The Centre for ECO^2 Vehicle Design

Operational Plan for 2024-2029

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1. Introduction

Building upon our successes

The Centre for ECO^2 Vehicle Design (referred to simply as ECO2) has been part of Vinnova's competence centre programmes since 2006, representing a significant success for all the partners involved. 20 doctoral, 10 postdoc and numerous smaller (i.e., SME, master's and senior) projects have been created and completed within the centre. In competition with other research centres, ECO2 has twice successfully re-applied for funding from Vinnova with the latest period starting in 2017.

Since 2017 alone, the centre's researchers have published more than 150 peer-reviewed journal articles and well over 100 conference papers. Each of ECO2's projects has contributed to increasing the knowledge base for dealing with functional conflicts in vehicle design. In addition to the students or researchers directly involved, these ECO2 projects have also engaged many more people within the centre's partners in discussions leading to a shared development and mutual benefits. For example, ECO2 educates engineers with relevant multidisciplinary skills, many of whom become employed at ECO2's industry partners and disseminate their knowledge and skills to others beyond those directly involved in a project.

In mid-2024, ECO2's participation in the current Vinnova Competence Centre programme will come to its completion. On the one hand, this is challenging for ECO2 as Vinnova's part-funding of the centre has amounted to 25% of the total budget since 2017 and the centre's identity has been built-up as a "Vinnova centre". On the other hand, it also provides an opportunity for the centre to re-establish itself independently, as a step towards securing new long-term external funding. While the Vinnova programmes have been central to building up a shared identity and a *partnership capital*, they have also been challenging in themselves as ECO2 has needed to react to changes over Vinnova's many evaluation cycles to remain competitive against other centres, which operated in different sectors with different prerequisites. Moving forward, much of the benefits of ECO2's established working partnership remain, including some external part-funding sources, so there exists a strong base to build upon as the partners see fit.

In this document, the plan for how ECO2 will operate in the coming five-year period is outlined.

1.1. Improving vehicles

An important area

The vehicle industry over many decades has been adept at continuously improving vehicles to best meet the customers' needs. However, the context for these improvements have expanded in recent years with greater emphasis on the transition to sustainable transport. This means that improved transport solutions must provide *mobility in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing emissions, such as carbon, and other environmental impacts across the full life cycle*. This expanded context for vehicle design goes beyond customer needs and means engineers must consider vehicles as part of wider systems.

Much of the attention around improving vehicles is often focussed on core technology developments, for example, silicon-carbide-based electric motors which are smaller and reduce losses; lightweight materials require less energy to move; the availability of more data and computational resources to optimise the design; and new battery chemistries that have a higher energy density. These are examples of how technology development and disruptions can, no doubt, provide opportunities to transition the transport system to a sustainable state. However, to effectively utilise such technologies and create sustainable solutions, there are many conflicting interdependencies that arise when integrating them in established systems, which must be resolved. With batteries for example, the challenges around using them include life-cycle and supply-chain considerations, but also how properties such as the battery mass connects to vehicle's engineering performance attributes. Here, importantly, batteries not only are an energy source; they also demand energy to move them as part of the vehicle and as such are interdependent with energy losses of the vehicle. More specifically, batteries have an energy density much lower than current hydrocarbon fuels (roughly 40 times lower), so batteries directly impact on rolling and acceleration resistance losses (via mass), and transport capacity (via volume). This also significantly changes wider design considerations in these areas as battery-related losses place a significantly new and altered premium on some considerations over others, such as the need to reduce rolling resistance in tyres becomes more important. Integration of new technologies and the resolution of such trade-offs or functional conflicts is essential to improving vehicles within a sustainable transport context.

While it is possible for engineers within a single discipline to improve an isolated technology (e.g., improving battery energy density), the complex and interdependent problems that arise out of sustainability motivations are often inherently multidisciplinary. This means balancing trade-offs between different considerations and finding more globally optimal solutions. However, existing models and methods are often mono-disciplinary and not readily compatible with models from other disciplines. For example, the timescales involved in heat and flow simulations for motion-cooling applications are quite different making combining them in a concurrent simulation challenging; and this is before differences in life-cycle timescales are considered. New multidisciplinary approaches, in terms of models, methods and competences, are needed that go beyond advancements within disciplinary and organizational silos.

1.2. ECO2's vision

What ECO2 contributes

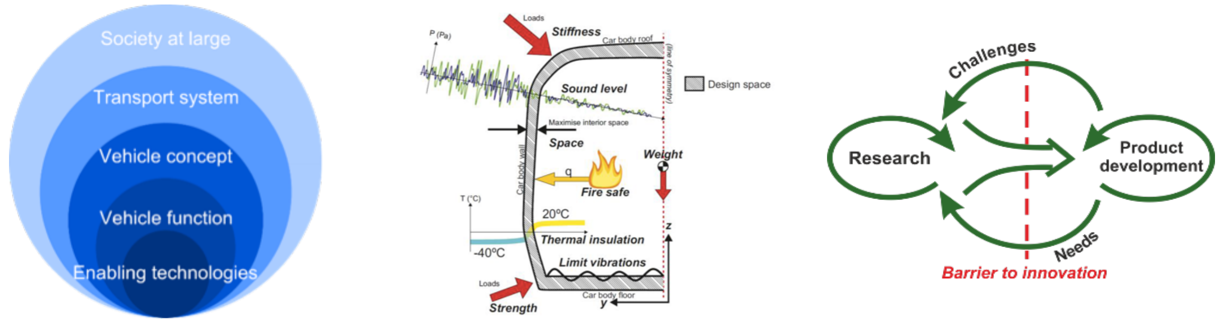
ECO2 is the foremost competence centre addressing the challenge of improving vehicles towards sustainable transport in terms of jointly building *competence,* developing *methods,* and creating *knowledge* needed by our partners and the sector. For example, Scania are now on their third generation of ECO2 PhD competences, with previous and current students jointly building upon earlier efforts. Similarly, the knowledge developed in ECO2 enabled, for example, Alstom (formerly Bombardier) to design lightweight railcar bodies earlier than competitors. The centre has also acted as a unique forum for stakeholders in the wider Swedish-based vehicle industry to collaborate, including even competitors like AB Volvo and Scania and to find synergies across vehicle types.

Moving forward into 2024 and beyond, our ambition is to build upon what we have achieved so far. This means that much of focus and organisation will remain the same, while some aspects are developed and improved. Our activities will still focus on the design of vehicles that provide better mobility for resources they consume, while producing fewer negative impacts – this is at the heart of vision.

Our vision in ECO2 is to drive resource efficient vehicles for sustainable transport.

We mean this vision both in the sense that we want our activities to be a driving force for research efforts in Sweden and beyond, and that we want our efforts to significantly contribute to the realisation of this top-level goal. We want to continue to be a research environment where Swedish academia and vehicle manufacturers work together to create the competence, methods and knowledge needed by our partners.

To do this we also intend to continue with our three over-arching strategies, which align with the needs for improved vehicles (see Section 1.1) and having proved successful over the years. These are to *support a cross-scalar perspective*, to *tackle multifunctional conflicts* and to *promote cross-fertilisation of ideas* – as illustrated in Figure 1.



A cross-scalar perspective *Multifunctional conflicts* *Cross-fertilisation of ideas*

Figure 1: ECO2's strategies.

The cross-scalar perspective means that we view technology development and the improvement of vehicles in a wider context. At the same time as working towards society's need for sustainable transport, we recognize that the devil is in the detail and the engineering knowledge, methods and competence must but developed. So, when developing and integrating technology we must alternate between top-down (analytical) and bottom-up (synthesis) perspectives.

The multifunctional conflicts means that as we seek to improve the resource efficiency of vehicles we realise that one change can lead to another because of interdependencies, and trade-offs must be resolved for overall improvement. Rather than trying to isolate functions, we embrace the conflict and see resolving multifunctional conflicts as a means to achieving improvement and innovation.

The cross-fertilisation of ideas means that we have a mind-set to go across organisational and disciplinary silos when seeking improvements. In addition to creating benefits for the individuals and partner organisations, we see our collaboration as a way to jointly contribute to shared challenges.

1.3. Connecting the pieces

ECO2's role in the eco-system

The eco-system of ECO2, illustrated in Figure 2, is a dynamic network structure involving research formations both on national and international level, education, funders, industry, authorities, and research institutes. The broad and dynamic ecosystem of ECO2 create broad-based interactions which offers individual partners to generate more added value to be part of ECO2 than performing research and development on individual basis.

Figure 2: ECO2's eco-system — collaborating towards future resource efficient vehicles.

2. Research Focus

Over the years, ECO2 has prided itself as a centre that not only creates a discussion forum but more significantly undertakes its own unique research. This has been thanks to our shared vision and strategies, but also to the precepts that our research should be multidisciplinary, applicable to different vehicle types and of interest to multiple partners. This latter point also implies that the research we undertake in the centre is precompetitive (*not today's problems but tomorrow's solutions*) and so allows competing industry partners (i.e., Scania and Volvo trucks) to collaborate and share within the context of the centre. These precepts will be continued in the coming period. However, the research content will be developed to focus on main areas of interest for the partners that contribute to our vision.

2.1. Motion, construction, and surroundings

Towards resource efficient vehicles

Resource efficient vehicles for sustainable transport is a multi-dimensional challenge. Vehicles use resources such as energy and materials, and, in addition to providing beneficial mobility, they result in negative impacts such as material waste, airborne emissions, and noise. Essentially vehicles need to provide better mobility for resources they consume, while producing fewer negative impacts. To do this the *knowledge*, *methods*, and *competence* that we develop in ECO2 will be channelled primarily towards improving these areas. This is illustrated in Figure 3, where the development of, for example, models for real-world rolling resistance are applied to vehicle design for efficient vehicle motion; physics-based residual useful life of materials are applied to vehicle design for circular vehicle construction; and equivalent representative noise sources are applied to balancing vehicle-to-surroundings interactions. This work will also make use of enabling technology development in, for example, machine learning. These topics will be the core of ECO2's research focus.

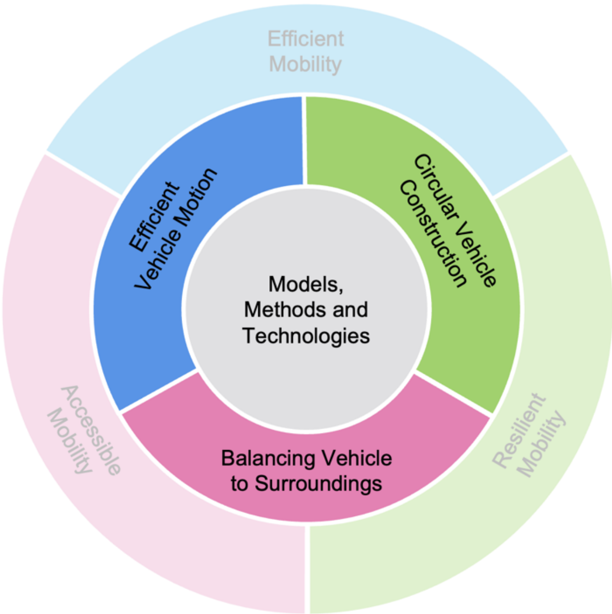


Figure 3: ECO2's research focus channels development of core multifunctional models and methods into vehicle design for efficient vehicle motion, circular vehicle construction and vehicle to surroundings.

The core topics also interconnect with higher level dimensions of sustainable transport such as efficient, accessible, and resilient mobility, also included in Figure 3 as the wider context. For example, circular materials use is a key component of securing future access to materials and retaining the competitiveness of the automotive industry. So, while the centre's research may not directly address questions of resilience, our work will contribute to and interact with these topics. It will be similar for other higher-level considerations with, for example, access to urban streets due to noise and particulate emissions, and overall efficiency demands for transitioning to electro-mobility. So future projects will span across these dimensions while retaining a core technology and engineering focus.

2.2. Leveraging previous and ongoing research

Maintain activities within a beneficial environment.

Some projects initiated in the 2017-present period will continue into the new phase. These projects are summarised in Table 1. It is important that the researchers involved can continue to benefit from the ECO2 collaborative environment through to their completion, and that the results are disseminated effectively amongst the ECO2 partners. These projects also add to a long list of successfully completed projects within the centre, summarized in the illustration in Figure 4.

Table 1: Summary of ongoing projects going into new period.

Project	2024				2025				2026				2027			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Motion cueing in driving simulators (HV)																
Vehicle conceptualisation and subsystem interaction (SKA)																
Autonomous driving and motion sickness (IY)																
Rolling resistance and optimisation of vehicle-road interaction (LY)																
Noise-exposure mapping from road traffic (SB)																
Zero emission off-peak urban deliveries (SV)																
Optimal vehicle design for sustainable services (RA)																

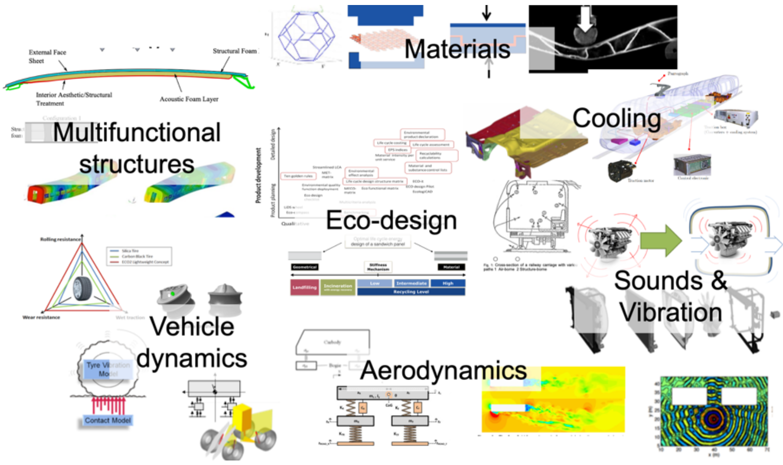


Figure 4: Summary illustration of completed PhD and postdoc projects within ECO2 grouped to show some of the core competences within centre.

These projects not only illustrate the successful results of the centre in the past, but also the competence that has been built up since 2006 by assembling core competence groups from the partners and is the foundation for future activities. In other words, these are the areas that the centre has excelled within and remain the core groupings as we shape the future topics.

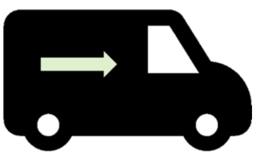
It also represents the combined investments of the partners over the years and is indicative of the built-up *capital* within the centre in terms of knowledge and people involved. For example, we have many previous ECO2 doctoral students who now work at industry partners and are involved in projects and supervision of current doctoral students. When defining new projects for the coming period of ECO2, it is important to see that this capital is leveraged effectively, at the same time as renewing and developing new areas of interest. We should build upon our heritage.

2.3. New projects areas

Joint interest and centre projects

The definition of each new project for the coming period goes beyond the scope of this operational plan. It is part of the process of the coming period, which is discussed more in Section 3. However, here we give illustrative example of the content of the project areas in the coming period, which will be complemented with others as they emerge. The intention is to initiate a number of complementary projects in each area.

Area 1: *Go further* – Efficient Vehicle Motion



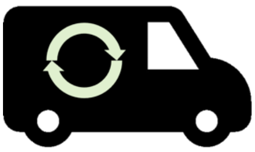
Vehicles consume energy during use, primarily to provide motion, but also for heating/cooling, infotainment, and driver assistance. In this area the research focusses on how motion can be provided as efficiently as possible.

This area includes topics such as:

- **Real-world rolling resistance**. Rolling resistance is one of the main consumers of energy in vehicles and so has a direct influence on the range. Today, tyres are rated in terms of rolling resistance using standardised test at 25 degrees, under steady-state conditions and on a curved surface. However, this is seldom reflective of real conditions and could even be misleading with better rated tyres providing higher resistance under certain conditions. Also, for heavy vehicles it can take up to two hours to reach steady-state resistance values, so these significant transients often invalidate static values during real-world operations. An improved understanding of real-world rolling resistance, for example under varying weather conditions, will not only improve range predictions but also intersect with important aspects such as handling, comfort, noise, tyre wear, wet traction, etc.

- **Total vehicle energy demand.** Aside from overcoming resistance to motion, vehicles' auxiliary devices, such as thermal management, driver assistance and infotainment, currently consume significant percentages of vehicle energy, particularly at lower speeds. This is expected to increase, with for example increased use of sensor, advanced driver assistance systems, on-board computing, and autonomous vehicles. Range predictions based on driving behaviour and vehicle motion alone will increasingly underestimate energy demands. An improved knowledge of total vehicle energy demand will not only improve range predictions but also intersect with comfort and safety.
- **Vehicle energy management.** Non-conventional drivetrains, such as battery or fuel-cell electric vehicles, are still heavily limited in their range, particularly for heavy trucks and trains. This makes managing the energy use a key aspect of their operation as energy is an operational constraint. This can mean dynamically reacting to operational scenarios and configuring subsystems accordingly. For example, in managing component cooling using active or passing approaches. An improved knowledge of the coupling between the technological, functional, and operational parameters affecting vehicle energy management will increase vehicle range and enable the greater use of alternative drivetrains.

Area 2: ***Building better*** **– Circular Vehicle Construction**



Vehicles are constructed from a variety of materials in components and subsystems with varying lifespans. In this area the research focusses on how these materials can be used in an effective and circular manner.

This area includes topics such as:

- **Data for circular operationalisation.** Much of the material investment into vehicles is lost to manufacturers in the linear economy. However, understanding when and where different circular strategies can be implemented is unclear given that different components and subsystems, such as batteries, degrade at different rates within vehicles, and this degradation is dependent on usage profiles. Machine learning and data-driven methods provide an opportunity to utilise usage data to predict the residual useful life of subsystems, identify the best circular strategy that can be applied, and ultimately plan material use over multiple life cycles. This would enable more effective use of material resources, increasing the extracted value, while also reducing the associated environmental burdens.
- **Use of novel and lightweight materials.** Lightweight composites and bio-based materials offer the possibility to reduce the environmental footprint of vehicles. However, their use in vehicle construction is dependent on many factors, with their ability to meet mechanical requirement and cost to the forefront. Balancing these factors requires a better modelling of the mechanical properties of these materials within multi-objective frameworks. This would enable greater use in a variety of vehicle applications, such as composite rail bogeys etc., and would promote more cost-effective and efficient solutions.

Area 3: ***Benefits and burdens*** **– Balancing Vehicle to Surroundings**

Vehicles interact with the infrastructure and population in their surroundings. In this area the research focusses on how interactions such as the need for charging infrastructure and the emission of noise can be integrated better in the design and trade-offs balanced.

This area includes topics such as:

- **Emissions and certification.** The challenge in reducing vehicle environmental impact is not just in the reduction of emissions in general (e.g. exhaust, acoustic, particulate matter) but also in their accurate assessment and strategic management. Considering noise emissions, current models, such as the use of monopoles, do not adequately address the complexities of real-world sources, for which refined models (e.g. monopole clusters) are required to provide more realistic and economically viable tools for vehicle design and regulatory compliance. In combination with this, multifaceted emission modelling seeks to integrate diverse emission data, including acoustic and particulate emissions, into dynamic maps which could serve as the foundation for intelligent traffic systems that dynamically route vehicles based on their emission profiles, optimizing fleet deployment to mitigate overall environmental impact.
- **Vehicle-infrastructure dynamics.** As urban spaces evolve, the dynamics between vehicles and infrastructure becomes increasingly intricate, and use of system dynamic modelling may serve the purpose of anticipating and adapting to these changes, promoting vehicle designs and allocations aligned with foreseeable scenarios. For example, simulating a range of traffic conditions and their effects on infrastructure, may allow to proactively adjust vehicle features and distribution to enhance functional synergy between moving and static elements of urban transportation systems. Optimality in this area may be targeted in terms of performance, safety, and sustainability in the evolving landscapes of vehicle use.
- **Vehicle to grid integration.** The electrification of vehicle fleets presents unique opportunities for energy management within the broader grid system. For instance, exploring the integration of energy harvesting technologies in electrified vehicles, and examining how these may contribute back to the grid while parked or in motion, may be combined with the need for strategic allocation and management of the fleet and charging stations, seeking ways to maximize energy efficiency and resource distribution. The analysis of patterns of energy usage and vehicle behaviour may provide the foundation to a grid-supportive system where electrified vehicles are not just consumers of energy but also supplemental providers, smoothing out demand peaks and contributing to overall resilience.

More details of working ideas for new projects are included in the appendix.

3. Organisation and Financing

In addition to generating knowledge, methods, and competence within ECO2 projects, it is also important that these are structured in a relational environment where they can be leveraged to have the greatest impact. ECO2 will continue to bring about change in how its members perceive and approach the challenges of sustainable transport. This section sets out how the centre will work, both organisationally and financially.

3.1. Partners and associates

A beneficial centre with self-determination and collaboration

For the upcoming period the centre's current seven partners will continue their involvement. These are Scania, AB Volvo, Volvo Cars, Alstom, VTI (Swedish National Road and Transport Research Institute), and KTH Royal Institute of Technology. These partners span industry and academia, with the centre creating a collaborative partnership between these sectors. These seven partners constitute the *core partners* of the centre.

The centre is hosted and coordinated by KTH, meaning that it will continue to follow the guidelines and rules applicable to KTH centres. For example, the board members, chairperson of the board, and director are appointed by the Vice-Rector for Research of KTH. However, further details regarding the running of the centre will also be set out in a centre agreement between the partners, which will follow closely the previous centre agreements, with the exception of Vinnova's involvement.

Core partners will steer the focus of the centre and oversee the assembly and use of resources by the centre. As before, this will be done via the centre's Board and the Centre Management Group (CMG). Partners will each have a representative on the Board, with KTH having two, and will make formal decisions about the centre (e.g., on the initiation or inclusion of new projects) in consultation with the Director and the CMG.

The centre Director will lead the CMG, and together will take care of the day-to-day running of the centre's activities. The CMG will be composed of KTH staff and will also reflect the assembled disciplinary groups with the intention of maintaining the centre's multidisciplinary and multi-vehicular precepts. Additionally, the Director and CMG take forward proposal to the Board on the further development of the centre.

Additional partners may be adjoined to the centre as *associate partners*. The motivation for this would be primarily to complement the competences and research activities within the centre, as opposed to purely networking reasons. Associate partnership may entail an annual membership fee to recognize the benefit of access to the centre and to contribute to additional administrative costs incurred. The intention is that associate partners would engage in the research environment, both directly in projects and indirectly at, for example, centre meetings and events. However, associate partners would not have a Board membership and so would not have a direct steering role in the centre. The terms of associate partners would be detailed in a collaboration agreement/memorandum and approved by the Board. For example, associated partner may have a non-voting adjunct representative at Board meetings at the discretion of the Board. Such a partnership could be applicable to former SME partners (a Vinnova categorisation that is no longer applicable) and existing international partners such as the University of Graz (sustainable product development) and the University of Eastern Finland (optimisation).

3.2. Building Competence

People are important!

While individual projects will generate results on specific relevant topics, much of the benefit of this work will come from how the projects are interconnected in the overall project portfolio and how the centre's partners access and contribute across these projects.

Here, the Centre Coordination Group (CCG) will continue to be at the heart of ECO2 forming a connected internal network with strong links between the projects and the partners, and within each partner organization. The function of the CCG is to connect research activities at each partner in the centre's research. As such the CCG consists of the two representatives from each core partner along with the KTH-based CMG and other research leaders at KTH, and meets four times a year. As the centre's research is multidisciplinary, this should be reflected in composition of the CCG, with one Technology Manager (TM) and one Environmental Manager (EM) from each partner.

The CCG should always be central to the discussion on project generation, with a mind on not only how projects outcomes can be used by their organisation, but also how they can connect individuals from their own organisation with others within the centre (across the partners), and so create constructive project groupings and improved project content. So, CCG members should act as ambassadors for the centre and conduits into their own organisations and contribute to a collected and developing competence base within the centre.

The centre Researcher Group is a more informal grouping with the aim of creating dialogue amongst the doctoral and postdoc researchers and the centre management, and a good flow of information internally in the centre. The group has rotating responsibility given to two members to lead activities such as discussions on *handling a PhD*, publications strategies, informal social events, etc.

These groupings go beyond direct transfer-of-knowledge to create a shared culture within the centre with an emphasis on multidisciplinarity, collaboration, consensus, gender equality, etc. This reinforces the research content and contributes to developing well-rounded people with the required multidisciplinary competences.

3.3. Core and complementary projects

A greater mass

In the coming period there will be a greater dependency on assembling the centre's project portfolio with the help of a variety of funding sources. Previously, Vinnova's headline funding meant that most projects were clearly defined and funded within the centre's framework. Additional projects, which became associated with centre, only added to the portfolio without shifting the ECO2's centre of mass. Their connection was loosely defined as including funding beyond the centre's agreement (i.e., in the context of the Vinnova programme), often without a need to acknowledge them as part of the added value of the centre. This possibly over-emphasised the significance of the Vinnova co-funding.

Moving forward it is important to make a clearer distinction between the *core* and *associate* projects and recognise the complementary benefits of both. *Core projects* are those that the partners reciprocally initiate and coordinate with a view to the centre's vision, strategies, and research focus. This means that they constitute the partner's minimum contribution to the centre's research activities and are directly subject to the coordination of the partners via the CCG and Board. This collaborative assembly, in itself, is an added value of the centre as each partner has access to research mass greater than the project(s) that they take into the centre framework. So, for example, one industry partner might create an industry project on a topic they prioritise with the understanding that other partners are responsible for creating additional projects that are also of interest to and beneficial to the first partner. The assembling of the projects like this within the centre also means that the content of the projects can benefit from the feedback within the centre.

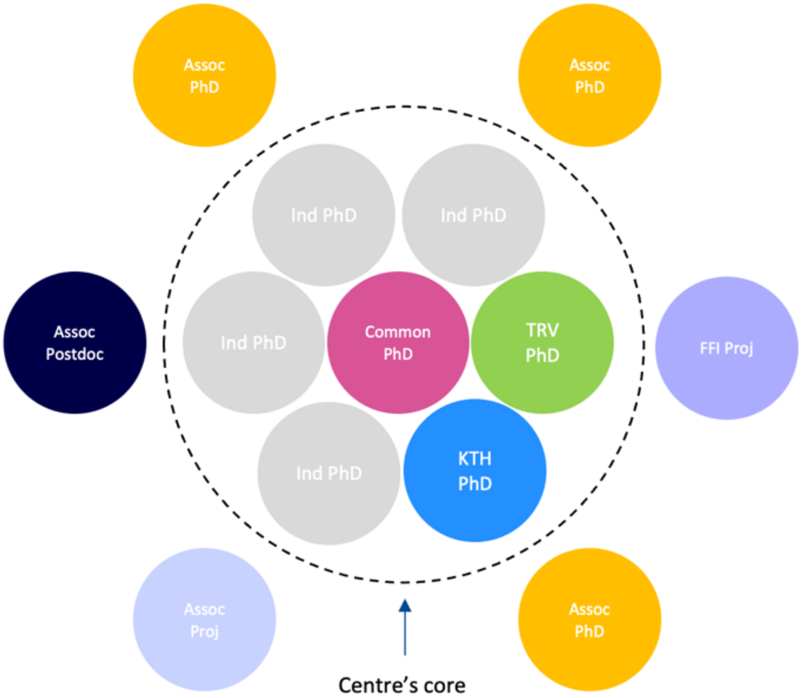


Figure 5: Core projects are those that constitute the partner's contribution to creating a shared portfolio, while associate projects are additional projects that often arise due to the existence of the core and complement them.

In additional to these core projects, *associate projects* are those that arise through external funding applications, and which come into the centre's environment because their content adds to or is complementary to the core projects. The centre has a long record of including such projects, with examples including LEnOp (Formas), Sidvind (Vinnova MSCAIF), ECCENTRIC (EU) and AERIALIST (EU). These projects often come about because the existence of the centre gives the centre's researcher the base to apply for additional funding, and involvement in centre dialogue creates research ideas that feed into these applications. In other words, they are secondary benefits that are largely dependent on the existence of the centre. It then becomes natural and mutually beneficial to add these projects to the centre's portfolio. Additionally, some projects become associated with the centre because of their relevant research content and the mutually beneficial effect of including them. In this way the associate projects, regardless of the specific financing, are an additional added value for the partners that are dependent on the core.

It should be noted that that although both core and associate projects are beneficial, the more bottom-up nature of how associate projects come about means that their generation and content is not steered by the centre in the same way as the core projects. The centre's leadership should therefore oversee that the inclusion of associate projects does not lead to an undesired drift with time of the centre's research focus, and that the core focus is maintained.

At the time of writing (December 2023), three core projects are already up and running for coming period along with 2 associate projects that stretch well into the new period are ongoing. The intention is that each core partner will contribute at minimum one doctoral (or equivalently sized) project into the centre's core in a reciprocal nature. So, in total for the coming the period there should be six-to-eight core projects plus associate projects meaning that the total number of projects within the centre may be slightly reduced but still comparable with previous periods – consistent with ending of Vinnova's 25% co-funding.

3.4. Enabling the work

The minimum needed to run the centre.

For ECO2 to continue to operate in the coming period it is an imperative to ensure a minimum organisational and financing structure to maintain the core research projects and activities of the centre. Given the reciprocal nature of the core project structure, it is important that the financing of this core is done in a transparent and reciprocal way and that the interdependencies are understood.

Previously within the Vinnova programme, co-financing was based on the *one-third principal* with one-third income coming from Vinnova, one-third from KTH, and one-third from the other six partners combined. This was complemented with funding from associate projects. This previous financing model can be referred to as the *one-third-plus model*, where the *plus* recognises that roughly 10% of the funding from 2017 to 2022 came from associate project funding, i.e., on top of the Vinnova programme requirements. It is also worth noting that, in addition to this extra associate funding, during the same period both KTH and the other partners surpassed the minimum requirements in terms of real costs incurred (i.e., in-kind contributions), meaning Vinnova's contribution accounted for approximately 25% of the total financing of the centre.

For the upcoming period, the intended model can be referred to as a *50-50-plus model* (or one-half-plus as a more direct comparison with the previous) meaning that half of the core financing comes from KTH, half comes from the other six core partners, and that this will be complemented as previously with associate project funding.

The composition of this financing model is illustrated in Figure 6 showing the planned income by source on an average annual basis. The bottom half shows planned KTH contributions, and the top half shows contribution from the other six partners.

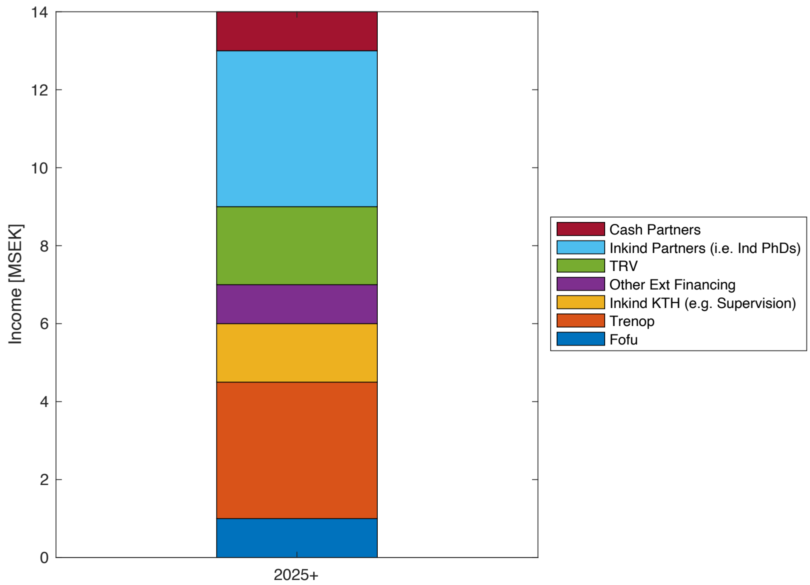


Figure 6: Average yearly minimum budget contributions by source.

Stepping through each contribution in Figure 6, *Fofu* (Forskning och forskarutbildning) is base funding from KTH centrally allocated to ECO2 to support activities and is typically approximately 1 MSEK per year. *Trenop* is an allocation from the Strategic Research Area (i.e., appointed by the

Swedish government) via KTH amounting to 3.5 MSEK per year. These two sources will be used to enable KTH's core research activities within the centre (e.g., via a PhD/postdoc project), coordination of the centre's research, management and leadership of the centre, direct engagement of KTH staff, and organisation of ECO2 events. As such, they are critical to the planned operation of the centre. However, these allocations are also conditional on the continued operation of the centre with reciprocal contributions from the other six partners as outlined here.

In addition to these KTH cash contributions, the *Inkind KTH* contribution will be in the order of 1.5 MSEK/year, which is related to research supervision and other indirect (non-remunerated) activities. Previously, this KTH inkind contribution has been roughly 3 MSEK per year so the future planned minimum is a conservative commitment, even taking into account the expected change in the total number of projects (see Section 3.3). On top of this the *Other Ext. Financing* is the aforementioned associate project funding. Previously, these sources of funding (from Formas, EU, etc.) have summed to 2 MSEK/year on average, so again 1 MSEK planned here is a conservative commitment. The intention here is to exceed this minimum, but with the ability to do so partially dependent on the availability of the Fofu and Trenop allocations.

The *TRV* income is a legacy contribution to the centre's financing from Trafikverket through specific projects within the EURail framework. Two projects started in 2023, with one industry PhD student at Trafikverket and one PhD funded at KTH (For more details Appendix A1). Nominally, these projects contribute a minimum 800 kSEK/year each and are expected to run until 2028. Additionally, a shorter postdoc position is also funded via EURail/Trafikverket. In total, the estimate is that this contribution amounts to 2 MSEK/year until the end of 2026. It should be highlighted that, similar to the KTH Fofu and Trenop contributions, this commitment is already in place, and it is for the centre partners to leverage this with the centre framework.

For the remaining five partners, the priority is also to ensure a minimum level of project engagement that equates to a minimum reciprocal financial commitment to the centre. For this, a stencil commitment of one ongoing project (i.e. industry PhD project or equivalent with supervision) is taken as the minimum level. Here the assumption is that this translates into 800 kSEK/year in-kind per project so 4 MSEK/year inkind combined for the five partners. Additionally, it is expected that the non-KTH partners will make a combined cash contribution of 1 MSEK/year, which is a continuation of previous contributions. This will be used, for example, to fund a PhD/postdoc project jointly defined within the CCG and based at KTH. The exact division of these inkind and cash minimum amounts amongst the five partners will be set out in the centre agreement for the coming period.

Note, once again, that the 50-50-plus model set out here is in terms of minimum contributions, with the intention that by doing this in the centre agreement, a stable core of centre activity can be established for the coming period. Also, by clarifying the reciprocity, that conditional allocations, such as *Trenop* or industrial PhD projects, can be motivated internally at the partners involved.

Clarifying that certain projects are core ECO2 projects as part of agreed commitments to ECO2 (as opposed to a looser network of projects) also enables secondary positive feedback into the centre, beyond enabling associate projects, etc. One specific example is that each completed PhD unlocks a 200 kSEK *doctoral allowance* (*doktorspengar*) from KTH. Tagging specific projects as *core ECO2 projects* tied in with reciprocal financial contributions by the partners helps channel these allowances back into ECO2's economy rather than it being potentially dispersed elsewhere. With 10 PhDs from the 2017-2022 period and an estimated six-to-eight core doctoral project in the coming period, these allowances sum up to enable, for example, an additional three-year postdoc and again are a benefit of maintaining the centre's core.

3.5. Timeline for new efforts

What and when the partners should undertake to do

As the current transition period ends on 30th June 2024 the plan is to begin the new phase of ECO2 from 1st July 2024 with an initial duration of 5 years. This is to avoid/minimise a gap in activity, to maintain momentum and conditional funding sources.

During the second half of 2023 and first half of 2024 all partners will prepare for projects that will start in the second half of 2024. For example, internal industry PhD projects will be defined and synchronised with internal timelines for such activities so that they can be initiated once the new agreement is in place. At the same time, a new centre agreement will be prepared in line with this document. It will be based on previous agreements with minimum commitments for each partner to be agreed upon via the CCG and Board. The new agreement should apply from 1st July 2024.

Table 2: Summary of ongoing projects and new projects in the new period. Green indicates core projects, while orange indicates associate projects.

Project	2024				2025				2026				2027				2028				2029			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Motion cueing in driving simulators (HV)																								
Vehicle conceptualisation and subsystem interaction (SKA)																								
Autonomous driving and motion sickness (IY)																								
Rolling resistance and optimisation of vehicle-road interaction (LY)																								
Noise-exposure mapping from road traffic (SB)																								
Zero emission off-peak urban deliveries (SV)																								
Optimal vehicle design for sustainable services (RA)																								
Residual useful life for circular design (HB)																								
Cost Optimization of Lightweight Components in Rail Vehicle Design (PB)																								
Energy management of rail vehicles with alternative powertrains (KA)																								
New Ind PhD (Alstom)																								
New Ind PhD (AB Volvo)																								
New Ind PhD (Scania)																								
New Ind PhD (Vovlo CC)																								
New PhD (VTI)																								
Equivalent modelling of complex acoustic sources monopole clusters (FFI)																								
Source noise characterisation and equivalent source modelling (EURail)																								
New associated project																								

4. Impacts and Benefits

In continuation of the contributions made by ECO2 while growing through the different phases, the Centre expects to extend its influence, by leveraging cutting-edge research in fruitful collaborative partnerships.

4.1. Expected direct results

Anticipated number of projects and PhDs, papers, etc.

For the coming period it is expected that ECO2 will generate a continuous dissemination of research in different formats, mainly as conference contributions, peer-reviewed publications, and PhD dissertations, in parallel with the regular transfer of knowledge enabled by the different Centre activities. The Core Projects are the main drivers of these outputs, while Associated Projects will support and strengthen the main research areas and their visibility. The aim is to run 6 to 8 Core Projects that clearly depict the research strategy of the centre, and at minimum 4 to 5 Associated Projects, of which 1/3 will be PhD project-equivalents while the remaining will span shorter-term,

more specifically targeted objectives, e.g. via post-doctoral or researcher projects. The aim is to contribute to the state of the art of pre-competitive research methods and models for sustainable vehicle design and development.
From 2017 to 2022 alone, the centre's researchers have published more than 150 peer-reviewed journal articles and well over 100 conference papers. It is expected that this publication rate will continue at similar levels as the centre transitions to its new setup, while concluding ongoing projects from the previous stage and incorporating new PhD candidates. The engagement of PhD supervisors and members of the management group in parallel research constellations will also contribute to maintain the visibility of the centre and keep the research dissemination consistent.

4.2. Leading the way

Connecting industry partners, system perspective challenges.

As ECO2 turns to its next phase of developments, our guiding vision remains to pioneer resource efficient vehicle design by seamlessly integrating industry insights with systemic challenges. This forward-looking approach is not just about advancing technology; it's also about creating a synergistic ecosystem where industry partners and academia converge to drive transformative change in transportation.

Impact Through Collaboration: Our unique position with the diversity of engaged actors within ECO2 enables us to address challenges from a holistic perspective. The collaborations facilitated through ECO2 are not just channels for sharing expertise but are a means for innovation, where multifaceted challenges are approached with a multifunctional mindset. This collaborative framework has already demonstrated its value, and ECO2 will continue this mode of operation to ensure a significant impact.

Benefits of a Systemic Approach: By maintaining our core focus on the vehicle while acknowledging its role within the broader transport system, we ensure that our progress is both technically profound and contextually relevant. This dual approach allows us to address foreseeable design challenges while considering long-term implications on infrastructure, urban planning, and environmental sustainability. The result is a portfolio of research that is not only precompetitive but also deeply integrated with the evolving needs of society and the transport industry.

Future Outlook: Looking ahead, ECO2's role as a leader in sustainable vehicle design is set to expand. We aim to deepen our engagement with industry partners, exploring new frontiers in vehicle efficiency, material sustainability, and emission reduction. Simultaneously, we will further develop our systemic perspective, via the complex interplay between vehicles, infrastructure, and the urban environment. This expanded focus will include addressing emerging challenges in electrification, autonomous technologies, and smart infrastructure integration.

Catalysing Industry-Wide Change: Our ambition is to transcend beyond being a centre of excellence in research; we aspire to be a catalyst for industry-wide change. By promoting a culture of cross-fertilization of ideas and embracing multifunctional conflicts, ECO2 will not only continue to contribute to the technological advancement of individual vehicles but seeks to also play a pivotal role in contributing to shape the future of sustainable transport.

Our commitment to bridging industry and academia, coupled with our focus on systemic challenges, positions us uniquely to lead the way in creating a more sustainable, efficient, and resilient transport future.

4.3. Consolidated efforts

Better than alternative

The table below highlights some of the differentiating points between aiming at industry-academia collaboration in direct partnership, vs maintaining a Centre-wide collaborative environment, thus avoiding a dissipation of efforts due to a lack of coordination.

Collaborating as a Research Centre	Collaborating in Direct Partnership
Visibility and credibility: Enhanced credibility to secure funding (ease of implementation, recruitment capacity, higher impact).	**Efficiency vs scope:** Efficient for specific, small external seed funding (at the expense of scope limitations).
Multidisciplinary platform: Supporting links between a diversity of experts and promoting contacts between partner companies.	**Targeted, focused research:** Narrow areas easier to sell internally within partner organisations.
Structured Collaboration Frameworks: Providing neutral ground for partnership, mediating and managing competitive concerns with established processes for collab- oration, IP sharing, and publication.	**Simplified IP/confidentiality agreement** adjusted to punctual collaboration, and limited to smaller consortia.
Stability for fundamental research: Critical for risk-taking, fundamental (pre-competitive) research, and innovation.	**Higher TRL** with competitive concerns.
Flexibility in Research Orientations: From Ideas, needs, and partnership to seeking complemen-tary funding opportunities.	**Constrained project-generation process:** From available funding opportunities to matching ideas and consortium.
Cross-fertilisation of projects in connected areas, Centre-wide re- search clusters.	**Isolated initiatives.**
Dependency on External Funding: co-funding, availability of Centre-wide seed funding.	**Dependency on External Funding:** primary source in most cases.
Leveraging university infrastructure: Access to KTH funding, diverse talent pool, and more.	
Robustness of relationships/contact: Partnerships not relying exclusively on individuals but on roles providing access to a broader network.	
	Streamlined Decision-making: Direct contact, better control of content, process, and reporting.

4.4. Follow-up

Meeting and surpassing expectations

The coming phase of the centre will be for five years. During this time a short annual status report will be prepared. Previous annual reports to Vinnova comprehensively accounted for all activities and costs (for example, including lists of new contacts established; categorise regions where research exchanges took place, etc.) for all partners and were lengthy and time consuming to create, and were targeted at Vinnova's evaluations. Unlike these, future reports will provide a more concise overview of research activities and outcomes (publications, PhDs, etc) in relation to ECO2's research topics, along with an update on planned activities for the coming year. Financial reporting (beyond cash amounts) will be on the basis of translating research activities into cost estimates via stencil amounts. So, this reporting will be aimed primarily at summarising what the activities and results are while highlighting added-value outcomes, and providing transparency for the partners that minimum commitments are being met. Additionally, the report will be aligned with wider communications efforts, for example, by making the report (or a version of it) public.

The ambition is that by operating the centre as outlined in this document for the coming period, ECO2 will continue to develop and be beneficial to the partners and individuals involved, making significant contributions to resource efficient vehicles, and will continue beyond 2029.

Appendices

A1. Description of new established projects.

These are projects that have started or will start soon and form part of the core projects for the coming period.

Residual useful life for circular design
Postdoc: Hamza Bouchouireb (Feb 2023 –Jan 2027).
Core project at KTH. Budget 4 MSEK.
This project aims at operationalising circular thinking to accelerate the transition towards - and the concrete implementation of - circular business models within the automotive industry. This area leverages the centre's expertise in machine learning and data-driven methods, design for sustainability and resource efficiency, as well as vehicle engineering to develop critical decision support tools that will effectively enable the deployment of circular business models throughout the vehicles' life cycles. In practice, this area will cover the development of predictive models that will quantify the Remaining Useful Lifetime (RUL) of vehicle subsystems within currently used vehicles, as well as relate their historical use patterns to their expected failure modes. This deeper data-based understanding of the vehicle subsystems' degradation, failure and use patterns will subsequently feed into the development of tools that will systematically identify the highest-ranking circularity strategies on the circularity ladder that can be applied to a given used vehicle component. In doing so, the life of the aforementioned vehicle subsystem is extended, thereby leading to the more efficient use of the resources associated with its manufacturing. In doing so, not only is the subsystem's environmental impact reduced, but the transportation value extracted from it is also increased. Ultimately, the goal of this area is to incorporate these data-driven and circularity-oriented component models within a larger integrative design for sustainability tool that will facilitate the design of circular vehicle subsystems, which have a tailored and built-in ability to undergo multiple life cycles within a circular business model, from the earliest stages of the conceptual vehicle design process.

Energy management of rail vehicles with alternative powertrains
Doctoral student: Karolina André (May 2023 – Apr 2028)
Project at Trafikverket/EURail. Budget 4 MSEK.
Battery-driven Electrical Multiple Units, Hydrogen-powered trains, or other trains with non-conventional traction chains present an alternative to reduce the carbon intensity of non-electrified railway lines. These concepts are still limited in their mileage, making the management of the utilized energy a key aspect of train operation. Energy Functions are operational constraints applied to the railway system at subsystem level to improve energy efficiency. These functions are a combination of management operations within a certain technical subsystem, so they typically need a technological implementation that can dynamically interact with the operational scenarios the train or the driver creates, either at vehicle-level or at infrastructure-level. The integration of new powertrains and energy functions in railway systems requires additional research to understand the coupling between the technological, functional, operational, and system-level parameters. The research will focus on the energy management of railway systems with limited energy availability considering vehicle, infrastructure, and operational constraints.

Cost Optimization of Lightweight Components in Rail Vehicle Design *Doctoral student: Péter Bondár (May 2023 – Apr 2028).* *Core project at KTH via Trafikverket/EURail. Budget 4 MSEK.* The doctoral thesis delves into the design of lightweight composite structures for rail vehicles. The research explores the potential of lightweight composite materials, to significantly reduce the weight of rail vehicle components without compromising performance. Utilizing computational modelling, simulation tools, with multi-objective optimization algorithms, the study aims to identify the most optimal designs that meet the mechanical requirements, while minimizing costs and weight. The lifecycle cost analysis will be conducted to evaluate the long-term economic benefits of lightweight composite structures. The findings of this research will provide valuable insights for rail industry stakeholders. This study strives to foster a more sustainable and economically efficient rail transportation system by promoting cost-effective and weight efficient solutions.
Source noise characterisation and equivalent source modelling *Postdoc: To be recruited.* *Associate project at KTH via EURail. Budget 1.2 MSEK.* KTH/ECO2 will contribute to WP 3 (Noise and Vibrations) in the Rail4Earth project, on two specific tasks directly linked to ongoing and past activities within ECO2. The first task seeks to further improve the characterization of noise sources. The aim is here to apply current methodologies for simulation of exterior and interior noise for different categories of rolling stock. Based on the experiences obtained in ACOUTRAIN, FINE1, FINE2 and the state-of-the-art of tools used by operators and manufacturers, the task will focus on the improvement of the characterization of aerodynamic acoustic sources and in the complete exterior/interior noise correlation of models. The scope of the studies will be to verify and validate the processes that could be used for virtual testing for different categories of rolling stock: urban, regional, highspeed train, and to see the benefits of the use of the simulation. The second task is focussed on noise perception indicators particularly targeting the influence of tonal components on perceived annoyance in various configurations (exterior and interior noise). ECO2 will contribute here with noise maps accounting for the selected indicators in order to identify sensitive zones and potential mitigation strategies to exposure to noise.
Equivalent modelling of complex acoustic sources with clusters of monopoles *Researcher: To be recruited* Associate project with FFI pre-study. Budget 500 kSEK In a context of rapidly evolving requirements and legislation for greener and more silent vehicles, transportation noise emissions remain the second most deadly environmental pollutant in Europe. This calls for drastic shifts in the vehicle industry, including the ongoing transition to an electrified transport system, but also the need to continue introducing innovation at virtually all levels of the design chain and vehicles components (engine, electric driving units, compressors, fans, pumps, tire, …). Addressing these design challenges requires modelling techniques enabling to reduce development times while ensuring to reach ever-increasing performance targets. In this objective, both the road and rail transport industry have aligned targets, attempting to establish digital twins enabling both a cost-effective design and a transition towards virtual certification. For this purpose, this FFI project intends to investigate advanced techniques in order to enable the simulation of complex sound radiation pattern from truck components using equivalent sources consisting of clusters of monopole acoustic sources. This FFI pre-study will be conducted in collaboration with Volvo AB.

A2. Description of continued project

The following are projects continuing from the previous period (starting 2017) and will continue into the coming period.

Objective evaluation and and development of motion cueing in driving simulators *PhD student: Henrik Hvitfeldt (started Jan 2020)* For more rapid and cost-efficient development, the usage of driving simulators has increased in the automotive industry. The focus area of this project is to develop a methodology for objective evaluation and development of motion cueing in moving base driving simulators. Motion Cueing Algorithms (MCA) are used to transfer a vehicle's inertial motion into the confined space of a moving base simulator. The current state of the art of MCA evaluation relies heavily on subjective comparisons between driving existing physical vehicles and driving the corresponding virtual vehicle in the driving simulator. In addition, current MCAs generate motion sickness due to false cues. To be able to widen the concept and enable multi-scalar application including to subjectively test disruptive vehicle concepts in early phase development, objective methods will be necessary to develop and tune MCAs without the need for physical vehicles. The objectives are: 1) understand which range of motion cueing is important for the fidelity of the perceived motion by using a human centred approach, 2) develop a generalised methodology for quantitative MCA evaluation for moving base driving simulators, 3) develop an improved MCA that is correlated and validated over a wider range of user cases and vehicles compared to the traditional MCAs using said methodology.
Autonomous driving and motion sickness *Industrial PhD student (Volvo Cars): Ilhan Yunus (started June 2019)* Motion sickness is a well-known issue for some people when travelling in vehicles and even more people when they are focusing on other things such as reading. For the complete success of autonomous vehicles there is a need to align the design and control strategies of autonomous vehicles so that people can make use of the time when travelling with them. Starting from the driver/passenger in the vehicle, there it is important to identify vehicle performance parameters in relation to what triggers motion sickness. With the help of motion sickness prediction models, new technical innovations needed within vehicle dynamics control and motion planning control can be developed to minimise the risk of motion sickness in autonomous vehicles. These are important tools in the early design stage of development on how to control and design autonomous vehicles so that the functional conflict between safety, comfort and performance is handled for the complete success of autonomous vehicles when it comes to economic and social benefits.
Vehicle conceptualisation, compactness and subsystem interaction *PhD student: Sai Kausik Abburu (Started November 2020)* Interdependencies exist across many vehicle sub-systems (e.g. propulsion motor and cooling unit) and between many levels of the wider transport system (e.g. wheel and track/road wear). Such interdependencies arise during design conceptualisation, when functional requirements are mapped to design parameters. The objective of this project is to develop methods to capture and predict these interdependencies in the vehicle level, with the aim of improving the integration of innovative technologies within existing vehicle architectures that can be optimised against specific functional requirements. As a practical case, novel compact rail vehicles drive solutions are being studied in order to analyse their vehicle-level improvement possibilities when introducing them in a conventional train.

Measurements and simulations of rolling resistance to enable energy optimisation of vehicle-road interaction *Industrial PhD student (VTI): Lisa Ydrefors (started October 2018)* The main resistive forces for vehicles to overcome are aerodynamics, inertia, internal friction and rolling resistance. Reducing the rolling resistance for future vehicle designs creates a possibility to reduce the energy consumption and thereby making the future vehicles more economical as well as ecological. When optimising for reduced rolling resistance contradictory requirements such as force generation for maintaining safety and performance, as well as the road surface need to be aligned. The objectives are: to establish a credible measurement method for rolling resistance on flat road under controlled conditions (lab environment), to create a scalable simulation model of tyre rolling resistance and friction forces for vehicle dynamics simulations, to validate the developed model by measurements and finally to perform optimisation studies by assuming the innovative vehicle concept that for each wheel one can control traction, braking and wheel angles (wheel corner modules).
Noise-exposure mapping from road traffic Co-financed project: 1-year ECO2 funded project (2021), then associated PhD project with Region Stockholm funding 80%, ECO2 funding 20% *Researcher: Sacha Baclet (started January 2021)* The project seeks to demonstrate recent advances within real-time multimodal traffic and noise monitoring over large urban areas. One of the main objectives it to produce, among others, a Geographic Information System (GIS) dynamic tool to visualise, in real-time, the impact associated with a variety of means of transportation in terms of noise exposure, at a very refined time scale and geographic granularity. This associated demonstrator is intended to pave the way for complex, multidisciplinary optimisation, e.g. including traffic efficiency, noise and pollutant emissions, support for dynamic geofencing technology, supporting ongoing efforts and implementation of measures for a sustainable urban environment and public transport system, in a context of growing demand for urban mobility. In particular, the outcome of the research is aiming at enabling an optimal use of space and time (i.e. time segments associated with different profiles of traffic and use of infrastructure) in dense urban areas to promote a cleaner, smart and sustainable mobility.
Zero Emission off-peak Urban deliverieS -- ZEUS Co-financed project: EU KIC EIT Urban Mobility 90% funding, ECO2 10% funding *PhD student: Siddharth Venkataraman (started January 2019)* The project is aiming at deploying a concept for silent and emission free city deliveries providing a more liveable, cleaner, and safer urban space. ZEUS aims to demonstrate the benefit of shifting high volume retail deliveries in cities from peak hours to off-peak time. Anticipated testing will demonstrate solutions meeting the expectations of stakeholders (e.g. city, citizens, retailers and logistic companies). For this purpose, a data-driven, in principle real-time, traffic noise monitoring and mapping methodology is being developed taking into account several categories of vehicles, in order to assess the impact of a range of different traffic scenarios, including the nighttime deliveries.
Optimal vehicle design for sustainable services Co-financed project: ITRL & FFI HITS project 90 % funding, ECO2 funding 10 % Industrial PhD student (Scania): Raphael Andreolli (started October 2021) Sustainable transport demands a better understanding of how new vehicles and their inherent func- tions will affect the system level, and vice versa, concerning future goods delivery needs

compared with today’s system. This will require research on methods to effectively address the system-level effects that influence the early design process, as well as acquire constraints from system level that will have an effect on the vehicle and inherent designs and functions. The hypothesis for this research is that connecting system levels from detailed vehicle systems, agent-based micro/macro simulations and studies on organisational structures and business models will give an enriched analysis that can generate a set of methods and processes on how to design and analyse an urban goods delivery solution.