

National roadmap for electric road systems

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Swedish Transport Administration

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National roadmap for electric road systems in brief

The national roadmap for the development of electric road systems for the 2018-2022 period is based on considerations in this report and is specified in brief below.

1. Market and funding

Issues relating to the composition of the stakeholder network, suitable business models and financing strategies and forms of procurement need to be elucidated in depth in order to promote and pave the way for a broadened market. Efforts focusing on delivering a final report by the end of June 2018 are commencing in parallel with other activities in the electric road system programme. External expertise is required for this work.

A description is provided on the basis of three different scenarios to indicate how a roadmap for electric road systems could be formulated as regards stakeholder networks and business models/funding. It is suggested that scenarios be based on:

- a central government model
- a regional/local public sector led model
- a model with more extensive private involvement.

The issue of appropriate balance between ongoing research and demonstration facilities and more specific implementation of technology for electric road systems and measures for promoting the broadening of the market need to be assessed on an ongoing basis, which will then make it possible to deal with these within the scope of the Swedish Transport Administration's electric road system programme.

2. Promote, contribute to and pave the way for a broadened market and greater competition between the transmission systems by raising more systems to TRL level 5-6.

This will be achieved by supporting the development of new electric road system technologies and ensuring that the systems are verified and demonstrated in an authentic environment, both technically and in terms of safety. Siemens systems in Sandviken will be at Technology Readiness Level (TRL) 6 when the technology has been demonstrated in its entirety. Elways technology is currently being tested on a public road outside Arlanda. Business models, payment systems, services, etc. are not included in the demonstrations, however. Further funding for development may be needed even after the electric road system technologies have been demonstrated in an authentic environment. The number of suppliers and the amount of competition with regard to each electric road system technology need to increase over time.

The Swedish Transport Administration would like to implement another one or two demonstrators so as to be able to raise new electric road system technologies to TRL 6. There are several different candidates:

- Volvo AB and Alstom are developing a collector that may be ready for demonstration within the next few years. Alstom is developing in parallel a ground-based conductive electric road system technology based on their commercial electric road systems for trams.

- Elonroad AB is developing a conductive technology and has built a test track 200 metres long in a secluded location in Southern Sweden. According to the schedule, this may be transferred out to a public road over the next few years.
- Bombardier has an inductive technology. This technology has not been fully developed, but it should be possible to demonstrate it within the next few years if the company prioritises its development.

3. Prepare and implement a major electric road system pilot.

The purpose of an electric road system pilot is to raise the technology to TRL 7. This includes not only verification and demonstration of the technology, but also demonstrating the entire electric road system with peripheral services, payment and access systems, etc. The view is that this can be done in an initial stage by planning electric road systems on a number of alternative routes. These routes should be at least 20-30 km long and subject to heavy traffic. A number of different prospective routes have been identified, but a further inventory is necessary.

4. Create a long-term plan for the construction and development of electric road systems

A long-term plan for the establishment of electric road systems will be compiled after analysis of ownership, funding, possible road routes, technical solutions, etc..

Public costs for the next few years are estimated to amount to 150 million SEK, excluding any costs for building and implementing electric road system pilots during this period. Raising a further two electric road systems to TRL 5-6 will probably require as much public funding as the pre-commercial procurement procedure. In this example, approx. 70% was made up of public funding. The total cost was around 125 million SEK, of which the Swedish Transport Administration paid 95 million SEK. The planning of three to five electric road system routes is estimated to amount to around 25 million SEK.

It is difficult to assess the broadening of the supplier market, but as things stand at present it is assumed that it will be possible to stimulate it within the various electric road system projects taking place on a global level. Financial systems can be developed within the regular R&I budget.

Summary

Planning, utilisation and the target scenario in terms of transport policy

Heavy goods vehicles are responsible for almost 89% of product volumes transported domestically, while cars are responsible for over 90% of traffic work. Heavy goods vehicles travelling by road are responsible for around 25% of the road transport system's energy utilisation, and more or less the same percentage of carbon dioxide emissions. The Riksdag (Swedish Parliament) has made a decision on a climate law which will involve a compulsion to reduce carbon dioxide emissions from the transport sector by at least 70% by 2030, before reaching a zero level in 2045.

The main idea with electric road systems is to reduce the dependency of heavy vehicles on fossil fuels, to reduce carbon dioxide emissions and also to ensure good provision of transport for commercial purposes in the fossil-free society of the future. Good provision of transport of this kind must not involve impairment of safety or the cultural or natural environment.

The technologies for de-fossilisation of heavy goods vehicles are being developed but are limited as yet. Up to 2030, market stakeholders are of the view that diesel with admixed biofuels such as hydrogenated vegetable oils (HVO) and fatty acid methyl esters (Fame) will be the dominant technology for de-fossilisation of heavy goods vehicles. In the longer term, electrified powertrains may replace internal combustion engines.

A general preliminary analysis has been carried out with regard to benefits in terms of transport policy. This shows that a reduction in carbon dioxide emissions will be the biggest advantage. Emissions of carbon dioxide and nitrogen oxides have been calculated for three routes of different lengths, with different traffic intensity, with varying penetration of electric road system technology. The effect of cars' use of electric road system technology has also been calculated for the routes by way of comparison.

Nitrogen oxide emissions will also be reduced. Nitrogen oxides chiefly cause problems with local air quality and health, and analyses of these emissions will become more meaningful when we know where electric road systems will be utilised. It is not thought that noise emissions will be affected as vehicle speeds are what primarily determine noise levels along roads.

Different electric road system technologies will have different impacts on safety and natural and cultural environments. Technologies using suspended wires have an obvious visual impact on the landscape. The present design is a prototype, and there is scope for improvements to the design.

It is not possible to observe any tangible impact on road safety, either in risk analyses or in practice (on the basis of more than a year of testing in Sandviken). In terms of road safety, the risk of skidding may primarily be caused by differences in friction between the electrified rail and the surrounding surface. It is not thought that electric road systems based on rails on the ground will affect the landscape or the natural and cultural environment. The risks inherent in technologies using live rails in the ground are linked mainly with electrical safety. Electrical safety will be primarily ensured by applying standards from the fields of rail and tram transport. If it has not been possible to apply comparable standards in risk assessments, every system and its components must be safeguarded by means of tests and a documented risk analysis ensuring that sufficient safety is achieved.

Funding

One significant element when planning the introduction of electric road systems is to devise models with regard to how the facilities required are to be owned, funded and paid for. The government finances and owns most of the road infrastructure, while fuel and power for charging electric vehicles are provided under market conditions. Electric road systems are systems that involve these areas, and whether the government or the market is to own them cannot be assumed.

This paves the way for various funding models, e.g. development of electric road system technology on the road network in a public and private partnership (PPP), with the government as the client and project funding from private stakeholders. The government can then compensate the PPP counterparty with accessibility-based charges or transfer the traffic risk to the PPP counterparty by means of a concession, for example.

Funding and ownership models may also vary depending on which stakeholders and electric road system technologies will be involved. The choice of a funding model is also dependent on the extent to which a decision is made to electrify the road network, and on whether the system applies only to heavy vehicles or to cars as well. A business logic and business model that suits one technology will not necessarily suit another business model. How charges and taxes on both fuel and electricity develop will have a major impact on the business models.

As the forthcoming planning period will probably primarily involve carrying out further demonstrators and pilot projects, and as the electric road system technologies are still undergoing development, it may be relevant to use procurement procedures based on some kind of cooperation between the government as a road owner and stakeholders in the private sector.

Sweden has gained momentum as regards the development of ERS compared with the rest of the world thanks to active research and development work. Continued research, development and demonstration are of the utmost importance, and if it turns out that technologies emerge as early as the next planning period that would be appropriate to implement on a commercial basis, the Swedish Transport Administration will work to support earlier implementation, thereby helping to bring about faster development of the Swedish electric road system market.

Electric road system technologies

There are currently three main focus areas as regards technology for continuous, vehicle-related transmission of power from the infrastructure to electric road vehicles:

- conductive transmission via overhead lines
- conductive transmission via rails or conductors in the road
- inductive transmission via electromagnetic fields from the roadbed

All three types have been tested in some form. The technology involving overhead lines has made the most progress. Overhead lines are not suitable for cars as the distance between the roof of the vehicle and the lines will be too great. Siemens has built a section 2 km long on the E16 outside Sandviken where a Scania lorry has been operating since June 2016. A similar section was constructed in 2017 to the port of Los Angeles, using Mack trucks and others. Three projects, each covering around 5 km, are being planned in Germany, and in agreement has been made to construct one section in Hessen in 2018.

Conductive transmission via rails in the carriageway has not made as much progress in its development. Rosersbergs Utveckling AB is demonstrating Elways AB's technology on a section 2 km long on road 893 outside Arlanda. ElonRoad AB has built a test facility a few hundred metres long outside Lund and is planning to carry out tests in Mariestad, commencing in 2017¹. Alstom has developed its tram technology and tested it together with Volvo AB's current collector on a section 300 metres long on the test track in Hällered.

Inductive technology has been tested by Bombardier on a closed track in Germany. In Korea, KAIST University has demonstrated a technology for urban buses on a route in the town of Gumi. In the US, five universities involved in the SELECT project are working on inductive technology. According to the schedule, a demonstration will take place using a 5-axle semitrailer in the winter of 2017/18 with the aim of achieving a Technology Readiness Level (TRL) of 6.

Planning and utilisation

It is thought that electric road systems will be able to assist with both long-term climate targets and transport policy targets. This primarily involves the consideration target, specifically the limiting of climate impact with which electric road systems will assist by making it possible for vehicles to become independent of fossil crude oil. There may also be positive contributions to the general generation target in that electric vehicles do not generate exhaust emissions. In the longer term, electric road systems may also help to achieve the function target by ensuring that the transport system has plenty of access to energy that is sustainable in the long term. Depending on how costs and instruments develop, electric road systems may also help to increase commercial competitiveness due to the fact that new systems and solutions will be developed in Sweden and result in lower transport costs. Initial assessments show the carbon dioxide emissions from lorries may be reduced by more than 200,000 tonnes for relatively busy sections 250-300 km long if 70% of these lorries use the electric road system. This traffic flow is essentially equivalent to the traffic flow of heavy vehicles on the Stockholm-Malmö-Gothenburg route, a distance of 1,365 km. The benefits may increase if cars use the electric road system as well.

There needs to be further analysis of which roads are appropriate for electrification and which group of road users is to use the electric road system. The first sections of electric road systems will probably be linked with areas with a stable transport requirement over time, probably with shuttle service elements. This work must take place in partnership with regional stakeholders and intended users and suppliers of the electric road system.

Different electric road system technologies will need varying adaptation to the landscape and natural and cultural environments. It is thought that ground-based technologies will have less impact, while technologies involving overhead lines will have a clearer impact on the urban environment and landscapes from a road user perspective and with regard to residential and outdoor recreation considerations.

The Swedish Transport Administration or the stakeholder responsible for the construction and operation of infrastructure must be compliant with the legal requirements specified in the Environmental Code and the Historic Environment Act, for instance, when adapting the infrastructure. The Roads Act and the Railway Construction Act also specify a general requirement

¹ <https://mariestad.se/Mariestads-kommun/Foretag--Naringsliv/Test--och-demonstrationsplats-Mariestad/ElectriVillage.html>

indicating “that attempts must be made to achieve an aesthetic design” and that “the urban environment and landscapes, and natural and cultural assets, will be taken into account”. This is also applicable to the design, instruction and operation of infrastructure for electric road systems.

Standards and regulations

Making a switch towards a more transport-efficient society in which electric road systems are assumed in the long term to become part of the government road network in Sweden is dependent on a coherent legal framework. This involves a framework which underpins parallel development lines such as automation, sharing economy, digitisation, electrification, etc. and which emphasises the importance of efficiency and the impact of regulations in community planning.

An initial analysis has identified a number of areas where legal aspects need to be reviewed: access to land for the construction of necessary infrastructure, funding for construction and operation of necessary infrastructure, instruction and operation of necessary infrastructure and distribution of power to the electric road system network. The Swedish government, via the Swedish Transport Administration, has what is known as right of way for the existing public road network. It is unclear as to whether land outside the road area can be earmarked for components of the electric road system. If the electric road system infrastructure is to be owned by a stakeholder other than the Swedish Transport Administration, right of way cannot be applied directly. However, it is possible for the Swedish Transport Administration to grant a permit for construction of facilities within road areas.

A similar situation occurs in respect of power grids and power distribution. Permits, or what are known as grid concessions, are generally required for all high-voltage lines. Any legal entity running grid operations must not trade in electricity at the same time. This means that the stakeholder that owns the power grid is prevented from selling power for vehicles via its grid. However, there are options for constructing internal grids as an alternative to grids requiring concessions. For electric road systems, an internal grid would need to be constructed within the road area and used to provide the owner’s own system with power, at least in part. Whether transmission to vehicles on public roads can be considered to constitute transmission to the owner’s own system is unclear.

Power supply

It must be possible to provide either low-voltage power (cf. trams, approx. 1000 volts) or high-voltage power (cf. trains, approx. 16,000 volts) to vehicles. The low-voltage option involves lower vehicle costs but higher infrastructure costs. The opposite is true for the high-voltage option. The electric road systems currently being developed are all of low-voltage type. Both AC and DC voltage systems are being tested. The Swedish Transport Administration is of the opinion that low-voltage systems will be tested over the next five years.

Current from the public power distribution grid will need to be transformed in batches in order to power vehicles. This takes place over three stages:

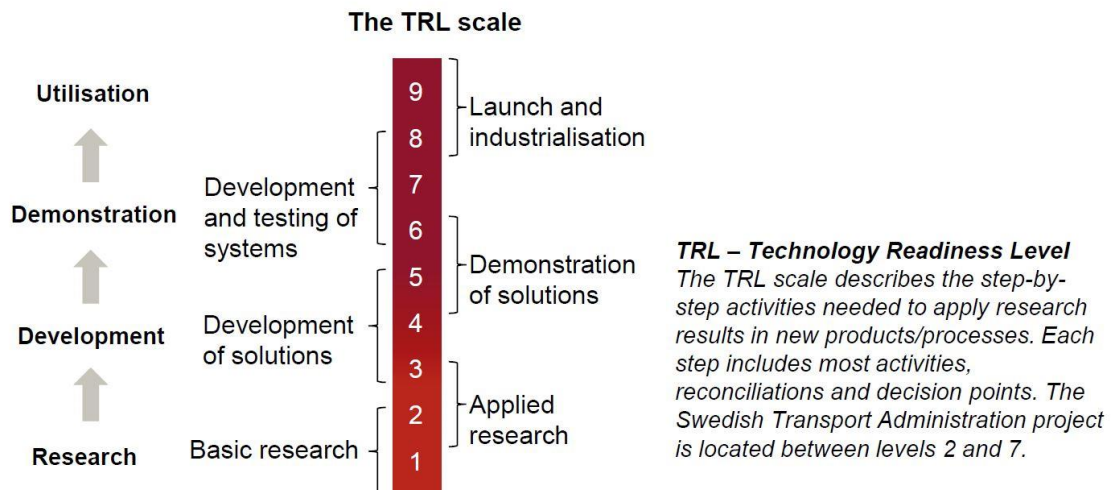
- A high-voltage grid parallel to the road, in or near to the road area, will probably need to be constructed as there is normally no existing grid for connection points to a sufficient extent.
- Transformer stations, which convert high voltage into low voltage, need to be constructed every two or three km along the road.

- Low-voltage grids for final distribution to vehicles need to be constructed in accordance with the design of the technology in question.

The identity of the proprietor of the electric road system needs to be investigated. However, it is important for the Swedish Transport Administration, in its role as the road owner, to have access to the electric road system facilities for the purposes of operation and maintenance of the road infrastructure.

Glossary of terms

| | |
|----------------------|---|
| Electric road system | Roads and their peripheral equipment which permit the transmission of electricity to vehicles in motion, regardless of the technical solution applied |
| ERS | Electric Road System |
| EV | Electric Vehicle |
| Fame | Fatty acid methyl ester |
| FFF | Fossil-free traffic survey, based on SOU 2013:84 |
| SVRI | Strategic Vehicle Research and Innovation |
| IVID-SVRI | Integrated Vehicle and Infrastructure Development within SVRI |
| H2020 | Horizon 2020 |
| HVO | Hydrogenated vegetable oil |
| PPP | Public and private partnership. |
| RISE | Research Institutes of Sweden – Sweden’s research and innovation partner for trade and society |
| Traffic work | Number of km |
| Transport work | Number of tkm |
| VTI | Swedish National Road and Transport Research Institute |
| TRL | Technology Readiness Level – see the sketch below. |
| BMUB | Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety). Germany’s Ministry for the Environment |
| T&E | Transport & Environment – a European environmental organisation working with transport |
| ADT | Annual Daily Traffic, the number of vehicles passing a certain point on an average day |



Purpose

The general objective of the transport policy is to ensure provision of transport for citizens and the business community throughout the country that is sustainable in the long term and effective in socio-economic terms. The Riksdag has also decided to adopt a target to reduce emissions from domestic traffic, except for domestic flights, by at least 70% by 2030 (compared with 2010).

The FFF survey (SOU 2013:84) states that electric road systems offer potential for reducing dependency on fossil fuels. Demonstration projects involving electric road systems are currently taking place in order to provide information on how these work in practice. The Swedish research programme has commenced as part of a partnership involving industry, authorities and universities. However, as things stand at present electric road systems are not sufficiently well developed or tested, as either technical solutions or transport systems, to an extent where they could be used regularly.

There is a very high rate of development as regards electric road systems and other fossil-free alternatives. It is imperative for Swedish authorities and companies to get involved in this development and show that Sweden has an ambition to remain at the cutting edge of technical development. In the long term, electric road systems may help to attain transport policy targets by reducing carbon dioxide emissions and increasing energy efficiency in the transport system. Electric road systems also expected to contribute to greater socio-economic efficiency and bring about an increase in jobs. A collective national roadmap and action plans linked with that are needed in order to ensure successful development of electric road systems.

Description of problems

Heavy goods vehicles are responsible for almost 89% product volumes transported domestically. Heavy goods vehicles travelling by road are responsible for around 25% of the road transport system's energy utilisation, and more or less the same percentage of carbon dioxide emissions.² The Riksdag (Swedish Parliament) has made a decision on a climate law which will involve a compulsion to reduce carbon dioxide emissions from the transport sector by at least 70% by 2030, before reaching a zero level in 2045. Similar tendencies present themselves in other parts of the world, and stakeholders involved in the conversion of the transport sector are very much in agreement that electrification has an important part to play.

The forecast increase in freight transport work, in combination with attempts to make the freight transport system fossil-free, presents a monumental challenge. Long-term instruments will be needed in order to drive this changeover. Every transport type will be needed to ensure a sustainable supply of goods. Therefore, every transport type must be permitted to develop both individually and together in cooperative solutions. This will also reinforce reliability and redundancy in the overall transport system.

The publicly funded Swedish road network is almost 15 times as long as the equivalent rail network. Road network capacity is generally good. The road network reaches more or less everywhere in Sweden. Railways and shipping reach only a small percentage of the destinations for freight

² Elvägens möjligheter (text processed from a round of bidding for R&I programmes for electric road systems, August 2015)

transport. These forms of transport could stand responsible for the entire transport route for only a minor percentage of transport operations. The road therefore carry approx. 89% of the freight transported within Sweden, and lorries are responsible for 65% of all transport work in Sweden.

These ratios may only change marginally over the next few decades. The capacity of the rail network is already utilised extensively, and redundancy is limited³. Thus the road network will continue to stand responsible for most of the transport work in the Swedish freight transport system for the foreseeable future. This is precisely why it is extremely important for goods vehicles travelling by road to reduce their energy consumption and environmental impact.

Given the research and knowledge we have at present, it is not apparent that heavy goods vehicles will be capable of carrying the power required in order to complete long journeys. If it is to be possible to run them on electricity for the most part, it is necessary to have another energy storage facility on board, such as fuel cells, or else electricity must be supplied continuously while the vehicle is in motion. There are a number of different technical solutions with regard to how lorries could be powered more or less continuously along their transport routes.

The FFF survey⁴ states that electric road systems offer potential for reducing dependency on fossil fuels. The Forum for Transport Innovations has emphasised heavy road vehicles' dependency on fossil fuels as a strategic field. As things stand at present, neither electric road systems nor other technical solutions are sufficiently well developed or tested to an extent where they could be used regularly.

Technological development is facing a number of major challenges. The development of electric road systems is taking place in parallel with the development of other fossil-free technologies. How are they developing, and at what pace? If Sweden focuses on electric road systems, will this make the country profitable in socio-economic terms, or will other technology do this so that these are not used? Investments in road infrastructure will be costly and time-consuming if longer sections are to be electrified. Electric road systems therefore need to be built using a technical solution that ideally is compatible with as many vehicle types as possible. It must also last for long enough to allow investments in vehicles and infrastructure to become financially reasonable to implement.

Background

The technical solution involving the transmission of electricity to a vehicle moving on a road has existed since 1882, and trolleybus lines have been operating since 1902. In Sweden, trolleybus services were provided in both Stockholm and Gothenburg from 1941 up to the early 1960s. Goods vehicles powered by catenaries were also found in countries such as Germany and the Soviet Union in the first half of the 20th century, up to the 1960s. Sweden had a combined line for trolleybuses and tractor units for freight between Södra Station in Stockholm and Kvarnholmen in Nacka, a distance of around 5 km, between 1941 and 1959. A new trolleybus line was commissioned in Landskrona in 2003. But beyond this, the field has largely lain fallow up to the last decade.

The IVA project "Transport 2030" submitted its final report in 2010. This contained not a single word about electric road systems. There was no discussion on electric road systems among the experts from authorities, industry and universities who worked on the project. A lot has happened in the

³ Järnvägens kapacitet 2015, Swedish Transport Administration 2016:038

⁴ Fossilfrihet på väg, SOU 2013:84

seven years since then. As far as the Swedish Transport Administration is concerned, the issue arose due to proposals from two development companies. Elways AB and Svenska elvägar, which had developed their concepts with funding from the Swedish Energy Agency. In June 2012, the Swedish Transport Administration worked on behalf of the government to present a survey into the options for using electrically powered lorries to transport iron ore from the mine in Kaunisvaara⁵, which opened later that same year. This assignment did not include carrying out new research, but the situation in the field was summarised and a proposal for funding principles was presented.

A lot has happened over the last few years as regards research, development and demonstration. A list of a selection of reports and scientific articles can be found in Appendix 1. Overall, it is our view that R&D initiatives ordered or started in Sweden within the public part of the field will have turned over up to 280 million SEK by 2020. The dominant projects are the Swedish Transport Administration's pre-commercial procurement of demonstrators (approx. 210 million SEK), the research platform for electric road systems (just under 30 million SEK) and other Swedish Energy Agency and SVRI programmes assisting with industrial development.

Besides the above, and industrial development is taking place that it is not possible to foresee in its entirety. When Siemens made their eHighway technology public in 2012, this had been developed internally at Siemens beforehand. When Nikola Motor presented their plans for a fuel cell-driven lorry in 2016, industrial development lay behind this in a similar way. The same thing happened when Tesla presented its battery-powered lorry in 2017.

It is very difficult to assess how extensive industrial commitment is to the field of electric road systems. In the car industry, only Honda has developed a solution – an arm on the side of the car which is folded out and collects power from a railing parallel to the road. The attitudes of other car manufacturers vary from uninterested to dismissive as regards electric road systems. Essentially, the emphasis appears to be on further development of technologies based on batteries and fuel cells. This attitude may possibly be re-examined if electric road systems turn out to be a successful concept for heavier vehicles, if electric road system technology is appropriate for cars. If the technology can also be used for stationary charging, this may possibly act as a springboard for the development of dynamic charging systems.

Development in the field of electric road systems is at a very dynamic stage. Three main focus areas are being developed and tested as regards continuous transmission of power from the infrastructure to electric road vehicles:

- conductive transmission via overhead lines
- conductive transmission via some form of rail or conductor in the road
- inductive transmission, via electromagnetic fields, from the roadbed

Two demonstrations of different conductive technologies for electric road systems are taking place in Sweden. Another handful of systems for the dynamic transmission of electricity are being developed, a number of them in Sweden. A strategic 4-year R&I programme has been established via SVRI and the Swedish Transport Administration. This programme is focusing on criteria for and effects of electric road systems on communities and industry.

⁵ Swedish Transport Administration 2012; Malmtransporter från Kaunisvaaraområdet och elektriskt drivna lastbilar – 2012:147

In ERTRAC⁶, the R&I agenda for electrification has been developed to include heavy vehicles as well. This is gradually also being reflected in rounds of bidding as part of Horizon 2020.

A pilot study into the electrification of the road network around London has taken place in the United Kingdom. In Germany, plans are in progress for three electric road system pilots involving transmission via suspended wires. Similar demonstration to the one taking place outside Sandviken is taking place in the US.

In Utah, plans are afoot for a demonstration of an inductive transmission system for transportation by lorry. Inductive electric road systems are also being developed in Korea, Spain and Israel. In Norway, a pilot study is taking place on the electrification of the E39, and Nord FoU is discussing electric road systems as a potential joint initiative.

The first international scientific symposium on electric road systems took place in Sandviken in June 2017.

This “research boom” in the field of electric road systems must be viewed in light of international climate targets. More and more stakeholders and analysts have come to realise that very extensive use of heavy goods vehicles will be part of our future, so these vehicles need to be released from their dependency on fossil fuels. Electric road systems may be part of the solution. This is why development, testing and demonstration of electric road system solutions are important in the next few years.

More technologies need to be verified so that they can become procurable and contribute to the creation of a market for electric road systems. Ongoing initiatives need to be monitored, and the results of these need to be analysed and compiled into a roadmap for electric road systems in a future society without fossil fuels.

Market stakeholders and funding

Market stakeholders

One significant element when planning the introduction of electric road systems is to devise models with regard to how the facilities required are to be owned, funded and paid for. These different aspects are included in what can be termed a stakeholder network. A stakeholder network comprises a number of different stakeholders and interfaces that operate in an environment with a number of interfacing environmental factors.

The business model and distribution of responsibilities can be formulated in different ways depending on the structure of the stakeholder network. Factors such as the choice of technology may also influence the design of a business model. The balance between stakeholders and the public and private sectors is another significant aspect.

This section describes the stakeholder network on a superficial level. It provides a starting point for a more in-depth analysis and understanding of significant aspects in the next stage of the work on a national roadmap for electric road systems.

⁶ European Roadmap Electrification of Road Transport, Status: final for publication, 3rd Edition, Version: 10, Date: June 2017 http://ertrac.org/uploads/documentsearch/id50/ERTRAC_ElectrificationRoadmap2017.pdf

The electric road system market

The current market and the actors involved can be described in diagrammatic form as shown in the figure below.

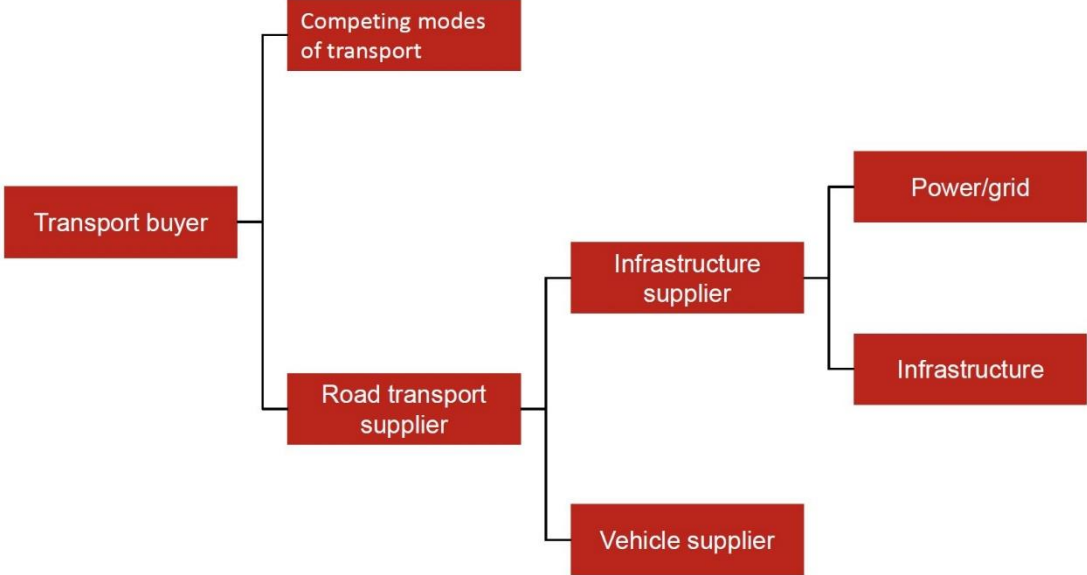


Figure 1 Stakeholder network for electric road systems – as a diagram.

Figure 1 specifies a number of significant functions and their functional/logical links that need to be present in the network building up the electric road system organisation. It does not go without saying that the functions will be organised into separate organisational units, but that may well be the case. Whether vertical or horizontal integration can be anticipated is dependent on factors such as how risks and interfaces defined between functions/stakeholders: this is discussed in transaction cost theory, for example.

A number of external factors define limits as to how these stakeholder networks operate and influence them continuously. This can be described as shown in Figure 2 below.

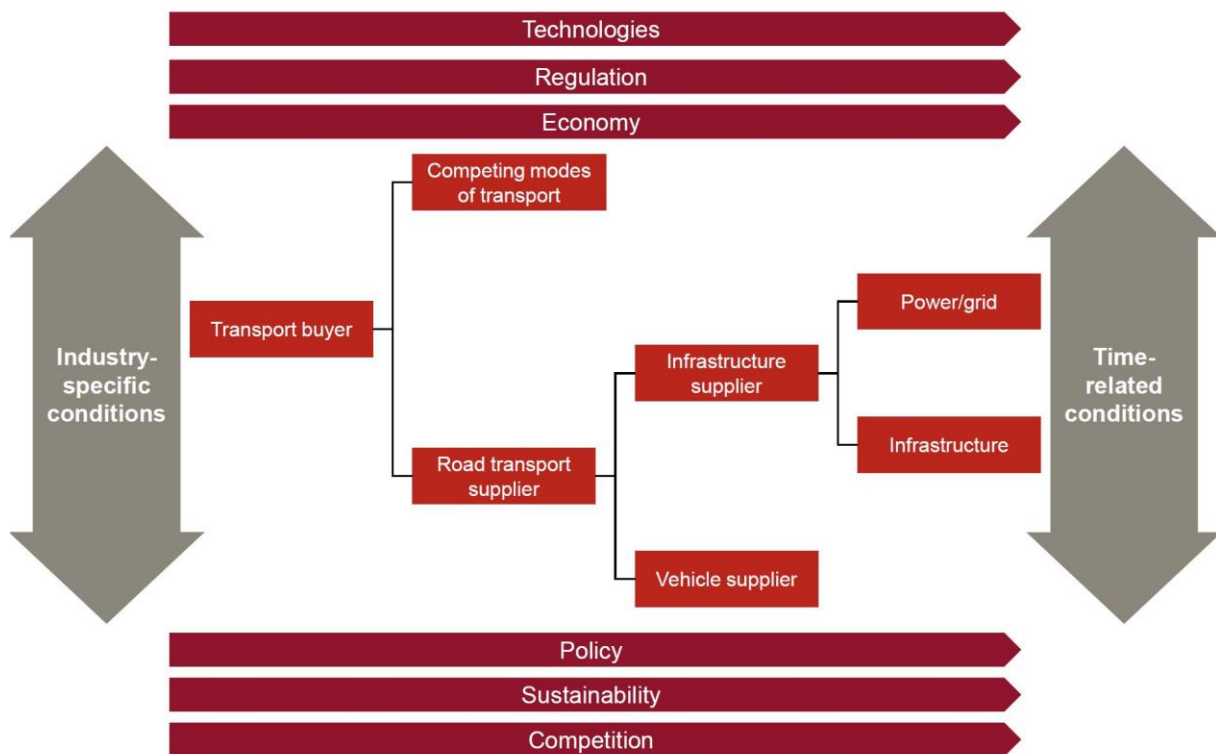


Figure 2 Actors network for electric road systems – and limit-defining factors

The transport system – and this is largely true of fields such as electric road systems – is made up of actors that are organised in the private sector. These in turn are owned by private sector stakeholders that are funded by customers that voluntarily buy the services offered by the stakeholders – in other words, there is competition. In addition, certain functions are provided by public sector stakeholders. Public stakeholders are owned by the government, regions or municipalities and are largely funded by taxes (sometimes charges) and ringfenced with some form of compulsory element, such as a monopoly or compulsory duties.

The balance between functions provided in the public sector and those provided in the private sector is changing over time. This is being influenced by technology, the economy and politics, but also by what is known as path dependency. Path dependency means that ingrained patterns for organisation tend to have a strong supporting capacity rather than being justified logically or rationally.

There are two different relationship form types in the network described; those characterised by the private – private relationship, and those characterised by the private – public/private relationship.

The relationships between private stakeholders involve previously developed roles that do not primarily need to be influenced to any great extent by changing the fuel for transport. In this respect, it may primarily be a matter of facilitating the transition from one technology to another by adapting functionality throughout entire networks and reducing risks/costs.

An alternative where functions/services should be transferred from market-organised actors to public sector organisation does not appear to be a primary option. Against this is the basic view that functions that can be provided in competition and on market-like terms should be provided in this manner in the future as well. However, what should be subject to more fundamental review is whether the arguments for retaining public provision of infrastructure when electric road system

technology is introduced are still sufficient. For historical reasons, the government has chosen different paths for railways and roads in that respect.

Fuels for road traffic are provided under market conditions, while electricity for rail traffic is provided (conveyed) by the government via the Swedish Transport Administration. Whether the logical links between the infrastructure's "core services" (roadbed/surfacing with peripheral equipment) and facilities for providing inductive or conductive charging technology are to be considered so obvious that this would justify government ownership, and which forms of ownership are legally possible, need to be analysed in greater depth.

Direct government funding is the basic model for services/functions that it is considered appropriate for the government to own as regards electric road systems. Charges may be considered for utilisation of the infrastructure, that in this case these are permitted in accordance with the EU's rules incorporated in Swedish law. It is generally not possible to earmark revenues from such charges for specific purposes according to Swedish law. Therefore, tax instruments may be an alternative to charges.

Alternative funding models may be examined for functions/services provided by the government. For example, it may be possible to implement development of electric road system technology on the road network in a public and private partnership (PPP), with the government as the client and project funding from private stakeholders. The government can then compensate the PPP counterparty with accessibility-based charges or transfer the traffic risk to the PPP counterparty by means of a concession, for example.

The extent to which there is scope for stakeholders (transport companies and transport buyers) to pay for the costs inherent in investment in electric road system technology is in turn dependent on which fuel taxes the government chooses to apply to the power supplied for road traffic. This is one of the most crucial factors when building up a business model for electric road systems.

The various models examined also need to be adapted to the various technologies discussed. A business logic and business model that suit one technology will not necessarily suit another business model.

The view of how electric road system technology is to be implemented and utilised is a further aspect that has to be analysed. A number of different models are possible; everything from relying on local and regional initiatives to a larger-scale rollout of new technology. Given the major uncertainty as regards the choice of technology, it appears to be reasonable to bring about a number of local facilities during an introductory period where various technologies can be tested. This follows the pattern dating back to the 19th century, when the railways were developed. The government or a private stakeholder will then have to take on the task of refining the use of technology, business arrangements, etc.

For the electric road system market to develop as effectively as possible, experience may also be drawn from other parallel markets and infrastructure areas. In general, the opportunities for rapid market building appear to be favourable if the following aspects are met and taken into account.

- **Standards** – Voltage levels, AC or DC voltage, the height of overhead lines above the road, and distances between lines. The same open descriptions are needed for solutions in the roadbed. It is imperative to find a balance between the elements of the system that are protected by patents and other rights, and those that are open for various stakeholders to use. It is important not to lock the system into excessively tight patterns, etc., so as to

pave the way for competition. This means that special solutions of various kinds in order to meet the demands and wishes of individual suppliers should be avoided.

- **Procurability** – Open standards, multiple suppliers, competition, etc. provide a foundation to allow solutions to be procured/provided by a number of different stakeholders.
- **Clear market communication reduces risks** – A clear declaration of intent, open, communicated standards, procurable solutions and clarity from the Swedish Transport Administration and the political system give stakeholders more opportunities to assess risks in the market. This makes development funding cheaper and allows the development of the entire technical field to be accelerated.

The driving force for various parties in the network relating to electric road systems varies, relating to direct and indirect effects of electrification. Electrification will facilitate the development of current working methods, but will also pave the way for completely new business logic, new products and new services. There are differences in business logic between different parties and technologies, due mainly to incentives and assignments. Targets for some are instruments for others, problems for some are opportunities for others. All actors involved in the value chain are needed, but understanding that there are different driving forces is key.

Attention always needs to be paid to the balance between research, development, implementation and utilisation, along with the ambitions of various parties to patent ideas and earn money along the way. Nowadays, researching, surveying, running demonstrators, developing products and patenting various ERS components using public funding is almost a business concept in itself. This is a reasonable way forwards, but it cannot be allowed to become too great an element in the ongoing development of electric road systems. It is important to take steps towards implementation as soon as possible in order to meet expectations from the political system and maintain momentum in the development of the Swedish electric road system market.

Funding

In terms of function, electric road system technology can be introduced in various ways. The funding model selected relates to who is to own the facility, which technology is selected and the stakeholder structure in the various instances. The need for investment – and the subsequent need for maintenance – for a new facility of this kind is relatively extensive, although the overall amount is dependent on which technology is selected. At this stage, the various technologies have very different costs. The choice of a funding model is also dependent on the extent to which a decision is made to electrify the road network, and on whether the system applies only to heavy vehicles or to cars as well. Investment in electric road system technology of a scope that essentially allows it to contribute to attainment of the emissions targets for the transport sector (approx. 2,000 km) will probably generate a funding requirement of at least 30-40 billion SEK.

One crucial issue as to whether a charge-based model under market conditions can be introduced is which taxation will apply for the electricity supplied to vehicles using electrified roads. General taxation of electricity, in the same way as for the use for other transport purposes, will provide reasonable scope to allow development of essential parts of the infrastructure as well. At the same time, it will probably also provide scope to provide vehicle owners/carriers/transport buyers with financial returns that are so great that they will perceive switching to electricity as an attractive option.

If the government were to choose to apply higher tax to electricity supplied to electric road systems in order to compensate for any tax shortfall that may result from a reduction in fossil fuel sales, the calculation criteria may rapidly worsen, which may make it difficult to implement introduction using private stakeholders as the driving force. Uncertainty relating to future instruments is relatively great and may affect electric road systems in a variety of ways. For instance, a distance-based instrument applied to all transport may affect the profitability of electric road systems in a different way to the taxation of electricity.

At a general level, potential funding (and organisation) models for introduction of electrification may be:

- Central government funding and ownership
- Central government funding and ownership by the central government and regions/municipalities
- Central government funding and ownership by private stakeholders
- Regional/municipal funding and ownership (probably on local streets/at ports, etc.)
- Private funding and ownership/commitment to operation (e.g. with a concession model as for the 4G mobile phone network)
- Private funding with central government guarantees and private ownership

A model involving exclusively central government funding would mean that relatively essential additional investment and maintenance requirements would be added to the government's infrastructure planning – which is already subject to stringent prioritisation – and to the budget. Without a doubt, this would lead to other urgent objects being removed from the plans, which may be less desirable. In this case, vehicle owners/carriers will nevertheless need to be charged for the cost of the electricity, as is the case with railway operations, in order to remain (reasonably) competition-neutral. The fact that the government would end up in a competitive situation in relation to fuel companies as a result of such a procedure and over a relatively long time, is something that would require in-depth analysis. This may involve severe complications as regards competition neutrality. One advantage of this model is that it would maintain the government's/the Swedish Transport Administration's right of disposition over the road system as other stakeholders would not need to be afforded access in order to carry out installation work.

The degree of involvement, in terms of funding and ownership of facilities for electric power from regions and municipalities, brings other issues to the fore. The regions are becoming increasingly involved in infrastructure issues, primarily as regards planning, but currently bear no responsibility for owning and running the facilities (with a few exceptions). The municipalities have such responsibility, this relates mainly to local infrastructure facilities such as roads and streets in towns, at ports, etc. If regions and municipalities were interested in extending their responsibilities in the field of electric road systems, this may lead to a need for changes to the law; which, from experience, may be complicated. The relationship between the central government and the regional and local government sector is often filled with difficult trade-offs.

One advantage of private involvement in the funding and ownership of facilities for electric power (and operation) is that it can be built up as a relatively separate system alongside the rest of the infrastructure funding. This is logical, given the fact that the government decided back in the 1940s, after extensive surveys, not to get involved in the supply of fuel for road transport, e.g. by nationalising the petrol companies, as was discussed at the time. The distribution of roles has meant that private companies have been responsible for the distribution and provision of fuel on a market characterised by reasonable degree of competition. The supply of fuel has been stable, the cost level

for distribution has generally been perceived as reasonable, and technical development of new fuels has worked reasonably well from this perspective – all within the scope of the predominant internal combustion engine technology.

The organisation of the supply of electricity to railways can also be taken as an analogy. Here, the Swedish Transport Administration provides the infrastructure and also sells electricity. However, unlike in the case of the supply of fuel for road transport, there is a certain government subsidy for the electricity infrastructure that benefits rail transport. From a competition neutrality perspective, it could be argued that the government ought to offer electric road vehicles the same subsidy; but further consideration of this is necessary. The fact that users of electric road systems should reasonably be able to choose from a variety of electricity suppliers appears to be natural and in accordance with the principles for the general regulation of the electricity market. There needs to be investigation of whether a private stakeholder providing infrastructure for electric power along roads will be regarded as a grid owner and concession holder from the standpoint of electricity legislation.

There is much to indicate that a model with private involvement for electric power along roads could also be successful in parallel with how fuel is supplied to vehicles dependent on fossil fuels. However, a number of practical and formal issues need to be examined.

Private stakeholders will probably demand some kind of guarantees from the government, as the party responsible for infrastructure, if they are to make investments in electrification. This may be in the form of a technical standard or legal rules that result in a clear perception of the playing field. Some kind of ultimate loss cover guarantee in case the initiative fails may also be assumed to be likely, particularly if there is a great deal of uncertainty relating to the choice of technology, etc.

Nevertheless, it would be possible to grant the right to build and operate electric power infrastructure along major roads to municipalities and private companies as well, in more closed facilities at industrial centres, ports, public transport, etc., using some kind of concession model as a basis.

The Swedish Transport Administration, for example, could offer companies the opportunity to bid on the right to hold a concession of this kind for specified road sections, with indicated technology/functionality, for a period of 20 years. In return, they would be allowed to charge users within the scope of an established price system. The price of these concessions could vary considerably depending on the level of ambition, tax rules and perceived risk level. A high price would probably drive price levels upwards. A lower price could pave the way for a discussion on whether the companies granted concessions will make unreasonable profits. Competition between multiple stakeholders participating in concession procedures and grids being made available for distribution of power from a number of different utility companies are probably crucial to the success of the model.

Some kind of public/private cooperation as a model for developing and running the electric road system infrastructure could conceivably strike a happy medium. Similar analyses of risk distribution, funding costs, streamlining potential, etc. need to be carried out here, as with all arrangements involving public/private cooperation. The Swedish Transport Administration has recently submitted a report on these issues relating to high-speed railways⁷. Observations and conclusions relating to alternative forms of funding can largely be transferred to the electric road system infrastructure as

⁷ *En svensk höghastighetsjärnväg – alternativa former för finansiering och samverkan*, report to the National Negotiation on Housing and Infrastructure from the Swedish Transport Administration, with consultants EY and Advokatfirman Lindahl, February 2017.

well. For this purpose, a Government Committee has submitted an interim report (SOU 2017:13) analysing the advantages and disadvantages of alternative funding and organisation. The Committee proposes implementation of a programme with what is known as PPP, which includes three major projects, with a view to creating an experience base in Sweden.

If the government or another public sector party implements the investment and commissions the system before then transferring the entire system, or operation of the system, to an external party, preferably in the private sector, this strikes another happy medium. A number of stakeholders on the financial markets have a major interest in making such capital investments, which means that the required returns are relatively limited at present. This model may also be of relevance to the electric road system.

The payment flows in the various model will go between users of the electric road systems to the party responsible for the costs for capital and operation of the system. A division between infrastructure and electricity may be necessary, depending on whether the system is opened up to more electricity suppliers. It is crucial to create a model and distribution of roles where a sufficiently large proportion of the potential energy streamlining from electrification is transferred to transport buyers and carriers so that there are sufficiently strong incentives to utilise the facility. One way of ensuring this is to use the agreements that regulate the development of the system. Another approach is to ensure that there is sufficiently strong competition between various stakeholders in the system.

The closer relationships between various stakeholders in the system that will be developed around the electric road systems need to be studied further and are dependent on a number of the factors outlined above.

Procurement, awarding concessions, etc.

Procurement of systems for electrification and/or the awarding of concessions is one instrument in the development of electric road systems and markets for electric road system technology and the operation of electric road systems. The procurement or the awarding of concessions can be used as a method, depending on whether the government wishes to run the business under its own auspices with government funding or to pave the way for stakeholders in other sectors to provide electric road systems. At the same time, it is not possible to rule out the fact that the government or the Swedish Transport Administration may pave the way for stakeholders in other sectors to construct electric road systems that require no procurement or awarding of concessions.

As the forthcoming period will probably primarily involve carrying out further demonstrators and pilot projects, and as the electric road system technologies are still undergoing development, it may be relevant to use procurement procedures based on some kind of cooperation between the government as a road owner and stakeholders in the private sector. This can be achieved by means of a negotiated procedure, for example, or by forming an innovation partnership in order to take the next step in development.

At the same time, it is not possible to rule out the fact that a partnership between the government/Swedish Transport Administration and other parties could be organised in the form of what is known as a public-private partnership in which a company with a specific focus is set up in order to channel the partnership project. It is not possible to rule out the fact that such a partnership

could be organised via a formal procedure other than a procurement or awarding of a concession, but it may also be appropriate to use these forms for public-private partnership as well.

The appropriate forms for running the partnership and procurement are largely situation-specific and need to be analysed carefully in each individual case.

Activities

- A project is to be initiated in the autumn of 2017 in parallel with other activities in the electric road system programme, with a view to completing a final report by the end of June 2018 which provides a more in-depth explanation of the issues discussed above. External expertise will probably be needed for the project.
- It is suggested that three different scenarios be devised in order to indicate how a roadmap for electric road systems could be formulated as regards stakeholder networks and business models; a government model, a regional/local model and a model with extensive private involvement.
- The issue of appropriate balance between ongoing research and demonstration facilities, more specific implementation of technology for electric road systems and measures for promoting the broadening of the market also need to be assessed on an ongoing basis within the scope of the Swedish Transport Administration's electric road system programme, for instance.
- Issues relating to procurement forms and partnership forms as referred to above should be included in the project.

Technological development

Dynamic transmission technologies

There are currently three main focus areas as regards technology for continuous, vehicle-related transmission of power from the infrastructure to electric road vehicles:

- conductive transmission via overhead lines
- conductive transmission via some form of rail or conductor in the road
- inductive transmission, via electromagnetic fields, from the roadbed

All three types have been tested in some form. The technology involving overhead lines has made the most progress. Overhead lines are not suitable for cars as the distance between the roof of the vehicle and the lines will be too great. Electric road systems with overhead lines, for heavy vehicles, have been tested on the Siemens test track, 2 km long, which is situated east of Berlin. Full vehicle integration has taken place in partnership with Scania for tests in Germany and Sweden. Integration in three different lorries, one of which is a Mack, is also taking place in the US.

Testing involving overhead lines on public roads began in Sweden in 2016 and in the US in 2017. The Swedish test is taking place on a 2 km section of the E16 motorway near Sandviken. The American test began in the summer of 2017 on a 1.6 km section of highway near Los Angeles (City of Carson). This is being managed by the South Coast Air Quality Management District (SCAQMD).

Elways AB has developed a live rail that is recessed in the road surface. This technology has been tested on a test track 400 metres long near Arlanda. Vehicle installation and the technology for switching between segments with rails have not been documented publicly as yet, but this forms part of the project. The next step is to test the electric road system on a public road 2 km long with the vehicle technology fully integrated in a DAF lorry, using E-Traction and a ZF powertrain.

Alstom has carried out tests involving power rails in the road together with AB Volvo on a test track 300 metres long at the Volvo test site in Hällered. Vehicle integration has been carried out as part of a Slide In research project, which is funded by the Swedish Energy Agency.

The Swedish Energy Agency is currently funding a research project which will demonstrate, in 2017, a solution involving a rail on the road which is based on technology by Elonroad. The biggest difference between this and the solutions by Elways and Alstom is that live parts of the Elonroad technology are always fully covered by the vehicle.

Bombardier has spent more than five years researching dynamic inductive power transmission as a further development of its Primove commercial static solution. This system has been integrated in a Scania lorry and tested on a closed test track, 80 metres long, in Mannheim, Germany, as part of the Slide In project.

Commercial company OLEV, a spin-off company at KAIST University in South Korea has invested 50 million dollars in inductive power transmission since 2008. Their solution has been undergoing testing on a public road on the KAIST Daejeon campus since 2012. A bus route with two buses, with a total of 144 metres of installed coils, has been operational in Gumi since 2013.

An EU project headed by Spanish company Endesa, involving an electric bus route in Málaga using an autonomous bus, began in 2016. This route is based on inductive power transmission developed by CIRCE. Eight 80 cm-long 50 kW coils are installed along the road, which is 100 metres long. The autonomous bus is supplied by Gulliver.

The Transport Research Laboratory (TRL) in the United Kingdom has worked on behalf of Highways England to complete a pilot study on dynamic inductive power transmission along a network of major roads in the UK.

Germany's Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has issued an invitation to fund the demonstration of electric road systems based on overhead lines. Installation on public roads is expected to begin in 2017. The first of at least three projects has already been procured and will be implemented around Frankfurt in the federal state of Hessen.

The Norwegian Public Roads Administration is funding the Norwegian research organisation SINTEF for implementation of the ELINGO study, which is studying a wireless ERS solution on the E39 coastal road. This project is being coordinated with Swedish research projects.

The extensive EU project FABRIC demonstrated dynamic inductive power transmission on two test tracks in 2016. Inductive technology developed by the SAET Group has been tested on a test track near Turin, Italy, using a Fiat van. The second demonstration has been installed at the Vedecom test track in Satory, France. This power transmission technology is based on the commercially available static charging solution from Qualcomm, and has been installed on a Renault van.

ElectRoad in Israel has a 30-metre inductive transmission test track in Caesarea, Israel. This technology will be tested on a 800-metre section of a public transport route in Tel Aviv in 2018. This

project receives funding from the Israeli government. If the outcome of this project is good, a section 18 km long between Eilat and Ramon International Airport may undergo development.

There is no natural PE terminal for the vehicle chassis when charging vehicles from a conductive electric road system. This can be dealt with by means of what is known as “double insulation”. However, this is a complex and impractical solution on modern vehicles. Instead, some form of galvanic isolation is required between the “electric road system” providing the supply and the vehicle’s electric powertrain. Such isolation may be constructed in a number of ways, but solutions that are cost drivers/weighty/demanding in terms of volume are frequently required. Although solutions exist for commissioning small vehicle series, vehicles adapted for electric road systems are not mature for commercial applications as yet. Thus further development of the actual electric road system technology also requires development of vehicle technology adapted for electric road systems. Such issues should be addressed by SVRI (Strategic Vehicle Research and Innovation), for example.

Supplementary and competing technologies

Development of fossil-free technologies and fuels for heavy goods vehicles

Development of fossil-free technologies for driving road vehicles is progressing at a tremendous pace. As regards cars in particular, the batteries have now achieved a capacity and maturity that give fully electric cars a range of up to 400-500 km. They are starting to become commercially competitive and increasingly independent of charging infrastructure beyond what is offered by homes and places of work.

The heavy vehicle side of things has also been developed. Fully electric, battery-powered buses and distribution vehicles for commercial use are now available, primarily within densely populated areas with charging infrastructure (for buses) and limited distances (for distribution vehicles). However, vehicles running on electricity only have total weights of up to 26 tonnes⁸.

This is reflected in the report Roadmap to climate-friendly land freight and buses in Europe, 2017, issued by Transport & Environment (T&E). This states the opinion that electrification by means of batteries is the fastest, most cost-effective way of removing fossil fuels from distribution vehicles and buses, but that there is a great deal of uncertainty as regards which technologies are effective for really heavy lorries (>40 tonnes).

There are few options for really heavy vehicles (40-74 tonnes) and long distance travel (more than 100 km). The commercially available alternative involves admixture of liquid biofuels (HVO; Hydrogenated vegetable oils, and Fame; fatty acid methyl esters) in diesel. This admixture is currently estimated to represent around 18% of heavy goods vehicles’ energy consumption (Swedish Environmental Protection Agency, 2016) and hence an equal share of traffic work. A distinct advantage of this admixture is that it can be mixed into existing diesel and requires neither a special powertrain nor special infrastructure. A distinct disadvantage is that both HVO and Fame are in short supply already, and they will be even more scarce in the longer term. Sweden uses a large proportion of the international amounts produced. Biofuels in the form of ED95 (ethanol) and biomethane

⁸ IEA. 2017. The Future of Trucks - Implications for Energy and the Environment. Insight Series 2017. International Energy Agency

(biogas) are used by heavy vehicles – primarily buses and lorries for distribution purposes – to a limited extent.

No other fossil-free technology for heavy goods vehicles is commercially available at present. However, research is taking place into dimethyl ether (DME), alcohols and other fuels. Sweco has carried out a survey in spring involving interviews with around 30 stakeholders working in transport⁹; vehicle manufacturers, electric road system manufacturers, fuel suppliers, carriers, analysts and academics, looking at their views on the development of fossil-free technologies to 2030 and 2045 respectively. Sweco has assessed the development of the technologies and the markets up to 2030 and 2045 on the basis of their responses and Sweco's own expertise in the field¹⁰.

The technologies assessed

De-fossilisation of the transport sector involves a range of different prospective measures such as energy-efficient vehicles, energy-efficient usage of vehicles and systems, planning, alternative energy sources and sustainable fuel and electricity. Streamlining vehicles and systems is a positive measure, but remaining vehicles need to be powered in a sustainable way in order to achieve freedom from fossil fuels. The technologies can be roughly divided into two groups; those using internal combustion engines of various kinds, and those with electric powertrains. Technologies can then be combined into various hybrid powertrains.

Usage can be divided into two groups for **biofuels**, admixture in diesel for conventional diesel engines – known as drop-in – or in dedicated engines. Today's diesel engines can run on more or less any amount of HVO, but with a max. 7% admixture of Fame, as long as the end product is still compliant with the specification for diesel.

ED95 (an ethanol fuel) and DME (dimethyl ether) are fuels for compression engines (where the fuel is ignited by means of compression, as in diesel engines, and not using spark plugs), but these cannot be mixed together or with ordinary diesel. These fuels require unique engines, fuel systems and distribution systems. The same is true for LNG (Liquefied Natural Gas)/liquid methane, which require engines that use spark ignition. CNG (Compressed Natural Gas), or *fordonsgas* – vehicle gas – as it is known in Sweden, is a fuel of biological or fossil origin (and mixtures thereof). Engines that run on methane generally use spark ignition, but there are technologies that use compression ignition, known as dual-fuel or methane diesel. Lightweight vehicles often use methane in combination with petrol in engines that use spark ignition. As the various biofuels require different infrastructures for distribution, as well as different engines, there is clear competition between these fuels and technologies.

Fuel cells are essentially an electric technology. The engine that runs the vehicle is electric, but the energy comes from hydrogen gas that is converted into electricity and fuel cell. Besides pure hydrogen gas, hydrogen can be obtained from other hydrocarbons, which may require a reformer on board the vehicle. Development and fuel cell trials have been ongoing for a number of decades. The annual "Fuel cell industry report 2016" implies that the industry is still small and vulnerable, and largely dependent on funding. The industry itself does not perceive this technology to be a dominant solution, and it will take some time to establish large-scale systems. The industry has also responded

⁹ Sweco; Avfossilisering av tunga fordon – en rapport till Trafikverket juni 2017

¹⁰ Sweco; Avfossilisering av tunga fordon – bedömning av utvecklingen, ett PM till Trafikverket, juli 2017

well to political signals and the wishes of its customers. Cars that run on fuel cells are now available for sale and operational in Sweden as well. However, there are only four fuelling stations throughout the country, so there are still not many of these vehicles around. As yet there are no commercially available vehicles that run on fuel cells and can be used for heavy transport.

Electrofuels are hydrocarbons produced from hydrogen gas and carbon dioxide. The processes for this are energy-inefficient and are not well developed as yet. Nevertheless, a pilot study¹¹ implies that it would be possible, under certain conditions, produce fossil-free methanol using wind turbines in Västra Götaland. Many factors such as production costs, access to electricity and carbon dioxide need to be studied in greater detail before it is possible to assess the potential of electrofuels in the transport sector of the future.¹²

Electric road systems (ERS) are based on the principle of supplying electricity to the vehicle – either directly for propulsion or for storage in batteries – as it moves. The technology is either conductive (the current is transmitted via catenaries) or inductive (the current is transmitted without direct contact by means of electrical induction). Both technologies are being developed for heavy vehicles, and two conductive technologies are being demonstrated in Sweden.

Costs are often crucial when deciding between different technologies with less climate impact. This is something which is emphasised by parties such as the Volvo Group¹³. Some examples¹⁴: A tank for LNG is 70% more expensive than a similar tank for CNG. Compared with batteries, hydrogen gas has as much energy density/volume and 300 times as much energy density/weight at a pressure of 70 MPa. However, the hydrogen gas tank requires 4 times as much space as a similar tank for diesel, and its design requirements are much more stringent than for the diesel tank. Calculations indicate that a 260 kW diesel lorry would cost just one-quarter of the price of a similar lorry with fuel cells at present. The majority of cost comparisons between different technologies indicate that diesel is a cheaper fuel than the fossil-free alternatives, if new infrastructure costs are to be included¹⁵.

The use of alternative technologies is not just limited by availability and price, but also by distribution options. In Sweden, for example, there are around 60 CNG facilities¹⁶, but the gas is used mainly by cars and local fleets of heavier vehicles such as refuse collection lorries and buses. Of the fleet of cars and heavy vehicles, around 1% of these run on gas. The equivalent figure for buses is 17%.

The answers provided by respondents to the Sweco survey must be viewed as assessments for both the development of the technologies and the markets for them. They also include hopes for the development of the technology preferred by the respondents themselves. The ability to gain support for a technology may largely be crucial to the future of that technology. Thus the results of the survey should not be interpreted as a truth about the future, although the assessments for 2030 will probably be more accurate than those for 2045. Foreseeing development up to 2045 is so much more difficult.

Besides the technical development of vehicles and fuels, society and transport systems also face prospective significant changes. Various services such as mobility as a service, shared mobility and

¹¹ Liquid wind; Storing energy by making fuel, 2017

¹² Brynolf, S. Taljegard, M. Grahn, M. Hansson M (2016). Electrofuels for the transport sector: A review of production costs. Renewable and Sustainable Energy Reviews (In Press)

¹³ Position on Directive 2014/94/EC

¹⁴ OECD/IEA 2017; The future of trucks

¹⁵ OECD/IEA 2017; The future of trucks

¹⁶ OECD/IEA 2017; The future of trucks

autonomous vehicles may also views on mobility and transport. These issues will be monitored, and a partnership will be created with the Swedish Transport Administration's digitisation programme.

Development to 2030

All respondents and Sweco are of the opinion that fossil diesel will remain dominant in the market for a long time. Nobody seems to believe that transport using heavy goods vehicles will be independent of fossil fuels by 2030. Most people are of the opinion that low admixture of biofuels in diesel will make the greatest contribution to fossil freedom as regards heavy goods vehicles, although clean biofuels or high admixture of biofuels may make a small contribution. Electric road systems and fuel cells will be limited to demonstrators or individual sections. Batteries will primarily be used for very short distances in combination with other technologies.

Although there are minor differences in the perceptions of various groups, everyone seems to agree that battery technology will not be technically or commercially mature as an individual propulsion technology for really heavy vehicles by 2030. The energy density of batteries has quadrupled between 2009 and 2015 (IEA, 2017), but as yet this is nowhere near the energy density that would allow them to be used in really heavy vehicles.

Electric road systems with conductive transmission may have begun to play a part, while at best the development of fuel cells will still be at the demonstration stage. The development of alcohols and liquid methane is largely dependent on how the development of regulations, instruments and market trust in these fuels. This trust appears to rest with diesel engines, as the fuel and technology already exist and do not need to be developed, along with the fact that instruments (reduction obligations, etc.) favour low admixture. Alcohols and methane require both technical development and customers who are prepared to invest in new technology and good infrastructure for distribution of the fuel.

The same could be said of fuel cells as regards fuel distribution infrastructure. However, fuel cells can power any electric motor, and electric motors already exist and can also be used with power from electric road systems and batteries. The development of fuel cells for heavy vehicle applications is also progressing. Both Scania and Toyota and Nikola Motors are developing vehicles. Sandviken AB is contributing to this development by supplying specially designed sheet metal for the actual fuel cells. Broad industrial support for fuel cell technology may give electrification an advantage over the development of various specific biofuels.

The overall assessment of the market in 2034 alternative fuel technologies will then involve:

- 1) admixture of biofuels in diesel
- 2) alcohols, methane and conductive electric road systems
- 3) fuel cells and electrofuels
- 4) batteries

Development to 2045

The major differences between 2030 and 2045 are relating to the development of electrification, access to biofuels and the issue of what they are to be used for, plus the local importance of regulated emissions. A transition from diesel to natural gas (fossil methane), for example, is dubious

from a climate perspective, but at the same time it will help to improve air quality by reducing emissions of hydrocarbons, particulates and nitrogen oxides.

By 2030, it is obvious that internal combustion engines running on diesel and biofuels will be dominant as regards heavy vehicles. Hence the regulated emissions will also remain at around the current levels. Heavy vehicles in urban districts will need to be regulated with prohibitions, green zones similar measures in order to reduce levels of these emissions that are hazardous to health. Already, in the aftermath of the diesel scandal, a number of European cities are discussing completely or partly banning diesel vehicles due to their impact on air quality. Disruption due to noise and vibration are other important local aspects. Local environmental considerations may thus be one of the driving forces for more rapid electrification, which is an important reason for the South Coast Air Quality Management District in Los Angeles in the US¹⁷. By 2045, electrification may be an alternative to these measures and may have made so much progress that justification of such measures for health reasons is not necessary. Local environmental considerations may thus be one of the driving forces for more rapid electrification. Transport & Environment is of the opinion that if we are to achieve zero emissions by 2045-50, this has to be based on fossil-free technologies generated by electricity, while internal combustion engines running on biofuels or electrofuels may complement electrification.

Biofuels must reasonably be regarded as a limited resource. Sweden already imports much of the available HVO¹⁸. The availability of sustainable raw materials for biofuels that are competitive in terms of cost is the primary limiting factor. Changes to instruments and regulations, e.g. updating of the EU's Renewable Energy Directive, poses a significant risk to this market. In the long term, applications other than goods transport will compete for the available biofuels. It may be difficult to replace internal combustion engines with electricity in aviation and shipping applications in particular. Therefore, a larger proportion of the available biofuels may be steered towards aviation and shipping.

By 2045, many market stakeholders are of the view that fuel cells in particular may have developed into a commercial application for heavy goods vehicles. This would mean that electrified powertrains could receive power from electric road systems, fuel cells and batteries, and that internal combustion engines of various types would be on their way to being phased out.

Figure 3 below shows a Sweco summary of the results of its survey and conclusions from a number of reports in the field. Together, provided view of how the market shares for the various technologies (in terms of traffic work) may have developed by 2020, 2025, 2030 and 2045.

¹⁷ Clean Fuels Program 2016 Annual Report and 2017 Plan Update, SCAQMD

¹⁸ Swedish Energy Agency (2016). Drivmedel och biobränslen 2015 - Mängder, komponenter och ursprung rapporterade i enlighet med drivmedelslagen och hållbarhetslagen. ER 2006:12

| | Current situation | | 2020 | | 2025 | | 2030 | | 2045 | |
|------------------------------------|---------------------------------|-------|---------------|-----|---------------------------------|-------|--------------------------------|-------|-------------|-------|
| | Qualitative | % | Qualitative | % | Qualitative | % | Qualitative | % | Qualitative | % |
| Gaseous biofuels | Pre-commercial | 0-0.1 | Commercial | 0-1 | Commercial | 1-5 | Commercial | 2-8 | Commercial | 2-10 |
| Liquid biofuels | Commercial | - | Commercial | - | Commercial | 2-5 | Commercial | 2-5 | Commercial | 20-40 |
| Drop-in | Commercial | 18 | Commercial | 26 | Commercial | 33 | Commercial | 44 | - | 0 |
| Electric road systems (conductive) | Development/early demonstration | 0 | Demonstration | 0 | Demonstration | 0-0.5 | Commercial | 1-10 | Commercial | 10-40 |
| Fuel cells | Development | 0 | Development | 0 | Demonstration | 0 | Pre-commercial | 0-2 | Commercial | 5-25 |
| Electrofuels | Demonstration | 0 | Demonstration | 0 | Commercial | 0-1 | Commercial | 0-5 | Commercial | 1-10 |
| Batteries | Development | 0 | Development | 0 | Development/early demonstration | 0 | Demonstration? Pre-commercial? | 0-1 | Commercial | 2-15 |
| Diesel | | 82 | | 74 | | 58-63 | | 41-53 | | 0-20 |

Figure 3. De-fossilisation of heavy vehicles – estimated development (Sweco, July 2017)

Conclusions

Up to 2030, diesel with admixed biofuels such as HVO and FAME will be the dominant technology for de-fossilisation of heavy goods vehicles. Changes to conditions involving regulations and instruments, among other things, may alter the situation. In the longer term, there is much to indicate that electrified powertrains will replace internal combustion engines.

Electric roads could be capable of contributing to electrification and progressing the electrification trend. It is highly likely that there will be a number of parallel sources of electricity: dynamic charging and direct transmission of electricity via electric road systems, fuel cells with on-board energy storage facilities in the form of hydrogen gas or some other hydrocarbon, and batteries. These systems will complement one another rather than competing.

Liquid methane, alcohols, CNG and other bio-based fuels for dedicated engines may constitute local niche applications for limited vehicle fleets.

The development of the market for electrofuels will be dependent on the electricity market and the availability and price of fossil-free electricity.

Given this fact, the Swedish Transport Administration is strengthened in primarily supporting the ongoing development of electrification; particularly electric road systems, as there is not much chance of these being built without the support of the Swedish Transport Administration. The Swedish Transport Administration should also monitor ongoing development of fossil-free propulsion technologies, particularly as regards electric powertrains.

Planning and utilisation

Benefits and effects of electric road systems

There is limited knowledge of the benefits and effects of electric road systems. The benefits and effects referred to in this section are therefore based on a number of uncertain parameters and

criteria. This is inevitable as there are no traditional causal links, calculation values or demand calculations. Therefore, it may be appropriate to carry out sensitivity analyses with regard to speed, the proportion of electric vehicles, etc.

Vehicle costs

Vehicle costs must be produced for both conventional vehicles and electric vehicles. The calculation parameters used can be set up as shown in the table below.

| | |
|-------------------------------------|-------------------------|
| Time dependency, SEK/vehicle-hour | Driver’s pay |
| | Capital cost |
| Distance dependency, SEK/vehicle-km | Reduction in value |
| | Tyres |
| | Maintenance and repairs |
| | Other |

Road wear

The analysis method and socio-economic calculation values for the transport sector, known as ASEK, include differentiated marginal costs for operation, maintenance and reinvestment for heavy vehicles, with regard to the total weight of vehicles. These are specified in SEK per vehicle-km. Road wear from a vehicle is proportional to the vehicle’s number of standard axles. A vehicle of average weight has 1.3 standard axles (SA), and so road wear – which we assume is dependent on axle weight – is differentiated using factors that correspond to the difference in the number of standard axles.

There is nothing to indicate that electric vehicles will cause wear that is different to the wear caused by conventional vehicles. Some studies indicate links between wear and vehicle mass. Electric vehicles for electric road systems will not necessarily be heavier than conventional vehicles, particularly as large batteries are not needed for electric road system vehicles.

Besides the road wear caused between tyres and the carriageway, electric road systems May also generate particulate emissions via the contact face between the pantograph and the overhead line or the collector and the electrified rail. The significance of these emissions will be studied within the Research and Innovation Platform for electric road systems.

Emissions including carbon dioxide

Emissions factors are applied to estimated fuel consumption. We have to take into account carbon dioxide (CO2) and nitrogen oxide (NOX) emissions.

The particulate emissions expected to be reduced with electric road systems are primarily those found in rural areas: i.e. there are regional environmental effects in play. The harmful effect of particulates is fairly low there and is not valued in monetary terms. The local health effects of particulates can be calculated only when the distance (and hence the exposure) is known. Hence we will disregard particulate emissions in this context.

Three sample calculations have been performed for three different fictitious road sections with different annual daily traffic levels (ADT) in order to see the extent by which carbon dioxide and nitrogen oxide emissions could be reduced. This is shown in the tables below. Tables 1 and 2 based

on just heavy vehicles using the electric road system, while Tables 3 and 4 show the corresponding effects for light vehicles. Data indicates reduced emissions from the road transport sector. From a life cycle and system perspective, emissions arise in other subsystems; and producing electricity, for example.

Table 1: Carbon dioxide (tonnes/year) from heavy vehicles

| Km | ADT, heavy vehicles | CO2 emissions, entire section, no electric vehicles | CO2 reduction with 10% electric vehicles | CO2 reduction with 40% electric vehicles | CO2 reduction with 70% electric vehicles |
|-----|---------------------|---|--|--|--|
| 40 | 2,000 | 18,104 | 1,810 (2,633 thousand SEK) | 7,242 (8,556 thousand SEK) | 12,673 (14,447 thousand SEK) |
| 25 | 5,000 | 28,288 | 2,829 (3,225 thousand SEK) | 11,315 (12,899 thousand SEK) | 19,801 (22,573 thousand SEK) |
| 270 | 5,000 | 305,505 | 30,550 (34,827 thousand SEK) | 122,202 (139,310 thousand SEK) | 213,854 (243,794 thousand SEK) |

Table 2: Nitrogen oxide (tonnes/year) from heavy vehicles

| Km | ADT, heavy vehicles | NOX emissions, entire section, no electric vehicles | NOX reduction with 10% electric vehicles | NOX reduction with 40% electric vehicles | NOX reduction with 70% electric vehicles |
|-----|---------------------|---|--|--|--|
| 40 | 2,000 | 67 | 6.7 | 26.8 | 46.8 |
| 25 | 5,000 | 132 | 13.2 | 52.9 | 92.6 |
| 270 | 5,000 | 1,429 | 142.9 | 571.6 | 1,000.3 |

Table 3: Carbon dioxide (tonnes/year) from light vehicles

| Km | ADT, light traffic | CO2 emissions, entire section, no electric vehicles | CO2 reduction with 10% electric vehicles | CO2 reduction with 40% electric vehicles | CO2 reduction with 70% electric vehicles |
|-----|--------------------|---|--|--|--|
| 40 | 18,000 | 36,792 | 3,679 (4,119 thousand SEK) | 14,717 (16,777 thousand SEK) | 25,754 (29,360 thousand SEK) |
| 25 | 35,000 | 44,712 | 4,471 (5,097 thousand SEK) | 17,885 (20,389 thousand SEK) | 31,299 (35,681 thousand SEK) |
| 270 | 20,000 | 275,940 | 27,594 (29,177 thousand SEK) | 110,376 (125,829 thousand SEK) | 193,158 (220,200 thousand SEK) |

Table 4: Nitrogen oxide (tonnes/year) from light vehicles

| Km | ADT, light traffic | NOX emissions, entire section, no electric vehicles | NOX reduction with 10% electric vehicles | NOX reduction with 40% electric vehicles | NOX reduction with 70% electric vehicles |
|-----|--------------------|---|--|--|--|
| 40 | 2,000 | 63.1 | 6.3 | 25.2 | 44.2 |
| 25 | 5,000 | 76.6 | 7.6 | 30.7 | 53.7 |
| 270 | 5,000 | 473.0 | 47.3 | 189.2 | 331.1 |

The tables above indicate that the major benefit of heavy vehicles that run on electricity would be a reduction in carbon dioxide emissions. Of course, this is not very surprising as the aim of electric vehicles – at least in Sweden – is to reduce carbon dioxide emissions.

As regards the carbon dioxide benefit for heavy and light vehicles respectively, this is dependent on the distance and ADT. In general, it can be stated that the longer the distance, the greater the benefit for heavy vehicles compared to light vehicles.

Noise

Tyre noise is completely dominant at speeds above 50 km/h.¹⁹ Therefore, the noise effect will be marginal as regards heavy vehicles, which mostly operate in rural areas. That said, electric vehicles – primarily light vehicles – may be significant in urban environments where vehicles travel at low speed.

Electricity mix

Given the reasoning behind this section, it is assumed that the electricity used for the electric road system and vehicle operation will originate from the Swedish electricity mix²⁰. For the most part, this will be produced from hydroelectric power and nuclear power: in other words, it will be fossil-free. Thus it is assumed here that the production of electricity used by electric vehicles will not give rise to carbon dioxide emissions.

Environmental and climate impact from a life cycle perspective (LCC)

Electric road systems are a completely unique type of road, and at present we have no templates for calculating figures as regards climate impact. Existing templates based on conventional technology can be modified on the basis of existing knowledge and the knowledge obtained from research in progress, e.g. the research and innovation platform for electric road systems. The Swedish Transport Administration works in close partnership with the Research and Innovation Platform for electric road systems, which is examining the effects of electric road systems on health and the environment.

However, calculations show that if heavy vehicles using the Stockholm-Malmö-Gothenburg route (1,365 km) make a complete transition from fossil fuels to electric power, this would involve a reduction in carbon dioxide emissions of 1 million tonnes a year. This is more than 2% of Sweden's emissions of greenhouse gases from fossil fuels. The calculations relating to carbon dioxide emissions from electricity production should be based on the Swedish electricity mix. Here, hydroelectric power and nuclear power make up the majority of the electricity produced.

¹⁹ According to Mikael Ögren, noise expert at VTI, tyre noise is completely dominant at speeds above 50 km/h. Traffic on hills and accelerating traffic are exceptions to this. According to Mikael Ögren, switching from diesel to electricity would therefore have only a marginal impact on noise levels.

²⁰ Referral of regulations on sustainability criteria for biofuels and liquid biofuel, Referral from the Swedish Energy Agency, ref. no. 2017-010464

Landscape, nature and cultural environments

A very long-term approach is often adopted as regards the structure and function of road and rail environments. They have to be able to withstand wear and tear and the elements – 24 hours a day, 365 days a year. The Swedish Transport Administration architecture policy states that our facilities have to be characterised by good architecture; or, in other words, well thought out design that works in combination with the landscape and its people. Over the years, post structures – for example – have been developed and adapted to what has been considered good design. Constructing new infrastructure for electric road systems, not least electric road systems involving overhead lines, involves encroaching upon the landscape. The extent of this encroachment is dependent in part on the technology selected, but also on factors taken into consideration during planning and design. This also includes the infrastructure needed for linking the electric road system to the public power distribution grid.

Electric road systems based on technology involving suspended wires (e.g. Siemens eHighway) affect/alter the urban and rural landscape from a road user perspective, but also in terms of residential and outdoor recreation considerations. The road currently being demonstrated is a prototype, and there is scope for improvements in the design and adaptation to the landscape. The posts are primarily designed to be able to withstand collision forces without causing live lines to fall onto the carriageway. It ought to be possible to achieve this functionality with a sleeker design.

The way in which the live lines are suspended may convey a sense of being in a tunnel to anyone driving beneath the lines. The lines may also limit visibility and make it harder to read the road environment and landscape. A design with fewer catenaries could reduce this sensation and also give road users more of an opportunity to read the road environment and adapt the facility to the existing landscape.

Electric road systems can be constructed within an existing road area and so do not need to take up further land, apart from the land that may be required for setting up the transformer stations (the electrical facilities at the interface between the high-voltage grid and the low-voltage grid). These transformer stations need to be positioned along the road and spaced approximately two kilometres apart. When planning electric road systems, it is necessary to take into account where transformer stations are to be positioned in relation to existing road facilities, the design/formulation of these, where they are to be located and how access to each transformer station is to be guaranteed. Using the four-stage principle, electric road systems can be described as an activity between stage 2 and stage 3. An electric road system can be regarded as a measure that brings about more efficient utilisation of the existing infrastructure by bringing new functionality to the road facility without affecting the capacity of the existing road facility. At the same time, electric road systems mean limited refurbishment of the road facility.

Electric road systems that are based on inductive or conductive technology in the carriageway involve no impact on the landscape, apart from the addition of transformer cabinets.

The Swedish Transport Administration or the stakeholder responsible for the construction and operation of infrastructure must be compliant with the legal requirements specified in the Environmental Code and the Historic Environment Act, for instance, when adapting the infrastructure. The Roads Act and the Railway Construction Act also specify a general requirement

indicating “that attempts must be made to achieve an aesthetic design”²¹ and that “the urban environment and landscapes, and natural and cultural assets, will be taken into account”²². This is also applicable to the design, instruction and operation of infrastructure for electric road systems.

The government has decided that the significance of biodiversity and the value of ecosystem services must be generally known and integrated in economic positions, political considerations and other decisions in society, where relevant and reasonable. This target must be met by 2018.²³

To live up to this responsibility, the Swedish Transport Administration has introduced a guideline landscape (TDOK 2015:0323). This guideline covers the interaction with and influence on the landscape due to roads and railways, which includes planning and investment, and reinvestment, operation and maintenance. The guideline must influence the production of both early strategic planning documents and more specific documents for planning, project design, operation and maintenance, along with the processes that steer this work. The next time this guideline is reviewed, attention should be paid to how electric road systems influence landscapes and natural and cultural environments, depending on the type of transmission technology.

Electric road systems may influence landscapes, natural and cultural environments on account of their physical design, and also on account of the influence electromagnetic fields may have on the natural environment. Of the groups of animals identified in the guideline, it is thought that in particular bats and aquatic animals could be affected by electric road systems. Bats are protected according to the Species Protection Regulation (2007:845), but there has been a relatively small amount of study into the interaction between infrastructure and bats; and even less study into the interaction between bats and electric road systems. Aquatic animals, not least migrating fish, may be affected by electromagnetic fields. When planning electric road system infrastructure, attention should be paid to which parts of the road need to be equipped with technology for dynamic transmission, and which parts should be free of electromagnetic fields.

Birds may also be affected by electric road systems, primarily electric road system technology based on overhead lines. This field has been studied to a relatively great extent on an international level (power grids, railways, etc.)²⁴. When designing overhead lines, consideration should be given to minimising the impact on birds. Electric road systems may also involve positive effects on the natural environment by powering wildlife warning systems, for example.

Effects on safety

Electric road systems should be capable of influencing safety on a given section of road. The opinion and focus of the Swedish Transport Administration is that electric road system sections must offer safety equivalent to that on other, comparable sections. In other words, the electric road system must not pose any additional risk to road users or individuals adjacent to the road section.

Safety requirements for the facilities – Safety requirements for both existing and new infrastructure must be examined in terms of both road safety and electrical safety, but also from a general safety and vulnerability perspective. Safety aspects may be of significance, not least when it comes to

²¹ The Roads Act, 4 and the Railway Construction Act, chap. 1(3).

²² The Roads Act, 13 and the Railway Construction Act, chap. 1(4).

²³ Government decision M2012/1171/MA. (26 April 2012).

²⁴ Protecting Nature in Power Grid Planning. Recommendations from the BESTGRID project. Handbook. Birdlife International.

deciding how large an area has to be earmarked for the infrastructure, e.g. so that necessary safe distances can be observed. The safety requirements that will be applicable will ultimately be determined by the technical solution selected.

One basic principle when it comes to safety work is to produce a risk analysis for the entire system; and the stakeholder closest to the operation, frequently the technology supplier, is responsible for the risk analysis. This is because this supplier has the most detailed knowledge of the operation and also has the most knowledge of the potential risks that it may involve.

A risk analysis must include all safety aspects, the risk of accidents and risks as a consequence of deliberate incidents such as sabotage and other criminal activities. The National Safety Strategy emphasises a number of areas that have a bearing on the transport system and hence electric road systems as well, such as “Safeguarding the security, safety and health of residents” and “Safeguarding the provision and protection of important social functions”.

An electric road system facility must also be implemented in accordance with good technical electrical safety practice so that it provides adequate security against injury or damage to property on account of electricity. The basic safety requirements in accordance with ELSÄK-FS 2008:1 3 chap. 1-9 must be applied. The regulation (SFS 2016:363), section 6 must be applied in terms of electromagnetic compatibility. Taking into account applicable technology, equipment must be designed and manufactured so that it does not generate electromagnetic interference at a level that would prevent radio or telecoms equipment or other equipment working as intended, and be of such resistance that the electromagnetic interference that can be expected when used as intended does not lead to the function of the equipment being impaired to an unacceptable extent.

In the pre-commercial procurement of electric road systems, the Swedish Transport Administration has chosen to specify requirements for every technology on the basis of the criteria of the technology in question. This has taken place without compromising on safety. As a result of this, suppliers can verify their safety work in three different ways:

1. By applying a standard developed for the application
2. By applying a standard developed for a comparable application
3. By applying systematic safety work based on general safety principles with explicit estimates of risk

As electric road systems are not included in legal texts or standards as a concept, there is no general systematic safety work on which to fall back. As a result, standards for comparable applications have been used (case 2, eHighway), or systematic safety work has been developed (case 3, Elways). New electric road system technologies require support through research and innovation in order to develop them, both technically and in terms of safety, to a demonstrable development level.

The issues are handled slightly differently depending on which technology is used for transmission of power from infrastructure to vehicle.

Technologies using suspended lines

The preliminary assessment of safety issues linked with this technology is manageable. 45 risks have been analysed within the demonstrator at Sandviken. No incidents of note have occurred in the period of just over 12 months since the facility was commissioned.

The power lines are live 24 hours a day as long as the electric road system is operational. The posts that are used to suspend the lines are protected by a reinforced side rail (H2) to prevent collision. According to the Swedish Transport Administration's standard, a normal side rail (N2) is sufficient. Should the power lines or their suspension break, the live lines are designed to roll up and remain suspended in the air, and the current is switched off at the same time. No live parts should then be at a height that can be reached.

Transformer stations will be positioned above the back slope, so there is a small risk of collision with them.

The technology does not involve any impact on the carriageway itself, other than wear on the carriageway (channelling) possibly resulting in the eye following the lines and vehicles making less lateral movement than normal.

Overtaking of electric vehicles does not present a problem greater than overtaking other vehicles. Electrified vehicles also have options for continuing to drive using battery or diesel power or in the event of a power outage, so no vehicles remain stationary and hence block the road on account of a lack of power.

Technologies involving electrified rails in the road

A number of different technologies based on installing rails in the road and powering vehicles via a current collector (wiper contact) beneath the vehicle.

There are two kinds of risks involved: electrical and traffic-related.

The electrical risks are linked to the rail itself, which is powered up when vehicles pass over it. Unlike the technology involving suspended power lines, longer sections are never live. The live sections vary between 1 and 50 metres (difference between the technologies). Regardless of the length of the sections, the rail is only powered up when the vehicle enters the section and is then powered down when the vehicle has left the section. In the case of technologies using shorter sections, the vehicle always covers the live part of the electrified rail. In the case of technologies using longer sections, the power is switched off when the vehicle is stationary or moving slowly (the vehicle is then running on battery or diesel power). The aim of this is to prevent people on the road accidentally coming into contact with power when vehicles are queueing or stopped or in the event of accidents. Resetting the rail in the tarmac may also limit the options for accessing live parts.

Installing an electrified rail on the road or recessing it into the road involves working on the carriageway in a way that may present safety risks in terms of traffic. A metal rail has different friction properties to asphalt/concrete, for example. This is particularly significant in terms of two-wheeled vehicles. The risk of skidding or longer braking distances is increased if the friction properties of the road surface vary. If the rail is installed in a way that causes it to project by more than 4 mm above the surface of the roadway, this breaches the Swedish Transport Administration's regulations *Vägar och gators utformning* (VGU, Road and Street Design) concerning the evenness of the roadway.

It is always the supplier's job to ensure and demonstrate that the product supplied is compliant with regulations and safety requirements. As regards electrified rails in the roadway, development has not yet progressed far enough for any system to reach a development level that meets these requirements for continuous operation.

Technologies using inductive transmission

Technologies based on inductive transmission mean that there is no physical contact between the vehicle and the electric road system. This also means that there are no electrical components that are exposed to road users or the general public. The same is applicable to the effects in terms of traffic. As the transmission technology is beneath the road surface, there is no risk of falling lines, protruding metal rails or other friction properties. On the other hand, inductive transmission involves risks associated with electromagnetic radiation. Electromagnetic radiation may affect electronic equipment and human health.

The electromagnetic compatibility (EMC) regulations already specify clear requirements with regard to how high-voltage systems – for charging or propelling electric vehicles, for example – are to be designed, and how they are to be used and maintained²⁵. Limits for non-ionising radiation devised by the Swedish Radiation Safety Authority and the International Commission on Radiological Protection have also been devised with regard to the acute impact on health, exciting the nerves. According to these guidelines, radiation in public places must not exceed 6.25 µT. The long-term effects of being exposed to magnetic fields, particularly within the area used for charging vehicles, have not been investigated thoroughly. However, the Swedish Radiation Safety Authority does specify that there are no established health risks inherent in weak electromagnetic fields.

Electric road system sections

In the case of electric road systems, every kilometre of road that is electrified and every electric road system vehicle creates additional costs compared with conventional diesel propulsion, while every kilometre driven using electric power saves money. The greater the extent to which individual vehicles travel on electric road systems each year, the more money is saved. The same is applicable to investment: the fewer kilometres of electric road system that are manufactured and the fewer vehicles that are manufactured, the lower the investment cost. In this context, it is important to ensure that the electric road system is not too short, otherwise the study would be adversely impacted by the fact that the vehicles would spend a lot of time reloading (heavy vehicles) or parked (cars).

Electric road systems can be described in a number of different ways depending on factors such as the structure of the system, the stakeholders and vehicles that have access to the electric road system and the forms of ownership. Roughly, electric road systems can be divided into open and closed systems, Figure 4. In the closed system, the electric road system and transport work are maintained entirely by private stakeholders as part of a defined production system. Transport on an industrial estate or an industrial shuttle service are examples of such systems. These systems are relatively easy to assess as the transport work over time is known and the majority of the analysis work can be carried out from a business perspective. The risk is manageable, but the overall potential is relatively low as transport assignments of this type represent a relatively small proportion of national traffic work involving heavy vehicles. Initial calculations have shown that a relatively large transport base is required in order to achieve profitability. According to the report

²⁵ Elsäkerhet och elektrisk infrastruktur för transportsektorn. Swedish National Electrical Safety Board, ref. no. 17EV372

Förstudie av affärs ekosystem för elvägar²⁶ [Pilot study of business ecosystems for electric road systems], a 30 km long section will require 50 lorries, with each lorry travelling back and forth 8 times day, all year round.

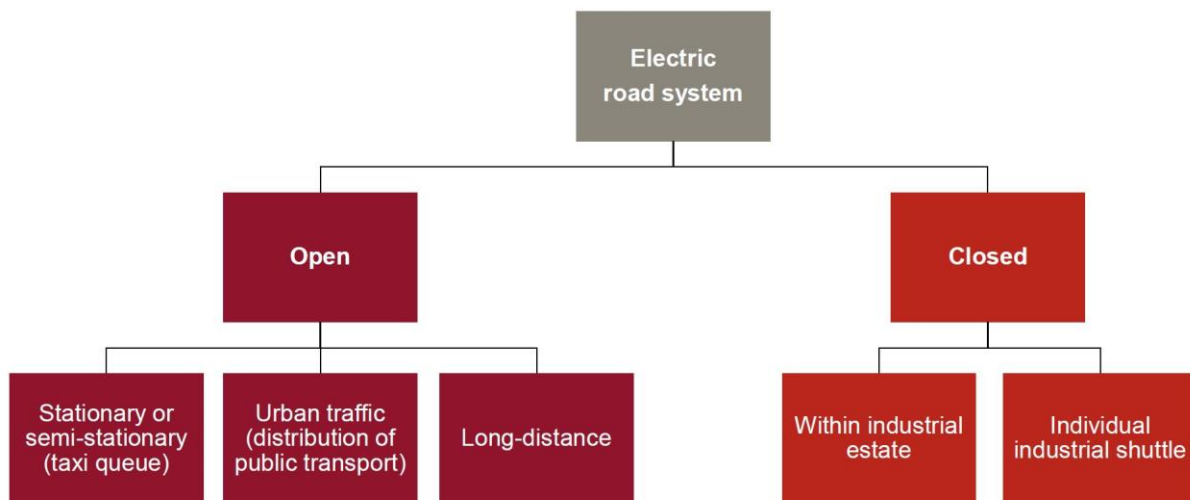


Figure 4. Basic division of different electric road systems

Open electric road systems involve non-discriminatory access to the system. Essentially, all stakeholders operating on the road section in question can connect to the electric road system. Open systems require relatively high levels of Annual Daily Traffic (ADT) to ensure that the percentage of electric road system vehicles is sufficiently high. There is greater risk with an open system than with a closed system as more mutually independent stakeholders have to interact with one another. In an open system, the majority of transport operations will probably originate from or terminate at locations outside the electric road system area, and so vehicles that also work outside the electric road system will be needed.

It may be important to look more closely at the following factors when investigating and selecting electric road system sections during an initial development stage:

- Important target points for heavy vehicles
- Important target points for buses and light vehicles
- High ADT with a large proportion of shuttle services
- The presence of individual stakeholders with stable transport work involving shuttle services
- Proportion of the total transport route that coincides with the intended electric road system section
- Stable need for transport over time
- Interested stakeholders
- Interaction with other types of traffic
- Importance of the section in an electric road system network developed in the future

²⁶ Sundelin, H. Mellquist, A-C., Linder, M. Gustavsson, M. Börjesson, C. and Pettersson, S. (2017) Förstudie av affärs ekosystem för elvägar. RISE/ICT Viktoria

There needs to be further investigation into which factors should be crucial when investigating and subsequently selecting electric road system sections and the process and methodology as regards how this is to be achieved. This work must take place in partnership with regional stakeholders and intended users and suppliers of the electric road system. The chances of achieving profitability can be improved if light vehicles also use the electric road system. However, car manufacturers have shown little interest in this to date. Ongoing work on investigating electric road systems should also include light vehicles in the analyses.

Activities

- To ensure that the functionality and safety of every transmission technology are acceptable by applying proven methods and technologies.
- Research and Innovation for bringing more electric road systems that have not yet made that much progress to a demonstrable development level.
- When constructing electric road systems, the Swedish Transport Administration's internal regulations relating to safety in connection with roads and road systems, among other things, should be reviewed.
- To investigate how access to transformer stations is to be guaranteed in a manner which is effective, safe and suited to the landscape.
- To investigate whether safety issues are affected by forms of ownership for electric road systems.
- To adapt the Swedish Transport Administration's guidelines on the landscape to also include electric road systems and any impact they may have on the landscape, protected species and other animals.
- To carry out a detailed socio-economic calculation, including production of basic causal links.
- Analysis of consequences and benefits of linking various road user groups to electric road systems.
- To plan for and implement one or two more demonstration projects.
- To plan for and implement a pilot project at system level.
- To devise a plan for utilisation of electric road systems, including factors for appropriate electric road system sections, a method for investigating electric road system sections, clarification of the process for investigating and selecting electric road system sections, and proposals for the next National Plan for the transport system (for the period 2022-2033).

Standards and regulations

Making a switch towards a more transport-efficient society in which electric road systems are assumed in the long term to become part of the Swedish government road network is dependent on a coherent legal framework. This involves a framework which underpins parallel development lines such as automation, sharing economy, digitisation, electrification, etc. and which takes into account the need for efficiency and the impact of regulations in community planning. It is important even at this stage to consider and investigate whether there is any need for changes to existing regulations in

order to achieve optimum design of facilities belonging to electric road systems, along with their funding, ownership and operation.

The present regulations mean that physical planning for roads primarily takes place within the scope of the Roads Act (1971:948) and the Roads Regulation (2012:707). This planning requires coordination with various subjects at different levels under public law, but also with subjects under private law. Some of the laws affected are the Environmental Code, the Planning and Building Act (2010:900), the Land Code, the Local Government Act (1991:900; 2017:725 after 1 January 2018), the Public Procurement Act (2016:1145), the Public Procurement Act relating to utilities (2016:1146), the Concessions Procurement Act (2016:1147), the Electric Power Act (1997:857), the Electrical Safety Act (2016:732), the Electromagnetic Compatibility Act (1992:1512), the Energy Tax Act (1994:1776) and the legislation under union and international law on which all or parts of the national legislation are based.

Besides the legal considerations highlighted in the text below, the construction and operation of electric road systems will bring to the fore other legal issues that could give rise to a need to make amendments to the law. This may relate to factors such as issues relating to liability for damages, processing personal data, planning procedures/building permits, site protection and safety requirements for facilities.

To be able to carry out a more in-depth analysis of the regulations, the operation has to be concretised to some extent. This is why this is merely an introductory, general analysis that aims mainly to highlight areas and issues that should be examined in greater detail.

Development of the electric road system network brings the following main areas to the fore:

- Access to land for the construction of necessary infrastructure
- The need for grid concessions for the construction and use of electrical systems for infrastructure
- Power distribution
- Review of standards

The description below uses separate headings for the criteria regarding land access, construction and operation and power distribution. As regards funding construction, a legal analysis should take place on a rolling basis and in connection with the continued considerations of the various funding models and their applicability. It can already be stated that such an analysis will need to include factors such as the issue of whether the provisions on charges in the Act (2014:52) on infrastructure charges on roads are applicable to the construction of facilities for electric road systems on existing roads.

Land access

The Swedish government, via the Swedish Transport Administration, has what is known as right of way for the existing public road network. Right of way arises when the road maintainer earmarks land or other space for a road pursuant to an established road plan or, in special cases, pursuant to a written agreement. Making it possible to guarantee land access for necessary infrastructure for the electric road system network by means of right of way, just as for the present road network, is a reasonable starting point. Whether it is possible solely to rely on right of way is uncertain, however, and it will probably be necessary to review and partly amend the regulations stating whether it should be possible to rely on right of way in order to obtain land access for the whole of the necessary infrastructure.

To be able to obtain right of way to land needed for the facilities in question, these must be covered by the definition of road equipment in the Roads Act, i.e. an arrangement that is permanently needed for the existence, operation or use of the road. Whether all parts of a facility for transmission of power for vehicle propulsion can be considered to constitute road equipment according to the present definition is uncertain. Transformer stations may be mentioned as an example of a part of the facility that may not be included.

Assessment has taken place so that if a new function is added to an existing road, a new road plan will be required. The option of propelling vehicles using electricity via lines does in all probability constitute a new function that will require adoption of a new road plan for relevant sections. How far away from the road itself that road equipment can be positioned is not entirely clear at present. It may be necessary to clarify this, and also to clarify whether the road equipment must always have physical contact with the road or other road equipment. The distance is significant to the extent of the road plan, and hence also to the issue of which facilities may be covered by the right of way and the facilities for which land can be earmarked with right of way.

When developing electric road systems using conductive transmission of power via overhead lines, it will be necessary to perform tree management along the power line/road. This means that the Swedish Transport Administration may need to access land outside the regular road area. Land access via right of way provides no opportunity to resolve the issue of access to areas outside the road area via easements, for example.

If the infrastructure is to be owned by any party other than the Swedish Transport Administration, it is dubious whether facilities belonging to the infrastructure will be considered to constitute road equipment. This in turn means that it will probably not be possible to apply the provisions of the Roads Act for land access. However, it may be noted that the Swedish Transport Administration has the opportunity to grant permission for the construction of facilities within road areas with the terms and investigation requirements considered reasonable, as stated in section 43 of the Roads Act. So in other words, the fact that the infrastructure is owned by someone else does not rule out construction of the infrastructure as required within the road area.

However, access to land outside the road area must be resolved by means of a voluntary agreement, by obtaining right of way, or by means of an expropriation procedure initiated by the owner of the facility. This is something that should be taken into account and investigated further in connection with considerations relating to land access and funding and future owners of facilities. The issue of government funding may also be brought to the fore if the infrastructure is owned by any party other than the government.

Grid concessions

Grid concessions, i.e. permits for constructing and using high-voltage lines, are generally required for all high-voltage lines. Grid concessions are normally valid until further notice, but they may also be subject to time limits. Anyone granted a grid concession has exclusive rights to the transmission of electricity on behalf of another party within the concession area, known as running grid operations. These exclusive rights come with obligations, including the obligation to supply electricity via the grid in accordance with the terms and conditions specified in the electrical legislation and standing responsible for the operation, maintenance and safety of the grid. A grid fee is charged for the grid operations by the parties connected to the grid, and a special permit is required for assignment of grid concessions. Holders of grid concessions are obliged to meter or estimate consumption on the

part of electricity users and to report the results to relevant parties. Grid operations are run by legal entities, which means that grid operations can be run by either a company owned by the government or a private company.

Any legal entity operating in network must not trade in electricity at the same time. This means that if the Swedish Transport Administration owns the power grid, the Swedish Transport Administration is prevented from selling power for vehicles via its grid.

The chances of the Swedish Transport Administration being granted a grid concession are limited at present due to the provision in the Electricity Act stating that grid concessions must not be granted for areas that coincide wholly or partly with another concession area.

One alternative to constructing a grid requiring a concession is to apply the exemption clauses on internal grids in accordance with the Regulation (2007:215) on exceptions to the requirement for a grid concession pursuant to the Electricity Act, referred to below as the Exemption Regulation. An internal grid will not be covered by the concession obligation, and according to the regulation it may be constructed within the area for a road in order to meet traffic needs. It is already probable that the Swedish Transport Administration is able to construct and operate a high-voltage power cable within the road area if it is intended to meet traffic needs. This grid would then be regarded as an internal grid. The fact that this network would extend over relatively long road sections would probably not present an obstacle. However, it must nevertheless be noted here that the rationale for the said regulation specifies that an internal grid should not have an excessively large spread, and this is because the concession holder must not be affected too adversely. For a power grid to be considered to be an internal grid, the party in possession of the grid or power line is required to use the grid for transmitting power to its own operations. Whether transmission to private vehicles on public roads can be considered to constitute transmission to the owner's own system is unclear.

According to the Exemption Regulation, constructing an internal grid which is primarily intended to meet vehicles' power needs is permitted, but a grid of this kind must be what is known as a low-voltage grid, which restricts future technology selection.

As regards the transmission of power to other parties from internal grids, this may only take place in the special cases indicated specifically in sections 24-29 of the Exemption Regulation. Such transmission must never take place in power grids of other types. These provisions do not specify internal grids within road areas.

As stated above, what is covered by the expression "meet traffic needs" is unclear. Whether this includes transmission of electricity for private vehicles is uncertain, which is why it is currently unclear as to whether such transmission is to be regarded as transmission to another party, and whether or not this is covered by the ban. Even if it is permitted according to the regulation, there must be noteworthy reasons for transmission of electricity on behalf of someone else to be allowed to take place in the power grid.

It may be noted that there is also provision which regulates internal grids within the traffic area for railway, tram, metro and trolleybus operation with a view to meeting the power needs of these forms of transport. The rationale for the Exemption Regulation states that transmission of electricity on behalf of someone else from an internal grid within the stated traffic areas should not be permitted. This is because such transmission is not referred to in sections 24-29 of the Exemption Regulation.

Another restriction for the internal grid is that this will probably exclude any stakeholder other than the road maintainer, i.e. the Swedish Transport Administration, from owning the grid.

Power distribution

One aspect relating to the distribution of power that should be given special consideration is the fact that road traffic fuels are currently provided under market conditions and that any government distribution/sale of power for vehicles may have an unwanted impact on competition on the fuel market. The power market in Sweden is deregulated, which means that electricity consumers have the right to buy electricity from a supplier which they themselves choose. Although the supply of electricity to vehicles in motion is an anomaly on the current power market, whether it is possible to justify a scheme whereby power is provided by a single stakeholder if technical criteria for competitive distribution are in place should be considered carefully. If the Swedish Transport Administration nevertheless supplies power for vehicles using Swedish electric road systems, whether this right should be enshrined in law, whether setting fixed tariffs by means of regulations is appropriate, or whether amendment to any element of the electricity legislation may be required should be considered. If road users are to be able to choose power suppliers, specific demands may be defined for the metering of power usage in accordance with the Electricity Act.

According to the Fuels Act (2011:319), anyone supplying a fuel for road traffic purposes (including electricity) and is liable to pay tax must submit an annual emissions report to the Swedish Energy Agency. Anyone selling power is regarded as a fuel supplier.

Standards

Issues relating to which demands are to be made of product and component development with regard to electric road system technologies and responsibility for these when they are available on the market; standards, insurance solutions, third party effects and inadequate performance are different in nature. The same issues relate to the electric vehicles that are intended to operate in future electric road systems. This refers to the provisions relating to vehicles; those focusing on the nature and equipment of the vehicle, e.g. the issue of which requirements should apply in relation to electric vehicles, and provisions relating to inspection to ensure that electric vehicles are also compliant with applicable requirements.

The purpose of standardisation is primarily to facilitate industrial production and help to bring about a good pace as regards the spread of innovations. Industrial winners and losers are created at the same time. This is why there are frequently conflicts with regard to standardisation issues. Standardisation also takes place at various technology levels in an innovation process. On the one hand, components and interfaces in technologies can be standardised, which is frequently a technical and industrial process undertaken by standardisation committees. On the other, the overall design of electric road systems may be standardised. There is also an international, industrial policy-related aspect to this issue. Which electric road system technologies people believe will become successful on the market, and the extent to which they should be subject to standardisation work, is a frequently recurring issue.

Different stakeholders have different views in this regard. Countries with a large percentage of transit traffic are in greater need of a pan-European standard for electric road systems in countries

which import or export large volumes of their goods via the international waterways. The automotive industry is keen to see appointment of a “champion” among technologies so that efficient production of large vehicle series is made possible. The parties that own or manufacture different electric road systems have the same interest, albeit on the condition that their system is the one that is named the “champion”. People wanting electric road systems in their towns and people wanting electric road systems for transporting the goods do not necessarily share the same view of which system is most appropriate. This is dependent on which transport application is to be supported. The issue for the Swedish Transport Administration is similar; which vehicles should be electrified? But it also has to take into account the issue of the conditions under which electric road systems can be constructed on the government road network, and at what cost.

The requirement specification will vary depending on the choice of technical solutions with regard to how the electric road system will be designed and how power will be transmitted to vehicles. One example of existing rules affected in the event of construction of an electric road system is the fact that there are now more applicable technical regulatory requirements that have to be observed when establishing an electric road system, irrespective of the technical solution.

- In the road: bearing capacity, longitudinal evenness, transverse evenness, friction, visibility, adaptation to road markings, electrical safety rules.
- Above the road: Clearance. Height requirements with regard to power along/across the road. Safety zones require necessary safety measures according to the regulations in order to protect road users in the event of collisions/vehicles leaving the road.
- At the roadside: Safety zones require necessary safety measures according to the regulations in order to protect road users in the event of collisions/vehicles leaving the road.

Activities

- Developing electric road systems will involve a need for clarifications and amendments to the Roads Act and the Roads Regulation, among other things. Amendments to other statutes such as the Electricity Act may also be relevant. However, an in-depth analysis is required; which is why the Swedish Transport Administration is currently unable to provide a precise description of the need for constitutional amendments.
- To summarise, the advantages and disadvantages of and practical criteria for constructing or procuring a grid requiring a concession or having such a grid constructed, or alternatively constructing an internal grid, have to be investigated further. A long series of factors should be considered in an investigation of this kind, including the criteria for land access depending on the form of ownership, the public procurement requirements that may be specified at various stages, who are to be considered the end-users of electricity and any obligation to facilitate the choice of power supplier for end-users of electricity, who is to be liable to pay grid fees and how such grid fees are to be determined, practical issues relating to the maintenance of and access to both existing facilities and facilities for electric road systems, etc.
- Something that should be given special consideration in connection with the issue of who should preferably be granted the right to provide a grid for an electric road system and the forms when granting such a right is whether any element of the procedure could be viewed as a funding measure that is subject to the rules on prohibition of government funding. This issue should be analysed specifically and from a broad perspective.

- The views of various stakeholders on standards need to be obtained prior to further investigation.
- There is a need to devise a standard for the construction, running and operation electric road systems.

Power grid construction

The public road network has currently no developed power grid along the road for the electricity required to meet the needs of the road. Electricity subscriptions provided by a power supplier with an area concession are available in certain locations where power is required for the road, e.g. for lighting or pump systems. The subscriptions that already exist are positioned too far apart and are not designed to be used for vehicle operation. Introducing electric road systems will bring about a need for power along large sections of the electrified road, and except in exceptional cases power distributors do not have complete grids along the roads with sufficiently high transmission capacity.

The public power grid may also need to be adapted/developed with regard to aspects other than the need for power. Electric road systems will place a different load on the power grid than is currently the case. Research and possibly innovation are required in order to clarify the effects and needs that the power grid may need to meet on account of electric road systems. The Swedish Transport Administration and the Swedish Energy Agency are responsible for ensuring that this is done.

New sufficiently strong public power grids can be needed if there are no existing one where it is needed. Probably will it also be a need for a high-voltage cable network (approx. 10-30kV) along the road within the road area as part of the road infrastructure. The applicable regulations Regulation (2007:215) on exceptions to the requirement for a grid concession pursuant to the Electricity Act (1997:857) permit an internal grid of this kind to be constructed “in order to meet traffic needs”. This cable network will probably need to be connected to the regional grid or a sufficiently strong local grid within the medium-voltage grid.

With a distance of a kilometre or more, the high voltage needs to be converted to a lower voltage in an electrical installation, Figure 5. After that, the lower voltage is distributed to the electric road system’s transmission system, and finally to vehicles. Although electric road system facilities for transmission of energy from the public power distribution grid vehicles are being developed, it should be possible to determine joint standards for technologies, voltage levels, outputs and communication protocols relatively soon.



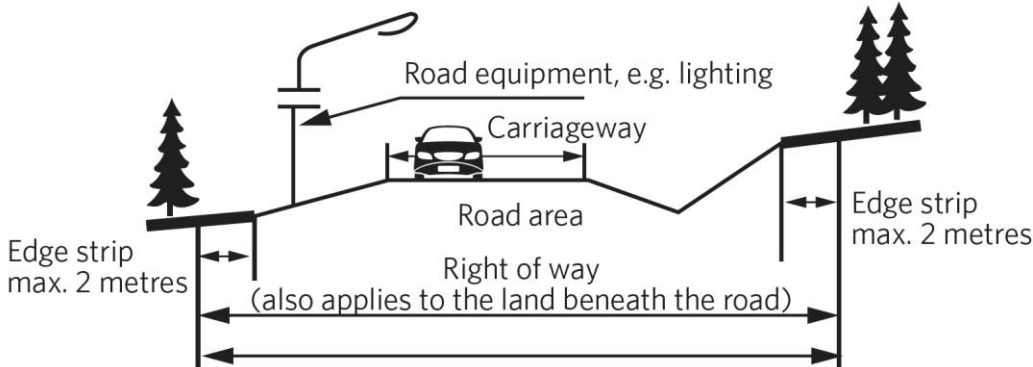
Figure 5. Example showing the potential structure for an electrical installation along the electric road system.

If the electrical installation cannot be accommodated within the area for the road, it is unlikely that the Swedish Transport Administration will be able to construct it as part of the internal grid without extending road area. See Figure 6 for what may be included in the road area. The road area may be extended either by means of a voluntary agreement with the landowner, or by means of right of way obtained via a road plan in accordance with the Roads Act (1971:948). Introducing electric road systems may mean that the present provisions of the Roads Act will need to be reviewed on the basis of needs along the road linked with high-voltage cable networks, the electrical installations along the electric road system and the electrical installation on the road, nearest to vehicles.

Road area for public road

Road area is the land taken up for road equipment.

Road equipment is an arrangement permanently needed for the existence, operation or use of the road.



Example of road equipment: lighting, dam, ditch, slope, carriageway

Figure 6. Road area for a public road

The electric road system solutions currently being tested in Sweden use a strategy whereby vehicles are powered with a voltage of around 600 – 800 V DC or AC. This is a low voltage, and within the definition of low voltage. (This means voltages of up to 1500 V DC or 1000 V AC.) Advocates of this claim that it is the best solution from a vehicle perspective. The costs for vehicles will then be lower, and the components needed for vehicles will already be available on the market. For an electric road system infrastructure, the low voltage is a disadvantage in terms of economy and energy efficiency. The infrastructure’s power supply facility nearest to the vehicle (catenary, contact rail) with a lower voltage level must have a supply at relatively close quarters from a stronger power grid for the power supply to vehicles to be acceptable, given the transmitted power and reasonable transmission losses: in other words, “inexpensive” vehicles mean more expensive, more extensive infrastructure. The most appropriate supply voltage to vehicles from an overall perspective, taking vehicles and infrastructure into consideration, will be studied within CENELEC/TC9X in 2018.

Structure of the power grid from the public power distribution grid to vehicles in the electric road system:

See the figures in the illustration below.

1. The public power distribution grid (regional or medium-voltage grid owned by a company with an area concession)
2. The high-voltage grid parallel to the road and within the road area
 - a. will probably be constructed within the road area and be owned by either the road infrastructure manager or another stakeholder.
3. The electrical installation in the interface between the high-voltage grid and the low-voltage grid.
 - a. will be constructed as part of the electric road system infrastructure and be owned by either the road infrastructure manager or another stakeholder. The electrical installation and the electric road system our integrated facilities that are intended only for the electric road system.
4. The low-voltage grid including the electrical installation in the interface closest to vehicles.
 - a. will be constructed as part of the electric road system infrastructure and be owned by either the road infrastructure manager or another stakeholder. Clear rules and boundaries linked with access to and operation and maintenance of the road infrastructure and the electric road system infrastructure need to be developed if the owner is anyone other than the road infrastructure manager.



Figure 7. Principle for powering an electric road system

Activities

A number of activities linked to the the power supply system for the electric road systems and vehicles need to be implemented.

- The supply voltage for vehicles that is most appropriate from a socio-economic standpoint needs to be analysed. Should AC or DC voltage be used, and at which voltage level?
- The need to standardise the voltage level, transformer outputs, etc. in the parallel grid.

- What rules and requirements are applicable to the supply of electricity to vehicles and the opportunities for users of electric road systems to choose energy suppliers. Should road users be able to buy electricity from any energy supplier, or does the Swedish Transport Administration have to be the supplier?
- Provide a general analysis of the need for energy (electricity) and power along the electric road system network, along with possible connection points, taking into account opportunities and obstacles linked with ongoing and anticipated changes to/development of the public power system.

Appendix 1

1. Reports and essays relating to electric road systems, linked with the Swedish Transport Administration and Swedish efforts relating to the field of electric road systems.
2. Grontmij 2010; Förstudie elektrisk vägar – elektrifiering av tunga vägtransporter, P Ranch.
3. Grontmij 2011; Elektrifiering av E4 Södertälje Helsingborg – Översiktlig samhällsekonomisk analys, M Haraldsson.
4. KTH 2012; Förstudie Eldrivna godstransporter på väg, H Ingvarsson.
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10. Chalmers University of Technology 2013; Comparative LCA of Electrification Alternatives for Long Haul Trucks, A Björkman.
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20. SEC, Swedish Electromobility Center 2015; Cost Analysis of Electric Land Transport, H Bängtsson, M Alaküla.
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22. Viktoria Swedish ICT & KTH 2016; The Maturity of Electric Road Systems, H Sundelin, M.G.H Gustavsson, S Tongur.
23. ERTRAC, Smart Grids & EPoSS 2017, European Roadmap electrification of Road transport, 3rd edition.
24. Royal Institute of Technology 2017; Exploring window of opportunity dynamics in infrastructure transformation, S Tongur, M Engwall.
25. Viktoria Swedish ICT 2017; Förstudie av affärsekosystem för elvägar; H Sundelin et al.
26. Chalmers University of Technology 2017; The effect of electric roads on future energy demand for transportation; D Jelica.

27. Chalmers University of Technology 2017; Electric Road Scenarios, rapport från AP1 i FoU-plattformen för elvägar, F Johnsson.
28. Viktoria Swedish ICT 2017; Delrapport arbetspaket 7, Affärsmodeller, tillträde och betalsystem FoU-plattform elvägar, C Börjesson.
29. Sweco AB 2017; Avfossilisering av tunga fordon, F Mohseni et al.



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