# Road map theme 5: Vehicle-grid interaction

## Introduction

With a significantly increased proportion of electric vehicles in society, the vehicle fleet will require an increased need for electric energy and power. This will have a significant impact on the operation of the electricity system, in particular since an electrification of other sectors such as industry and the built environment is also expected. There is already a debate on, and concern over limitations in transmission capacity in the regional grid into several cities such as Uppsala, Stockholm and Malmö. Thus, there is a need for research on how a ramp-up of electric vehicles can be integrated into the electricity system, including how this will interact with other electrified systems in society. Theme 5 '*Vehicle-grid interaction*' deal with the system interaction between the electric vehicles and the electricity supply infrastructure, including the prerequisites and demands for generation, transfer and utilization of power and energy. Further on, when discussing the charging infrastructure, we refer to the system between the vehicles and existing grid connection point and it might include other equipment than the charger such as local energy production, energy storage etc. The theme covers research on all kinds of electric vehicles, such as passenger cars and heavy-duty trucks, but also vessels for air and maritime transportation.

The theme includes four different aspects, as shown in Figure 1: Vehicle-grid physical interaction including power supply; Vehicle-grid data, communication and security interaction; Human/Consumer perspective; and Holistic challenges. These aspects are strongly related, and a holistic approach is often required to set realistic boundaries to identified problems. Several areas are related to other themes in SEC, and an important role for the theme will be to collaborate with the other thematic areas and to be SECs interface to other competence centers within the power system area.

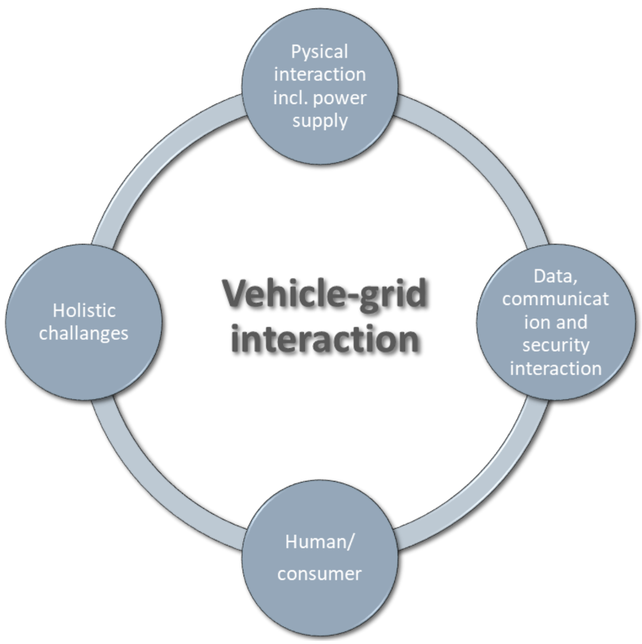


*Figure 1:* Different aspects related to the vehicle-grid interaction.

The 'Vehicle-grid physical interaction' addresses the physical and partly hardware-related needs and abilities necessary for enabling the vehicle-grid interaction. Moreover, the 'Vehicle-supply infrastructure interaction' addresses the system effects of the electrification of the transportation system. An increased share of electric vehicles will likely result in a substantial increase in peak power demand if no action is taken to provide smart integration of the vehicles (and other electric vessels) in the electricity system. There is need for research which can study the interaction between electric vehicles and the electricity supply infrastructure (generation and distribution) under different assumptions on charging strategies for both light and heavy-duty vehicles, including conductive as well as inductive charging – static and dynamic. An example of the benefit of the transport fleet electrification is that smart charging (including V2G) can create a value for the electricity supply system by reducing the need for investments in peak power. This calls for studies on possibilities for sectoral co-operations, such as between utility companies and vehicle manufacturers or vehicle owners. Moreover, there is also a trend showing that an increasing share of electricity supply will be delivered at lower voltage levels in the form of both wind power and distributed generation. The latter may involve solar PV-battery systems where the battery system can be a combination of stationery and vehicle batteries. These trends will have implications on system effects, grid demands and requirements for new power systems electronics. Another important area to be investigated is related to different aspects of charging at higher power levels: there is a need to identify limitations and requirements on additional power supply infrastructure. Other aspects that could be included in this theme are, e.g., energy storage systems and local power supply, V2G, microgrids, DC-grids and cross-vehicle-type standardization.

In the modern world there is a need for a lot of data and communication transfer for realizing systems interaction, such as the one between vehicle and grid. Aspects of data generation and processing will need to be investigated, as well as how data is used, making sure that it is done in a safe and data privacy compliant way. By keeping in mind the data, communication and security aspects from an early stage, the whole (holistic) systems can be designed in a more integrated way. When applying system and holistic thinking it can happen that the best elements put together are not necessarily the ones with greatest synergy and value creation. Hence, it is important to not research the best hardware and the best data/security separately, but together.

Nowadays, the human and consumer needs, desires, capabilities and limitations are important and crucial aspects to consider for the interaction between vehicle and grid to take place. Therefore, the human perspective needs to be included and understood for a successful design and development of this interaction. Some aspects that will be important for the theme to examine are charging times (user need/desire) vs. charging powers (system capabilities and deployment), the physical interaction (ergonomics), cognitive interaction and interaction with the system as a user.

It is considered of great importance to add to the theme portfolio projects with interdisciplinary perspective, addressing different holistic challenges and what the impact will be on the vehicle-system-grid.

## Scope and boundaries

The purpose with the theme is to answer the question on how the interaction between vehicle and power system should be done in order to maintain a stable power system and at the same time make sure that all vehicles can be provided with intended function. This implies a good knowledge about vehicle user profile, charging strategies and other energy consumption and power demand in the society. The importance of this is further enhanced by the ongoing and foreseen electrification in other sectors, especially in industry. The ambition of this theme is to identify the requirements and demands necessary to fulfil the scope. These requirements include aspects on when, where and how charging (and discharging) should occur. Both static and dynamic charging solutions should be considered.
Some important scopes of the theme are listed below.

- Research about the interaction between EVs, the electric power grid and the electricity supply system.
- Limitations imposed on charging due to constraints in the local grid and the vehicle.
- Optimal placement of charging stations and e-road segments (ERS).
- Grid stability over time (sub-hour, hour, day, week, month, year).
- Holistic V2G, accounting for adverse system effects in vehicle, charger and grid.
- Quantification of grid reinforcement requirements and investigation of alternative solutions.
- Predictions of future energy and power demands and impact on the power system and on vehicles.
- Traffic flow modeling including power system analysis.
- Automated charging.
- Charging of self-driving vehicles.
- Stationary storage and renewable energy supply in connection to larger charging points or ERS.
- Analysis of current and future policy instruments and regulations. Modification needed for a successful implementation of electromobility solutions.

Some of the areas of the theme is closely related to the other themes within SEC and there will be several projects that also will relate to other theme(s). As a boundary, specific technical solutions or different charging technologies (hardware) will not be treated within this theme: this is included in thematic area 2 'Electrical machines, drives and charging'.

## Current Trends and Needs

There are several different trends when it comes to interaction between vehicles and grid. One example is smart charging. The basic idea with smart charging is that you can decide when and where a vehicle should be charged. One question which arises is for which actors should smart charging be optimized, i.e., for the EV users, society, vehicle industry or grid owners? Furthermore, do smart solutions which are ideal for all involved actors exist?

Moreover, we see a shift in power generation and we are including more renewables and develop a power system that tolerates more variations in electricity generation. There will be a possibility for electric vehicles to support the electricity grid and the energy system so that both EVs and renewable electricity generation have a positive impact on power quality, for example.

More and more sectors (i.e., trucks, busses, maritime vessels, aircraft, transports used for

mining, forest industry etc.) are facing a shift to electromobility. These together with an increased use of electric cars, will increase the need for a higher power output from the grid. Therefore, it is necessary to investigate how to achieve a successful integration, based on the requirements and extent of the demand.
Vehicle to grid (V2G) is a concept being discussed. With V2G it is possible to use the car's battery pack as a power source for the electric grid: the power flow in the system becomes bi-directional. Other terms related to this concept are V2H (vehicle-to-home) where the power flow exchange is limited to the house and V2X (vehicle to everything) related to the communication and information exchange between several objects such as power system, status of other cars, power production etc. There are also more terms used for identifying the communication as V2D (vehicle-to-device), V2I (vehicle-to-infrastructure), V2N (vehicle-to-network), V2V (vehicle-to-vehicle) and V2P (vehicle-to-pedestrian). Today, there is a lack of clear incentives for V2G.

The manufacturing of batteries is facing an upscaling phase and the demand is expected to be greater than supply of a period of time. Therefore, there will be a need for studies where the use of the battery is optimized. Within this theme area, the focus will be to study charging solutions where the battery pack can be smaller in size and study solutions that will prolong their lifetime.
Dynamic charging and wireless charging are two other options for charging that can complement and sometimes replace the static plug-in charging.

Some more identified needs within this area:

- Different charging strategies; when, where, how and why?
- Holistic assessment of BEV (battery electric vehicle) vs. ERS (electric road system)-connected PHEV (Plug-in Hybrid Electric Vehicle) vs. FC(H)EV (fuel cell (hydrogen) electric vehicle) including infrastructure.
- LCA including climate impact and other impact categories as well as resource and energy efficiency etc.
- Investigation to expose and quantify energy losses from Infrastructure (i.e., local HV/MV grid) to vehicle (energy storage) and visa-versa. Review incentives to improve overall system efficiency. Review any technical alternative/observation point which would enable continuous improvements.
- Are ERS realistic given the grid today? What would be required to enable widespread installation/use of ERS? Analysis of the economic values of ERS.
- Analysis of how a strong ramp-up of electrification can be integrated in the electricity system and the electric grid. This should consider interplay between, and the importance of, different flexibility measures in the grid, where smart charging of EV including V2G are promising options to handle solar and wind variations.
- Energy efficiency – grid to wheel efficiency.
- Cost and scalability – Optimal investment for todays and future demands and the ease of scaling.
- Stakeholders and actors today and tomorrow for the interaction vehicle to grid.
- Impact of other trends – autonomous drive, micro mobility.
- Cross-vehicle-type standardization.
- Regulations and incentives.
- Energy management & Charging control, Decentralized and self-regulating, V2G.

- Grid security, e.g., to avoid poor electrical quality (intentional and unintentional).
- Safety for the vehicle and the infrastructure during smart charging.
- Data security, GDPR and more if the grid owner can control the charging.
- Optimization of smart charging in different grids and from a national perspective.
- Communication: Peer2Peer solutions, cybersecurity, data privacy, AI, improve convenience (move operations and decisions from human to machine).
- Charging strategies for battery optimization (size and service life).

## Strategic research areas

Within the theme, there is a need for research projects that are based on models/data that are realistic from both a power system and a vehicle perspective. We also encourage projects with experimental verifications. Furthermore, we see a need for studies at different system levels; from individual vehicles to a complete fleet of vehicles. The main question for the theme is to evaluate different charging strategies; when, where, how and why? Different areas (Vehicle-grid physical interaction including supply; vehicle-grid data, communication and security interaction; Human/Consumer perspective; and Holistic challenges) can be linked to this and we encourage research projects that addresses several of the areas that are mentioned in the roadmap. Four areas that have been identified are:

**Charging at lower power levels**

**Charging at higher power levels**

**Charging infrastructure; a system perspective**

**Need and use of energy storage in the power system**

## Forecast (5 years, 10 year, 15 year perspective etc)

**5 year**

-Communication standards for interaction is in place, further developed power tariffs and 2nd gen smart meters, roaming and plug & charge type functionality is rolled out. Better usage of energy and power with functions as asymmetric power consumption. Chargers and charging clusters can be dynamically controlled by the available power in the grid, based on user preferences. V2G becoming clearer, but strongly influenced by learning on local steering & control and how flexibility markets & regulation develops. ERS regulatory & standardization topics handled/ completed. First market/ commercial pilot implemented (but not yet fully delivered?). We will have a range of maritime pilots completed to set new standards and market models. Many transformers on all levels have been retrofitted with sensors, feeding data to control centers.

**10 year**

-There will be a mix of conductive and inductive charging on the market, V2G is standardized & implemented in commercial products and financial incentives are implemented. Business cases developed for aggregation actors to gross energy market. Standard ERS for commercial application proven or superseded by battery technology improvements & competition from hydrogen + fuel cells. Other transport segments (maritime & aviation) are partially electrified.

**15 year**

-Consolidation and surviving companies. High penetration of Electric Vehicles in society as well as mature standards and market praxis when it comes to technical solutions. This will lead to a high focus on standard solutions that are proven and accepted. ICE in a higher degree driven by synthetic/biofuels. New energy actors/traders. Peer-to-peer energy trading. More common with carpooling in densely populated cities acting in a timely integrated ecosystem. Heavy commercial road transports electrified – Combination of technology solutions. Maritime applications significant electrification. Short distance 400 km flight, democratic flights.

## Relation between theme areas:

| Strategic research area | Intelligent Vehicles & Systems | Electric Drives & Charging | Energy storage | Environment & Society | Vehicle-grid interaction |
|---|---|---|---|---|---|
| **Charging at lower power levels** | | | | | |
| **Charging at higher power levels** | | | | | |
| **Charging infrastructure; a system perspective** | | | | | |
| **Use of 2nd life batteries in the power system** | | | | | |

# SWOT analysis: Electromobility and power system

## S — STRENGTH

- **Technology and development**
- Strong in AI, data and communication
- Strong vehicle industry pass.car + commercial veh. + off-highway mach. (+ boats + aviation)
- Battery tech: Northvolt etc.
- Emob research (as ERS projects) at various universities, high quality
- Sweden has a relatively strong electric grid and CO2 neutral electricity production.
- Long engineering experience in both power grid technology development and power generation development.
- Broad technology portfolio

- **Society**
- Innovation and environmental awareness
- Focus on innovation from politics + agencies
- Innovative IT companies, startups
- Huge interest on electrification amongst decision makers
- Strong PRA (Green deal, Paris agreement)
- ISO standards exist to base it upon

- **Collaborations**
- Traditional tight collaboration politics+industry through governmental procurements
- SEC & Co (collaboration academy + industry)

- **Economy**
- Trends in sharing economy
- Still low market penetration, time to fix it!

## W — WEAKNES

- **Technology and development**
- Technology-driven development instead of need-based
- Limitations in voltage levels
- Limitation in power transmission capacity at some locations
- Limitations in load control
- Lead-times for power system expansion
- Academic and industry silo mentality, driven by financing
- Lots of inertia to develop the grid (NSI)

- **Society**
- Conservative countries & cities (slow change)
- Immature standards now (e.g. Island mode, Vehicle to load. Communication and security)
- Culture of bold innovation decreasing, incremental improvements for better shareholder value
- Waiting for the optimal technology (public actor)
- Legal-/Regular Policies not in time (concession)
- Competence in new areas

- **Collaborations**
- Academic silo mentality, driven by financing
- It takes time to build up new collaborations (automotive industry, community, power grid companies)

- **Economy**
- Low market penetration
- Culture of bold innovation decreasing, incremental improvements for better shareholder value

- Other
- Nobody looks wide enough today, ie takes a holistic perspective on the complete system

## O — OPPORTUNITIE

- **Technology and development**
- Multimodal transport solutions, shorter range
- Autonomous vehicles and invisible charging
- Electric energy storage solutions
- Area that can help the power grid
- 2nd life for batteries, whole industry goes for emob
- Have smart power control and grid topology solutions to overcome limitations in the power system.
- Combine expansion of decentralised power production and charging.
- Reduce emissions, more sustainable solutions

- **Society**
- Legal- /Regulation policies
- New types of customers
- New roles (flexibility market, solution model)
- New jobs and innovations

- **Collaborations**
- Cross-industry collaboration (veh.OEM+power+IT) and partnerships
- We are at the beginning of an electrification of several sectors where there is still the opportunity for actors to work together

- **Economy**
- Cheap (local) renewable electricity generation
- New roles (flexibility market, solution model)

- **Other**
- Sweden's leader in sustainable solutions for charging electric vehicles.

## T — THREATS

- **Technology and development**
- Local power grid overload
- Cybersecurity
- Time to set the technical solutions and communication
- Power grid limitations, takes long time to fix
- Unregulated technologies that might have a negative impact on SAIDI
- Several sectors will be electrified simultaneously
- High power for charging trucks and busses are needed
- Some charging strategies can have a negative impact on battery lifetime and efficiency

- **Society**
- Bureaucracy on all levels
- Standardization efforts take time (international alignment needed, though)
- EU law prevents traditional coll. politic+industry
- Stranded asset concerns/ legacy (timing issue)

- **Economy**
- Reduced price for fossil fuels
- Low electricity prices (With high amount of production from fossil fuels)
- High electricity price
- Tax models that will be less favorable for EVs
- Investments costs
- Poor regulated responsibility/Peer-to-peer trading

- **Other**
- Dependent on rare earth metals and other limited resources
- Reduced interest in electric cars and electric vehicles