sccer mobility Swiss Competence Center for Energy Research
Efficient Technologies and Systems for Mobility

ETH zürich

The Key Performance Indicators of the Swiss Mobility System

A systemic approach to research activities within the SCCER Mobility network

Project report

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Contents

Executive Summary

In order to fulfil the requirement from the 2017 evaluation, "to establish the key performance indicators (KPIs) for all SCCER Mobility solution pathway", the task was assigned to the Learning Lab: Future Transport System. The results of the study, including a list of selected KPIs, and the summary of expert discussions from all capacity areas (CAs) are presented here. The results of expert discussions include the primary research concepts within the whole network of SCCER Mobility activities, and the relevance of each concept to the selected KPIs of the Swiss mobility system, as a rate between 1 (not related or very low relevance) to 4 (clear and highly important relevance). In this respect, the ratings don't reflect the contributions or the results of each project, but highlight the relevance of the general topics for a sustainable mobility system in Switzerland.

The initial list of KPIs had three indicators: **emission reduction**, **scalability** and **cost reduction**. Based on the discussions, another indicator was added to the list as **industrial/ social implementation**. Then, for each capacity area a list of the main concepts was selected as the concepts can summarize the main research activities discussed by the experts. The selected concepts don't necessarily cover all projects of the CA.

A total number of 31 experts contributed to the development of this project in different ways, through participating in the pilot phase, filling the survey, participating in expert discussions, project management and providing feedback. The full list of contributing experts (in alphabetical order) follows:

Shelly Arreguin, Kay Axhausen, Jürgen Biela, Konstantinos Boulouchos, Felix Büchi, Priscilla Caliandro, Francesco Corman, Valerio De Martinis, Andrea Del Duce, Thibaut Dubernet, Gil Georges, Stefanie Hellweg, Stefan Hirschberg, Raphael Hoerler, Ueli Kramer, Merla Kubli, Kunal Masania, Martin Raubal, Mireia Roca-Riu, Gloria Romera Guereca, Roman Rudel, Christian Rytka, Alejandro Santis, Kurt Schenk, Katja Stengert, Max Stöck, Benedikt Sturny, Cristian Udrea, Andreas Ulbig, Andrea Vezzini, Pengxiang Zhao

For each CA, the results include the relative relevance of the concepts to the KPIs, and the solution pathway that incorporates each concept. The solution pathways show the relationship between the main concept and other prerequisite or future concepts/applications. This is important since the concepts across CAs are not in the same level of technological readiness; therefore, it helps to understand the relative position of each concept in the wider surrounding environment.

As a complementary analysis, it was investigated how the concepts could be clustered based on their relevance to the KPIs and the general classification of research activities (being part of a specific CA). For clustering algorithm, the concept of **cosine similarity** was used, as a measure of similarity between each pair of concepts. The algorithm was implemented in three levels for a robust analysis:

- Based on KPI ratings only
- Based on KPI ratings and CA groups (A or B)
- Based on KPI ratings, CA groups (A or B) and CAs (A1, A2, A3, B1, B2)

Then, for each level, a network of similarities was constructed. By keeping the highest 20% of similarities, the clusters of concepts for each network were identified. Comparing the results of all three networks, resulted in the identification of four clusters. A brief summary of results follows.

CA A1: Components and Systems for E-Mobility

Table 1 summarizes the key concepts and their relevance to the KPIs in CA A1. This CA is primary focused on charging infrastructure, battery system management and the electrification of specialized vehicles. KPI analysis reveals this CA has a very high orientation towards industrial/social implementation, and one reason is the existence of demonstrators along with research projects in this CA. Scalability is another KPI with relatively high relevance, while cost reduction and emission reduction have moderate relevance in this CA.

Table 1. The summary of research concepts and KPI ratings for CA A1

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Bidirectional wireless power transfer	***	*	****	*
Demonstrators of specialized electric vehicles	***	**	*	****
Battery safety in special conditions	*	**	**	****
Battery system characterization	**	****	*	**
Battery testing for thermal and electrical performance	*	**	**	***
Interfacing batteries for voltage boosting	*	****	***	***
Cost-efficient ultra-fast conductive charging	**	***	***	**

Considering the solution pathways, a variety of applications can be facilitated by these concepts. Bidirectional wireless power transfer can help regulating the grid through providing a virtual battery, while ultra-fast conductive charging has applications as supercharger and in marine industry. Voltage boosting via interfacing batteries, apart from conductive charging, has applications in hybrid locomotives. Battery technology research ranges from cellular thermal identification, which leads to battery system identification, to considering battery failures and testing safety in special conditions, such as underground operations. It also includes demonstration of specialized electric vehicles, which have special applications, such as in farming.

CA A2: Chemical Energy Converters

The key concepts and KPI ratings for the CA A2 is summarized in table 2. The primary focus of this CA is on two broad set of activities: renewable hydrocarbon-operated hybrid or internal combustion engine powertrains with improved efficiency, and simplified renewable hydrogen operated fuel-cell systems with reduced costs. Emission reduction has a high potential relevance, while scalability and industrial/social implementation have a moderate rating. Cost reduction is the KPI with the lowest score in this CA.

Table 2. The summary of research concepts and KPI ratings for CA A2

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Evaporative cooling and compaction of fuel cells	***	*	***	**
Diesel to natural gas combustion system characterization	***	*	*	**
Efficiency increase in pre-chamber combustion	****	***	*	**
Energy management system in hybrid bus	*	***	**	****

Regarding the solution pathways, the characterization of diesel to natural gas combustion system, and efficiency increase in pre-chamber combustion, facilitate power to gas, and shift to natural gas combustion systems. Battery installation and the recuperation of braking energy lead to energy management in hybrid buses, which result in energy consumption reduction in Trolley buses. Finally, Evaporative cooling and compaction of fuel cells by removing cooling circuit and water injection/evaporation facilitates fuel cell operation in high temperatures.

CA A3: Minimization of Vehicular Energy Demand

Table 3 summarizes the key concepts and the KPI ratings for CA A3, which deals with aerodynamics, rolling resistance and light-weighting materials. The main activities are centered on high-volume production of new light thermoplastic components, in order to be used in producing light weighting materials, development of bio-inspired light composites, as a disruptive approach for developing composites by imitation from nature, and the optimization of vehicular energy demand and energy flow.

Table 3. The summary of research concepts and KPI ratings for CA A3

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Economic/ environmental LCA of interior light-weighting material	***	*	***	***
Scaling up part production for light-weighting material	***	****	**	*
Nature-inspired composites	**	***	*	**
Standards for composite permeability measurement	**	****	*	***
Vehicular energy demand estimation	**	***	**	*

In general, these activities have a high degree of scalability, which relatively receives the highest rating in this CA. Furthermore, these activities have a moderate effect on emission reduction, and industrial/social implementation. Cost reduction has a mixed and relatively low rating.

The solution pathways are mainly towards developing composites for light-weighting material. Life-cycle assessment (LCA) of interior light-weighting material reduces carbon footprint and facilitates sustainable material production in automotive applications. High-efficiency in-line coating contributes to scaling up of fiber bundles and increases the performance of the composites. Furthermore, nature-inspired composites facilitate the development of super stiff composites. Participation in worldwide benchmarking exercise contributes to the development of standards for composite permeability measurement, which speeds up part production. Finally, vehicular energy demand estimation, including the materials, facilitates the real-world simulation of energy demand in vehicles.

CA B1: Design, Demonstration and Dissemination of Systems for Sustainable Mobility
The key concepts and KPI ratings for the CA B1 are summarized in table 4. This CA is primarily focused on the demand side of the mobility system and highlights spatial planning and IT-based communication to understand demand for services. It also looks at the supply side, by focusing on the infrastructure requirements for road, rail and refueling. Regarding the KPIs, this CA has the highest ratings for cost reduction and emission reduction. Scalability and industrial/social implementation have a relatively moderate relevance in this CA.

Table 4. The summary of research concepts and KPI ratings for CA B1

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Energy efficiency optimization in rail operation	**	**	****	***
GPS-based dynamic mobility pricing	***	***	****	**
Grid Impact assessment of e-mobility	***	**	****	***
Optimal fleet for energy infrastructure	**	***	***	*
Environmental assessment of household mobility behavior	****	***	*	**
Green mobility as a service	****	*	**	***
Spatial planning for environmental impact of urban mobility	****	***	**	***

Solution pathways range from operational efficiency and infrastructure optimization, to changing behaviors. Data monitoring and analysis of infrastructure usage, lead to energy efficiency optimization in rail operation, thus cost reduction. Grid uncertainty estimation and optimizing energy infrastructure for e-mobility, facilitates grid impact assessment, and helps utility companies in their investment decisions. Furthermore, analyzing daily consumption profiles leads to finding patterns of energy demand, which can help us find optimal fleet for energy infrastructure and the bottlenecks in the energy infrastructure operation.

On the behavioral side, assessing mobility pricing facilitates individual nudging techniques, and the introduction of dynamic mobility pricing for reducing congestion and emissions. Looking at household energy and environmental profiles for the quantification of household mobility impacts helps us to assess the environmental aspect of household behavior and develop incentive systems for changing mobility behavior. Tracking technology can also facilitate the personalization of services and changing passenger transport behaviors. Finally, analyzing mobility patterns in cities can contribute to spatial planning and optimizing urban mobility, in order to reduce urban mobility demand and emissions.

CA B2: Integrated assessment of mobility systems
Table 5 summarizes the key concepts and the KPI ratings for CA B2, which started by focusing on the supply side of the mobility system and tried to cover all kinds of technologies, fuels and vehicles. Then, it also considered the demand side, which needed to

be integrated in a holistic approach by taking into account different dimensions of sustainability, including the economic, environmental and social aspects. The KPI analysis shows a relatively high relevance for emission reduction and cost reduction, while scalability and industrial/social implementation have a relatively low score.

Table 5. The summary of research concepts and KPI ratings for CA B2

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Lifestyle analysis for changing mobility demand	***	**	**	*
Mobility sharing for changing mobility demand	***	*	**	*
Nudging to change fuel-efficient car purchasing behavior	****	*	***	*
Performance assessment of future car technologies	****	**	****	*
Nudging passenger behavior for emission reduction	****	**	*	***

The solution pathways include the assessment of new mobility services and technologies, in the forms of new packages, performance assessments and behavioral change. Patterns of commuting and lifestyle classification, deal with lifestyle analysis for changing mobility demand and the adoption of new mobility services. Classification is also done on car users in order to trigger mobility sharing as a factor for changing mobility behavior and providing sharing offers. Gamification framework materialized in apps, facilitate the calculation of energy saving options, and nudging passenger behavior in order to reduce emissions. Nudging is done for photovoltaic owners as well; where bundling offers are provided in order to change electric vehicle purchasing behavior and increase the customer acceptance of electric mobility. Finally, indicators for technology assessment are prerequisites for energy system model and life cycle assessment, which help us to develop scenarios for the future of car technologies and assess the performance of emerging systems.

Clustering by similarity

Calculating the similarity between all the concepts within all CAs, and developing a network of all interconnected concepts, lead to the identification of four clusters.

Cluster1: decarbonization in a testbed

This cluster includes technological and social innovations as niches, with the aim of reducing emissions, without considering business and technical limitations at the moment and within the project boundaries. Therefore, it is characterized by 'high emission reduction', 'low scalability' and 'low industrial/social implementation'. This cluster is comprised of six concepts of "bidirectional wireless power transfer", "evaporative cooling and compaction of fuel cells", "lifestyle analysis for changing mobility demand", "mobility sharing for changing mobility demand", "nudging to change fuel-efficient car purchasing behavior" and "performance assessment of future car technologies".

Cluster 2: cost matters!

The second cluster takes a systemic view to the cost structure of a specific technological or social innovation. At the technical layer, system optimization and life cycle assessment help to reduce costs, while at the social layer, socio-economic factor for reducing costs are investigated. In this respect, the 'cost reduction' KPI characterizes the main orientation of this cluster. Five concepts constitute the cluster as "economic/ environmental LCA of interior light-weighting material", "energy efficiency optimization in rail operation", "GPS-based dynamic mobility pricing", "grid Impact assessment of e-mobility" and "optimal fleet for energy infrastructure".

Cluster 3: Green innovation first, then cost!
This cluster includes a broad set of technical and social innovations, characterized by high "emission reduction", but low "cost reduction" measures. It means from a social perspective, there are activities with the aim of social and behavioral change in order to reduce emissions, but cost is not a factor within the context of the project. From a technical perspective, the new technologies have clear contributions to emission reduction, but cost is not a concern, which naturally means new technology is more expensive than the existing ones. This cluster includes eight concepts of "demonstrators of specialized vehicles", "diesel to natural gas combustion system characterization", "efficiency increase in pre-chamber combustion", "environmental assessment of household mobility behavior", "green mobility as a service", "high-efficiency coating for light-weighting material", "nudging passenger behavior for emission reduction" and "spatial planning for environmental impact of urban mobility".

Cluster 4: Even more technology!
This cluster is composed of concepts and activities, which are part of the 'A' CAs. They are more focused on the business and technical aspects of new technology development, formalized as high "scalability", and high "industrial/social implementation"; but interestingly, "emission reduction" KPI has a low score here. Advances in systems that are either already decarbonized to some extent, or the size of the market is very small, partially explains the reason for low emission reduction potential. Seven concepts comprise this cluster: "battery safety in special conditions", "battery system characterization", "battery testing for thermal and electrical performance", "energy management system in hybrid bus", "interfacing batteries for voltage boosting", "nature-inspired composites" and "standards for composite permeability measurement".

1 Introduction

This project started to fulfil a requirement from the 2017 evaluation, "to establish the key performance indicators (KPIs) for all SCCER Mobility solution pathway". As the requirement implies, it needs a set of KPIs and established pathways. Therefore, the project started with a list of selected KPIs, with the potential to change the original indicators during the project. At the same time, the roadmaps of all Capacity Areas (CAs) were used as the starting point to formulate the solution pathways.

Research activities and CAs in the SCCER Mobility network differ in terms of their goals and methods, and include a variety of activities at different levels of technological readiness. Therefore, a consistent method was needed in order to be used as a standard way of summarizing research ideas, their relevance to the selected KPIs, and formulating the pathways. Gathering the main ideas within each CA, complemented by secondary data such as published reports, presentations and publications was the starting point to fulfil the objectives of the project.

In order to gather data, first a survey was developed and distributed among the experts from all CAs. Then, the survey questions were transformed to a questionnaire in order to conduct expert interviews. At the end, a combination of both methods was more efficient due to the availability of experts, the level of details each expert wanted to provide, and experts' personal preferences. The logic and the building blocks of the survey/ questionnaire were first discussed with the Capacity Area (CA) coordinators, and one external reviewer; then they were distributed to the Principal Investigators (PI) of all CAs. During summer 2019 a pilot test was conducted with CA A1 in order to test the structure of the method, and the results were compiled and complemented with the monitoring reports submitted to the management office of SCCER Mobility (2018 – 2019) and the presentations of the CA coordinators in the annual conference of SCCER Mobility in September 2019. The preliminary results were presented to CA coordinators for their feedback, before approaching other CAs.

The structure of data collection is depicted in figure 1. It is assumed in order to address the aim of this project, two main steps should be taken. The first step is focused on internal analysis of research projects, where we try to understand the content and scientific contributions of different research projects, as well as their scientific exchanges; then in the second step, the relevance and implications for society and selected KPIs are analyzed. The outputs of this analysis, depicted as orange boxes constitute the main results.

Step 1: internal analysis

The first step starts with summarizing the research activities as the results of different research projects. For each project, the main objectives and potential contributions are gathered; then, it is tried to rate the relevance and relative importance of these contributions for the business and industrial sectors. In order to understand these contributions better, the potential applications are identified and their relative importance is rated.

There is the possibility for the existence of more than one strand of research in each CA. It means there can be more than one solution pathway. For each research strand, the relationship of different research activities to each other or to research projects outside this CA is asked. By finding other relevant research projects and their associated research topics, as well as rating these relationships, the initial pathway is formulated.

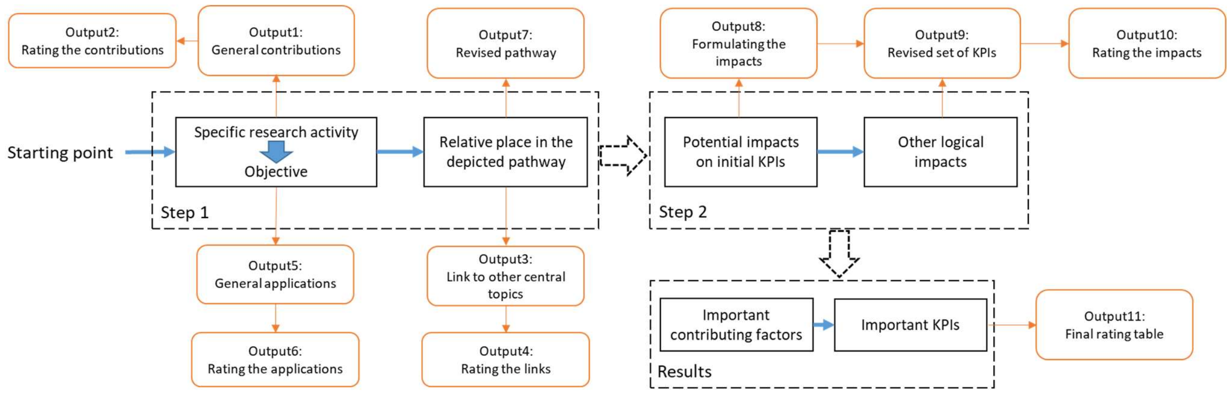

Figure 1. General method structure

Step 2: external analysis

In the second step, there are three predetermined Key Performance Indicators (KPIs) of a sustainable mobility system as “cost reduction”, “emission reduction” and “scalability”, followed by another important KPI, “industrial/social implementation” that emerged out of expert opinions. These indicators can be defined as:

- Cost reduction: the potential of contributing to the cost reduction of new technological solutions, or facilitating cost reduction by other innovations, in a clear way
- Emission reduction: the potential of contributing to the emission reduction of new technological solutions, or facilitating emission reduction by other innovations, in a clear way
- Scalability: the potential of extending the domain of innovative solution to other sectors, geographical areas or innovation systems, or facilitating the scaling up of niche innovations for mass production
- Industrial/social implementation: the extent innovative solution is being tested with industrial actors, or applied by social actors in daily life in order to test the applicability of the solution. This indicator tries to bridge the gap between scientific research and real world conditions

In this respect, the potential impacts of the main topics covered in the pathway to these KPIs are formulated.

Final results

Based on the inputs provided in the previous steps, a table of impacts is developed. It is composed of the updated list of KPIs and the main subjects or contents of research activities. Based on the ratings and the relationships between different topics and projects, the final impacts are summarized in the rating tables.

2 The questionnaire and the initial survey

Based on the structure explained above, a set of questions was designed in order to gather information about the orange boxes depicted in figure 1. During the expert interview process, depending on the amount of secondary data available for each project, the interviews were customized and the question sets were shortened for each expert. The sections and their associated questions are summarized below.

General projects:

1. Please specify the main SCCER Mobility projects you are involved and briefly explain their general objectives

Scientific contributions:

2. Considering the outcomes of all these projects, how do you summarize the main scientific contributions of these projects?
3. Based on the answers you specified in the previous section, how do you rate the relative importance of these contributions to the corresponding scientific community?

Potential applications:

4. Considering the general objectives of your projects, what could be the potential applications and practical implications?
5. How do you evaluate and prioritize the relative relevance of these applications and implications?

Relevance for other projects:

6. What are the other important topics within the SCCER Mobility network, as well as industrial projects, with collaboration, exchange or relevance to your projects? Please briefly explain how they are related to your projects. Some potential examples are: projects to be started in future as the next steps of the current projects, projects in other teams and groups which provide input to this project, projects in other teams and groups which use the results of this project
7. Please evaluate the relative degree these projects and their topics are related to your projects.

The Key Performance Indicators: In this section, we focus on the general applications and implications you specified, and we try to understand on what extent they contribute to the development of a sustainable transportation system. The evaluation is based on three Key Performance Indicators: "cost reduction", "emission reduction" and "technological scalability". Technological scalability means the extent an innovation or technology product can be scaled up or contribute to the mass production of a final product.

8. The first KPI is impact on "cost reduction" of technologies and applications. Please briefly explain, to what extent you think the general applications and implications you specified can contribute to this KPI.

9. The second KPI is impact on "emission reduction" of the whole transportation sector. Please briefly explain, to what extent you think the general applications and implications you specified can contribute to this KPI.
10. The third KPI is impact on the "scalability" of new technological innovations and technology products. Please briefly explain, to what extent you think the general applications and implications you specified can contribute to this KPI.

Other important measures

11. In your opinion, are there other logical contributions to other important factors, or key performance indicators not mentioned in this list?
12. To what extent you think the activities of this capacity area in general, and your research team in particular, contribute to knowledge transfer within the SCCER network, and how the SCCER facilitated the potential exchanges?
13. How this CA and your research group are connected to industry? Such connection could be as third-party funding, collaboration on specific projects, etc. Please specify different types of connections you know within the context of your projects.
14. To what extent, the main activities and research projects in this CA and your research group are related to international projects and institutions? Such relationships can be in the form of research collaborations, EU funding, etc.

3 Results

In this section, extensive results for each CA are presented.

3.1 CA A1: components and systems for e-mobility

The Capacity Area A1: "Components and Systems for E-Mobility" is formally composed of two main areas of activity. The first area is focused on the "electrification of specialized vehicles", which applies advanced algorithms for battery and cell models. Some of these models have been introduced to battery management systems and integrated into new applications.

The second area is centered on "power electronics for batteries" and consists of two main subjects. The first subject deals with the integration of batteries in large vehicles such as trains and locomotive with very high-level voltage, which makes the adaptation of the batteries necessary. The second subject deals with charging infrastructure, in the sense of finding out what the most efficient way to build up chargers is, especially for wireless charging infrastructure.

Data gathering and analysis for this CA, resulted in the identification of seven concepts.

i. *Bidirectional wireless power transfer*

The concept of "bidirectional wireless power transfer" adds value to the convenient inductive charging by opening up the possibility of using batteries in the vehicle as a home-storage system. In this respect, the concept of vehicle to grid looks at the battery in electric vehicles as a temporary storage device; therefore, it enables decentralized energy storage, contributes to grid stability and expands the usage of renewable energy. In other words, aggregation of a large number of vehicles creates a large virtual battery, which can act as a regulation power for the grid. This process requires the possibility to transfer power from the car back to the grid. Current wireless power transfer (WPT) systems do not allow this. The aim of this activity is to close this gap and the results generate knowledge of WPT system with high power levels, and can enable very fast charging of electric vehicles using the WPT technology.

This activity is important for developing cost and energy efficient high power charging (15% efficiency increase). It facilitates transition to battery electrification via wireless systems, thus contributes to electrification and emission reduction in the mobility system. Furthermore, it is linked to the general "battery research", since battery charging is closely linked to the behavior and performance of the batteries, as well as to the "models for advanced magnetic devices", since power electronic converter system requires new or better magnetic devices.

ii. Demonstrators of specialized electric vehicles

Demonstrators facilitate the testing and real-world implementation of solutions. High level of industry participation creates a big opportunity to increase the market acceptance of these technologies. Electrification of specialized vehicles and large trucks, clearly contributes to emission reduction. Furthermore, developing accelerated lifecycle testing methods increases the operational efficiency and contributes to lifetime emission reduction.

There are multiple demonstrators such as eDumper and Swiss E-Tractor. As an example, the pilot test "Swiss E-Tractor" is a case of integration in collaboration with Rigitrac as the industry partner. The small tractor works with all-electric drivetrain. Its low center of gravity improves its off-road capability. This type of vehicle has advantages for Swiss farmers who live in very hilly farms.

iii. Battery safety in special conditions

An important topic for battery testing is safety, and the consequences of battery failure under specific conditions. In activities around this concept, the impact of fire from batteries in underground infrastructures is minimized. Here the idea is to see to what extent emissions from electric vehicle fires in tunnels lead to contaminations that differ from conventional vehicle fires. In this respect, it is important to see whether special measures and equipment are required for handling contamination, and if it will have a lasting impact on the operation and safety of underground infrastructures. Amstein + Walthert Progess AG, V-S-H-, CETU and ASTRA are the partners collaborating with EMPA on this concept.

iv. Battery system characterization

Battery system construction based on thermal identification test-bench is the requirement to enable simulations from single cell to the final battery for a Lithium-ion based 36V battery. It starts from thermal characterization of a cell and extends to the design and optimization of the thermal behavior of the full battery package in collaboration with SBB. The simplified model allows to speed up the calculations for a fast adoption of the model to the battery and make it more efficient and practice oriented.

v. Battery testing for thermal and electrical performance

In order to develop advanced models for the thermal and electrical performance of batteries, extensive testing is done for lifecycle modeling of bus batteries, in collaboration with Hess Swisstrolley. The general idea is to test batteries under different conditions for calculating temperature, discharge rate and depth of discharge. These tests can lead to building up of an enhanced self-correcting cell module, where accuracy and robustness for Lithium-Ion batteries are enhanced through charge estimator algorithms. Then, the performance is tested based on experimental aging behavior to analyze the state of charging and the state of health. The health model deals with the issue of how long the battery will work depending on the type of operation.

vi. Interfacing batteries for voltage boosting

This concept focuses on new ideas for highly efficient and compact isolated converters for interfacing batteries, which will be used in future hybrid locomotives. Based on the results, a new dynamic control concept for active flux balancing in dual active bridge (DAB) is provided. DAB converters are solutions for battery interfaces in storage systems. Then, comprehensive models for designing power electronic interfaces for batteries are developed, and a full-scale prototype system is tested in collaboration with Bombardier.

Dynamic control in DAB converters and the associated prototype testing are important for battery interface design in storage systems. With applications in traction system, they contribute to achieving a higher power density. Such a higher density is achieved through the design of transformer and the cooling system, which resolves the issues related to environmental conditions and space limitations.

vii. Cost-efficient ultra-fast conductive charging

Batteries usually have relatively low-voltage applications, which would even qualify a car application as a high-voltage battery. There is a trend in electric vehicles to increase the traction battery voltage to 800 - 1000V. This is driven by the need for ultrahigh power charging (up to 350kW). The charging infrastructure being built right now is predominantly designed for 400V system. But in a locomotives with a needed voltage of 2800V the batteries should be connected, which is done by DC-DC converters. The conventional products in the market lead to problems due to safety requirements. One solution would be an isolated DC-DC converter. The goal of this activity is to investigate a booster concept, in collaboration with Thyssenkrupp Presta, in order to enable the driver of an EV to charge new 800V cars on 400V charging stations without expensive power electronics. In this context, different transmitter and receiver topologies can be compared, feasibility of both technology and cost efficiency is analyzed, and the results may enable ultrafast charging of electric vehicles by using conductive systems. Apart from applications in battery storage interface for traction applications, the results can be used in the development of superchargers and the marine industry.

Based on the brief summaries of each concept, and their links to other relevant concepts, the solution pathways for CA A1 is depicted in figure 2. In this figure, each row represents the solution pathway for one of the concepts explained above (in red), where the level of technological readiness or stages in the development of an innovation or technologies advance from left to right.

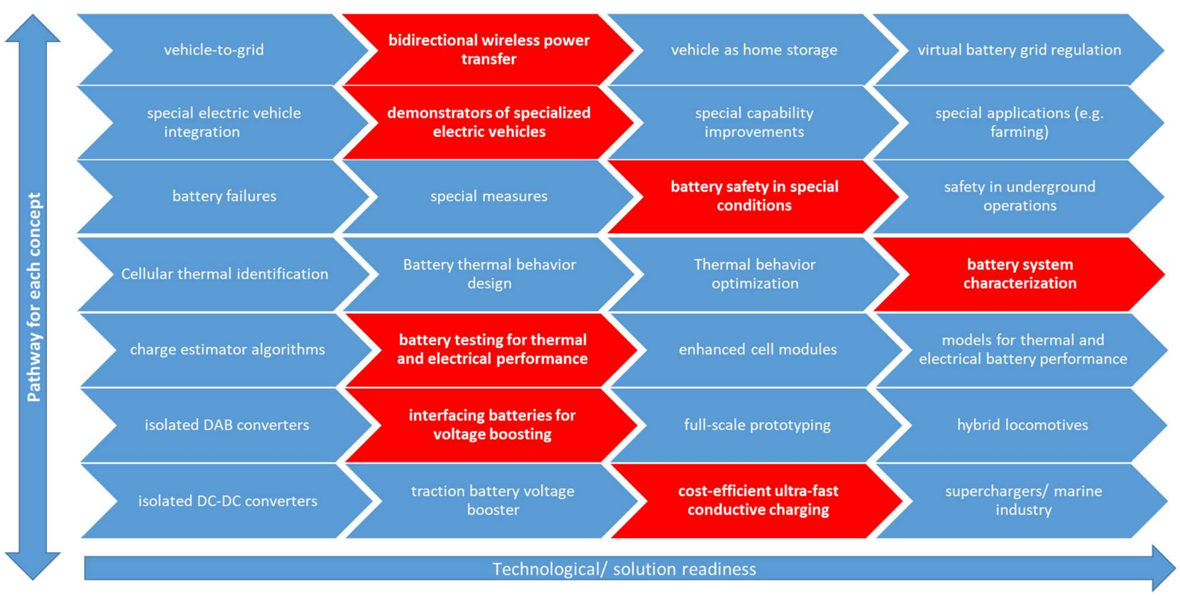

Figure 2. Solution pathways for CA A1

KPI ratings

Next to the battery itself, fast charging is the second bottleneck in e-mobility. Therefore, providing efficient solutions for fast charging is imperative to increasing the number of electric vehicles, which in turn is necessary to reduce both costs and emissions through scaling effects. It means wireless power transfer systems, high power charging and their associated concepts are important for emission and cost reduction. Electrification of specialized vehicles are also important for emission reduction, but to a limited scale.

Integration of new boosters into the EV systems allows for drastic cost reduction compared to today's available systems, in a separate system and with expensive connectors. Cost reduction is also an important indicator for conductive charging, since different topologies are compared in order to identify the most cost efficient solution.

Scalability has also a relatively high rating in conductive charging due to scalable applications in other industries. It is an important indicator for activities related to battery system characterization, where the system scales up from a cell to the whole battery package. Furthermore, interfacing batteries are used to increase the voltage and contribute to the scalability of battery solutions.

The level of industrial partnership is very high in demonstrators (electrification of specialized vehicles). There are also a variety of partners for testing battery safety in special conditions, and individual partners for implementing solutions related to different battery-related solutions such as thermal testing and voltage boosting.

Combining the general description of each concept with the relative relevance to the KPIs, leads to a rating table, as depicted below (table 6).

Table 6.The summary of research concepts and KPI ratings for CA A1

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Bidirectional wireless power transfer	***	*	****	*
Demonstrators of specialized electric vehicles	***	**	*	****
Battery safety in special conditions	*	**	**	****
Battery system characterization	**	****	*	**
Battery testing for thermal and electrical performance	*	**	**	***
Interfacing batteries for voltage boosting	*	****	***	***
Cost-efficient ultra-fast conductive charging	**	***	***	**

The aggregate ratings for all KPIs is depicted in figure 3. Each quadrilateral represents a concept, with impacts on all four indicators. This figure reveals the CA has a very high orientation towards industrial implementation, and one reason is the existence of demonstrators along with research projects in this CA. Scalability is another KPI with relatively high relevance, while cost reduction and emission reduction have moderate relevance in this CA.

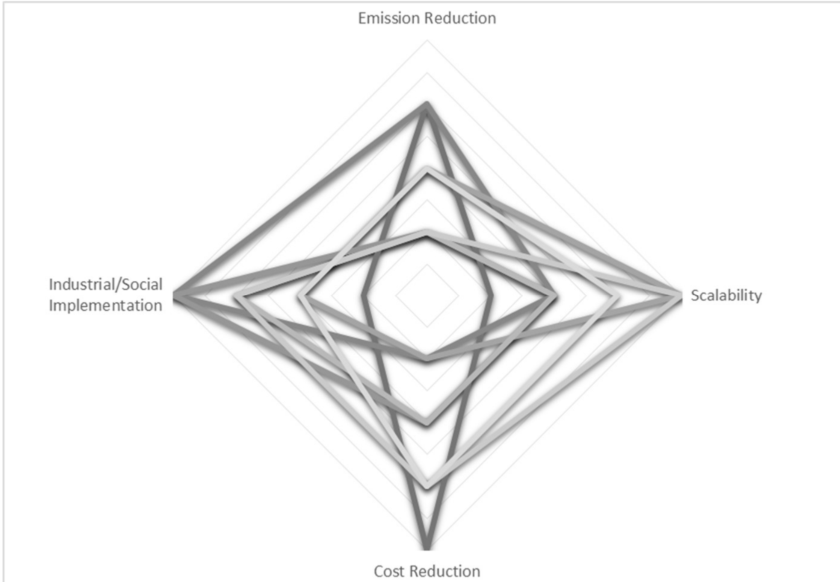

Figure 3. Aggregate KPI ratings for CA A1

3.2 CA A2: chemical energy converters

The Capacity Area A2: "Chemical Energy Converters" is composed of two general topics: renewable fuel-operated hybrid/IC engine powertrains with improved efficiency, and simplified renewable hydrogen operated fuel-cell systems with reduced costs. Therefore, efficiency improvements and renewable fuel generation are two important tracks within the activities of this CA, where different technologies entail different patterns of energy usage. Data gathering and analysis results in the identification of four main concepts:

i. *Evaporative cooling and compaction of fuel cells (FC)*

This concept, primarily materialized in the context of "model-based analysis of evaporatively-cooled fuel-cell system" aims to have a better understanding of heat transfer on cell level, and a quantitative understanding of effects on system level. Cooling of FC systems takes space in the FC for taking the fluid. The vision here is to get rid of the cooling circuit so the system becomes more compact and can operate in higher temperature by injecting water. Therefore, the stack volume becomes smaller and water is injected, which becomes evaporated and cools down the FC system. The stack volume is reduced by 35%, the humidification is even more needed, and system works under higher operating temperature and reduced system volume; thus, the cooling system can be also reduced. As a result, the volume and complexity of the system are both reduced.

This process resolves two issues: temperature, and water management in the FC. At high temperature, the process is balanced by gas humidifier. Water injection also resolves the humidification problem. Regarding the applications, this technology considers long-distance applications. The main FC applications are in lightweight-duty (LDV) and heavyweight-duty vehicles (HDV), and in stationary cogeneration (CHP). Considering applications in the transportation sector, compactness is the main issue for passenger cars. For HDV having a high temperature is the main issue, because the restrictions are higher. Therefore, it has implications for both. In partnership with Toyota, characterization of the water phase in gas diffusion layer in fuel cells is done in the materials developed by the company. However, there are significant challenges for implementation, and the main concern is whether research can solve these challenges.

ii. *Diesel to natural gas combustion system characterization*

This concept in general, and the project "adapted fuels" in particular, aim to investigate the shift from diesel to cleaner natural gas. Therefore, the concept is focused purely renewable energy, as part of the renewable fuel general track. The activity consists of experimental combustion investigation in optical energy test facility, for dual fuel (gas engine with diesel/alternative fuel ignition jet) and diesel combustion with alternative (tailored) liquid fuels.

The test set up for characterization of dual-fuel combustion processes was installed to investigate the ignition, flame propagation and combustion under engine-relevant conditions, and a wide range of process conditions and injection. The main outcomes show that it is possible to significantly reduce CO2 emissions, but also other pollutants. Furthermore, the relevance for industry are optimal conditions in terms of low emissions and operational stability. The fuels are produced in complex processes; therefore, at the moment cost is not a concern within this activity. Industrial actors such as BP and Shell can benefit from the results of this activity. Therefore, the concept is interesting for companies, but at the moment partnership is at the predevelopment phase

iii. *Efficiency increase in pre-chamber combustion*

This concept is partially on the efficiency improvement, and partially on the renewable fuel tracks. Materialized in the project "GasOn", as a European project, where many industrial partners are involved for research aspects rather than implementation. Control technology in pre-chamber combustion only exists for big engines. This activity tries to investigate a new pre-chamber combustion process for passenger cars. The target is to increase efficiency by 20% compared to a state-of-the-art gas engine, thus reduce emissions. The technical approach is to install an ignition chamber. Volkswagen was responsible for design, optimization and manufacturing of prototype engine hardware. The thermal efficiency is increased and there would be very low NOx emission.

The concept is applicable to power to gas, and renewable energy provided gas. The same infrastructure can be used over time in power to gas, which would lead to transition to zero emission systems. At the moment the focus is on methane, but over time there is potential for pure renewable fuel, depending on the availability of infrastructure. At the moment, impact on cost reduction is unclear, but in future CO2 cost would increase, which can increase the potential relevance from a cost perspective.

iv. *Energy management system in hybrid bus*

This concept belongs to the energy efficiency track of this CA and in collaboration with HESS, as the Swiss bus manufacturer and VBZ as the customer. Materialized in the project "Swiss Trolley Plus" with the main objective of developing energy management system of a hybrid trolleybus, it has the target of 15% reduction of energy consumption of Trolley buses. The process was to install a battery in these buses. Therefore, in buses with traction batteries, recuperation of braking energy is possible, leading to infrastructure costs savings, allowance of extending bus routes, and reduction in energy consumption.

The potential of cost reduction for the customer, VBZ, is still unclear, although increasing energy efficiency has cost implications. Diesel engine will be changed with batteries; battery is more expensive but there is the potential to save electric energy due to recuperation; which saves the need for OCS for the operator, thus changes variable costs.

Based on the brief summaries of each concept, and their links to other relevant activities and applications, the solution pathways for CA A2 is depicted in figure 4.

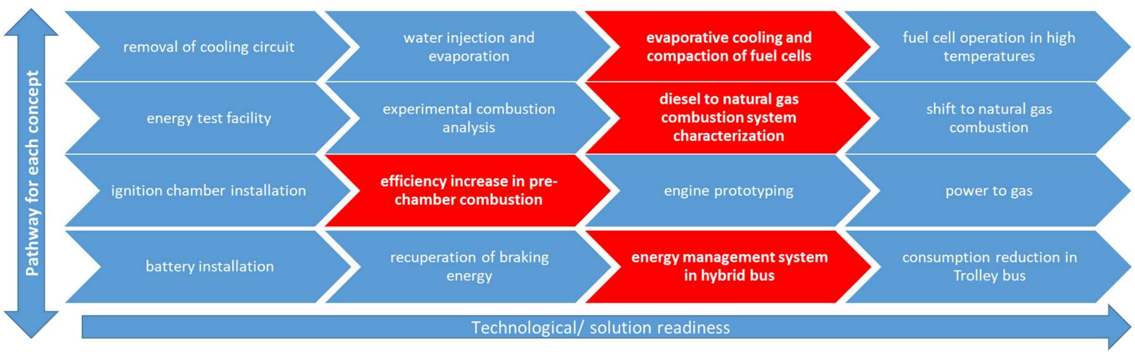

Figure 4. Solution pathways for CA A2

KPI ratings

Fuel-cell systems are part of road electrification, as an important antecedent of emission reduction. The same logic holds for diesel natural gas characterization, although infrastructure is still needed to exploit the opportunities. Efficiency increase in pre-chamber combustion leads to emission reduction by reducing energy consumption. Therefore, reducing the consumption of fossil fuels via transition to renewable fuels, and increasing efficiency are two important drivers of emission reduction in this CA.

Scalability is high in efficiency increase in pre-chamber combustion, since the same process can be done immediately for similar systems. Energy management in the trolleybus creates scalability as well, since it leads to the extension of bus lines, which increases the scale of the whole network.

In evaporative cooling of FC systems, higher power density is the main cost driver, although it is not the focus of the activity, but compactness leads to cost reduction. Cost reduction is not an important driver in other concepts as well, which highlights the potentials of focusing on cost-related factors in the later stages of the associated projects.

The highest level of industrial implementation exists in the trolleybus project and energy management in hybrid bus concept. There is collaboration with HESS to implement the solution and for VBZ, the customer. Other concepts have a relatively moderate level of industrial partnership for implementation, but there are partners for the development of concepts and data gathering.

Considering the general description of each concept and the relative relevance to the KPIs, table 7 summarizes the KPI ratings for this CA.

Table 7. The summary of research concepts and KPI ratings for CA A2

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Evaporative cooling and compaction of fuel cells	***	*	***	**
Diesel to natural gas combustion system characterization	***	*	*	**
Efficiency increase in pre-chamber combustion	****	***	*	**
Energy management system in hybrid bus	*	***	**	****

The aggregate ratings for all KPIs is depicted in figure 5. This figure reveals the CA has a very high relevance for emission reduction, by focusing on energy efficiency and renewable energy sources. Scalability is the KPI with relatively moderate relevance, while cost reduction and industrial/social implementation are the KPIs, which may need time to be incorporated in the context of these research activities, as the technologies mature.

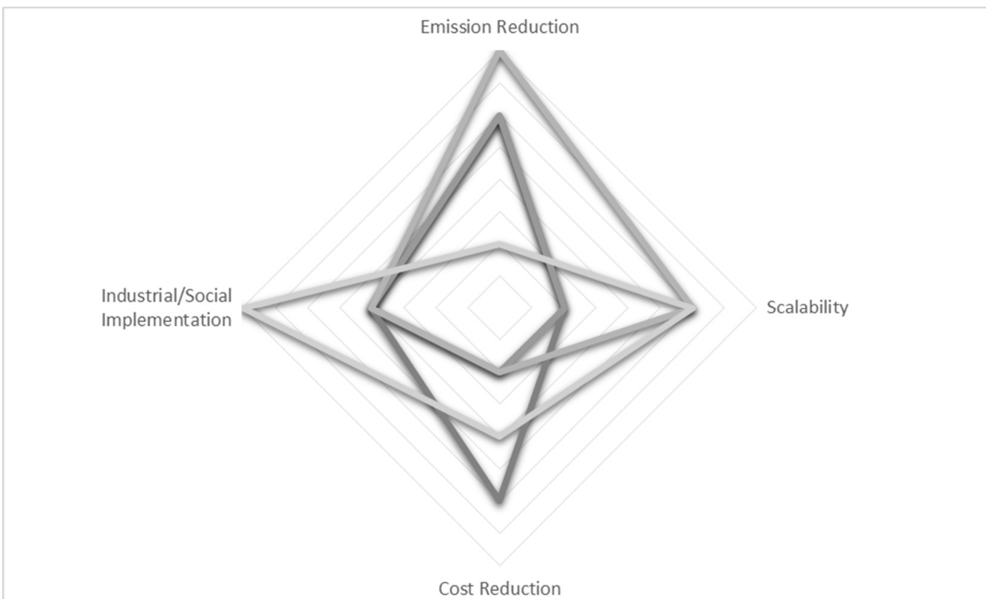

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Figure 5. Aggregate KPI ratings for CA A2

3.3 CA A3: minimization of vehicular energy demand

The Capacity Area A3 “Minimization of Vehicular Energy Demand” is focused on the supply side of vehicle efficiency, which deals with aerodynamics, rolling resistance and light-weighting materials. It is formally composed of three broad topics: “high-volume production of new light thermoplastic components” centers on materials to be used in producing light weighting materials. “Development of bio-inspired light composites” takes a more disruptive approach for producing composites by imitating nature. “Vehicular energy demand and energy flow optimization” take a systematic approach for calculating demand of a specific vehicle, by considering different engineered components, including light-weight materials.

Data gathering and analyzing results in the identification of five concepts for this CA:

i. Economic/environmental LCA of interior light-weighting material

Light weighting materials contribute to the reduction of total vehicular energy demand. However, the life-cycle assessment of their production is crucial, when total emissions and costs are considered. Therefore, Life-cycle assessment of the new products from economic and environmental aspects are done in order to investigate the production, usage and disposal of new materials. Existing processes such as Melt-RTM, thermoplastic direct impregnation and hybrid bio-component fiber production are analyzed and compared to realistic scenarios based on the data collection and analysis done by different research groups.

ii. Scaling-up part production for light-weighting material

There are different processes to speed-up or scale up part production for developing new light weighting materials. The aim of these processes is to merge high volume with light weighting and complex materials. A concept aiming to increase the performance of composites is high efficiency in-line coating. In this approach, instead of impregnating the dry fabric, a mix of the fiber and a surrounding polymer can be used, which are locally impregnated. Then there is scaling up from monofilament to fiber coating, in which fiber coating should be done in parallel. One issue with introducing the new material is the new interfaces. Fiber matrix interfaces are modified to be optimized in order to increase product performance.

There are other processes to develop new composites, for instance novel fabric architectures in cooperation with Tissa AG and 3D printing in collaboration with Solvay which facilitate permeability optimization. In order to produce composites at a higher scale, there are different traditional ways based on thermoplastic compression. To increase the scale, combination of injection molding and impregnation of fabrics with low viscosity is used. There are partners such as B-Comp to advance the outcomes in automotive applications. It uses lightweight and safe interior panels with thermoplastic fiber composites. The new parts are up 40% lighter than standard parts, without changing costs, and decrease carbon footprint by using less material, having less waste as more sustainable material.

iii. Nature-inspired composites

More disruptive approaches inspired by nature are the next generation of light weighting materials and processes. Super stiff and tough composites are composed of Nano-particles, use magnetic fields, and have very good orientation in nature, which can be imitated for these composites. The resulting materials are as tough as the traditional composites, but they are ceramics with their specific characteristics.

Cost is still not a concern, since the performance of new composites has priority over cost. Over time, LCA can be also added to the analysis, followed by scaling up and large scale structures.

iv. *Standards for composite permeability measurement*

Standards of measuring the permeability of the composites are developed and efforts are coordinated by participating in the worldwide benchmarking exercise. Different aspects such as in-plane permeability and the effect of compaction can be optimized in order to find out how composite microstructure allows speeding up of part production. So, the process for impregnation speeds up, while the performance of the system remains high, but the measurement is not yet standardized. The coordinating activity is facilitated by collaboration among different research groups.

v. *Vehicular energy demand estimation*

The central activity of this concept is modeling the real-world energy demand of on-road vehicles for both conventional and alternative propulsion systems of passenger cars. Based on the driving cycle, vehicle forces and driving situation, the end energy demand are calculated. It is shown reducing wheel-power leads to the reduction of energy demand by mass reduction, and the impact of light weighting is higher for conventional vehicles compared to battery-propulsion electric vehicles.

Based on the brief summaries of each concept, and their links to other relevant activities and applications, the solution pathways for CA A3 is depicted in figure 6.

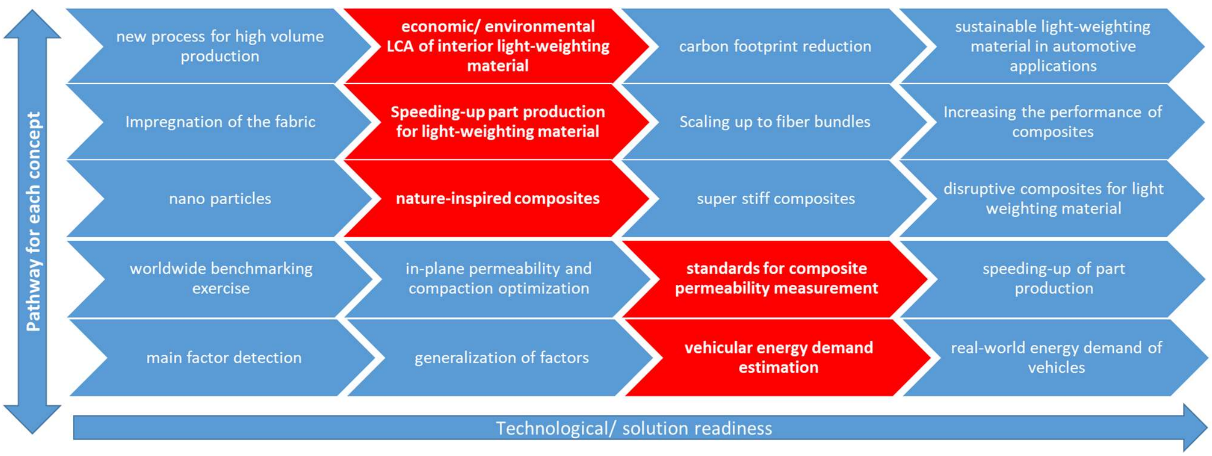

Figure 6. Solution pathways for CA A3

KPI ratings

LCA for light weighting materials facilitates emission reduction by focusing on the parts of the whole value chain, where the potentials of emission reduction are higher. Speeding-up part production is also relevant for emission reduction by contributing to the performance of light weighting materials and increasing energy efficiency. Other concepts have moderate and indirect impacts on emission reduction.

Clearly, the standardization has a high relevance for the scalability of processes for light weighting materials. The process for nature-inspired composites and the method for vehicular energy demand estimation are scalable, but the highest relevance is apparently for part production scale-up for light weighting materials.

Similar to emission reduction, LCA facilitates economic analysis of innovations at a systemic level, and identifies potentials for cost reduction in the whole value chain. Other concepts are mainly focused on basic research with low and moderate relevance for cost reduction. For scaling up of part production, cost reduction can be facilitate through scale economies.

Although LCA is not focused on technology development, and complements the analysis of the innovations, it is trying to use real data to develop realistic scenarios for environmental and economic analysis of technologies. Partnership for the standardization happens via coordinating activities, which facilitates the development of standards. Considering the general description of each concept and the relative relevance to the KPIs, table 8 summarizes the KPI ratings for this CA.

Table 8. The summary of research concepts and KPI ratings for CA A3

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Economic/ environmental LCA of interior light-weighting material	***	*	***	***
Scaling up part production for light-weighting material	***	****	**	*
Nature-inspired composites	**	***	*	**
Standards for composite permeability measurement	**	****	*	***
Vehicular energy demand estimation	**	***	**	*

The aggregate ratings for all KPIs is depicted in figure 7. This figure reveals the CA has a very high relevance for scalability, by focusing on processes to increase the speed of production and developing methods to speed up part production. Emission reduction is the KPI with relatively moderate relevance, while relatively low relevance for cost reduction and industrial/social implementation imply the nature of these concepts as basic research activities, which can include cost-related aspects and implementation in the next stages of associated projects.

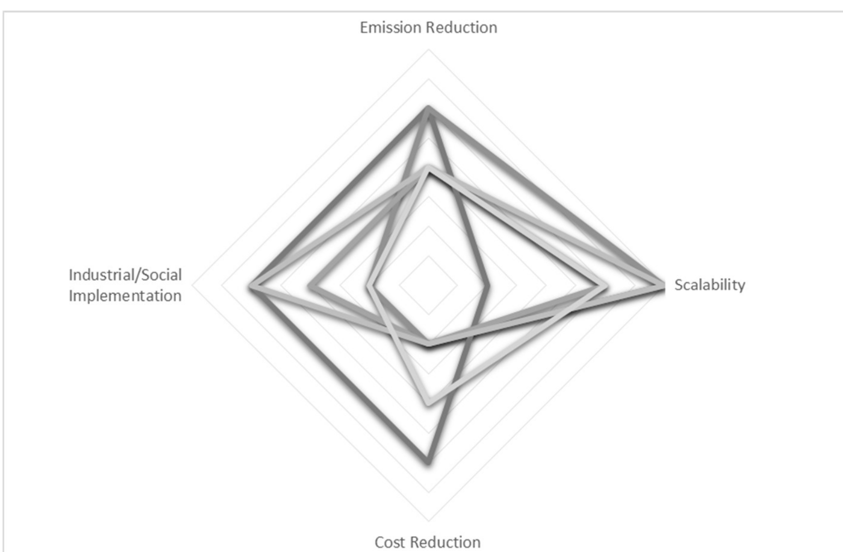

Figure 7. Aggregate KPI ratings for CA A3

3.4 CA B1: design, demonstration and dissemination of systems for sustainable mobility

The Capacity Area B1: "Design, Demonstration and Dissemination of Systems for Sustainable Mobility" is focused mainly on the demand side of the mobility system. It highlights spatial planning and IT-based communication to understand demand for services, and looks at car sharing, ride sharing, public transport, active transport and logistics as the building blocks of modal choice. Furthermore, this CA also looks at the supply side, by focusing on the infrastructure requirements for road, rail and refueling. Systems for mobility depend on user behavior, energy infrastructure, digital tools, assessment of future mobility technologies and linkages with urban planning and environment.

Design and optimization of the physical infrastructure for energy carriers (supply of charging stations, logistics, and rail technologies) is of special importance in this CA. The focus is on the rise of ICTs, implementing the use of information technologies as an enabling technology for an efficient transportation system. For this purpose, it is important to see how people actually move and what modes of transportation they use. So, a monitoring framework has been established to simulate and monitor people's spatio-temporal behavior in real time, in which the goal is to calculate and communicate energy saving options. In this respect, a need matching system is required, and the evaluation of behavioral change by considering the role of technology is the central theme.

In this respect, the CA is formally composed of three main areas of: "advanced use of ICT to optimize and change mobility behavior", "optimized infrastructure for renewable energy carriers" and "decision making tools for spatial planning". Data gathering and analyzing results in the identification of seven concepts for this CA:

i. *Energy efficiency optimization in rail operation*

In this concept, energy consumption and infrastructure usage of trains is analyzed over routes and across times. There is a 40% different in ranges between the consumption profiles; so, there is big potential to improve. One important contribution is to use on-board monitoring data, collected through sensors in pantographs and GPS systems through collaboration with SBB and BLS. By optimizing driver behavior, up to 15% energy saving can be achieved. It is already quite high, and best experimental result is 16%.

The efficiency creates cost reduction benefits for rail operators, but the impact on emission reduction can be indirect and via modal shift. This model and associated analysis are scalable to other contexts by collecting on-board data; therefore, data availability is the only limitation.

ii. GPS-based dynamic mobility pricing

The concept "GPS-based mobility pricing" combined the use of new technologies with the role of nudging. Personalization and analysis of individualized data are important in the context of the project. A survey is used to assess the acceptability of mobility pricing. Estimations are done by using MATSIM, the simulation model, and customized nudging for individuals are used to change passenger behavior. Therefore, the impact of information on behavior is analyzed.

Information about externalities and how to save money are provided to passengers. The technology tracks behavior to see how the system works, in order to see implications for congestion and emissions. Therefore, it includes dynamic pricing policies. ASTRA as a stakeholder of the research project, and the model provided by MATSIM can be scaled up for similar analyses. However, the real implementation of the model is the decision of the government to take action.

iii. Grid Impact assessment of e-mobility

In this concept, energy infrastructure optimization for e-mobility is done to help utilities use their grids more effectively, especially in the context of energy transition to renewable energy system. E-mobility is one of the challenges and the operation of the electricity grid as an expensive infrastructure needs a long planning horizon (20-40), equal to the lifetime of cables and transformers. However, the future system including e-cars is uncertain; how their charging and mobility patterns may look like, including the impact on the grid in peak times, and how to make them robust without over-investing. The goal here is to find useful upgrading strategies with targeted investments in sensors and grid reinforcement, and the integration into existing long-term grid upgrade strategy. Robustness of grid is analyzed by methods such as Monte-Carlo simulation based on grid analytics, in order to find out which factors have the highest impact. Scenarios consider different profiles for charging time, penetration rates, charging power and charger type. In this respect, the main approach performs time-series grid analysis. Measurement data comes from the grids, and the advantage is to use real data instead of very rough estimations, closer to the reality.

The method can be used for other scales and geographical areas, although it has not been implemented at large scales so far. The only limitation is data availability. From a cost-perspective, the cost of implementing this concept is only 100-1000 CHF, but the investment decisions ranges it facilitates are hundred thousand to million CHF. There is an implementation activity in the city of Winterthur for planning purposes, but the number of consulting cases is higher, to about 50 grid operators. Improving grid operation can contribute to emission reduction. Furthermore, reducing grid losses, caused by line heating, line overheating, or loss in transformer contribute to emission reduction.

iv. Optimal fleet for energy infrastructure

In this concept, the impact of optimal fleet composition for finding the bottlenecks in the energy infrastructure, provision of energy and on the patterns of energy demand are investigated. Based on one-day profile for many consumers, the charging behavior is estimated, and then it is analyzed whether the grid can satisfy the estimated demand. The results of such analysis may inform decisions on investments in new energy sources, with implications for reducing energy emissions.

This study is addressing the scale, or the resolution of the study, which starts at daily profiles for individual actors and scales up to the national level. However, little consistency exists between different databases; therefore, harmonization between different micro-census databases is a cumbersome work. In reality, utilities have no choice, but to use the results.

However, they are just reacting to changing situations. The main driver of change is deregulation which creates problems for utilities.

v. Environmental assessment of household mobility behavior

Within the context of environmental assessment for household mobility, mobility is considered as a consumable good. There are three different models for such an assessment. Building energy models is a physically based model, consumption model as a data-driven model and the mobility model which uses the MATSIM results. In the mobility model, travel behavior as a household consumption input is used in MATSIM, the simulation tool, to provide an incentive system in order to change household behavior and reduce environmental impact. Then, scaling is done according to population forecast.

From a technical perspective, environmental profiles are used in a bottom-up approach for the quantification of the impacts. Then, causal relationships of consumption areas and mobility is used to understand contribution to footprint, and the role of household income. Based on the analysis, mobility and housing consumption increases with decreasing urban density. Other factors with impact in relation to mobility are higher income, which has a higher impact on mobility, demographic factors and accessibility issues.

vi. Green mobility as a service

The concept of “green mobility as a service”, materialized in the project “SBB Green Class”, includes two mobility as service offers, and through an app people – 150 participants of the study - generate a lot of GPS tracks and mobility patterns. The original idea was to add personalization and individualized offers to behavioral change, and to analyze if green mobility as a service is a viable concept, and whether it can contribute to emission reduction. Besides, it considers if people would accept such an offer with the payment model included in the offer. E-cars and e-bikes were the alternative and based on the results, e-car can become part of the mobility mix in the long term. Furthermore, new mobility options can reduce CO2 emissions. In addition, e-bikes and trains combination really struggle to replace individual cars, and emission reductions are unstable, since total emissions are a bit reduced, but not in the same level as e-cars.

vii. Spatial planning for environmental impact of urban mobility

This concept aims to optimize urban mobility by spatial planning and including environmental performance. Spatial planning has impacts on the whole system components of urban transportation, including environmental impacts. The interface of users, technologies and infrastructure is analyzed in order to link mobility patterns with urban planning and environmental data. In this respect, the impact of urban structure and planning on urban mobility is investigated to find the drivers of mobility demand, with a focus on Swiss municipalities.

By optimizing urban mobility, the efficiency of urban mobility patterns increases, which leads to reducing energy demand and emissions. Although the impact on cost is unclear, there are lots of partners, including municipalities to implement the solutions, and the method is scalable to larger regions.

viii. Nudging passenger behavior for emission reduction

This concept, materialized in the Bellidea and GoEco projects (where the former is the successor of the latter) is shared between the CAs B1 and B2; therefore, it appears in both CA descriptions. It aims to analyze how people move and choose transport modes, and develops apps for recommending transport modes for changing mobility behavior. The app tries to detect transport modes and include advanced social interactions, persuasive factors and extrinsic motivation elements; then the barriers to large scale deployment are analyzed. Therefore, technology is used for calculating and communicating saving options to passengers in order to reduce emissions. It is done via the app that recommends the passengers the modes of transport and provides feedback. It has a gamification framework which aims to change long-term behaviors from using private cars to public transport. It calculates and communicates the energy saving option; thus nudges passenger behavior for emission reduction.

The main underlying logic is that technology is not sufficient. There are barriers, for instance how people can be nudged, in different modes, and based on vehicle types, powertrains, etc. Impact on emission reduction is part of the objective, and the solution has been implemented in some cities in the Cantons of Zurich and Ticino.

Based on the brief summaries of each concept, and their links to other relevant activities and applications, the solution pathways for CA B1 is depicted in figure 8.

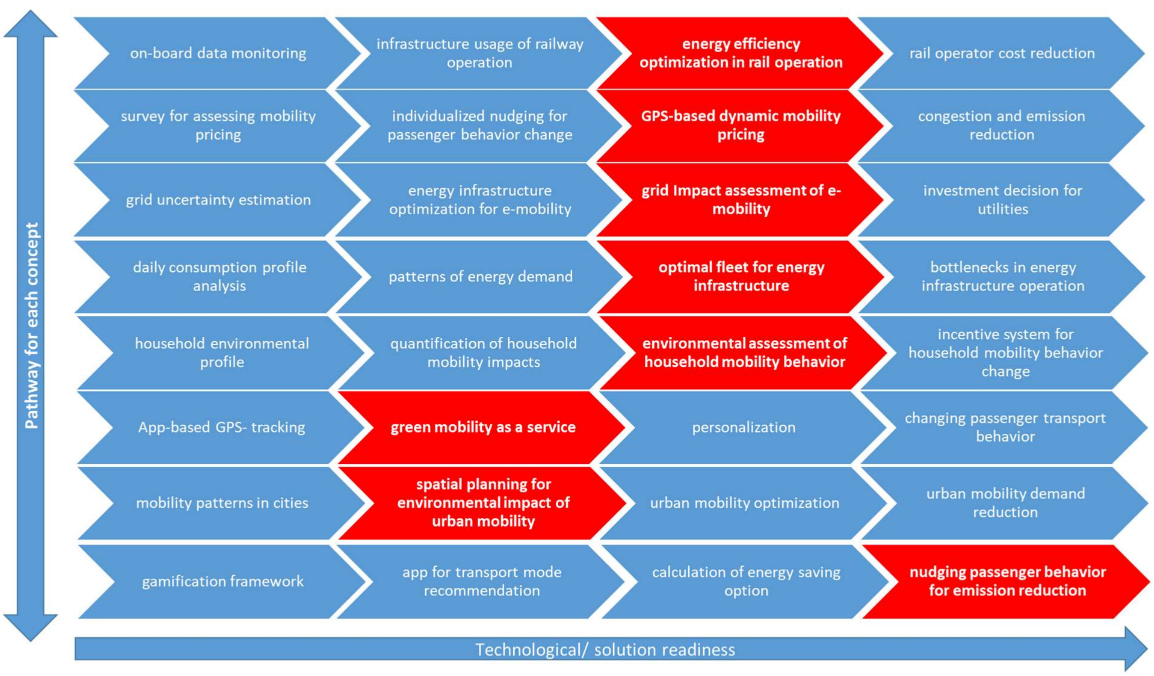

Figure 8. Solution pathways for the CA B1

KPI ratings

Using technology to change mobility behavior has clear contributions to emission reduction. Environmental assessment of household mobility behavior, green mobility as a service, and spatial planning for environmental impact of urban mobility have an important environmental component, which highlights emission reduction as an important objective in these concepts. GPS-based dynamic mobility pricing and grid impact assessment, have a relatively high relevance for emission reduction, although the main focus is on financial issues.

Scalability has a special situation in this CA, since there are methods and solutions that can be easily scaled up to broader areas or other sectors, depending on data availability, but it does not imply such a scaling-up has happened yet to check for requirements. Environmental assessment of household mobility behavior, GPS-based pricing and grid impact assessment have this characteristic, while calculating optimal fleet for energy infrastructure takes a bottom up approach, which is scalable, but with increasing level of complexity.

Cost reduction is an important indicator in three projects with focus on economic aspects, as energy efficiency optimization in rail operations, GPS-based dynamic pricing and grid impact assessment of e-mobility. Optimal fleet for energy infrastructure has a relatively high relevance for cost reduction as well, since it has implications for investment decisions on new energy sources.

In this CA, implementation has a substantial relevance at the social level, where apps and solutions are used by participants, especially in the green mobility project, as well as GPS-based pricing and environmental assessment of household mobility behavior. Other concepts such as spatial planning for urban mobility and energy efficiency optimization in rail operation have industrial partners that use the solutions for decision making

Combining the general description of each concept with the relative relevance to the KPIs, leads to a rating table, as depicted below (table 9).

Table 9. The summary of research concepts and KPI ratings for CA B1

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Energy efficiency optimization in rail operation	**	**	****	***
GPS-based dynamic mobility pricing	***	***	****	**
Grid Impact assessment of e-mobility	***	**	****	***
Optimal fleet for energy infrastructure	**	***	***	*
Environmental assessment of household mobility behavior	****	***	*	**
Green mobility as a service	****	*	**	***
Spatial planning for environmental impact of urban mobility	****	***	**	***
Nudging passenger behavior for emission reduction	****	**	*	***

The aggregate ratings for all KPIs is depicted in figure 9. This figure shows the CA has high relevance for emission and cost reductions, by trying to change mobility behavior towards decarbonizing mobility, while cost is an important incentive. Scalability and industrial/social implementation have moderate relevance, since these activities need decision making at other levels in order to be integrated with existing solutions or by incumbent firms. Implementation in other geographical areas, which is a visible application due to the nature of the projects, depends on governmental or business decision in those areas.

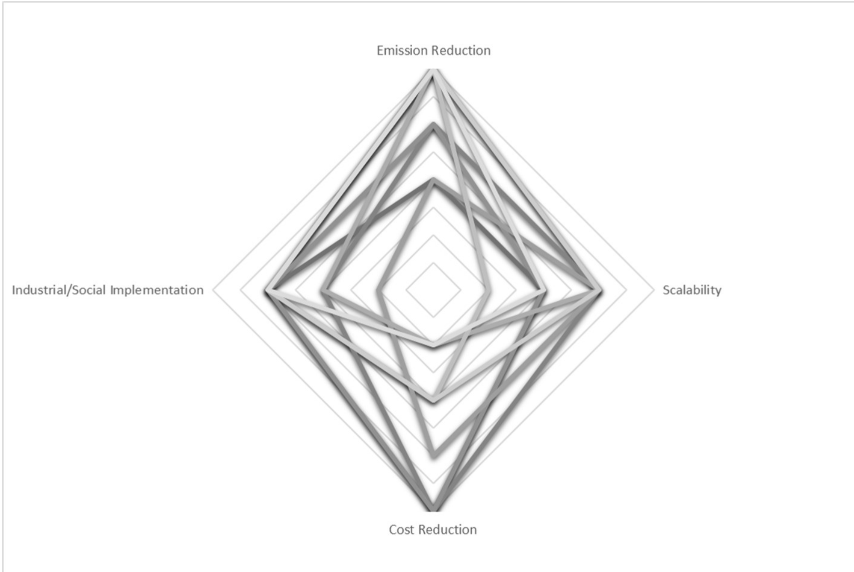

Figure 9. Aggregate KPI ratings for CA B1

3.5 CA B2: integrated assessment of mobility systems

The Capacity Area B2: "Integrated Assessment of Mobility Systems" started by focusing on the supply side of the mobility system and tried to cover all kinds of technologies, fuels and vehicles. Gradually, it also focused on the demand side, which needs to be integrated in a holistic approach by taking into account different dimensions of sustainability, including the economic, environmental and social aspects. Moreover, there are macroeconomic factors which are exogenous. It is formally composed of three main subjects. "Reducing or shifting mobility demand", looks at the socio-economic aspects, system transformation, investment decision processes and nudging behavioral change. In "integrated energy-mobility scenarios", the whole mobility system is analyzed by using big optimization models with full sector coupling. Finally, "assesses the future mobility technologies" takes an interdisciplinary approach sustainability analysis and assessment of risks, costs and environmental aspects.

Data gathering and analyzing results in the identification of five concepts for this CA:

ix. Lifestyle analysis for changing mobility demand

One aspect of reducing or shifting the mobility demand is lifestyle analysis. The logic behind this concept is that different lifestyles, attitudes and knowledge might have different impacts on the adoption of new mobility technologies and services. Furthermore, potential changes to mobility lifestyles in future have implications for mobility demands and services. In this concept, surveys are used to collect data on patterns of commuting to work, leisure trips for short and long distances, etc. Lifestyle analysis is based on an established questionnaire which results in the generation of nine different lifestyles. Based on the analysis, it is aimed to see whether some of the lifestyles are open to use sustainable modes, for instance public transport. Then, by trend analysis it is inferred which ones will grow and how they influence transformation to sustainable mobility system. The main applications can be for policy and social campaigns.

x. Mobility sharing for changing mobility demand

An important concept for changing demand is mobility sharing. For this concept, the impacts of electric or conventional car sharing on mobility is investigated by top-down segmentation. The aim of segmentation is to have groups with similar characteristics to be targeted, in order to test a switch or adopt strategy for behavioral change. Data is based on literature, which shows differences between categories. Then, sequential choice survey is used to see the differences within household groups.

The main application is for policy maker and decision makers in the mobility sector, as well as in cantons, in order to develop plans to accelerate the shift towards mobility sharing. This shift has implications for electrification, since switch can happen to small electric cars. It also creates financial benefits, and those whom are more willing and open to buy, are targeted to be offered by packages that can lower cost over time.

xi. Nudging to change fuel-efficient car purchasing behavior

In this concept, again nudging techniques are applied to promote purchasing fuel-efficient cars. Convergence of e-mobility and distributed renewable energy generation and storage are analyzed as “disruptive decentralization” by looking at the consumer and investor acceptance of electric mobility. Current trend is in favor of electric mobility. There are cheaper batteries, extension of battery range, which means higher capacity. It means technological barriers are decreasing and at the same time customer preference towards buying EVs is increasing. Therefore, looking at the socio-economic behavior of the adopters is important. For instance, the role that the sellers have in shaping the purchasing process of customers and the touchpoints through which EV purchases can be motivated.

There is collaboration from people using solar photovoltaics by using a survey, since they are assumed to have a likely tendency to switch to e-mobility. The analysis shows there are lots of complexity in the purchasing process, composed of five decision points as different stages, and five touchpoints, which together shape a new model for the purchase process which highlights the importance of car dealers in the process. To change the behavior of these PV owners, solutions are bundled and offered to them, including insurance, certificate of green electricity, etc. Collaboration with a utility company is part of analysis for pretesting the bundling offer collaboration. However, car dealers are still not motivated by the offer.

xii. Performance assessment of future car technologies

In this concept, indicators for technology assessment are developed in order to model the whole system and life-cycle assessment of technology. It provides basis for scenario development and assessing the future performance of technologies. External costs are assessed through modeling for all transport modes. In the central part of the model, the location and movement of cars are taken into account. First, the direct emissions are calculated, followed by emissions from the supply chain for life-cycle analysis. Then, the dispersion of physical and chemical reactions are investigated, for instance by analyzing the change of pollutants, concentrations and temperatures. The impact of these dispersions on human health, crop yields, buildings, land and ecosystem are analyzed; and finally external and monetary costs are calculated.

Apart from looking at the environmental dimension, other pillars of sustainability can be evaluated through sustainability indicators, and multi-criteria decision making tools are developed. These pillars include environment, economy, society and utility. Weights are given to the indicators and then different externalities are quantified. Based on the results, different alternative powertrain technologies can be compared to make decisions. In general, assessment is done for Greenhouse gas emissions, non-renewable energy use and life-time ownership costs. The results can be scaled up to other levels, and provide basis for decision making.

xiii. Nudging passenger behavior for emission reduction

This concept, materialized in the Bellidea and GoEco projects (where the former is the successor of the latter) is shared between the CAs B1 and B2; therefore, it appears in both CA descriptions. It aims to analyze how people move and choose transport modes, and develops apps for recommending transport modes for changing mobility behavior. The app tries to detect transport modes and include advanced social interactions, persuasive factors and extrinsic motivation elements; then the barriers to large scale deployment are analyzed. Therefore, technology is used for calculating and communicating saving options to passengers in order to reduce emissions. It is done via the app that recommends the passengers the modes of transport and provides feedback. It has a gamification framework which aims to change long-term behaviors from using private cars to public transport. It calculates and communicates the energy saving option; thus nudges passenger behavior for emission reduction.

The main underlying logic is that technology is not sufficient. There are barriers, for instance how people can be nudged, in different modes, and based on vehicle types, powertrains, etc. Impact on emission reduction is part of the objective, and the solution has been implemented in some cities in the Cantons of Zurich and Ticino.

Based on the brief summaries of each concept, and their links to other relevant activities and applications, the solution pathways for CA B2 is depicted in figure 10.

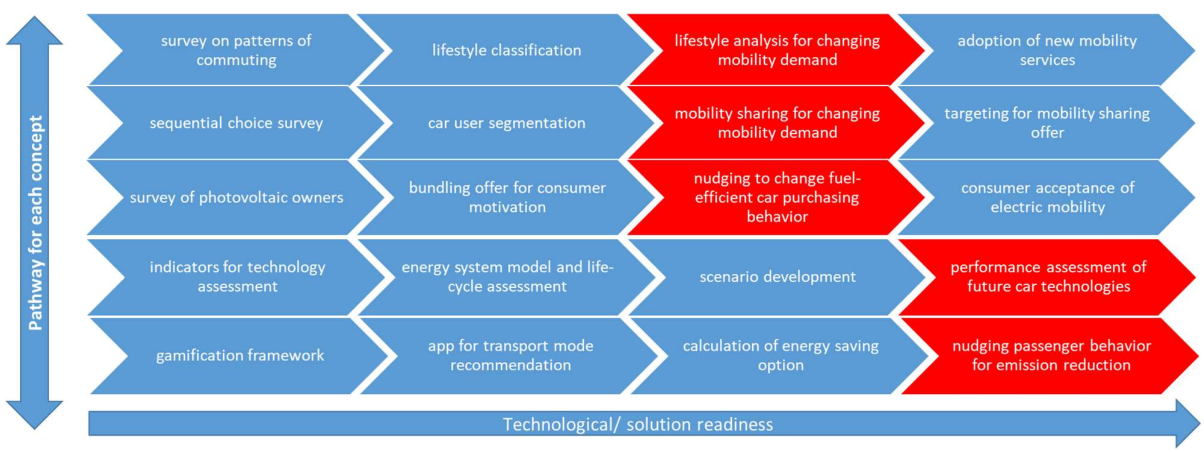

Figure 10. Solution pathways for CA B2

Impact on KPIs

Emission reduction is at the center of research activities and concepts of this CA. It is present in life-cycle analysis and performance assessment of future technologies, as systemic methods, to nudging techniques for changing mobility behavior and mobility sharing as a new solution. Therefore, all concepts have a high relevance to this indicator.

On the other side, due to the nature of these projects and the locality of concepts, both scalability and industrial/social implementation are either not applicable, or have a low relevance. Systemic tools have some degree of scalability, but they have lots of details, customized for the regions under study. Regarding implementation, nudging passenger behavior or emission reduction is the sole concept with implementation at the social layer.

From the cost perspective, performance assessment of future technologies considers cost as an important indicator for future. Nudging for purchasing behavior has implications for cost reduction, while mobility sharing and life-cycle analysis for changing mobility demand have moderate relevance to the cost reduction indicator.

Combining the general description of each concept with the relative relevance to the KPIs, leads to a rating table, as depicted below (table 10).

Table 10. The symmary of research concepts and KPI ratings for CA B2

Concept	Emission Reduction	Scalability	Cost Reduction	Industrial/Social Implementation
Lifestyle analysis for changing mobility demand	***	**	**	*
Mobility sharing for changing mobility demand	***	*	**	*
Nudging to change fuel-efficient car purchasing behavior	****	*	***	*
Performance assessment of future car technologies	****	**	****	*
Nudging passenger behavior for emission reduction	****	**	*	***

The aggregate ratings for all KPIs is depicted in figure 11. It is clear the CA has high relevance for emission reductions, and relatively high relevance for cost reduction, since emission reduction is part of the objectives of most of the projects, while cost is an important factor. On the other side, scalability has moderate relevance, since there is a very high level of locality in the design and customization of methods and processes, which creates lots of details to be changed in order to implement solutions at other scales or areas. Industrial/social implementation is the indicator with the lowest ratings, which partially reflects the nature of concepts in this CA, dealing with assessment of other activities or developing nudging techniques that need decision making by external authorities for real world implementation.

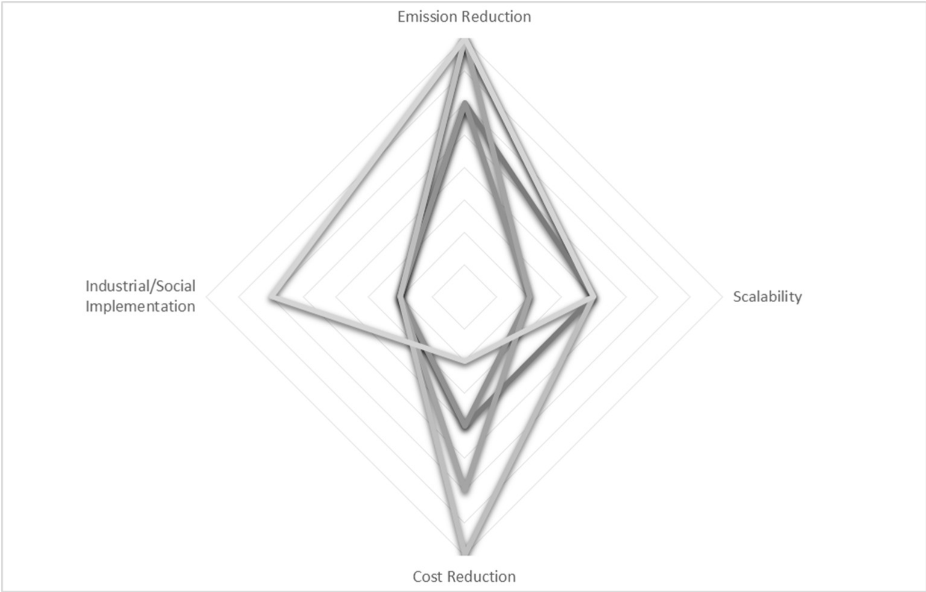

Figure 11. Aggregate results for CA B2

4 Clustering by similarity

As a complementary analysis, it can be inferred how different concepts might be clustered based on their relevance for the KPIs and the formal classification of research activities (being part of a specific CA). For this purpose, a network of concepts is constructed, where each node represents a concept and the links between each pair of node represents the degree of similarity between them. Of course in this situation, all nodes can be connected to each other and the network would be complete; but the weight of links are different, and clusters emerge while increasing the threshold to keep the links with a weight higher than the chosen threshold.

For the purpose of this research, the chosen clustering algorithm uses the concept of cosine similarity, as a measure of similarity between each pair of concepts. The algorithm was implemented at three levels for a robust analysis:

- Based on KPI ratings only
- Based on KPI ratings and CA groups (A or B)
- Based on KPI ratings, CA groups (A or B) and CAs (A1, A2, A3, B1, B2)

For each level, a network of similarities was constructed. By keeping the highest 20% of similarities, the clusters of concepts for each network were identified. Comparing the results of all three networks, resulted in the identification of four clusters. A brief summary of results follows.

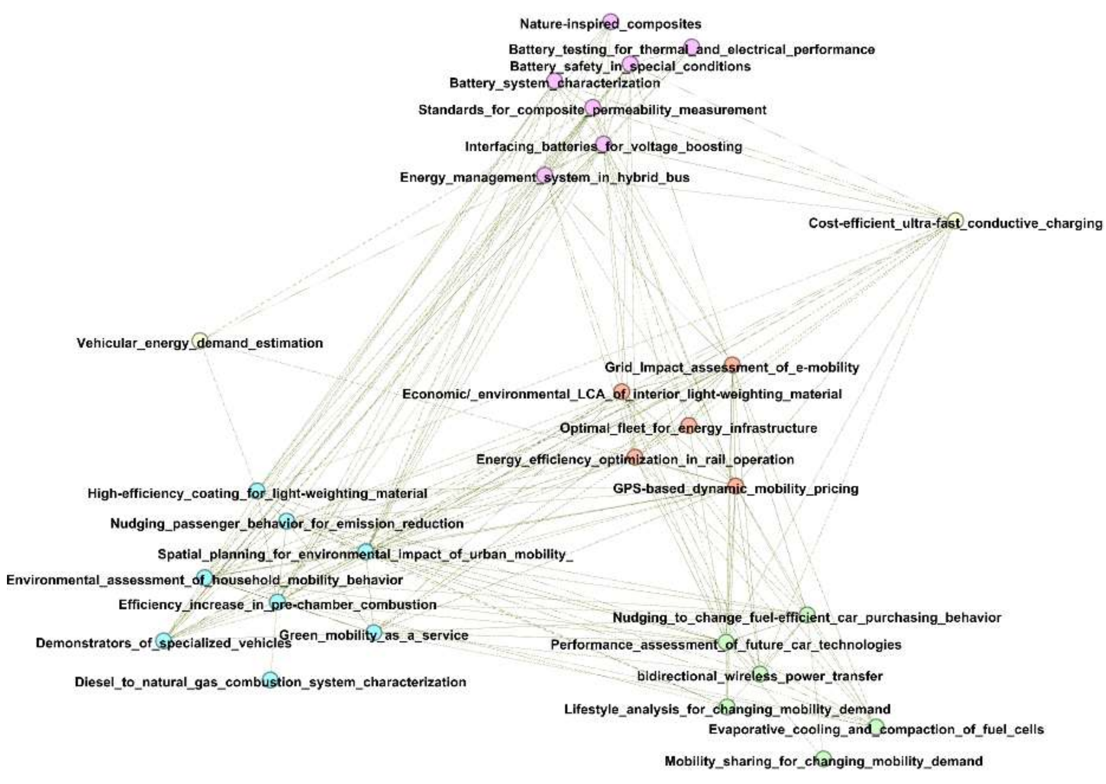

Figure 12. Four clusters of concepts within SCCER Mobility network

Figure 12 shows the network of clusters constructed based on the cosine similarity and after keeping the highest 20% of similarities. Visualization was done in Gephi, a Social Network Analysis (SNA) software. Based on the clustering algorithm and results for three networks, two nodes could not be allocated to any of these four clusters.

A summary of each cluster and their specific characteristics are presented below.

Cluster1: decarbonization in a testbed
This cluster is mainly composed of technological and social innovations as niches, with the aim of reducing emissions, without putting special focus business and technical limitations at the moment and within the project boundaries. Therefore, it is characterized by 'high emission reduction', 'low scalability' and 'low industrial/social implementation'. In includes six nodes of:

- Bidirectional wireless power transfer
- Evaporative cooling and compaction of fuel cells
- Lifestyle analysis for changing mobility demand
- Mobility sharing for changing mobility demand
- Nudging to change fuel-efficient car purchasing behavior
- Performance assessment of future car technologies

Cluster 2: cost matters!
The second cluster takes a systemic view to the cost structure of a specific technological or social innovation. At the technical level, system optimization and life cycle assessment help to reduce costs, while at the social level, socio-economic factor for reducing costs are investigated. In this respect, the 'cost reduction' indicator is the central factor in this cluster. Five nodes constitute this cluster as:

- Economic/ environmental LCA of interior light-weighting material
- Energy efficiency optimization in rail operation
- GPS-based dynamic mobility pricing
- Grid Impact assessment of e-mobility
- Optimal fleet for energy infrastructure

Cluster 3: Green innovation first, then cost!
This cluster includes a broad set of technical and social innovations, which can be characterized by high relevance to "emission reduction", but low relevance to "cost reduction" indicators. It means from a social perspective, there are activities with the aim of social and behavioral change in order to reduce emissions, but cost is not a factor within the context of research activities. From a technical perspective, the new technologies have clear

contributions to emission reduction, but cost is not a concern, which naturally means new technology is more expensive than the existing ones. It includes eight concepts of:

- Demonstrators of specialized vehicles
- Diesel to natural gas combustion system characterization
- Efficiency increase in pre-chamber combustion
- Environmental assessment of household mobility behavior
- Green mobility as a service
- High-efficiency coating for light-weighting material
- Nudging passenger behavior for emission reduction
- Spatial planning for environmental impact of urban mobility

Cluster 4: Even more technology!

The last cluster is composed of concepts that are part of the 'A' capacity areas. They are mainly focused on the business and technical aspects of new technology development, formalized as high "scalability", and high "industrial/social implementation"; but interestingly, "emission reduction" indicator has a low score here. Advances in systems that are either already decarbonized to some extent, or the size of the market is very small, partially explains the reason for low emission reduction potential. This cluster includes seven concepts of:

- Battery safety in special conditions
- Battery system characterization
- Battery testing for thermal and electrical performance
- Energy management system in hybrid bus
- Interfacing batteries for voltage boosting
- Nature-inspired composites
- Standards for composite permeability measurement

5 Conclusion

This research project tried to take a bottom-up approach for analyzing the relevance of research topics across SCCER Mobility for the selected KPIs of a sustainable mobility system in Switzerland. Such an analysis needs a generic method to be useful and applicable for analyzing a broad set of research activities ranging from basic scientific research to applied social research. It creates difficulties and limitations for comparing activities, and developing metrics for putting all concepts and outcomes at the same level of observation. Apart from this limitation, the relative KPI ratings and clustering analysis can provide insights on the overall picture of SCCER Mobility activities, which can be beneficial for future planning and organization of similar research initiatives.

For instance, although decarbonization of mobility system is an overarching objective of SCCER Mobility, decarbonization potentials can be inferred to be very different across the emerging clusters. Furthermore, cost reduction is an indicator that naturally is not very applicable for research activities focusing on the development of new technologies at a very early stage. At the same time, analyzing cost factors needs the inclusion of research activities focused on business models and cases for the compensation of investments and the allocation of costs among involved beneficiaries and stakeholders, by designing policies or developing business models. It seems the existing portfolio of research groups are mainly focused on technology development and engineering side of the innovation system, which needs complementary topics from research on the managerial and economic aspects of developing technologies, for a more systemic analysis.

Finally, such research projects in future can be done in parallel to the development of research concepts and projects, as a continuous work, in order to have a more systemic perspective over time on the emerging and changing directions of research. Such a parallel analysis can also provide potentials to use on-going results for steering the emerging research directions.

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