Ready to go? Technology Readiness and Life-cycle Emissions of Electric Road Systems

A discussion paper from the CollERS2 project

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Introduction

Despite rising electric vehicle sales, road transport is still dominated by fossil fuels usage. Globally, transport is responsible for about one quarter of energy related greenhouse gas (GHG) emissions and the largest share of the transport GHG emissions comes from road transport with about 72% (IEA 2021). Fortunately, technologies enabling low carbon road transport are already becoming commercially available or are under development. These technologies include the direct use of electricity in battery electric and plug-in hybrid trucks (BET and PHET) with stationary or dynamic charging via so-called Electric Road Systems (ERS), Fuel Cell Electric Trucks (FCET), bio-fuels and synthetic renewable fuels. These options are in different stages of commercialisation and development for heavy duty vehicles (HDV). The role of each in a future sustainable road transport system is still under debate (IEA 2021, Kluschke et al. 2019).

The present discussion paper is the result of an international collaboration on ERS research, the CollERS2 project. It summarizes key results of the first workshop with Swedish and German participants held in November 2021. This paper thus has a focus on one of these low-carbon road transport technologies: Electric Road Systems. The main aspects discussed at the CollERS workshop have been the life-cycle greenhouse gas (GHG) emissions of ERS in comparison with other technologies and Technology Readiness Level (TRL) of ERS. The former is key to understand the potential long-term contribution in GHG emission reduction and the latter is important to identify the remaining technical challenges and thus indicating *when* ERS could contribute.

The following Section 2 provides a brief technology background and points out the main technological differences between the technologies. Section 3 contains the main findings on comparative GHG emissions and on the technological readiness of different ERS technologies.

Background

Definition of available Technologies

In the heavy-duty vehicle sector, electric drives are considered very promising options for decarbonising road freight transport. A distinction can be made between trucks that use electricity directly (BET) or indirectly by means of hydrogen (FCET). In addition, a distinction can be made between the type of power transfer. In the case BET, power transfer is via stationary charging stations and the energy is stored in a larger battery. In the case of ERS-BET, the vehicle usually has a smaller battery and the power transfer is dynamically during the operation via an ERS. The ERS can be an overhead line, or a conductor rail for conductive power transmission or an inductive transmission by means of coils in the road surface and receivers on the underbody of the vehicle. FCETs in turn obtain the electricity from a fuel cell that is powered by hydrogen stored in a tank that can be refuelled at stationary hydrogen filling stations.

Among these options, the direct use of electricity in BET or ERS-BET have the highest well-to-wheel energy efficiency[1] and thus the least need for additional renewable energy plants in the future. Due to the additional conversion steps from electricity to hydrogen and back, FCET result in a well to wheel energy efficiency that is lower by a factor of 2 to 3 compared to direct electricity use, and thus in a higher demand for electricity (Plötz et al. 2018).

The costs and the additional weight of the large battery required in BET, especially with high range requirements in long-haul transport, pose the greatest technical challenges. While the initial charging infrastructure set-up mainly requires large investments for the grid connection, the initial infrastructure for ERS-BET represents a challenge for market entry, both in terms of high initial costs and in practice long lead times for a deployment on large scale.

Synergies of Technologies

Apart from obvious differences, the available truck technologies also have a range of synergies at different levels. For instance, all technologies have an electric powertrain, which offers economies of scale for important components that are beneficial to all propulsion options. From an operational perspective, it is also apparent that the propulsion concepts have a different suitability for the various demand profiles (e.g. in terms of driving range) and could thus complement each other.

With regard to the energy supply infrastructure, the synergies between BET and ERS-BET are particularly obvious. The combined use of ERS on long haul corridors - also for recharging the battery - and more widely distributed stationary charging points could considerably expand the field of application of BET (Plötz et al. 2021). From a load profile perspective, ERS potentially allow for a more continuous electricity demand and could thus reduce severe load peaks due to fast charging of BET during the day while drivers are on breaks.

Market availability, introduction strategies and scalability of technologies

Zero emission vehicles are still in a much earlier market phase for trucks than for passenger cars, lacking several years behind. While there are about 30,000 BET operating globally (IEA 2021), more than 90 % thereof in China, a limited number of FCET are currently operated in test trials and are not yet commercially available. ERS-BET in Europe are demonstrated in several test trials (Trafikverket, K. N. 2021, Göckeler et al. 2020), with one larger pilot already planned in Sweden and three ongoing projects on federal roads in Germany. Currently, the deployment of the Swedish pilot is being procured, where the design and construction is expected to be completed by 2025, then followed by the start of traffic operations ("E20, Hallsberg-Örebro" 2021). In Germany, according to the Federal Transport Ministry, ERS technology (overhead contact line) is to be further expanded within the framework of two innovation corridors (in Hesse and Bavaria) and combined with various alternative drive systems (BMVI 2021b). Experiences from the ongoing practical trials form the basis for this next stage of expansion.

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[1] The Well-to-Wheel efficiency combines the efficiency of fuel production (Well-to-tank) and the efficiency of the vehicle (Tank-to-Wheel).

Stimulated by ambitious CO_2 reduction targets also for heavy-duty vehicles (Axsen et al. 2020), many manufacturers have announced new electric truck models, even up to 40 t of gross vehicle weight (GVW). Over 100 models are announced globally for medium freight trucks (3.5 – 12 t GVW) and over 50 models for heavy freight (>12 t GVW) (IEA 2021). These trucks are basically the first-generation BET and are announced with ranges of 250 km in medium freight and 300 – 350 km in heavy freight trucks (IEA 2021).

On the other hand, several truck manufacturers as well as fuel cell and infrastructure providers have joined forces and announced a target of 100,000 fuel cell trucks on European roads by 2030. However, this appears ambitious when contrasted to the same companies' announcements of a commercial series FCET production start earliest in 2027. By that time, the second-generation BET will already be commercially available and in operation. All major truck manufacturers have announced more battery electric truck models for the coming years with significant market diffusion targets, including 20 – 60 % zero-emission truck sales, mainly BET, in 2030 in Europe (T&E 2021) and zero emission truck mandates of similar ambition in California.

At the CollERS2 workshop held in November 2021, it was widely agreed that BETs currently have the highest level of technological maturity. Further, with a view to manufacturer strategies, they have synergies with other applications and, in terms of economic operation and high user acceptance, show the highest potential for scaling up the number of vehicles by 2030. Also, regarding the necessary charging and refuelling infrastructure, stationary charging of BET is considered to have the greatest scaling potential in the coming years compared to hydrogen and ERS infrastructure. This is in line with findings from (Plötz et al. 2021).

Political framework conditions

Regarding the political framework and the development of targets for the use of alternatively fuelled trucks in road freight transport, increasing momentum has only recently become apparent. On a European level, the CO_2 standards for new truck registrations (Regulation (EU) 2019) are encouraging manufacturers to produce zero emission vehicles (ZEVs). Additionally, the revision of the Eurovignette Directive offers the possibility to privilege ZEVs in road costs in the future and the development of the alternative fuel infrastructure regulation (AFIR) (EC 2021) aims to provide planning security with regard to the basic energy supply infrastructure.

In Germany, a roadmap of the Ministry of Transport (BMVI 2020) has specified targets for road freight transport with defined milestones for the technologies under discussion. In three innovation clusters, the three technologies are to be tested on a larger scale in the near future (BMVI 2021). Additionally, an 80% funding of the additional costs of electric trucks is also intended in order to promote the early market ramp-up of electric trucks until 2024 (BMVI 2021a).

In Sweden, there is a policy to steadily increase the biofuel admixture in the existing fossil fuel mix until 2030 for both gasoline and diesel (Regeringen 2019). The biofuel share in gasoline will hence go from 4,2 % to 28 % and in diesel from 21 % to 66 % till 2030. A recent analysis (Trafikverket, K. N. 2021) indicates that the rapid development on BET, primarily for local and regional operations, together with the policy of an increased biofuel admixture has a negative impact on the socio-economical profitability of ERS in Sweden. In same analysis, it is deemed to be possible to achieve up to 85 percent of greenhouse gas emissions reduction from heavy vehicles in Sweden through a combination of stationary charging (BET) and a gradually higher share of renewable fuels in the existing fuel mix (Trafikverket, M. L. 2021). For ERS, Sweden has two on-going public demonstration tracks of ERS (EVolutionRoad and Smartroad Gotland) and is planning to deploy the first permanent ERS-facility in Örebro on the E20. This will be covering an approximately 21 km section, where the design and construction is estimated to be finalized by 2025 ("E20, Hallsberg-Örebro" 2021). To ramp up the introduction of low emission heavy vehicles, the Swedish government has decided to give 20 percent funding of the purchase price of an environmental vehicle, including powertrains for bioethanol, vehicle gas or electricity, in Sweden from 2020 to 2023, ("Klimatpremie" 2021).

Technology assessment

Life-cycle greenhouse gas emissions

Comparison of different technologies

Alternative drivetrain technologies can achieve reductions of GHG emissions during vehicle operation, but are associated with several other system changes as well which have implications for life-cycle emissions. This includes the provision of energy carriers (generation and transmission of electricity and hydrogen), changes to vehicles (especially additional components such as batteries, fuel cells and hydrogen tanks) and the required infrastructure, which all need to be taken into account in comparative analyses. Furthermore, vehicle maintenance and end-of-life processes should be considered. This calls for a life-cycle approach commonly referred to as life-cycle assessment (LCA)

So far, trucks have been subject of LCA studies to a far lesser extent than passenger cars. Ricardo Energy and Environment, ifeu and E4tech have recently conducted a comprehensive literature overview as part of a study for the European Commission (Hill et al. 2020). Almost 350 publications have been identified and screened for LCA results on road vehicles and it has been found that most available LCA literature on vehicles deals with passenger cars (87 % of the screened publications), whereas the other vehicles types (i.e. trucks and buses) only account for less than 5 % of the screened publications. Available literature also predominantly focuses on the comparison between Internal Combustion Engine Vehicles (ICEV) and Battery Electric Vehicles (BEV), both appearing in 28 % of the screened publications. Fuel Cell Electric Vehicles (FCEV) still have a lower coverage, with only 8 % of the papers, and LCA results on ERS have been unavailable at that time.

The study also calculated results for articulated trucks with different power trains in different base years for an average European situation. It further included the full vehicle cycle, but omitted roadside infrastructure such as the ERS system, high power chargers or hydrogen pumps. Though data does not reflect the latest developments and recent political targets after 2019, the Results Viewer accompanying the study provides results for a 2020 and 2030 situation for Germany and Sweden alike on a comparative basis (see Figure 1) and thus allows for a general discussion of life-cycle greenhouse gas emissions. The country specific variations mostly take into account the electricity grid mix.

Accordingly, BET and ERS-BET in Germany already in 2020 had a considerable advantage over conventional diesel combustion engine trucks (ICET) in the range of 30 to 40 %, despite the still high share of fossil electricity generation. ERS-BET show lower greenhouse gas emissions than BET due to the significantly smaller batteries. The advantage of fuel cell vehicles, solely using hydrogen from steam reforming today, is assessed comparable to BET. In a 2030 situation, the advantage of BET and ERS-BET is expected to increase to around 60 % in Germany due to an increasing share of renewable electricity generation, while it remains 30 % for fuel cell vehicles due to the assumed still predominant use of hydrogen from steam reforming.

In Sweden, the advantage of BET and ERS-BET compared to largely fossil diesel as used in Germany is already today in the range of 80 to 90 % and can thus only slightly increase until 2030. The advantage thus is much higher than for fuel cell vehicles, which also in Sweden have been assumed to be largely using hydrogen from steam reforming. Taking into account the favourable Swedish grid mix, hydrogen from electrolysis might thus have a further reduction potential, but suffers from low well-to-wheel efficiency of about 30 % compared to about 70-80 % for BET and ERS-BET.

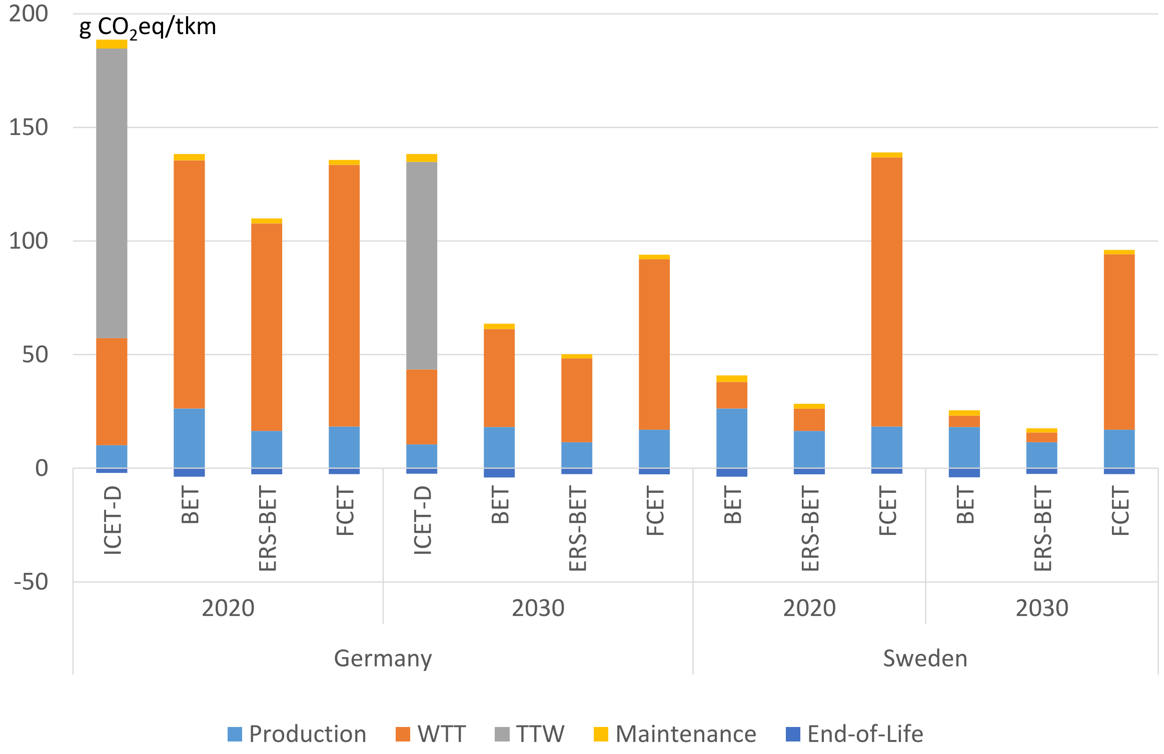

Figure 1: Lifetime impacts by powertrain type[2] for Artic Lorry 40t GVW in Germany and Sweden 2020 and 2030. Life-time mileage 800.000 km, BEV battery capacity of 990 kWh (2020) and 1450 kWh (2030), Hydrogen mostly steam reforming (100 % in 2020 and 90 % in 2030). Source: Results Viewer from (Hill et al. 2020).
Abbreviations: *WTT = Well-to-tank, TTW = Tank-to-wheel, ICET-D = Internal combustion engine truck with diesel, BET = Battery Electric Truck, ERS-BET= Electric road system battery electric truck; FCET = fuel cell electric truck, tkm = ton kilometre.*

Hence, from a policy perspective the results demonstrate clear climate advantages for ERS-BET over other concepts, mainly FCET, but also BET with large batteries. However, it is also important that infrastructure related emissions are considered, because they might be relevant in a comparative assessment of alternative powertrains (e.g. fast charging, hydrogen pumps, road electrification). Only few studies are available which focus or at least include hydrogen refuelling infrastructure for fuel cell electric vehicles or recharging infrastructure for battery-electric vehicles. (Bekel & Pauliuk 2019) show that the impacts of hydrogen and charging infrastructure can be relevant for passenger cars, but further analyses would be necessary to make robust statements for trucks. Impacts of overhead catenary infrastructure for trucks were calculated in (Jöhrens et al. 2020). During ramp-up of an overhead catenary system, it was concluded that infrastructure provision can be significant because only few vehicles are using the infrastructure. However, the overhead catenary infrastructure has a high life-time and impacts for an established system in 2030 have been calculated to be only 7 g CO_2eq per vehicle-kilometre. Nevertheless, a more in-depth study seems to be called for.

Differences in infrastructure related climate impacts of various ERS technologies

In most comparative studies of drivetrain alternatives and their carbon footprint, ERS is modelled assuming catenary overhead as representative infrastructure technology (see (Jöhrens et al. 2020) and

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[2] Due to the considerable deviation of the biofuel content in Swedish diesel fuel, ICETs are only displayed for Germany where the biofuel blend is similar to the average European situation.

(Hill et al. 2020)). However, also other ERS technologies than catenary overhead lines are under development, all transferring electricity to vehicles continuously from the power grid but using different infrastructure solutions and equipment. From an LCA perspective, it is of interest to investigate the differences between these ERS technologies and whether the conclusions described above between BEV-ERS, BEV, ICEV-D and FCEV change depending on which ERS technology and the adhering infrastructure is chosen.

Primarily, the alternative technologies to overhead catenary are conductive rail or inductive coil solutions, transferring power through a conductive rail installed on the road or through inductive coils installed under the road surface, respectively. Currently, the alternative ERS solutions differ on several points over their lifecycle in terms of e.g. material use, energy transfer efficiency to vehicles and the capacity of substations to transfer power to the system, which all are relevant from an LCA perspective.

There are only a few comparative LCA studies where different ERS technologies are considered, but none where a systems perspective is adopted to include all of these differences between the different ERS technologies. As a first point, this calls for further comparative LCA research with a systems perspective, taking into account infrastructure as well as other technical differences impacting power consumption et cetera.

If assuming the same level of electrification (percentage of the road), there is some evidence that the overhead catenary technology is associated with higher environmental impact per kilometre on the infrastructure side due to higher material use, compared to other ERS technologies (e.g. (Balieu et al. 2019)). However, as of today, the systems vary substantially with respect to the power transfer capacity, meaning that the technologies can provide electricity to a different number of vehicles on a given road length. Conversely, with a given traffic volume, ERS technologies that can deliver more power than required would not need infrastructure during the entire road stretch (level of electrification less than 100 %). During these gaps, batteries would likely power the vehicles and can be recharged on electrified stretches, which highlights the need for a system view, as larger gaps increases the requirements on the vehicles. This is of significance to the LCA comparison, as input materials and energy use for the infrastructure and the vehicles are impacted as a result.

Currently, the overhead catenary solutions being tested have an advantage in terms of power output to each section, with some estimates assuming a level of electrification of around 35 % for analysed roads, as compared to inductive solutions at around 90 %, see for instance white papers by (Wietschel et al. 2019) and (Natanaelsson et al. 2021). Considering this, the overhead catenary solution emerges as less burdensome compared to the other solutions (ibid).

Moreover, the energy transfer efficiency from the ERS to the vehicles is a relevant factor which seems to differ between the systems. Experience from railway applications indicate that the efficiency for overhead catenary is usually above 90 %, which is likely to be similar for ERS applications, and likely conductive rail applications as well. Based on the projects conducted so far, inductive coil systems result in lower transfer efficiencies on average, although with high variation (between 60-90 % according to one review by (Suul and Guidi 2018)). Lower efficiency means higher primary energy consumption, which could significantly affect LCA results due to the high share of use phase emissions associated with energy consumption, particularly in countries with high emissions intensity of electricity.

A key challenge is that technology development is pushing these technological boundaries rapidly, for all technologies, meaning that the system comparison may be quickly outdated. Nevertheless, level of electrification and energy transfer efficiency are important parameters to follow as they have large impact on the LCA comparison and should be further analysed going forward in the field.

Technology Readiness Levels

Within CollERS2, a Technology Readiness Level (TRL) assessment has been conducted. First, a brief literature review has been undertaken on the subject of ERS and TRL with the conclusion that there is very limited previous work on the assessment of TRL applied to ERS. Existing assessments are very generic and only covering the entire ERS-system without differentiation of different subsystems. The underlying data for this section are therefore mainly based on interviews with ERS-suppliers on their assessment of the technology development in light of current (demonstration) projects. To complement these views, experts from Germany and Sweden have been given the opportunity to share additional knowledge and experience. The preliminary TRL results have been presented, discussed and consolidated at the first technology workshop held in November 2021.

There are four ERS-suppliers involved in demonstration tracks on public roads in Sweden or Germany and are hence included in the assessment: Siemens eHighway (with overhead lines), Elonroad (with rails), Elways (with rails) and Electreon (with coils).

As ERS consist of several sub-systems, this assessment aims at a differentiated TRL assessment of the different subsystems (see Table 1) in relation to the four ERS-technologies above.

Table 1. Definition of different subsystems of an ERS.

Subsystem	**Definition of what is included**
Electicity supply	Grid along the ERS, including substations and management units
Road	Installation in road area (pavement, barriers, rails/coils/poles)
Powertransfer to vehicle	Transfer of energy into vehicles (receiver)
Daily road operation	Energy measurement, vehicle identification, payment & billing solutions
Vehicles	Truck, bus, van, passenger car

Initially, the definition of TRL levels from (Gustavson and Lindgren 2021) was used in this assessment. During the assessment, a need for minor adjustments did however arise, hence resulting in a slightly modified definition[3].

The preliminary result of the TRL-assessment is shown in Table 2. This assessment is based on interviews with the infrastructure suppliers and complemented by experiences from the test tracks. If a subsystem is divided into two cells, this corresponds to a new version of the system (e.g. old vs. new) or that the supplier is planning to radically change the system in the future to meet some kind of requirement. In general, the TRL values in the assessment differ slightly between the different subsystems within one and the same ERS technology, as well as between the different ERS-

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TRL 1. Basic principles observed and reported.
TRL 2. Technology concept and/or application formulated.
TRL 3. Analytical and experimental critical function and/or characteristic proof of concept.
TRL 4. Component and/or breadboard validation in laboratory environment.
TRL 5. Component and/or subsystem validation along test track and subject to any realistic weather condition.
TRL 6. Demonstration of the subsystem in an environment where the vehicle is propelled by power from ERS equipment along test track and subject to any realistic weather condition.
TRL 7. Demonstration of the subsystem in an environment where the vehicle with prototype power receiver, running along a public road during any realistic weather condition, and propelled and charged by power provided by a prototype power transfer subsystem installed in vehicle and deployed along the public road. The subsystem is working sufficiently for its application (e.g. meet the requirements on operational speed, accuracy, manage several vehicle, power supply in kW).
TRL 8. The subsystem has proven to work in its final form, under expected conditions. In almost all cases, this TRL represents the end of the true system development.
TRL 9. Once the subsystem is deployed at or for a customer, the exposure of unexpected conditions might lead to a need for additional adjustments of the system. Once these are managed successfully, the subsystem could for that context and conditions be defined to have reached the highest maturity of TRL 9

technologies. To pinpoint what is behind this difference is difficult, but during the discussions with the ERS-suppliers it has become clear that they, in general, face different types of challenges in slightly different areas. In terms of TRL's, the subsystem *Billing and payment solutions* is the one with the lowest TRL and correspondingly, the subsystem *Electricity supply* is the one with the highest TRL for all technologies.

Table 2. TRL assessment of different subsystems for the four ERS-technologies.

Supplier **Subsystem**		**Siemens EHighway**	**Elonroad**	**Evias**	**Electreon**
Electicity supply		TRL 8	TRL 7	TRL 7	TRL 7
Road		TRL 7	TRL 7	TRL 7 TRL 4	TRL 6
Powertransfer to vehicle	< 60 km/h	TRL 8	TRL 6	TRL 7	TRL 6
	> 60 km/h	TRL 8	Not tested	TRL 7	TRL 6
Daily road operation	Energy measurement	TRL 7	TRL 6	TRL 5 TRL 2	TRL 6
	Vehicle identification	TRL 6	TRL 6	TRL 6 TRL 3	TRL 7
	Billing and payment solutions	TRL 6	TRL 2	TRL 2	TRL 4
Vehicles	Truck	TRL 8	Not tested	TRL 7	TRL 6
	Bus	Not tested	TRL 7	Not tested	TRL 7
	Van	N/A	TRL 6	Not tested	TRL 6
	Car	N/A	TRL 6[4]	TRL 6	TRL 6

Incremental product improvements (e.g. increase in performance) which might move the TRL up one level should be distinguished from radical redesigns of the system in order to manage insufficient technology functions, which might significantly lower the TRL, for example if a radical redesign of the rail or receiver is required. Interviews being the sole data source for the evaluation, however, has been identified as challenging, thus the grading of the subsystem entails significant uncertainty. To complement the assessment, the ERS suppliers have been given the opportunity to also assess the TRL of their own subsystems. It has been observed that the ERS suppliers' assessments of their own technology are higher than those reported in Table 2. This might be because the underlying knowledge and information is higher for their own system compared to the others. On the other hand, also a bias towards the own product could be an influential factor. The main reasons behind the difference in TRL values will have to be studied in more detail in future continued work on TRL of ERS.

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[4] The car has been propelled and charged dynamically, but in low speeds (< 50 km/h), hence not fulfilling typical operational speed for TRL 7

Conclusions

A range of initiatives on a European level, such as CO_2 standards for new truck registrations, the Eurovignette Directive and Alternative Fuel Infrastructure Regulation (AFIR), will provide a significant incentive for electrified trucks in the near future. National policies such as CO_2-taxes and state funding of environmentally friendly vehicles also provides incentives. BETs currently have the highest technological maturity, but also other concepts are being tested and could be available in the coming years. Among these **ERS-BETs provide a range of synergies with the already developing market and infrastructure for BETs.** The aim of this paper was therefore to assess ERS with special emphasis on life-cycle GHG emissions and the Technological Readiness Level (TRL).

The comparative results on life-cycle greenhouse gas emissions are largely determined by the grid mix. While in Germany climate benefits of electrified trucks over diesel trucks using fossil fuel today are still limited due to a significant share of fossil electricity generation, they are already much higher in Sweden due to the higher shares renewable power. **The installation of low emission electricity generation capacities is thus key to ensure climate benefits of ERS-BETs and should also take into account the additional electricity demand from road transport.** The outlook to 2030 therefore shows huge potential for improvements also in Germany. The main differences between the technologies are due to conversion efficiencies. **Concepts, which directly use electricity (i.e. BETs and ERS-BETs), will continue to have a clear climate advantage over FCETs as long as not solely renewable electricity is used for hydrogen production.**

While energy in the usage phase (in Germany) and vehicle production (in Sweden) clearly dominate the life-cycle greenhouse gas emissions of electric trucks, infrastructure emissions have only rarely been assessed so far. There are some indications, however, that charging, refuelling or **ERS infrastructure might make a relevant contribution towards life-cycle emissions in the market ramp up phase but should be a minor issue in a scaled-up system (due to lower CO_2 emission from electricity productions)**. Comparing different ERS solutions, it has been found that inductive coil systems seem to have a disadvantage in terms of transmission efficiency. Nevertheless, further research is necessary on infrastructure impacts.

Variations in TRL have been found for different subsystems within a single ERS-technology as well as comparing a single subsystem for several ERS-technologies. In general, however, while the **fundamental technological challenges of ERS such as the electricity supply are rated with high TRLs for all available technologies**, billing and payment solutions apparently face further challenges. Further development is especially necessary in the area of energy measurement, vehicle identification and payment solutions, as these systems are characterized by a high degree of complexity and have several degrees of freedom in terms of number of involved actors and corresponding interfaces between both actors and subsystems of the ERS. Depending on involved actors (could differ between nations) and final functional requirements on these subsystems, a future need to radically redesign the systems might arise, hence lowering the TRL. In general, it is found to be challenging to eliminate the subjective aspect when assessing the TRL of different ERS technologies.

Overall, this technology assessment indicates that ERS-BETs have the lowest life cycle emissions of greenhouse gases among the analysed technologies. Infrastructure emissions need further investigation across the different technologies. The TRL of ERS-infrastructure, in terms of electricity supply (grid, transformers), power supply (road) and power receiver (vehicles) have been tested extensively and can therefore, from a technical point of view, be seen as quite mature for scale up. Operational aspects of ERS, however, still need further development.

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