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Regional electrified logistics system demonstrator supporting market transition

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Executive Summary

Opportunities in regional electrified logistics and challenges have been demonstrated by an innovative project, REEL, that mix confidential and open research & innovation. The system *demonstration* includes more than 60 battery electric *heavy-duty* vehicles, and associated *charging* infrastructure, operating various types of *commercial* goods flows together with 45 Swedish stakeholders, e.g., transport buyers, freight forwarders, haulers, terminal and grid operators, OEMs, national authorities, and academic partners. So far, this project has provided a deeper insight into systems of systems, end-user experiences, comparisons of *costs* between electric and diesel-powered solutions, and financing solutions.

1 The REEL project set up with both competition and collaboration

The transition to electrified logistics systems as requested by e.g. the European Union has led to a Swedish R&I-project; REEL, that will assist the implementation based on real experiences. A system demonstrator has been built up with over 60 electric heavy-duty trucks, whereof 20 are prototype trucks, operating several different types of goods flows, as food, general cargo, and bulk, making it possible to evaluate current benefits and challenges that exist now and create a base for future developments [1]. The project set-up concept, see Fig. 1, mixes separate competing consortia (“vertical”) activities addressing different logistics systems demonstrations and implementations focused on creating experiences and data, with joint team (“horizontal”) activities, performed by consortia and societal stake holders, together with academics addressing general issues that need to be settled before a large-scale transition can be initiated. In total 45 Swedish stakeholders e.g. transport buyers, freight forwarders, haulers, terminal and grid operators, OEMs, national authorities, and academic partners participate in the project [2].

Figure 1: Demonstrator set-up

A trustee unit collects, aggregates, and filters the data and information flow between the vertical and horizontal activities. The trustee unit has collected answers to more than 175 questions, from each vertical consortia member, through semi-structured interviews covering aspects as organizational info, logistic & operational set-up, hard-and software specifications, need for policy development, implications on business model, working environment, system architecture, interfaces, and scale-up potential. The 175 interview questions were set after two initial dialogues with logistic actors and in collaboration between CLOSER and the academic partners participating in REEL i.e. Chalmers University, Linköping University, and Lund University. Identified issues are addressed by horizontal working groups in collaboration with the trustee unit focusing on Policy & Regulatory Development, Business & Financing Model, Working Environment & Knowledge Development, System Arcitecture & Tools, and Interoperability & Interfaces. In addition, all partners are invited to common meetings during which experiences, results and challenges are discussed, also bi-lateral discussions are organized. The project is funded by the participating business partners and by the Swedish Vehicle Research and Innovation program, FFI, hosted by the Swedish Innovation Agency, the Swedish Energy Agency, and the Swedish Transport Administration.

2 Experiences from the Electrified logistic systems demonstrator

Experiences from the project reveal that electrified logistics systems often will be more complex to operate effectively than diesel propulsion systems, because of comparatively shorter vehicle driving ranges and longer charging times, and due to limited access to charging power. In addition, the cost for vehicles, charging equipment, and infrastructure for power supply will be higher, compared to diesel solutions. One reason for the high costs is that mass production has not yet been reached, but there are other reasons e.g. related to finding effective logistics patterns, and not fully used energy and power solutions. Additional advantages from operation of electrified vehicles are seen when distributing to loading bays in closed environments e.g. in under-ground garages. A few actors also saves time by not having to refuel with diesel. The system demonstrator built up in REEL so far include 63 trucks in order to start learning how to address the operational and economic consequences of electric vehicles and charging in different types of logistics flows and to compare with diesel-based solutions.

As the number of electric trucks operating from the same logistic entity, e.g. scheduled delivery loops from a terminal, increase, the complexity generated by the limitations in truck driving range, time and availability of power for charging, also increases. This generates a need for an interoperable system architecture for different cases that connect all the sub-systems and elements in the total logistics and power supply systems in order to enable a base functionality that will make it possible to maximize serviceability and effectiveness, as well as minimize environmental consequences and logistics losses. In the REEL project the truck OEMs have been working closely with the transport companies during the planning stage of the electrified cases. In many cases, simulations have been carried out together with the transport company to find most feasible routes. In most cases the simulations have been in-line with the outcome. However, a few of the first simulations have provided misleading information resulting in the actors purchasing trucks with more battery capacity than required.

3 Need of interaction between Transport-, Fleet-, and Charging-Management Systems

At this stage, the drivers are primarily the ones monitoring the vehicle’s range in real time. The transport companies are able to monitor the electric vehicles via the OEM specific Fleet Management Systems (FMS). Some actors monitor in real-time but for most it is done on a weekly or monthly basis. In cases where vehicles from several OEM’s are used, the various FMSs are used in parallel. A need for integration between those and the transport companies’ Transport Management Systems is expected to arise. The electric fleets will grow along with the complexity that arises, e.g. when transport assignment needs to be rescheduled when delays occur since additional factors have to be considered such as SOC as well as charger and power availability. Monitoring the drivers’ and vehicles’ performance will be of importance as the driving styles have a huge effect on the vehicles’ range.

Multiple actors state that Transport-, Fleet-, and Charging-Management-Systems operations will need to interact and exchange data for synchronization of truck time-tables and slots for loading and charging, considering availability of terminal gates and power, and also inform the local DSOs (distribution network operators) and energy suppliers of immediate and future needs. Some studies and developments are under-way but much more need to be explored. In Fig. 2, a tentative architecture high-lighting examples of needs for data interactions and interfaces. Some standardized interfaces are available, but there are gaps e.g. in the interface between Fleet- and Charging-Management Systems, which are currently being addressed by the project partners and internationally. Furthermore, new actor roles and responsibilities are appearing, e.g. regarding energy and power supply management.

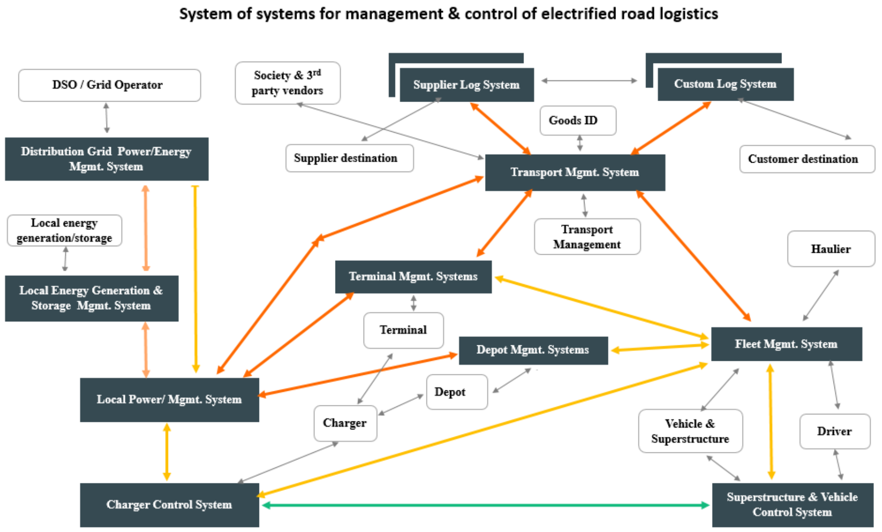

Figure 2: Systems of systems for management and control of electrified logistics solutions

There is a devious way ahead to setup real-time functional models for these types of systems. For some sub-functions e.g. energy consumption and long-time economic output there is some progress, but lack of models, data, and digital management and control systems are slowing down progress. Here, some of the needed data is generated and collected. Complementary projects are under way both for tightly integrated logistics operations and local energy and power supplies.

4 Economic comparison of electric and diesel powered solutions

A number of factors influencing and defining costs and benefits of logistics operations for electric and diesel driven transport have been identified through interviews with logistic actors in the project, see Table 1.

Table 1: Outline of a methodology for estimation of yearly average costs for electrified regional logistics and power supply systems.

Cost category	Cost element
Truck incl. superstructure (SS)	$\frac{Truck_{New-Residual\ value\ (RV)} + SS_{New-RV}}{Years}$
Charging infrastructure	$\frac{Charging\ hardware_{New-RV} + Safety\ installations_{New-RV} + Power\ grid\ upgrade_{New-RV} + Installation}{Years}$
Local energy production and storage	$\frac{Hardware_{New-RV} + Power\ grid\ upgrade_{New-RV} + Installation}{Years}$
Interest	$\frac{Total\ investment}{2} \times Interest\ rate$
Insurance, vehicle & road tax, parking, wash, and IT	$(Insurance + Vehicle\ tax + Road\ tax + Parking + Wash + IT)_{cost/year}$
Tires, service, and maintenance	$\left(Tires_{\frac{cost}{km}} + Vehicle\ service_{\frac{cost}{km}}\right) \times Yearly\ mileage_{km} + Charger\ maintenance_{cost/year}$
Energy	$Consumption_{kWh/km} \times Yearly\ mileage_{km} \times Energy\ cost_{cost/kWh}$
Grid transmission and energy tax	$Consumption_{kWh/km} \times Yearly\ mileage_{km} \times (Grid\ transmission_{\frac{cost}{kWh}} + Energy\ tax_{\frac{cost}{kWh}})$
Power tariff	*Depending on DSO price model*
Staff	$Driver_{cost/year} + Transport\ mgmt_{cost/year} + Other\ staff_{cost/year} + OH_{cost/year}$
Start-up cost	*Cost related to phasing in of new technology e.g. education, integration efforts, simulation, purchasing, sales, public co-funding administration, and other.*

The value of these costs and benefits depends, for example, on the number of vehicles that are sharing chargers, grid connection and will require accurate scheduling of the truck, loading and charging operations, to avoid logistics losses, for example, unproductive waiting times. The long electric energy transfer times are handled, when possible, by charging when the vehicle is standing still at terminals and destinations for operational reasons. Furthermore, the currently shorter driving ranges of electrified trucks can result in more complex transport and fleet management compared to diesel solutions. The total costs of electric compared to diesel truck operations are today normally higher due to higher vehicle costs, additional cost for charging infrastructure and other logistics losses. To compensate for the higher investment costs and lower energy related cost of electric compared to diesel powered operation; the daily operation is often extended in time.

High power charging will shorten the charging time but sometimes the power supply or truck power reception capacity is too limited, which leads to operational losses. These problems will often become more significant when the number of trucks to be served at a location shall be increased. There are initiatives to build local energy storages which can be used in connection to local energy production, to even out the grid outtake.

More than 40 logistic flows have been analyzed so far, whereof three flows are detailed in Table 2 and further described below.

Table 2: Description of three logistic flows

	A1	A2	A3
Mileage per year (km)	40,000	87,500	210,000
Operating hours per year (h)	2,000	3,625	5,600
Truck and superstructure	Rigid refrigerated, 6x2, 27 ton	Tractor & trailer, 6x2, 44 ton	Rigid & trailer, 6x2, 64 ton
Battery size (kWh)	300	300	600
Charging capacity (kW)	150	150	250
Charging	At terminal while reloading		

Cost data for the cases have been obtained through interviews with project participants and other stakeholders. For competitive reasons, a specific cost breakdown can not be reported in detail, and revenues are not presented. The energy prices for electricity and diesel have fluctuated much during 2022. In the cost comparison calculations on the following pages the average price for the period July to September 2022 are used both for MK1 Diesel and electricity. Sweden is divided into four geographical electricity areas; SE 1, SE 2, SE 3, and SE 4, with various electricity prices. Costs for grid transmission and power outtake varies depending on geography, time, and subscription model, also electricity energy tax varies depending on geography and type of business sector, each case's specific conditions are therefore reflected in the calculations. Interest rate is set to 4%. The salary for personnel is set to an average of 32,000 SEK per month and collective agreement conditions applies. In the interviews no significant differences were observed for cost related to insurance, road tax, tires, service, and maintenance when comparing the electric and diesel solution.

The first case, see Table 3, is based on one battery-electric rigid truck with a refrigerated superstructure and a total weight of 27 tons. The vehicle operates in urban areas delivering chilled and frozen food. It operates from 07:00-16:00 on weekdays, 250 days a year. The truck and its batteries are fully depreciated in 6 years. Installed battery capacity is 300 kWh and the total vehicle incl. refrigeration consumes 1.25 kWh/km, while the equivalent diesel vehicle consumes 0.27 l/km. The truck operates approximately 40,000 kilometres per year. In this case, the extra weight of the batteries has no impact on the operation, as the goods are rather limited on volume. The truck is charged during night and sometimes during lunch break if needed, using a 40 kW DC charger. The truck operates within electricity area SE 4.

Table 3: Economic comparison logistic flow A1 (SEK/year)

Cost category	Electric	Electric incl. public co-funding	Diesel
Truck (incl. superstructure)	700,400	560,400	333,733
Charging infrastructure	33,333	20,000	0
Interest	88,048	69,648	40,048
Insurance, vehicle & road tax, parking, wash, and IT	70,447	70,447	70,447
Tires, service, and maintenance	158,280	158,280	153,280

Energy	98,000	98,000	218,160
Grid transmission and energy tax	20,500	20,500	0
Power tariff	0	0	0
Staff	647,420	647,420	647,420
Total	1,839,528	1,667,795	1,463,088
% from Diesel option	+26%	+14%	

The second case, see Table 4, is based on one battery-electric tractor that operates in a repetitive hub-to-hub flow, transporting semi-trailers with consumer goods. The volume is the limiting factor; thus, the increased weight of batteries has not affected the availability of transport goods. The vehicle operates in 2-shift (06:00-15:00 and 16:00-23:00) on weekdays. The distance between the hubs is approx. 29 km, and the loop is repeated six times resulting in a total mileage of 350 kilometers on weekdays, 250 days a year. The truck and its batteries are fully depreciated in 6 years. Installed battery capacity is 300 kWh and the total vehicle consumes 1.2 kWh/km, while the equivalent diesel vehicle consumes 0.35 l/km. The vehicle is charged during breaks, between shifts and at nights with 150 kW. The charger is fully depreciated after 6 years. The truck operates within electricity area SE 2.

Table 4: Economic comparison logistic flow A2 (SEK/year)

Cost category	Electric	Electric incl. public co-funding	Diesel
Truck (incl. superstructure)	581,133	464,467	197,800
Charging infrastructure	128,333	77,000	0
Interest	85,136	64,976	23,736
Insurance, vehicle & road tax, parking, wash, and IT	78,366	78,366	78,366
Tires, service, and maintenance	205,625	205,625	191,625
Energy	205,800	205,800	618,538
Grid transmission and energy tax	48,216	48,216	0
Power tariff	48,600	48,600	0
Staff	1,234,221	1,234,221	1,234,221
Total	2,615,431	2,427,271	2,344,286
% from Diesel option	+12%	+4%	

The third case, see Table 5, is based on one battery-electric rigid truck and trailer that operates in a volume limited line-haul operation between two major terminals. The volume is the limiting factor, thus, the increased weight of batteries has not affected the availability to transport goods. The vehicle operates in 2-shift (06:00 – 15:00 and 18:00 – 03:00), 350 days per year. The two shifts result in a daily driving distance of 600 km. The truck and its batteries are fully depreciated in 6 years. Installed battery capacity is 600 kWh and maximum total weight is 64 tons. The total vehicle consumes 2 kWh/km, the equivalent diesel vehicle consumes 0.43 l/km. The vehicle is charged during breaks and between shifts with 300 kW charger at the operator's terminals. The truck operates within electricity area SE 3.

Table 5: Economic comparison logistic flow A3 (SEK/year)

Cost category	Electric	Electric incl. public co-funding	Diesel
Truck (incl. superstructure)	699,167	557,500	257,500
Charging infrastructure	533,333	320,000	0
Interest	199,800	153,000	30,900
Insurance, vehicle & road tax, parking, wash, and IT	132,421	132,421	132,421
Tires, service, and maintenance	258,340	258,340	242,340
Energy	823,200	823,200	1,832,880
Grid transmission and energy tax	204,750	204,750	0
Power tariff	129,600	129,600	0
Staff	2,089,822	2,089,822	2,089,822
Total	5,070,433	4,668,633	4,585,863
% from Diesel option	+11%	+2%	

Economic comparison shows that the difference between the electric and diesel powered solutions varies from +2 to +14 % when public co-funding of both charging infrastructure (40 % co-funding) and trucks (20% co-funding) can be obtained, see Fig. 3. As noted, the Total Cost of Ownership (TCO)for the diesel powered solutions are lower than for the corresponding electric solutions but with increased usage the imbalance is evened out. The geographic location of where the electric vehicle is charged is an important factor, for the period July to September 2022 the energy cost in electricity area SE 4 was almost four times higher than in electricity area SE 2. Furthermore, the electricity energy tax is reduced for a majority of locations in SE 1 and SE 2. From a cost perspective it is therefore more beneficial for actors located in SE 1-2 to introduce electric solutions than for actors located in SE 3-4. The analysis also shows that public co-funding of both vehicles and charging infrastructure is crucial to even out the TCO between electric and diesel-powered solutions. It must be noted that the TCO-calculations do not include the additional time for preparatory work for the electric solution that the logistic operator needs to do with regards to discussions with e.g. transport buyers, hardware suppliers, grid companies as well as applying for public co-funding. What also needs to be further examined is the cost effects when scaling up the system as this might cause extra costs related to grid upgrade as well as planning and steering of the operation.

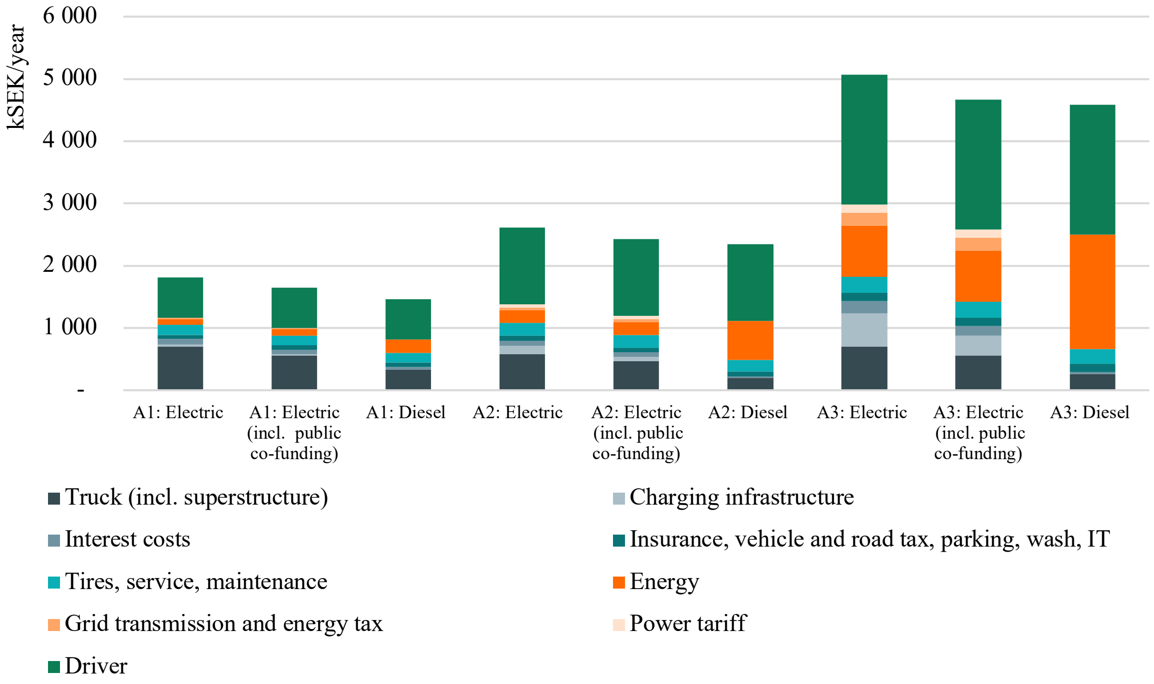

Figure 3: Economic comparison for three logistic flows

The analysis also points out the need for transport contracts that are aligned with depreciation time of trucks to reduce risk for the hauliers. If a faster depreciation time needs to be applied, the competitiveness of the electrical solution is impaired. As utilization of the electric trucks is in its early days, there are some uncertainties. The residual value of the vehicles is hard to estimate as second-hand market does not exist for the electric trucks at this stage. The degradation of the batteries, which is expected to be the most important factors for the residual value of the vehicles, is yet to be examined as the electric trucks have been put into operation quite recently.

In order to cope with these uncertainties, most of the participating transport companies in the REEL project see a need to increase the length of the transport contracts with their customers in order to ensure the utilization of their electric vehicles. At this early stage, implementation and operation of an electric truck often requires thorough preparations with the customer, and a customer willing to explore the new technology together with the transport company. If the transport contract is short, it might take time before the next assignment for the truck is found, resulting in the truck standing still and thus becoming a financial burden. Historically, when using diesel trucks, the participating companies have applied contract lengths spanning mostly from 12 to 36 months for transports. For electric transports, most companies consider it necessary to increase the contract length to an interval between 36 to 60 months. Such contract lengths have been applied for REEL transport flows. For some transport segments even longer contracts lengths are desired.

5 Financing solutions for electric trucks preferred by logistic actors

A majority of the transport companies in the REEL project have chosen to use operational leasing as the financing model for their battery electric trucks, see Fig. 4. Transport companies are unsure of the performance of the first-generation trucks, for example, with regards to battery degradation. They also believe that specifications for these trucks will be outdated in a few years' time due to the rapid development in the field. Thus, operational leasing is used to minimize risk of low residual value. The actors who forecast that they will continue to use operational leasing in five years from now, believe that these arguments will still apply at that point in time. Multiple actors state that the financing of trucks will be a hurdle for small hauliers. A solution to this, that some of the larger actors and the haulier network organizations sees is to themselves take ownership of trucks and lease those to smaller hauliers.

However, a shift from operational leasing to cash payment is noted in a five years' time. Actors that prefer this model state that they benefit economically through either cash payment and/or financial leasing. They expect that the performance of vehicles will improve in the coming years and that battery electric trucks will have a longer lifecycle than conventional trucks. Therefore, actors would like to keep the vehicles as long as possible in their own operation, some state up to 12 years, succeeding by shifting routes and operation as the batteries degrade and also to use the batteries for Frequency Containment Reserves to optimize battery value generation.

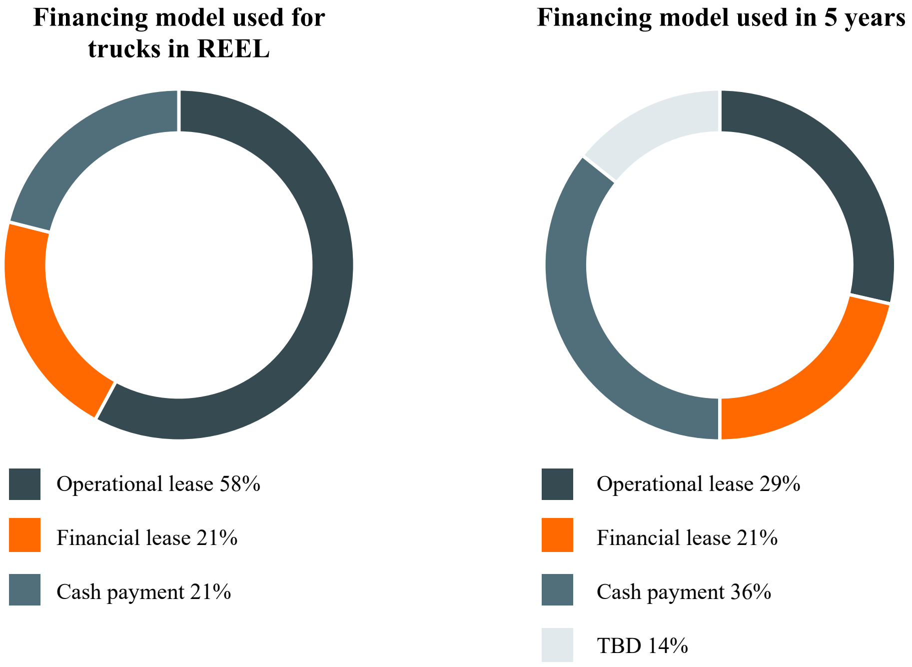

Figure 4: Preferred financing model for trucks

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Presenter Biography

Andreas Josefsson joined the Swedish innovation platform for sustainable logistics; CLOSER, in 2018 holding the role as responsible for developing and driving projects to accelerate the transition to energy-efficient and fossil-free freight transport in collaboration with industrial actors, academic institutions, and societal organizations, e.g. the REEL project targeting the electrification of regional logistics systems through demonstrating more than 60 electric HDVs in various types of goods flows together with 45 stakeholders including transport buyers, freight forwarders, hauliers, terminal and grid operators, OEMs, national authorities, and academic partners. Before joining CLOSER, Andreas worked at Volvo Cars and Accenture Strategy where he ran multiple projects related to logistics and supply chain development, in both Europe and China. He holds a M.Sc. in Supply Chain Management from Chalmers University of Technology and CSR & Sustainable Management from University of Buenos Aires.

Lars-Göran Rosengren joined Lindholmen Science Park (LSP), which host R&I-programs in e.g. mobility, 2014 in a role responsible for new multi-lateral project developments involving industrial and societal transport system providers, operators, and academics. Pioneering system demonstrators based on logistics, public transport, geofencing, user experience, digitalization & electrification for community building have been initiated and operated. Before joining LSP Lars-Göran worked for AB Volvo in 39 years, as President for Volvo Technology in 21 years, and responsible for setting up and operating R&I projects in engine combustion, catalysis, electric drives, electronics, human system integration, intelligent transport systems. He has also worked at Jet Propulsion Laboratory and for Saab Robot & Avionics System. He holds a PhD in Electrical Engineering from Chalmers University of Technology.

Magnus Karlström is Project Manager at Lindholmen Science Park and researcher at Chalmers University of Technology. Karlström's research interests are fuel cell vehicles, electromobility, strategy, life cycle assessment, and business intelligence. Magnus Karlström is part of the Program Council of the Swedish Electromobility Centre. He holds a PhD in Environmental Science from Chalmers University of Technology. EVS-25 in Stavanger was Karlström's first.