5G-based traffic optimization

Plan for reducing greenhouse gases with 5G and digital twin in the transport sector

REVISED EDITION October 9, 2024

5G Business
Author:
Niklas Linde
Lars Sandström

Content

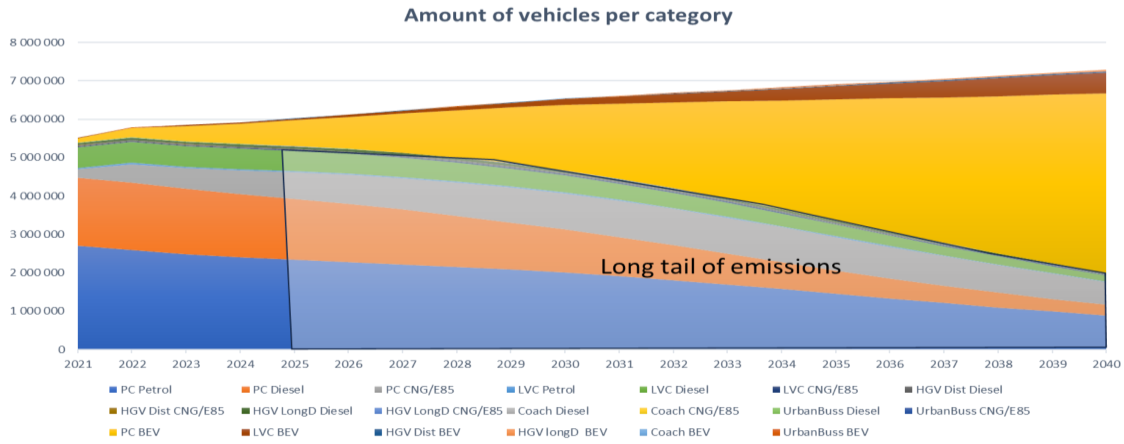
Acronyms

3GPP	3rd Generation Partnership Program, a collaborative organization in the telecom industry that sets requirements in 3G, 4G, 5G and 6G and how these should work together.
API	Application Program Interface
AR/XR	Augmented reality, a way to add information, or improve the image we see through smart glasses, with camera, microphone and speakers, and also with pupil tracking
AXIS	Product name for Ericsson telephone station system
C-ITS	Cooperative Intelligent Transport Systems, C-ITS is about the collaboration, interaction and communication between different types of ITS technologies, infrastructure for traffic, and different types of vehicles.
Digital Tvilling	Digital Twin describes the physical world in a cyber abstraction, i.e. moving and fixed objects are described with a data representation.
ETS	EU Emission Trading System, a system for trading emission rights
EW	Electronic Warfare, radio interference
GPU	Graphics Processing Unit, a unit within a computer organization, which is efficient for repetitive calculations on large data surfaces.
ICT	Information and Communication Technology
IoT	Internet of Things, small, compact and energy-efficient devices
IRL	In Real Life
ML/AI	Machine Learning/Artificial Intelligence
NVDB	National road database
OSI	Open Systems Interconnection
FRAME	Random Access Memory, fast-read memories
RTK	Real-Time Kinetics, a way to geo-position moving vehicles with GPS/GNNS with greater accuracy.

Conclusions and recommendations

Electric cars will effectively reduce the harmful emissions from the automotive sector. The automotive industry is investing in the transition to new electricity-based technology and this will have an impact on consumer markets, as will other technological transitions in other industries.

However, the change in the composition of the vehicle fleet takes time, resulting in a long tail of CO_2 emissions from fossil fueled vehicles from 2025 to 2040 totaling 146 million tons according to our calculations. These emissions accumulate in the atmosphere and need to be managed.



There are two key measures to reduce these emissions;

1. increase fuel blending with CO2 neutral fuels and
2. optimize traffic flows on the roads

In addition to these, a number of other measures can be implemented to stimulate the transition to electric cars, but we will leave these questions aside in this report. In this report, we focus on optimizing traffic flows so that fuel consumption is reduced and thus emissions of both CO_2 and nitrogen oxides (NOx).

International research points to a 15-40% reduction in harmful emissions in the road transport sector with the right traffic optimization methods. The image below shows that traffic optimization, together with fuel blending, can make a major contribution to reducing the number of harmful emissions in Sweden. Motorists' costs from the introduction of ETS-2[1] are inserted in the figure below, to indicate that there are benefits for motorists to obey and comply with traffic optimization – to save money, quite simply.

CO2 emissions, gross, transport sector 2025-2040 (kton)	145 616
Fuel blending (%)	10%
CO2 reduction avfter fuel blending (kton)	14 562
Traffic opimization over the period (2025-2040)	10% - 23%
CO2 reduction after traffic optimization (kton)	29 187
CO2 reduction after fuel blending and traffic optimization (kton)	40 830
ETS2 cost for drivers 2025-2040 (billion SEK)	66
ETS2 cost for drivers after fuel blending and traffic optimization	47
Cost reduction for drivers (billion SEK)	18

[1] We have assumed that the incorporation of ETS-2 shifts a cost of about SEK 1/liter (the benchmark) of fuel to the consumers.

The intended design of the traffic optimization will also contribute to a higher environmental awareness among drivers, create a calmer traffic pace and also provide drivers with better traffic information about disruptions from traffic diversions, accidents and difficult weather conditions.

We propose that new technologies and methods are now used to enable the entire vehicle fleet to contribute to reducing emissions by optimizing the driving capacity of the road network:

1. at what speeds a vehicle should move within to be most energy efficient. Optimize traffic management (traffic lights) in real time, for the modes of transport to be served.
2. in the event of events that are outside the normal capabilities of the system (accidents, temporary rescheduling, weather influences, etc.)
3. by being able to redistribute the offered traffic around the busy hour (rush hour).

Technologies to support this are new capabilities in the field of information and communication (ICT) which enables:

- Traffic optimization with traffic lights and along the roads
- Information to road users about suitable start times and most suitable suitable route[2]

A further key measure is that the entire rolling fleet can be included in traffic optimization, in order to achieve the impact targets.

We point here towards Augmented Reality - AR as a very promising technology. AR provides drivers with a very good situational awareness, where the drivers still can maintain focus on the surrounding traffic situation.

Telecom operators will account for the majority of the investment in general 5G infrastructure. The system's general characteristics to support AR-based services will also be able to support other commercial AR and other services alongside traffic optimization. The transition from GSM and UMTS to 5G, together with the strong 4G deployment, provides a robustness for public AR services.

As AR and other broadband service becomes increasingly advanced and also millimeter bands are required, we believe that cities must meet the operator’s needs to place the 5G system in the street spaces such as on traffic lights, lampposts, etc. 5G supports different ways to share radio infrastructure between several operators, which likely will be required due to lack of space. Plans are for several cities to connect the traffic light systems to fiber, which also supports the placement of 5G base stations, which requires large bandwidth for their back-haul feed.

The costs for road operators to introduce and maintain traffic optimization will be relatively low. The costs will be limited to fixed sensors and measures to connect and upgrade the traffic light controllers.

It is important to explore the business model for how a traffic optimization system can be shaped. There are many aspects to be considered

- Upcoming ETS-2 regulation with funding source for innovation and capacity expansion[3]. It is based on the "polluters pay" principle and is thus fair. Traffic optimization is an investment for the green transition, given the large amount of harmful emissions that are reduced in the transport sector.
- The support to municipalities for their investments in traffic optimization, as most vehicle movements take place in cities

[2] For this, a navigation support for the vehicles is also needed, which takes into account the current traffic state and the permissibility of different vehicles to travel on different roads (such as heights, weights, geo-fencing, for different categories of self-driving, etc.). The issue is topical as commercial traffic can easily be misled by commercial navigation apps.

[3] We also believe that this cost should be able to be covered by the payments from ETS-2 and that funds from the innovation and improvement funds can be used for this purpose, so that the costs of traffic optimization do not land directly on the municipalities, which maintain a large part of Swedish road maintenance. At an emission price of SEK 450 per ton (the EU benchmark), the accumulated revenue from emission rights in 2025–2040 will be as much as SEK 66 billion (which decreases to SEK 47 billion with traffic optimization), this leads to an additional cost of about SEK 1 per liter of fuel for motorists according to our calculations.

- Telecom operators must be given long-term financial incentives to invest in 5G communications and Twins. The placement of 5G millimeter wave devices in the street spaces is a clear incentive. The technology for traffic optimization can also support commercial AR services, which provides new commercial opportunities for telecom operators.
- Road operators may also impose special requirements on the availability of information processing and security of traffic data information, which is why certain costs for e.g. the twin may be borne by the road operators.
- Sweden has a very strong automotive industry and OEMs' business interests in vehicle traffic optimization must also be met.

The financial incentives for different actors – the oil in the machinery – must be crystallized out in order to capture the benefits of traffic optimization

Our conclusion is that traffic optimization should have a positive impact on emissions from the automotive sector and is an uncontroversial, simple and cost-effective way forward, which must be seized now.

Our recommendation is that research efforts are now made to estimate how large emission reductions traffic optimization can provide under Swedish conditions, and to shed more light on how new 5G and Twin technologies can be used and how a business model can be formed.

Introduction

5G Business Consultants proposes that a real-time traffic optimization is now introduced, based on 5G communication, sensors and ML/AI based Digital Twin, to quickly reduce greenhouse gases and harmful emissions from vehicle traffic.

We describe this in different parts

- Part 1 describing road traffic optimization modes of action, an overview of international studies and relationship to C-ITS
- Part 2 which describes the problem with that "emission tail" and how optimization and fuel blending are used to reduce emissions
- Part 3 which describes business models and the many aspects to be taken into account
- Part 4 describes an action plan where road operators, industry and research must now join forces
- In the Appendix, we do a deeper system description and explain how the study was done

Part I

Road traffic optimization

Traffic optimization aims to reduce harmful emissions by getting vehicles to move in the most energy-optimal way possible, which means that unnecessary starts and stops and speed variations must be minimized, and that the vehicles must move within the speed range where they are acceptably energy-efficient.

This in turn, means that the offered traffic to a traffic system must also not exceed the maximum traffic capacity that the system can serve. Road traffic optimization aims to let the traffic stay close to the maximum capacity of the transport system during busy hours, in order to get the maximum benefit from the road investment, but not to exceed it, as the system quickly collapses in which the capacity of traffic capacity is abruptly reduced, thus leading to reduced energy efficiency and an increase in harmful emissions. In addition, it may take time for the traffic system to return to an acceptable ability to handle traffic after such a collapse.

There is competition between different modes of transport in cities; pedestrian and bicycle traffic are increasing and public transport wants to be prioritized as it is more energy efficient and provides better utilization of the road investment. There is also competition on street space for parking, charging stations and other purposes.

Optimization requires real-time information on the state of the entire transport system, i.e. information on traffic flows and their capacity, current waiting times for buses, pedestrians and cyclists, and on emissions of emissions directly harmful to humans, such as nitrogen oxides. All of this leads to traffic optimization will become complex.

This how it goes

- Provide information to all vehicle drivers about set speeds, route choices and during busy hours, recommend start times to reach a certain destination.
- Adapt traffic (light) regulation, so that each mode of transport is served according to the quality criteria that have been set; in practice, that public transport must keep to the timetable within an acceptable variance, that cyclists and pedestrians do not end up in uncomfortable, annoying and disruptive queues, and that other vehicle traffic is served as energy-efficiently as possible
- In road traffic, uniform traffic speeds must be sought, which might impose further restrictions on overtaking with heavy traffic and that the heavier traffic may rather be adapted to train formation to reduce air drag. The maximum speed for smaller vehicles may also need to be reviewed, as the vehicles are well above the optimal energy consumption on e.g. 120 km/h roads.

Recent years advances in communication, computing and the use of neural networks (ML/AI) allow analyses and conclusions about complex relationships, based on very large amounts of information to take place in near real time. New ways for humans to interact with the cyber world (man-machine communication through e.g. AR), allow drivers to take part of traffic information's and at the same time keep their full attention on the surrounding traffic situation.

We believe that these opportunities should now be fully applied to the entire traffic system so that all vehicles can be able to participate in the traffic optimization, in order to actually reach the desired optimization effect.

This is achieved by:

- Use 5G communication for state sensing (5g terrestrial geo-positioning and optical recognitions) and communications to vehicle drivers
- Take full advantage of Augmented Reality (AR) through the new generation of eyeglasses that are now being launched on the market.

- Gather the traffic system's resources and state in a cyber information model – the Digital Twin – where information is made easily available for ML/AI based analysis for complex relationships over large areas, and give control recommendations to drivers, in real time.

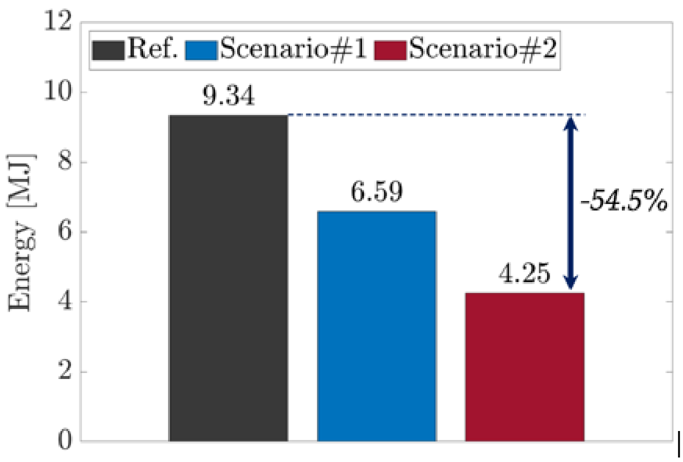
We suggest that 5G and Digital Twins technologies are to be used to support the traffic optimization system. This ensures greater technical security and access to a larger ecosystem of products and competencies for system development. 5G systems also gain a very high resilience to cyber and ether attacks, through the ecosystem's size and ability to face new threats. Also, 5G access to a diversified frequency range – from 700MHz through the GSM and 3G bands, to 3.5GHz band, on to the 24-28 and 40GHz frequency bands, which provides the required radio spectrum- robustness and diversity.

From an industrial perspective, there are similarities in the requirements from the traffic optimization system and from the emerging commercial AR/XR markets, and synergies become obvious.

Research studies

Many studies indicate that advanced optimization can provide energy savings of up to 40%. For countries like Sweden with a relatively low traffic density, it should be possible to reach 30% in large and medium-sized cities and for the traffic system as a whole around 20%.

Sweden and the Nordic countries are more sparsely populated than many of the large countries down in Europe, so it is interesting to find out how eco-driving can save energy even in more Swedish-like conditions. A very interesting study is from Italy (Politecnico di Torino, Energy Department) that has been done on a 96 km long stretch of road around Turin that included both city and country driving with connected vehicles (a Mercedes E300de, diesel pHEV).



Ref is energy consumption without speed optimization, Scenario 1 is with speed optimization and Scenario 2 is with speed and traffic light optimization

Now the study was done with some limitations, e.g., the simulations were done in a simplified urban model and under almost free traffic flow, but it is still very interesting results that are reported.
See also

- [Energies | Free Full-Text | Eco-Driving Optimization Based on Variable Grid Dynamic Programming and Vehicle Connectivity in a Real-World Scenario (mdpi.com)]
- See also Appendix A

Relation to C-ITS and other benefits that the 5G system provides to the traffic system

C-ITS is basically a concept for close-proximity communication between vehicles (G5 communication with is essentially is a WiFi based technology) to solve specific traffic tasks where the vehicles need to communicate directly with each other, but also with the possibility of retrieving road system state.
information's from road posts.
C-ITS have been enhanced to use 4G/5G communication as an alternative to road posts. This used in e.g. the EU/CEF funded Nordic Way-2 project to support autonomous long-distance freight transport for e.g. transmission of correction data for RTK, autonomous vehicles and for traffic optimization in cities (GLOSA / Time to green)

The proposed 5G-based traffic optimization system has an extended goal and scope and places higher demands on continuous connectivity and has a different approach to information management and analysis capabilities (digital twin). In the long term, we believe that 5G and Twin technologies are the most technically sustainable way forward, also being able to extend road safety to other road users (bicyclist, unprotected road workers, trams etc.) as well.

Densified 5G networks and twinning can also in the longer perspective, provide good support also for autonomous traffic, such as the use of terrestrial geo-positioning, and to solve tasks like recommended start time, route choices, and also guidance for access to services such as charging, parking, maintenance service, etc., as likely will be developed for a commercial AR/XR market anyhow.

This said, there is no contradiction between the current C-ITS concepts and a more evolved and generalized 5G/twinning concept. The 5G/twin concept address the entire vehicle fleet and includes also other traffic participants and its rests also on a much larger eco system. The concepts will find surfaces for integration's.

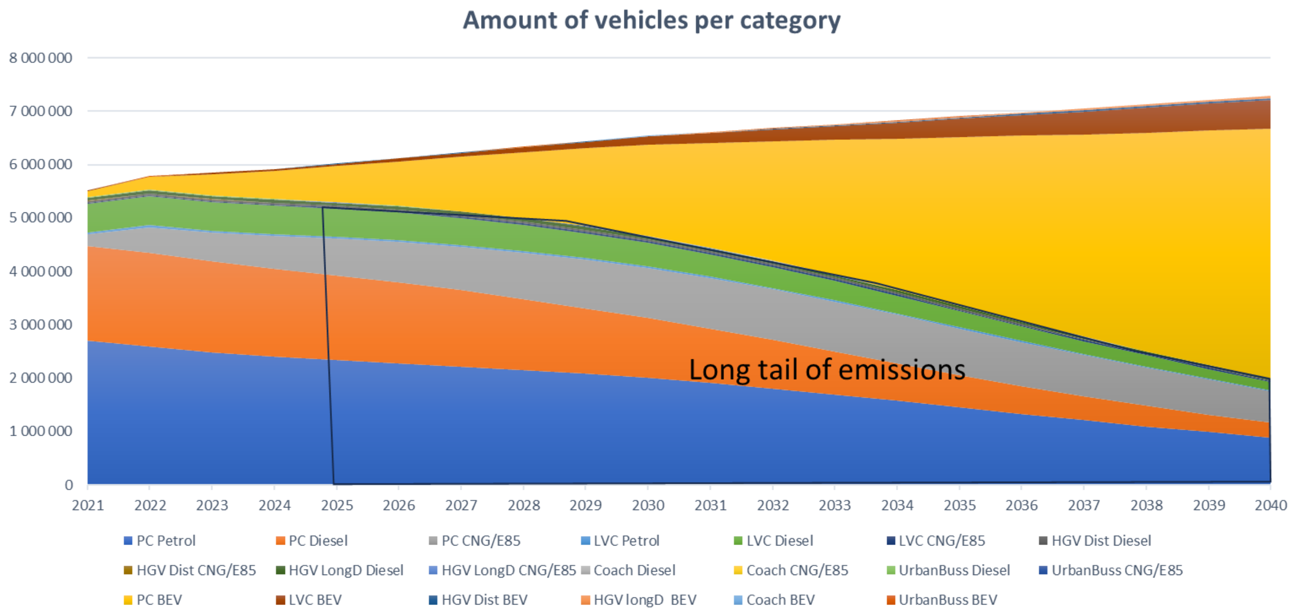
Part II

The transition to electric cars leaves a long tail of cars with internal combustion engines after 2040

Electric cars are very energy efficient and leave a low CO_2 footprint. Despite a quite positive outlook of the increased share of electric cars in the vehicle fleet, a "long tail" of cars with internal combustion engines will be left behind by 2040, leading to a significant CO_2 footprint that must be managed. Transport Analysis points this out in the report *Road Vehicle Fleet's Development to 2030*.[4]

Number of vehicles and distribution by type of energy

The figure below shows the forecasted number of vehicles from 2021 to 2040 per type of energy[5]. Despite the sharp increase in electric passenger cars, petrol and diesel-powered cars will still be the most common type of passenger car in 2030 with a tail that will continue well past 2040.



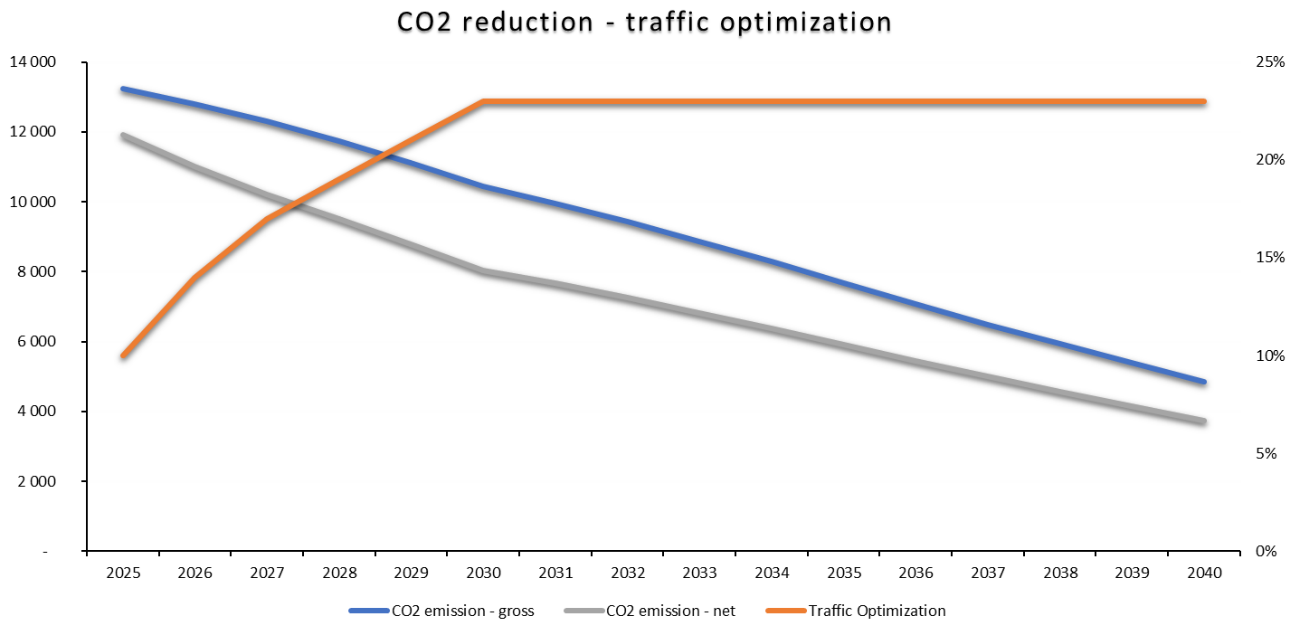
Source: Transport Analysis and the Swedish Transport Administration's forecast.

[4] https://www.trafa.se/globalassets/pm/2020/pm-2020_7-vagfordonflottans-utveckling-till-ar-2030.pdf

[5] TRV data for the development of the vehicle fleet to 2050

Traffic Optimization

5G Business Consultants has made calculations on what optimization can provide for emission reductions for the whole of Sweden, on the CO_2 "emission tail" to 2040, see the figure below.



Source: Transport Analysis, the Swedish Transport Administration's forecast and 5G Business Consultants' own calculations.

This example is based on

- 10% optimization gain from 2025, which will continue up towards 23% in 2030 and which will remain at that level until 2040.
- The accumulated CO_2 reduction from 2025 to 2040 is estimated to 20%, corresponding to about 30,000 kilotons, of the total CO_2 emissions from the transport sector, which is estimated at 146,000 kilotons from 2025 to 2040.

The optimization can also reduce nitrogen oxide emissions (NOx) and makes it easier to keep track of and manage these, which can reach harmful levels in many parts of cities.
Fuel blending (or e-fuel substitutes) does not reduce NOx in diesel cars, which is why optimization weighs more heavily for this emission category.

Traffic optimization combined with fuel blending

5G Business Consultants has made a composite calculation of traffic optimization and a fuel intake of 10% by 2040.
The image below shows that traffic optimization, together with fuel blending, can make a major contribution to reducing the number of harmful emissions in Sweden. Motorists' costs from the introduction of ETS-2 are also[6] inserted in the figure below, to indicate that there are benefits for motorists to obey with traffic optimization – to save money, quite simply.

CO2 emissions, gross, transport sector 2025-2040 (kton)	145 616
Fuel blending (%)	10%
CO2 reduction avfter fuel blending (kton)	14 562
Traffic opimization over the period (2025-2040)	10% - 23%
CO2 reduction after traffic optimization (kton)	29 187
CO2 reduction after fuel blending and traffic optimization (kton)	40 830
ETS2 cost for drivers 2025-2040 (billion SEK)	66
ETS2 cost for drivers after fuel blending and traffic optimization	47
Cost reduction for drivers (billion SEK)	18

Transferred to the EU and the rest of the world, the contribution is very significant, as a large part of the world's CO_2 emissions come from the transport sector, which itself creates around 7.3 billion tons of CO_2 annually and is the second largest emitter after electricity generation and heating[7].

Optimization means an energy consumption reduction, regardless of the type of energy and is therefore important even when the vehicle fleet is electrified.

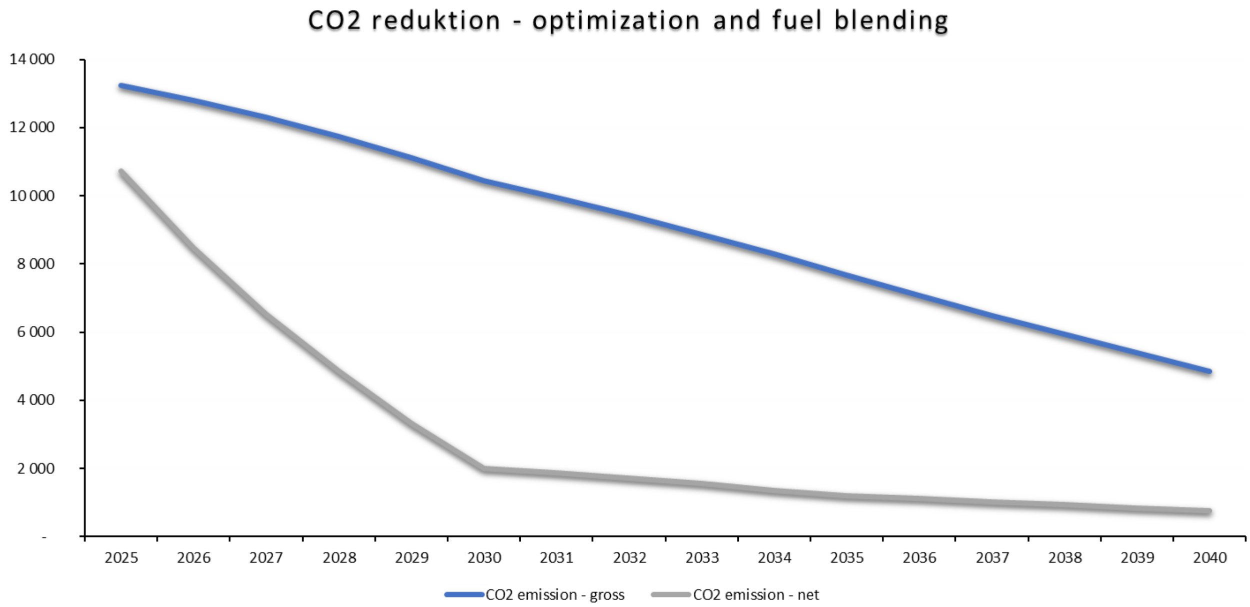
[6] We have assumed that the incorporation of ETS-2 shifts a cost of about SEK 1/liter (the benchmark) of fuel to motorists.
[7] https://ourworldindata.org/emissions-by-sector

Scenario with increased fuel mix and increased optimization gains

Assuming a more aggressive increase of CO_2 neutral fuel blending in diesel and petrol, from 10% in 2025 to 75% in 2030, and continued until 2040, as well as an increase in optimization gains up to 37% in 2035 and continued to 2040, we get an outcome as shown in the figure below.

The accumulated CO_2 reduction is estimated to 48,300 kilotons. This corresponds to a cost reduction for motorists of almost SEK 45 billion between 2025 – 2040. Without aggressive fuel blending and without traffic optimization the increased price per liter fossil fuel will be some 1 SEK/liter.

The figure below shows how CO_2 emissions can be reduced with an accelerated CO_2 neutral fuel blend.



Source: Transport Analysis, the Swedish Transport Administration's forecast and 5G Business Consultants' own calculations.

Are there restrictions on how high a fuel mixture can be achieved?

Our estimates for high levels of fuel blending show that the energy requirement will be about 30 TWh[8] in 2030 declining to about 11 TWh by 2040.

For bio-based fuel, this energy requirement, excluding quite significant manufacturing process losses, corresponds to about 10% of Sweden's total forest harvesting of about 93 million m^3 per year. There is certainly a variety of other biomass that is suitable, and that can also be imported, but the forest is used here as a yardstick to describe the size of the energy requirement.

[8] Nuclear power in Sweden produced about 52 TWh of electricity in 2022.

Part III

Business models

Introduction

Telecom operators will account for the majority of the investment in 5G infrastructure for traffic optimization. The 5G system's general characteristics will also be able to support other commercial AR services alongside traffic optimization, which is a clear investment upside for them.

The telecom operators' re-farm of their frequency portfolios to 4G/5G which means that both 5G coverage and capacity will be improved on roads around the country[9].

As AR becomes increasingly advanced, 5G also needs to make use the millimeter bands, particularly in cities. We argue that cities should meet these demands and allow placement of 5G apertures in the street spaces such as on traffic lights, lampposts, etc., and as the spaces are very limited, the radio infrastructure must likely be shared between several operators, which is supported today by the 5G RAN sharing concept.

The costs for road operators to introduce and maintain traffic optimization can stay relatively low. The costs will be limited to some sensors and measures to connect traffic light controls. Many cities plan to connect these to fiber, which is beneficial for 5G base stations, which require large bandwidth for their back-haul transmissions.

It is important to now start to explore the business model for how a traffic optimization system can be shaped. There are many aspects to consider, e.g.:

ETS-2

Upcoming ETS-2 regulation, with funding for innovation and capacity expansion[10], is based on the "polluters pay" principle and is thus justified. Traffic optimization is an investment opportunity for the green transition, given the large amount of harmful emissions that can be reduced in the transport sector.

The introduction of ETS-2 could mean more efficient pricing of transport emissions. This new scheme will cover CO_2 emissions from fuel combustion in buildings, road transport and other sectors (mainly small industries not covered by the existing EU ETS). The aim is to use the revenues from the EU ETS to support decarbonization initiatives in Europe and strengthen the transition to net-zero emissions, while ensuring continued economic growth. When the transport system is integrated into ETS, new market dynamics can be created.

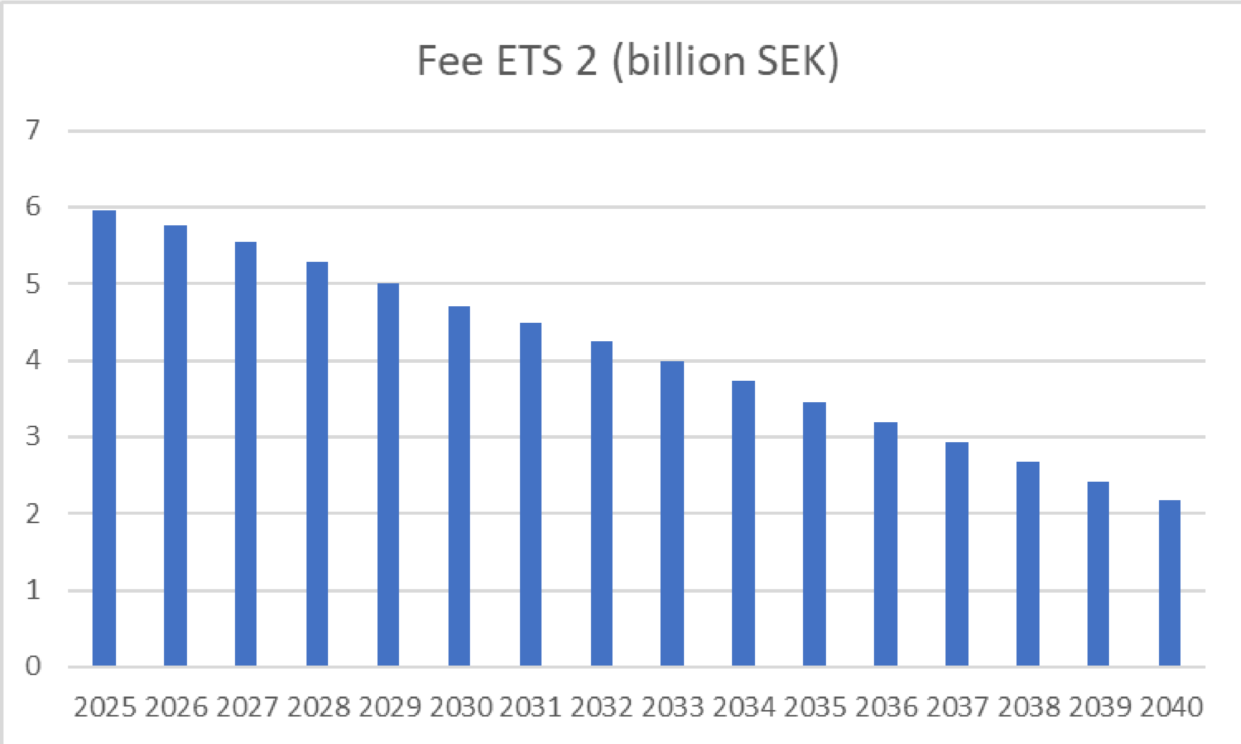
The incorporation of the transport sector into the Emissions Trading System (ETS-2) puts a price on CO_2 emissions and creates capital funds that support innovations and capacity building to reduce overall emissions, including in other sectors. These funds should be able to be used for innovation and capacity building of 5G-based optimization of Sweden's traffic system.

[9] The transition from GSM and UMTS to 5G together with the strong 4G deployment, provides a robustness for public AR services.

[10] We also believe that this cost should be able to be covered by the payments from ETS-2 and that funds from the innovation and improvement funds can be used for this purpose, so that the costs of traffic optimization do not land directly on the municipalities, which maintain a large part of Swedish road maintenance. At an emission price of SEK 450 per ton (the benchmark), the accumulated revenue from emission rights in 2025–2040 will be as much as SEK 66 billion (which decreases to SEK 47 billion with traffic optimization), and this leads to an additional cost of about SEK 1 per liter of fuel for motorists according to our calculations.

We have calculated that ETS-2 can make a contribution of between SEK 22-66 billion between 2025 and 2040 (SEK 22 billion in the aggressive but entirely possible scenario, SEK 49 billion in only 10% fuel blending and a maximum of 23% optimization gain).

The figure below shows annual auction revenues from emission rights for fossil vehicle fuels, excluding fuel blending and a CO_2 price of SEK 450/ton (the benchmark).



Financial incentives

The financial incentives for different actors – the oil in the machinery – must be crystallized out in order to capture the benefits of traffic optimization

Investing in 5G and Digital Twin:

Telecom operators must be given long-term financial incentives to expand 5G communications and the foundations of the digital twin, in order to meet the demands of a public service such as Traffic Optimization.

The placement of 5G millimeter wave devices in the street spaces is a clear incentive. The traffic optimization technology can also support telecom operators' commercial AR services and future more broadband-intensive services, such as "extended reality" XR[11], which provides new commercial market incentives for the telecom operators. These synergies are a prerequisite for the traffic optimization system to be introduced at a low cost in society.

Support for municipals:

All transport taxes today accrue to the state, city congestion taxes the exception. Means to support municipalities for investments in traffic optimization should be consider, as most vehicle movements take place in the cities and here is also where the major optimizations gain likely occur.

[11] 5G Business Consultants is now completing a new report on business models and new requirements for frequency use to better support, for example, new more advanced AR/XR services in the street spaces, which will be able to work seamlessly and frequency-efficiently outdoors and indoors for both commercial services and services of socio-economic interest, such as traffic optimization and autonomous vehicles/vehicles

Demands for resourcefulness

Road operators may impose special requirements on the availability of information processing and security of traffic data information, which is why certain costs for e.g. the twin may to be borne by the road operators (the services are operated as their own slice or in isolated machines).

Interests in the automotive industry

Sweden has a very strong automotive industry and OEMs' business interests in vehicle traffic optimization must be heeded and met.

There are technical synergies, and interest among several OEMs, to be able to use the emerging AR technologies also "built-in", to give an OEM unique selling-points, compared to the simpler design that is intended for today's rolling vehicle fleet.

Information ownership

There are also aspects to consider around information’s ownership, how it should be distributed and how information security should be maintained end-to-end and are topical in a business model.

Road operators have clearly an interest in being able to inform the entire fleet about events that are outside the normal driving capacity of the traffic system, such as in the event of accidents and severe weather conditions.

Road operators also keep essential data on the traffic system's more static resources such as roads and their accessibility for various vehicles and other traffic regulations, which are essential for the road traffic optimization to function. The road holders have clearly a distinctive role in this play.

Part IV

Action plan

Road operators, industry and research must now join forces together to capture the opportunity to substantially reduce the $C0_2$ emissions in the transport system. And this by using advanced communication and twin technologies, with a high influence of AI/ML

From an export industry perspective, this is a highly interesting market for the whole of Europe and globally, where traffic density and thus the optimization effects will be even greater, but Sweden should take the lead and show the way.

A significant part of the economic effectiveness of 5G optimization comes from 5G's generality and usefulness for both purely commercial services and for societal services of particular interest, such as supporting road traffic optimization.

It is therefore of the utmost importance that cities listen to the interests from telecommunications actors to be able to place 5G in the street space, to support traffic optimization and also to accelerate commercial service development in the city, which is also of great value. A rapid rollout of advanced 5G will create new ecosystems that create new economic value for the city – the high-speed railways of the new age. Cities will also be able to benefit greatly from advanced 5G for their own communication needs

Joining forces in the field of transport will lead the way for European capabilities to develop safe AI-based systems technologies for advanced applications[12].

Feasibility study

In October 2024, KTH together with 5G Business submitted an application for a 5-month FFI-funded feasibility study starting in January 2025.
The feasibility study includes two work packages, both of which are carried out within KTH

- AP1 that will verify and quantify possible optimization gains, without regard to the possible technical, user, organizational and financial constraints that may manifest themselves in an implementation
- AP2, which will provide an orientation on the technical, user, organizational and financial constraints that must be taken into account in order to achieve certain optimization gains.

[12] The system will be at the absolute technological forefront in being able to observe, decide and provide feedback within short real-time within complex decision models based on large amounts of information over large areas/populations, which can also gain sales in other markets such as in commercial XR and also in defense applications. The system harmonizes with the 6G Physical – Cyber Continuum structure.

Appendix

System design

Sweden has a proud tradition in system development at the absolute limit of what available technology offers. It is the hallmark of Swedish engineering to create cost-effective solutions for new applications at the technological forefront. Two good examples are the development of the AXE system, which conquered the world market, when electromechanical telecommunications systems were replaced by digital ones, and where many competitors simply did not keep up with technological developments. Another example is avionics in JA system 37, where requirements for new capabilities were translated into digital solutions, perhaps 10 years before the American aviation industry caught up. 5G is today at the technological forefront.

Briefly about the theoretical basis

Digital Twin describes the physical world in a cyber abstraction, where observations in the physical world, transmitted by communications, are made available for agents to make feed-back recommendations. The proposed system model is based on a 4-dimensional description of an object's status in the physical world; its geo-position *x,y,z* during a historical time lapse. The system is thus unlimited in scope and an agent has access to all objects in the entire system.

Digital twin operates in near real-time, i.e. observations, agents' decision time and feedback to objects with control recommendations can be supported up to 100Hz (10mS progress time) for some applications. The system can simultaneously support different process times and prioritize, in the event of resource shortages. The twin has also the ability to isolate processes, so that classes of observations, action decision and controls are isolated from each other (so-called." slicing" within the realization of the system)

What limits the agent's ability to operate over large spatial areas during a given process time is processing and time delays, where the time delay in communications (signals propagation speed in optic fibers) in practice becomes the limiting factor (but for which an agent can correct, when known).

Digital Twin supports parallel processes, where observations are shared, and where agents can be located across the entire system's distribution. Observations (objects) are not allowed to carry states for the purpose of agents communicating state relationships among themselves.

Twin can also create different 4D room projections for agents to solve different types of tasks, such as creating large room projections to observe the current volume of traffic in entire traffic areas, or to zoom in on a traffic intersection (and e.g. with the support of historical movements, predict a collision). The systems capability to share sensor information's and create parallel rooms, leads to virtually unlimited capacity.

Agents maintain decision-making state, and the state exchange between agents is a foundation of the system's overall decision-making ability, which can be supported by various principles, where reward models (GAI) are one for reaching composite optimal decisions.

The 5G communication system has an unlimited scope and has the role of interconnects sensor- and control organs (e.g. man-machine interfaces) with agents in the Digital Twin and supports up to 100Hz progress rate.

Briefly about the system's realization

Digital Twin will be realized through interconnected computers that form in local clusters. The clusters are fiber connected and operated by trusted parties. Telco's, road holders and OEM can all be part in the operations. The Twin supports deep slicing and each operating party have an entire own control over the application (i.e. set of observations, 4D data spaces, decision making algorithms, learning-sharing and controls). The twin will be operated federatively, interacting with the 5G system, which is why certain standards will be reached (information model and protocols).

To support a traffic system, a retake of the digital twin is needed. The goal is to find an architecture that can fully utilize software technologies for AI, and at the same time create an architecture that is open to other forms of data processing, and that allows for development-ability in many other dimensions as well.

KTH currently has leading knowledge in theoretical traffic optimization, with an high AI/ML influence. We also believe that the basic idea for breaking down complexity by using different projections of the traffic system (micro, mezzo, macro) can also be fundamental for the realization of traffic optimization, to break down complexity and get increased accessibility within the information processing, where more extensive multi nodal neural networks provide notable limitations.

A system design with a large element of AI also needs to take greater account of support for "built-in" training and abilities to monitor the plausibility of sensor information and control recommendations, so that these are "inbound" (to understand and prevent unnatural gradients, or other insanity that can affect the sense-control loop).

The real-time requirements and also the requirements for energy efficiency, require that all program execution must takes place as efficiently as possible, and that shortcuts in the system design can be allowed to, for example, streamline data replication (the need to share observations between different applications) within the entire range of the system, by directly using routing functions, in SDN or Internet protocols, as data replication between processors through ordinary IPC becomes unnecessarily resource-intensive?

A very computational effective real-time DB access is required. There are some options. Using a more straight forward 4-dimensional vectors (array) in RAM is one.

The 5G system can dynamically use frequencies bands distributed widely in frequency spectrums to create resilience for EW, which unfortunately has become an aspect to consider.

The 5G system can be applied in such a way that an increased resilience to (local) outages within individual mobile networks, users can be compensated for by switching over (roam) to another mobile network.

The 5G Geo-positioning developments in Releases -17 and -18 seems to satisfy the requirements to capture the traffic system's state. AR glasses or IoT emit their positions, which even at a lower vehicle penetration (>20%) should be able to give a statistically acceptable picture of the traffic system state at macro and mezzo level. At the micro level (e.g. traffic intersections), optical sensors will be need to provide an improved resolution.

New generations of AR/XR services and also AD, will make good use of millimeter wave radio equipment placed in the street space, in order to support more bandwidth and to achieve a better terrestrial geo-positioning resolution (<1m). This placement will also support more energy-efficient radio communications, and thus reduce the field strength in the airwaves. The millimeters waves high carrier bandwidth also magnify the doppler effects, thus demanding higher sub-carrier bandwidths, resulting in shorter symbol times, which are also more effectively mitigated by placement in the street space, as more radio wave reflections can be captured within the symbol time[13].

Services should work seamlessly and frequency-efficiently both outdoors and indoors, where radio interference will occur and have to be addressed. 5G O-RAN capabilities within shared radio infrastructure, shared frequency use and the use of traffic prioritization will support these challenges.

AR glasses will have considerable in-built computing power and through this, many new functions supporting the driver's perception of the world around them can be supported, such as attention to protruding objects, image enhancement at dusk, etc. (Vehicle's on-board real-time critical security functions shall not interact systemically with the Digital Twin).

[13] New waveforms such as OFTS are later than the general 5G rollout on the millimeter band and cannot reasonably be fully credited.

The system design is supported by currently available technologies and competencies (in 5G systems, VNF edge, array processing, ways of creating APIs, isolation, function orchestration, etc.)

Brief information about system requirements

Protection of users' privacy is designed in the sensor basic development so that, for example, image recognition and tracking are fundamentally designed in such a way that individual facial recognition or that tracking of vehicles through e.g. car registration numbers is prevented, in order to protect personal privacy.
The 5G system supports adequate system and user security, such as secure user authentication.
The Twins core system roles

- Monitoring and securing the system real-time properties,
- Provisioning of secure APIs, including crypto vectors
- Providing protection against cyber intrusions.
- Verify the origin of IRL sensor data and destined controllers
- Enforce rules for sensor sharing and sharing of episodes (memory lanes)

The quality and reasonableness of inference data and control recommendations takes place in the agent structures and requires special care and methods in the application development work. The twin will per se support simulation for evaluation of the system's behavior, before IRL information-inference is allowed.

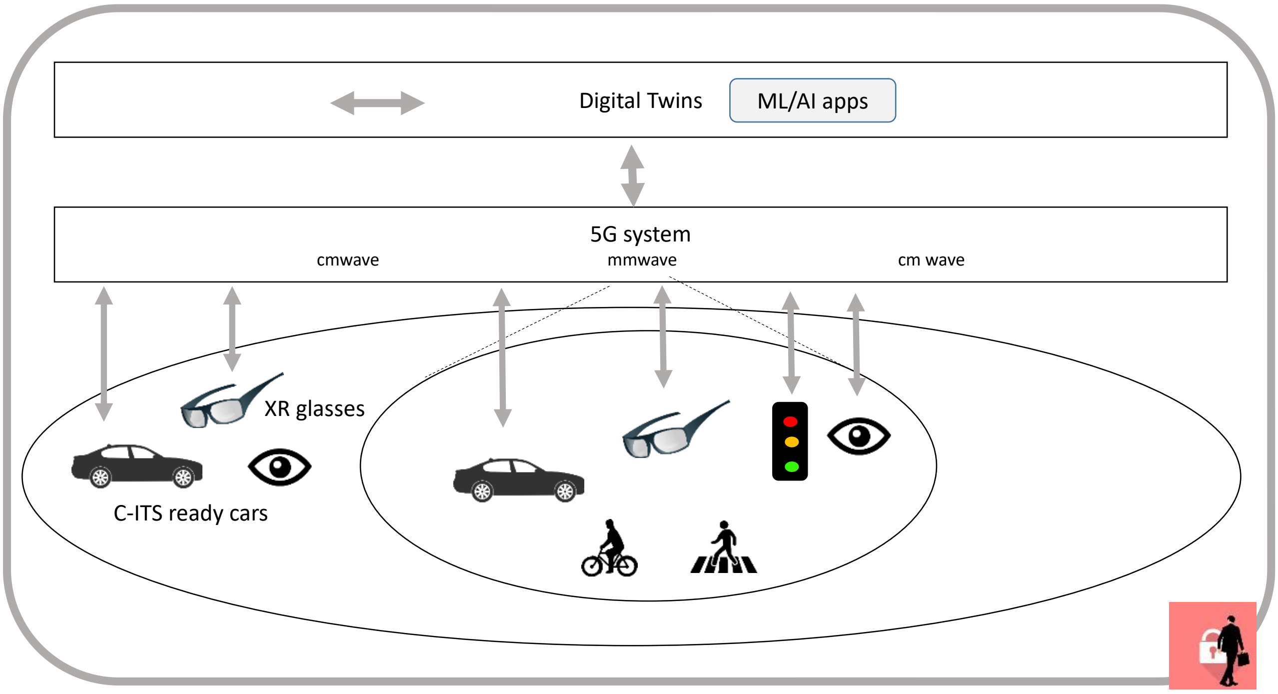
Particular to Traffic Optimization:

The composite system, where control measures also take place in adjacent systems such as in traffic control, can be built "failsafe", so that capabilities return to their basic function in the event of external disturbances or damages.

Road operators, the automotive industry and private service providers will contribute with information's that gives the system its capabilities and actually keeps the system alive.

It can be about

- NVDB data being imported and used for describing the traffic systems statical resources and regulations
- that the vehicles themselves provide traffic status information about e.g. slippery road conditions,
- or that electric charging providers, services and parking spaces are made visible to drivers (who can also be an agent in an autonomous vehicle).
- Road works contractors report the roadwork's set-up, such as speed reduction (blue sign) and temporary closures of part of the road.
- Accident situations and also minor road constructions can also be sniffed up by the system's own ability to detect deviations from normal (anomalies) in the traffic flows, including also certain road damages.


Digital Twins
ML/AI apps
5G system
cmwave
mmwave
cm wave
XR glasses
C-ITS ready cars

How the study was conducted

The study is based on:

- Calculations made on data from Trafik Analys (CO_2/km and vehicle type and average mileage per vehicle type), and on the Swedish Transport Administration's outlook on vehicle composition to 2050.
- Calculations are based on CO_2 equivalence data on diesel (MK1 2.36 kg CO_2 equivalents/litre) and petrol (2.66 kg CO_2 equivalents/litre).
- Scenarios regarding 5G feature content is according to the 3GPP functional development plan and outlook to 2029.
- Conversation with researchers in traffic systems.

5G Business Consultants is currently a common brand for Lars Sandström and Niklas Lindhe's personal companies and the report has been produced on their own initiative, without support from any other party.

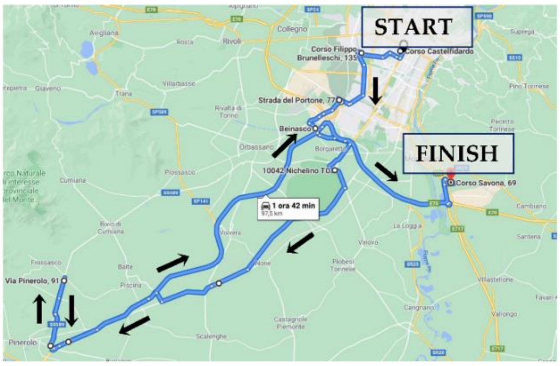
Appendix A

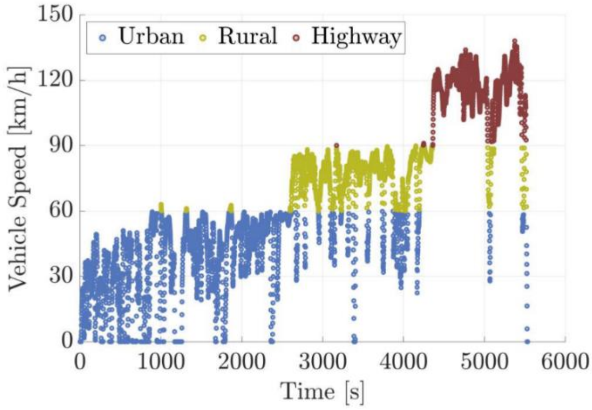
Summary of some research studies:

Eco-Driving Optimization Based on Variable Grid Dynamic Programming and Vehicle Connectivity in a Real-World Scenario, Energies 2023, 16, 4121 • Reference Scenario represents a typical real-world mission profile. It is an RDE-compliant route conducted on public roads in the surroundings of the Italian city of Turin. The route lasted approximately 92 min and was 96 km long	Energies | Free Full-Text | Eco-Driving Optimization Based on Variable Grid Dynamic Programming and Vehicle Connectivity in a Real-World Scenario (mdpi.com)
Energy Impact of Connecting Multiple Signalized Intersections to Energy-Efficient Driving: Simulation and Experimental Results. IEEE Control Systems letters, 7, 1297–1302 • Simulation results show that the V2I-enabled eco-driving control can reduce energy use by up to 40%, on average, compared to the baseline, depending on road attributes and vehicle powertrain type	Energy Impact of Connecting Multiple Signalized Intersections to Energy-Efficient Driving: Simulation and Experimental Results | IEEE Journals & Magazine | IEEE Xplore
Co-Optimization of Eco-Driving and Energy Management for Connected HEV/PHEVs near Signalized Intersections: A Review. • Currently, road transport constitutes a considerable proportion of global fossil fuel consumption, as well as CO2 and pollutant emissions. To mitigate transportation energy consumption, two primary approaches have emerged: the large-scale adoption of Hybrid Electric Vehicles (HEVs) and Plug-In Electric Vehicles (PHEVs), as well as the implementation of eco-driving strategies, which present an immediate and low-cost solution	Applied Sciences | Free Full-Text | Co-Optimization of Eco-Driving and Energy Management for Connected HEV/PHEVs near Signalized Intersections: A Review (mdpi.com)
Carbon Dioxide Emission Reduction-Oriented Optimal Control of Traffic Signals in Mixed Traffic Flow Based on Deep Reinforcement Learning - The significance of this study lies in its dual achievement: by presenting a flexible strategy that not only reduces the environmental impact by lowering carbon dioxide emissions but also enhances traffic efficiency, it provides a tangible example of the advancement of green intelligent transportation systems.	https://www.mdpi.com/2071-1050/15/24/16564

Appendix B

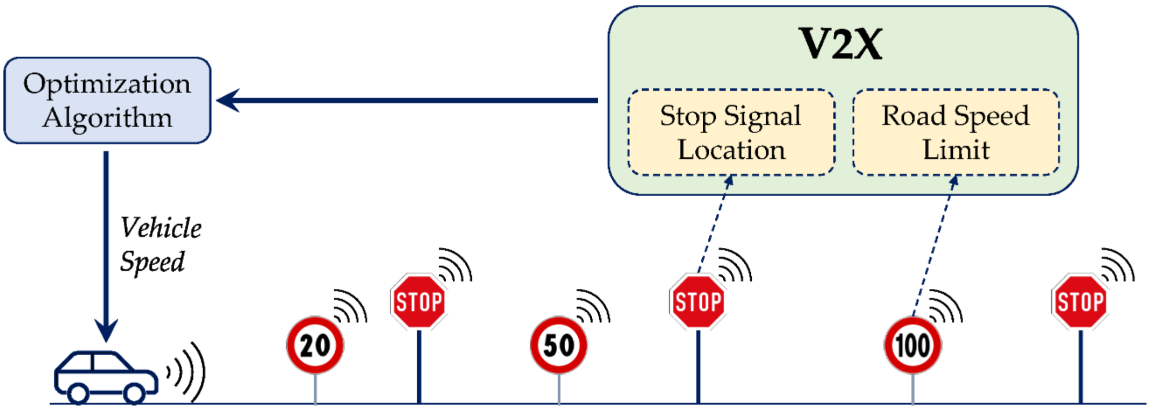
Politecnico di Torino, Energy Department studies:





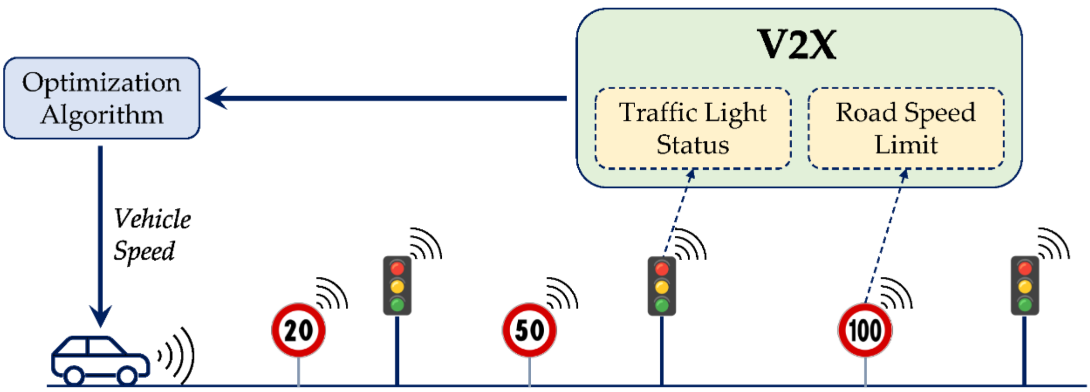
Scenario #1

Almost 30% of the energy savings can be achieved while reducing travel time by almost 10%. Regenerative braking was not considered in this analysis, so all energy required for braking was considered lost.

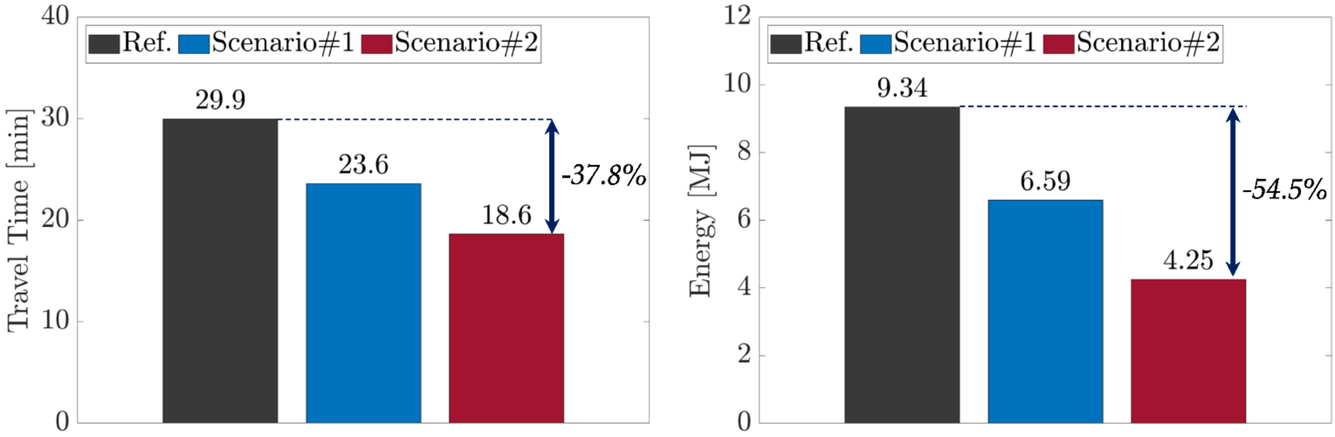


Scenario #2

Adaptation to traffic lights. In an urban environment, the energy required by the vehicle can be reduced by half while travel time is reduced by more than 35%.



Scenario #1 och #2



Se: [Energies | Free Full-Text | Eco-Driving Optimization Based on Variable Grid Dynamic Programming and Vehicle Connectivity in a Real-World Scenario (mdpi.com)]