeven for electrified road systems as compared to diesel road systems. The following likely needs to occur to make electrified road systems possible:

- Biofuels are used as the relevant comparison, rather than diesel (or at the very least: Environmental costs are taken very seriously in the capital investment appraisal.)
- Taxes in the long term remain as favourable for electricity compared to fossil fuels as they are today.
- The costs for electrified roads and grids drops to the scenario "Optimistic estimate" as a result of learning effects or other estimates having been pessimistic.
- The additional costs for electric vehicles/current collectors become so low that even private cars and trucks which do not regularly drive on electrified roads come with current collectors installed (the volume of traffic then quickly leads to savings becoming big.)

This said, the electrified road system is a possible technical solution for the problem of CO2-emissions. Even with the pessimistic estimates, we can imagine individual sections where the total cost is about the same for electrified road systems as for a diesel road system. Identifying such sections is dealt with in a chapter further down.

4. **Business ecosystems**

There are a couple of general characteristics for suitable stretches of road sections which can be gathered directly from the observation that electrified roads have higher fixed costs and lower variable costs than combustion engine roads. But for even more details, assumptions must be made regarding exactly how costs and technology will develop. For this we have assumed a fixed additional cost of 1,020 kSEK per km and year for the fixed infrastructure, 110 kSEK per vehicle and year, and diesel as an alternative energy source with environmental costs estimated according to ASEK 6.0 with taxes excluded from the calculation.

For electrified roads as compared to diesel roads, every road kilometre and every vehicle generally generate extra costs, and every kilometre driven generates savings. That's why for profitable electrified roads, you want as short a distance as possible on which a low number of electric trucks make very, very many trips. But the section must not be too short because then too much time is spent on loading and too few kilometres (on which savings are made) are driven. In the report we focus on the potential of electrified roads to bring major changes to the Swedish transport system, so we do not analyse the borderline case of extremely short sections where reloading becomes decisive.

4.1. *Open road sections - electrified road corridors*

An approach with great potential to achieve sufficiently high traffic volumes is a traffic system built on hybrid vehicles. In other words, trucks which can drive long distances together using electricity from the road, but which can switch to combustion engine when leaving the electrified road. In graphic terms, this system would be ideally represented as a long, densely frequented thick line that ends in a star consisting of several shorter, less densely frequented lines. E.g. a number of separate export industries can be located at the tips of the star outside of Borlänge, and the trucks drive using their combustion engines for a few km from these to the E16 at Borlänge, where they switch to the electric engines to take them to the port of Gävle. The section to be electrified is thus the E16 between Borlänge and the port of Gävle. Here we ask ourselves, what characterises sections where profitability can be achieved through electrification?
Underlying all sections is the same assumption as in the Gävle - Borlänge-case regarding the part of the section that really needs to be electrified, i.e. 60%.

4.1.1. *120 km – e.g. Borlänge to the port of Gävle via the E16*

In the case of Borlänge, it becomes clear that the section can pay off in many cases, including:

- 200 electric trucks driving along the section 1.9 times a day on average year-round (e.g. two round trips 365 times per year) 88% electrified road of the total distance.
- 300 electric trucks driving along the section 1.4 times a day on average year-round (i.e. 365 times a year) 66% electrified road of the total distance.
- 550 electric trucks driving along the section 1 time a day on average year-round (i.e. one round trip) 45% electrified road of the total distance.

4.1.2. *466 km – e.g. Göteborg – Stockholm via E4, R40*

This section is popular to model. It is possible to achieve profitability with. Some scenarios that would reach breakeven:

- 800 electric trucks driving along this section - in one direction - once a day year-round, i.e. an AADT (for the entire section, in each direction) of 400 for electric trucks. 800 trucks with current collectors installed comprise approx. 1.3% of trucks over 3.5 tonnes in Sweden (60,000 trucks, Transport Analysis 2015).
- 2,500 electric trucks driving along this section - in one direction - on average just under once a day year-round, i.e. an AADT (for the entire section) of 584 for electric trucks. 2,500 trucks with current collectors installed comprise approx. 4.2% of trucks over 3.5 tonnes in Sweden (60,000 trucks, Transport Analysis 2015).

The current AADT for the section for heavy trucks is difficult to determine with certainty, but a very rough and somewhat optimistic estimate is about 1,800 trucks in one direction between Mjölby and Linköping on the E4 (vtf.trafikverket.se, 2014). Between 22% and 33% of trucks on this section thus need to be driving on electricity, in the examples above.

4.1.3. *2,050 km – Sweden's motorways*

In the long term, electrifying the entire network of motorways in Sweden may seem attractive. In 2016, it consisted of about 2,050 km of motorway. Investment would be considerable, about 22 billion SEK (17.55 MSEK* 2,050 km * 60%). Annual costs for roads and grids would be 1.3 billion SEK per year calculated by annuity according to the cost estimates used in this section (incl. an assumption of 60% of the distance needing to be electrified and incl. maintenance). In the following scenarios, the investment for the system as a whole would pay off, provided that the Swedish Transport Administration's assessments of emissions (2014) are included in the calculation (but excluding taxes/revenue-neutral tax changes provided).

- 3,000 electric trucks (5% of trucks in Sweden) with every km of motorway having an electric AADT of at least 375. This corresponds to 98% of every electric truck's assumed total annual mileage (192,000 km).
- 6,000 electric trucks (10% of trucks in Sweden) with every km of motorway having an electric AADT of at least 454. This corresponds to 59% of every truck's assumed total annual mileage (192,000 km).
- 12,000 electric trucks (20% of trucks in Sweden) with every km of motorway having an electric AADT of at least 610. This corresponds to 40% of every truck's assumed total annual mileage (192,000 km).

4.2. *Compilation – desirable characteristics open stretches of road*

A collective and to a high degree qualitative assessment after having become familiar with various scenarios as set out above, based on the electrified road calculation, is that suitable stretches of road to begin with have the following characteristics:

- A distance of at least some 20 km, so that other activities, e.g. driving on other roads, or loading and unloading, do not take up too much time in relation to every kilometre driven on electrified roads for each truck.
- Around twice the number of kilometres trucks drive up and down the route every day.
    - AADT in one direction for electric trucks thus becomes twice the number of road kilometres.
    - AADT is not sufficient, it must be the same trucks over and over again. So there must be a number of trucks that frequent the same route regularly or even every day. It likely makes it easier to pass the diffusion process (investment decision) if these drive for only a few haulage contractors or drive for only a few clients, or if there is a clear opinion leader whom others tend to follow.

- The electrified route makes up a considerable proportion of the total distance driven by the trucks each year, preferably more than 60%.
    - For the trucks to be able to drive a sufficient number of kilometres on the electrified road.

In discussions with the Swedish Transport Administration, the following criteria have also emerged as playing a role when selecting a route:

- Few vehicles with a high degree of occupancy, the majority of km on the route of the total number of km driven.
- Elements of shuttle traffic
- A sufficient number of a specific haulage contractor's trucks drive the route
- The route should have suitable diversion routes and preferably be 2+2 or 2+1
- Relatively high energy consumption regardless of the type of goods
- Topography (preferably undulating rather than flat)
- State or municipal ownership

4.3. *Closed road systems*

Closed and private road systems, where a transport route is managed by private players as part of a delimited production system are attractive in the sense that they reduce the risk of certain investments becoming losses without other investments. For example that an electrified road is built but no trucks install current collectors and electric drive lines, or vice versa. In terms of the calculation, they also enjoy the benefit that the system becomes smaller: more specifically – a private player can account taxes not received as a cost reduction (which is not the case for a calculation from a societal perspective). This means that the savings per kilometre driven on electrified roads become considerably higher, as today's taxes on diesel are a significantly higher per transport task than taxes on electricity. Calculating in this way of course carries a certain risk, as the electrified road investment must be long-term and other taxes can change if the state begins to lose out on considerable revenue. It is also likely that few companies would consider it justified to include avoided environmental costs as savings in the calculation for an electrified road, which is more justifiable if the calculation is made from a societal perspective. But by and large the taxes are higher than environmental cost estimates commonly carried out.
If you include avoided diesel-related taxes and imagine an electrified truck route of 10 km, then 8 electric trucks need to be able to drive the route up and down 25 times per day 365 days a year to reach breakeven in terms of costs. If the truck achieves an average speed of 50km/h the driving time would be 2*25*10/50=10 hours – excluding loading and unloading!
With a route of 30 km with 50 trucks, every truck would need to make 4 round trips a day, 365 days a year, to reach breakeven. With an average speed of 50 km/h this is 2*4*30/50 ≈ 5 hours – excluding loading and unloading. This is likely possible. If we assume that every loading or unloading take 15 minutes, we would have to add 4*2*0.25=2 hours. The question is how many production facilities can keep 50 trucks busy 7 hours a week 365 days a year?

4.3.1. *Reflections – closed road systems*

Closed and private road systems (as part of a clearly delimited production system) have some advantages in terms of having presumably fewer diffusion barriers. Despite this, it does not look promising under the cost scenario ”Reference 1”. It simply seems as if very high volumes are required to reach profitability.
For areas with very high volumes, however, it can work according to this model. Possible cases could be ports and exceptionally large mines. It is, however, possible that the relevant comparison there is trains rather than diesel trucks, which falls outside the comparison alternatives we have examined here.

5. **Next steps**

The existing calculation sheet is primarily intended as an evaluation of the system's profitability on a societal level. The possibility to experiment with routes, number of cars and AADT makes it possible to identify potentially profitable routes and continue in-depth studies. The next step is to give the players that then come into question for the selected route/system a calculation basis for their own participation. This calculation sheet shall be prepared bottom-up, and be able to be adjusted to the individual players' business administration economic conditions. It is primarily intended to facilitate decisions regarding participation for individual players.

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