Report on GHG emissions in transport modelling

Interreg
Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
SUMBA

CONTENT

INTRODUCTION

Mobility is an essential part of daily life and vital for society and the economy. Our quality of life depends on an efficient and accessible transport system. At the same time, transport is also a major cause of pollution in the European Union (EU), contributing to climate change, air pollution and noise pollution. Most importantly, transport is also one of the biggest contributors to greenhouse gas emissions. Against the background of the discussions on reducing CO2 emissions and the fact that the transport sector has not seen the same gradual decline in emissions as other sectors, the evaluation of measures with regard to their CO2 reduction potential is becoming increasingly important.

Therefore, the project partners in the SUMBA+ project have addressed this issue and looked at how an assessment of the planned measures can also be made with regard to their effect on CO2 emissions. The focus was on the analysis of measures on transport demand and traffic flow and the resulting local changes in greenhouse gas emissions. Emissions resulting from the production, maintenance and, if necessary, dismantling of infrastructures and means of transport as well as electricity production were not considered.

As part of this work, two webinars were held on the topic and the project partners City of Växjö and Riga Planning Region have quantified the CO2 saving potential of their measures.

This report is a brief documentation of the work, complementing the detailed documentation that both project partners have also published. The first part summarises essential background information on the determination of transport-related CO2 emissions. This is followed by a brief summary of the two webinars and the main findings discussed. Sections three and four briefly present the approach and results for the two case studies of the city of Växjö and the urban area of Riga.

BACKGROUND INFORMATION ON DETERMINATION OF TRANSPORT RELATED CO2 EMISSIONS

Transport is one of the largest emitters of greenhouse gases. For emission calculation, the transport sector is divided into road, rail, shipping and air traffic. Within the SUMBA+ project, measures are evaluated that can have an impact on transport demand in passenger transport as well as on traffic flow. Accordingly, the further explanations focus on the determination of emissions in road transport.

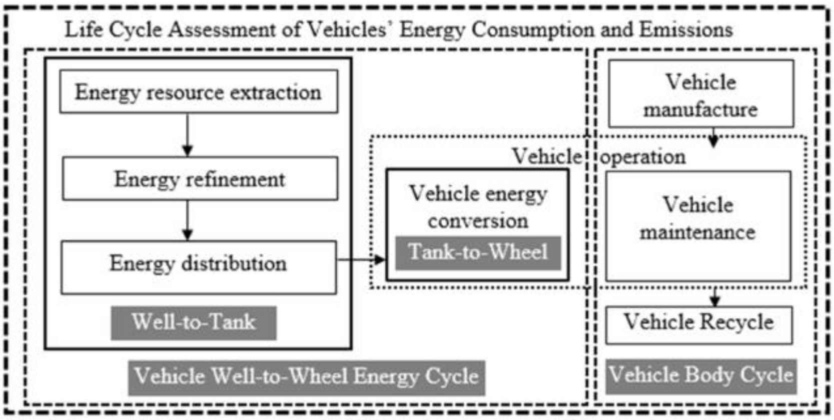

Figure 1: Framework of Life Cycle Assessment (Zheng 2021)

For the purpose of recording greenhouse gas emissions, different elements can be considered. As shown in Figure 1, an assessment of emissions over the lifetime of a vehicle includes both the emissions generated during the creation of the vehicle (Vehicle Body Cycle) and the emissions emitted during the operation of the vehicle (Well-to-Wheel). The Well-to-Wheel perspective covers the entire energy consumption and CO2 emissions of a fuel caused by production, supply and use and can be further differentiated: Well-to-Tank includes the emissions that occur during the provision of the respective fuel (e.g. extraction, processing and transport of the fuel), whereas Tank-to-Wheel records the emissions that occur during the combustion of fuels in the engine of a motor vehicle (see Figure 2).

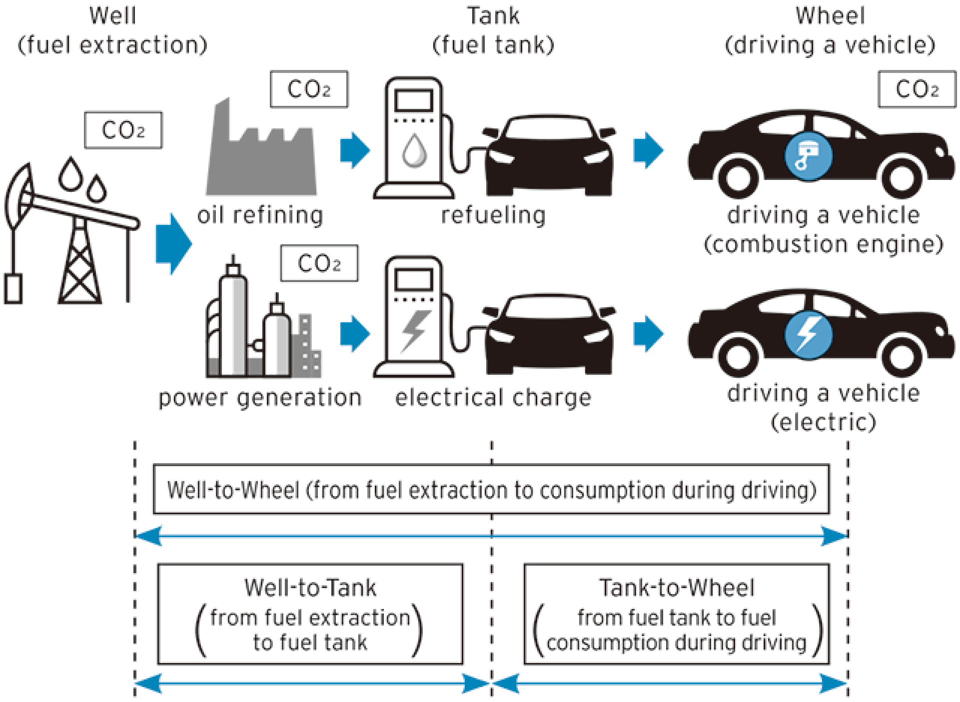

Figure 2: Conceptual diagram of Well-to-Wheel (Mazda 2016)

The statistics on CO2 emissions from the transport sector refer to a sub-sector in the energy chain of a vehicle that extends from energy input to energy output, i.e. Tank-to-Wheel (TTW).

The carbon content of fuels is constant; during combustion of the fuel, most carbon atoms combine with two oxygen atoms each to form CO2 molecules. Other compounds are hardly ever formed. Therefore, the amount of CO2 produced can be calculated directly from the consumption; burning one litre of petrol releases 2.33 kg of CO2, burning one litre of diesel releases 2.65 kg of CO2 (Juhrich 2016). Therefore, combustion-related CO2 emissions are calculated by multiplying the relevant fuel data, as obtained from statistics, by the applicable emission factors. In addition to direct CO2 emissions, the most important other greenhouse gases are also taken into account as CO2 equivalents - depending on their climate impact (e.g. CH4 and N2O).

However, the fuel consumption of vehicles themselves depends on various factors such as vehicle type, speed, and driving environment. With the help of emission factors, these different situations are reflected in order to obtain emission values that are as realistic as possible. They describe the emitted mass of a compound per driven distance and can be distinguished for various situations.

At least two emission models are available for the European region. The emission calculator COPERT (https://www.emisia.com/utilities/copert/) is coordinated and further developed by the European Environment Agency (EEA) and covers a large number of European countries and their characteristics. The second emission model HBEFA (The Handbook Emission Factors for Road Transport https://www.hbefa.net/e/index.html) was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. Today, further countries (Sweden, Norway, France) as well as the JRC (European Research Center of the European Commission) support HBEFA.

In a first step, vehicle strata are defined, where each vehicle stratum represents a group of vehicles with the same or very similar emission behaviour. The mix of vehicle strata corresponds to the fleet composition and can vary by country. For the calculation of emissions, it is not only the composition of the vehicle population that is relevant, but mostly the mileage-weighted composition, as different vehicle classes have different mileages. In addition, emissions from road vehicles are significantly dependent on the way the vehicles are operated and driven. For example, emissions are increased after a cold start compared to an already warm engine. Also of relevance are the driving patterns that predominate on a certain stretch of road or road type and in different traffic situations. Both of the above-mentioned emission models can reflect these aspects through the variety of emission factors available.

In a further step, the traffic volume must be determined with the help of traffic models, counts or estimates. In a final step, these values are multiplied by the emission factors to derive the emission quantities. As an example, the software PTV Visum for the macroscopic modelling of transport networks and transport demand, includes procedures for calculations of emissions by using the HBEFA emission factors for this purpose. Further information on the emission factors and the procedures can be found on the websites for the two emission models mentioned above.

WEBINARS ON MODELLING CO2 EMISSIONS

An international workshop on the use of traffic models as a basis for the analysis of transport-related CO2 emissions was planned as part of the project activities. Due to the pandemic, the international workshop was replaced by two webinars.

The first webinar aimed to give an introduction to the topic as well as theoretical background on emission modelling. Kay Gade from the DLR Institute of Transport Research introduced the topic by presenting the different transport-related emissions such as greenhouse gases, particles and noise, with a focus on greenhouse gases. It was also shown that the transport sector in the EU, in contrast to the other sectors, has not reduced its greenhouse gas emissions compared to 1990, but has further increased them. Furthermore, it became clear that 60 percent of the emissions were emitted by cars. In order to reduce emissions at all levels - from national to local in cities - a variety of measures are possible: measures to promote and strengthen a modal shift towards environmentally friendly and sustainable transport options, the reduction of transport volumes, the increase of electromobility as well as measures to improve traffic flow, to name but a few. Measures can have different effects on the transport system and the CO2 reduction potential in terms of time, space and amount. Against the background of scarce public funds, it can therefore be in the interest of the municipalities to evaluate measures also with regard to their reduction potential.

Against this background, Daniel Krajzewicz from the DLR Institute for Transport Research explained in detail how vehicular emissions are modelled, which input parameters are necessary and which inventory data sets are available. He also focused on the challenges that arise in emissions modelling as well as the different modelling levels and the level of detail of the different models. He also showed the two leading manuals on emission factors and in which (European) countries they are valid. His presentation was rounded off by showing selected project results.

In the second webinar, the speakers used project examples to present the challenges and results of determining transport-related emissions at different geographical levels, from a nationwide view to the level of an individual city and its measures. The first presentation by Stefan Seum and Dennis Seibert from the DLR Institute of Transport Research showed the procedure and results of a modelling of CO2 emissions from transport for the whole of Germany. The presentation by Daniella Bonilla Estrella from KCW Consulting for Public Transport followed on from this and presented the climate targets and mobility at the level of the German federal state of Bavaria, as well as initial approaches to evaluating the underlying measures. The webinar was concluded by the presentation of Therese Zieden from Ramboll Consulting. The presentation focused on the identification of the impacts of measures at city level. The project partner, the city of Växjö, is investigating to what extent car traffic can be reduced in the city centre. For this purpose, traffic that does not have the city centre as its source or destination is to be diverted to larger bypasses by means of construction measures, among other things. In addition to the traffic effects, the effects on traffic-related emissions have also been studied.

In total, about 50 participants took part in the webinars. The speakers and the participants of the webinars agreed that the assessment of measures with regard to their effects on greenhouse gas emissions is a useful extension of the existing assessment methods. However, the complexity of the calculation, the necessary input data and any necessary software requirements stand in the way of simple application, depending on the problem and the level of detail required.

The presentations of the webinars are attached to the report.

EMISSIONS AND TRANSPORT MODELLING IN VÄXJÖ MUNICIPALITY

During the SUMBA+ project, Växjö municipality used the help of its PTV Visum transport model to analyse transport-related emissions in the municipality today and in 2040. The method was used to assess different measures for promoting sustainable mobility: cycling walking and public transit. These measures include a circulation plan[1] that uses a series of street closures to direct car traffic to a ring road that, in turn results in safer streets for cycling and walking. In addition, transfer points such as park and ride and bike and ride were assessed in the model to predict their potential for increased intermodal travel from neighbouring villages to Växjö city. The potential, according to the model, was however not sufficient to create a meaningful reduction in car traffic and thus emissions. An emissions analysis was therefore omitted for this measure. Low potential is likely due the rural nature, and therefore low traffic demand, of the municipality outside the city and long trip times for intermodal trips compared to the car.

Emissions in Växjö municipality: method and results

The software PTV Visum has a built-in module for calculating traffic emissions. The module is based on HBEFA (Handbook of emission factors) 4.1 and uses all available parameters and factors that are available in the manual. Sweden is one of the countries covered by HBEFA.

The issue calculation in Växjö transport model depends on:

- Road type - The entire road network has been classified based on road types used in HBEFA.
- Road fleet - An approximate set of vehicle types in Sweden,
- Proportion of cold starts - An important factor that is calculated emissions from all cold starts.
- Reference year - In this case in 2018 and 2040.

The proportion of cold starts is the only one that does not have a default value and must be specified for each area in the traffic model. In this case, the proportion of cold starts has been calculated based on land use in each area. It has been assumed that 65 % of all journeys from a home are a cold start and that 20 % of all journeys from a workplace / commercial area are a cold start. The proportion of cold starts from home (journey start) depends on whether the car is in a heated garage / has an engine heater or not, or if the car has already been used during the day. As there is very little research on this and the variation is great in Sweden with the seasons, this has been considered a sufficiently good assumption.

The table below shows the results of the emission calculations, the calculations include both car traffic and truck traffic. The reason why CO and HC decrease is the increased proportion of electric cars that are adopted in the car fleet by the year 2040. PM has decreased since 1990 and still does today, this is partly due to better catalysts, partly to better materials in tires and asphalt. The same development is also predicted in the future. Emissions of CO2 and NOx, on the other hand, will increase in the future due to the increasing travel by car.

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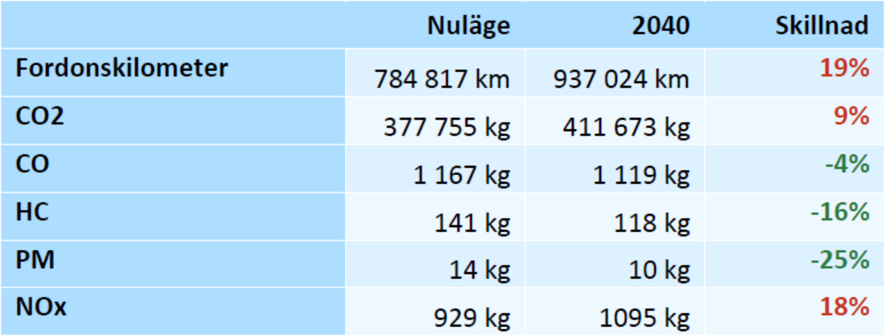
[1] A separate and more detailed study on the circulation plan for Växjö was conducted in SUMBA+ activity 3.2 and can be found on the project website, sumba.eu.

Table 1 - Comparison of total distance travelled and emissions. ("Nuläget" = current situation; "Skillnad" = difference)



	Nuläge	2040	Skillnad
Fordonskilometer	784 817 km	937 024 km	19%
CO2	377 755 kg	411 673 kg	9%
CO	1 167 kg	1 119 kg	-4%
HC	141 kg	118 kg	-16%
PM	14 kg	10 kg	-25%
NOx	929 kg	1095 kg	18%

Circulation plan

Emission calculations have been carried out for two alternatives of a circulation plan in Växjö, so-called alternative C (figure 1) and alternative E (figure 2), that were compared to the current situation (2018 reference). Alternative E has also been analysed with expanded major highway infrastructure projects, such as the Fagrabäck and Helgevärma junctions, and additional lanes on Norrleden. This third scenario is referred to as alternative E+.

The table below shows the results of the emission calculations for all scenarios. By design, the circulation plan allows cars to arrive at their destination but sometimes take a longer route to get there, often traveling on a so-called ring road to travel from one zone to another. As expected, the different scenarios resulted in longer total car travel distances in the city. Alternative C results in an increase of total driven distance by 2 %, with a 17 % increase for alternative E and 19 % increase for alternative E+. Emissions increase minimally with alternative C (3 %) but more sharply with alternative E (by 30 %) due to increased congestion. Alternative E+, with the infrastructure investments to junctions and highway capacity, reduces congestion and therefore emissions slightly by 19 % compared to current.

It should be noted that the sensitivity of the transport model to modal shift is not sufficient to predict a shift between the different scenarios. There is therefore no meaningful modal change between the current situation and the different scenarios, despite for example travel times increasing significantly in alt E. In reality, a shift in modal share in conjunction with alternative E might be sufficient to reduce congestion on the ring road and result in lower emissions for this scenario but not accounted for in the model.

Table 2 - Comparison of total travel distance and circulation plan alternatives (Fordonskm = total travel distance)

	Scenario 1 (Nuläge 2018)	Scenario 2 (Alt C)	Scenario 3a (Alt E)	Scenario 3b (Alt E+)
Fordonskm	1 284 349 km	1 314 189 km (+2%)	1 503 609 km (+17%)	1 526 495 km (+19%)
CO2	148 912 kg	153 758 kg (+3%)	193 442 kg (+30%)	177 802 kg (+19%)
CO	452 kg	458 kg (+1%)	497 kg (+10%)	480 kg (+6%)
HC	70.07 kg	70.44 kg (+1%)	74.04 kg (+6%)	71.76 kg (+2%)
PM	3.47 kg	3.58 kg (+3%)	4.48 kg (+29%)	4.11 kg (+18%)
NOx	409 kg	421 kg (+3%)	517 kg (+26%)	480 kg (+17%)

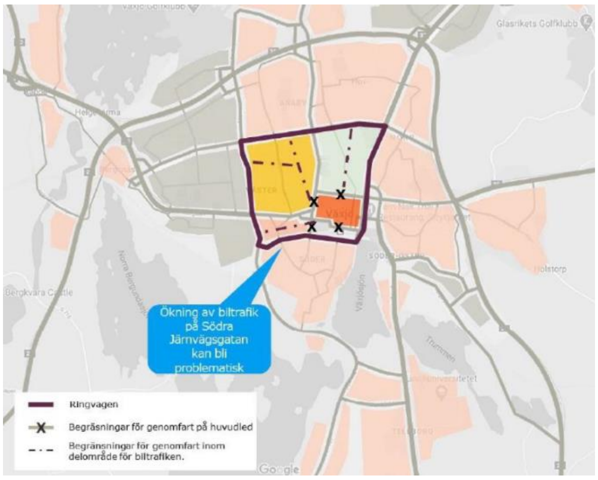


Figure 4: Alternative C

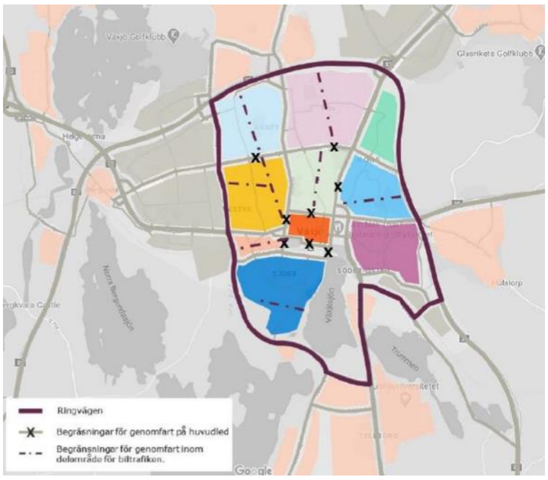


Figure 5: Alternative E

EVALUATION OF CO2 EMISSION REDUCTION POTENTIAL AND MODELLING FOR RIGA METROPOLITAN AREA

The transport sector and population behaviour have a significant impact on the quality of the environment. In the current situation, most CO2 emissions from the transport sector are generated by private car transport. It is essential to reduce trips by private cars by replacing it with public transport or micro-mobility tools. To assess and forecast the volume of CO2 emissions from the transport system in the Riga Metropolitan Area, a methodology has been developed to calculate the CO2 reduction in the implementation of the planned mobility points and cycling infrastructure development projects.

The report entitled "Evaluation of CO2 Emission Reduction Potential and Modeling for Riga Metropolitan Area Transport System (SUMBA +)" includes both the description of the current situation of Riga metropolitan area mobility and the methodology for calculating the CO2 reduction in the Riga metropolitan area. The methodology for the implementation of mobility points and cycling infrastructure development projects has been developed considering the existing mobility habits and flows of citizens, the availability of potential services, as well as examples of good practice in European countries. Riga metropolitan area transport system CO2 emissions reduction potential and forecasting are involved in the development of Riga planning region municipalities, passenger transport service providers, etc. The report should be integrated into mobility points and cycling infrastructure development projects to assess the reduction of CO2 emissions, both in the short term and in the long term.

The report concludes the potential and forecasting for the reduction of CO2 emissions of the Riga metropolitan area transport system and and can be found on the project website, sumba.eu. A presentation about the taken steps as well as the results was held at the final conference, the presentation slides can be found in Annex II.

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Juhrich, K. (2016). CO2 Emission Factors for Fossil Fuels. German Environment Agency (UBA). Online available https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf

Mazda (2016). Aiming to make cars that are sustainable with the Earth and Society. Online available https://www.mazda.com/en/csr/special/2016_01/

Zheng, G., Peng, Z.J. (2021). Life Cycle Assessment (LCA) of BEV's environmental benefits for meeting the challenge of ICExit (Internal Combustion Engine Exit). DOI: 10.1016/j.egyr.2021.02.039

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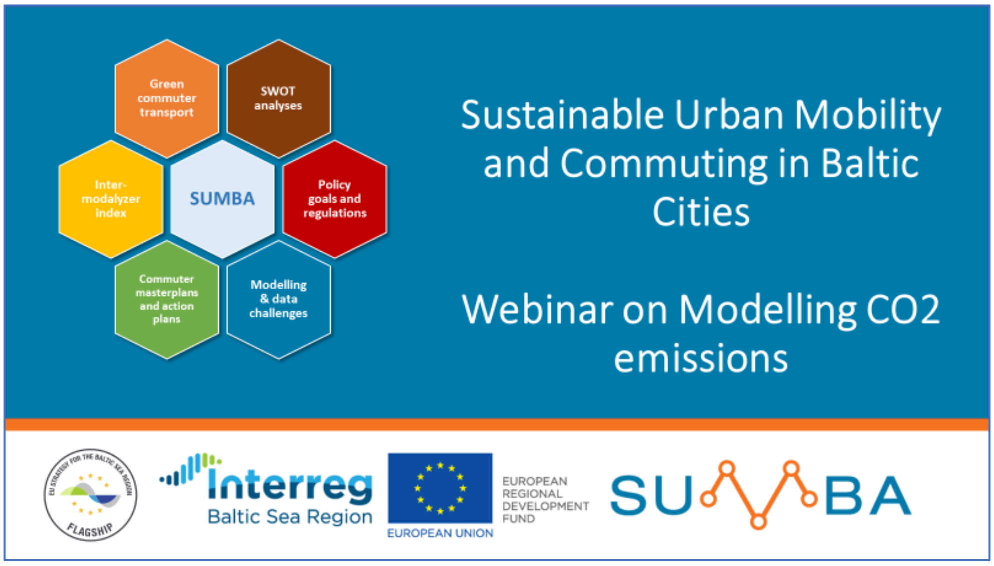
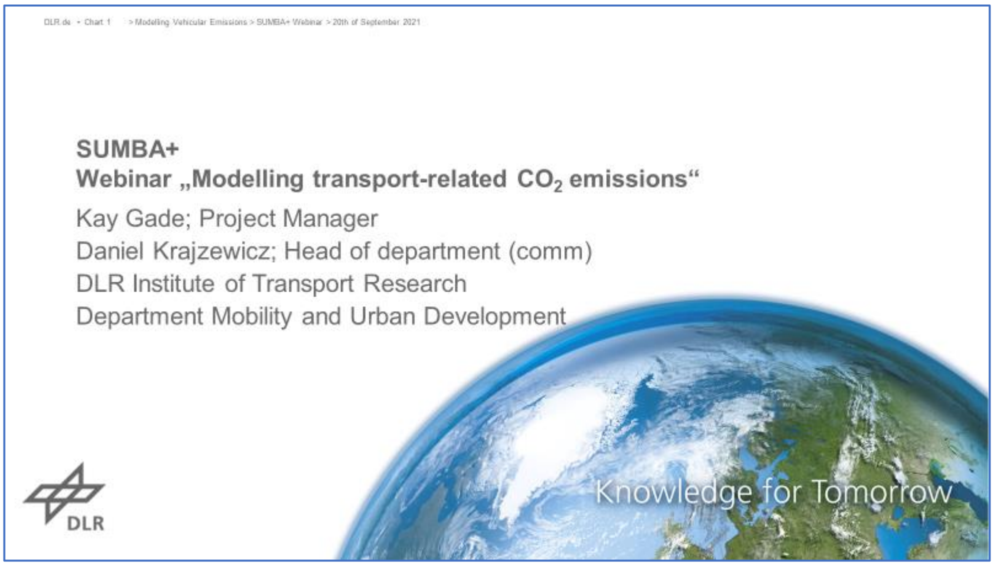
ANNEX I: SLIDES OF THE WEBINARS



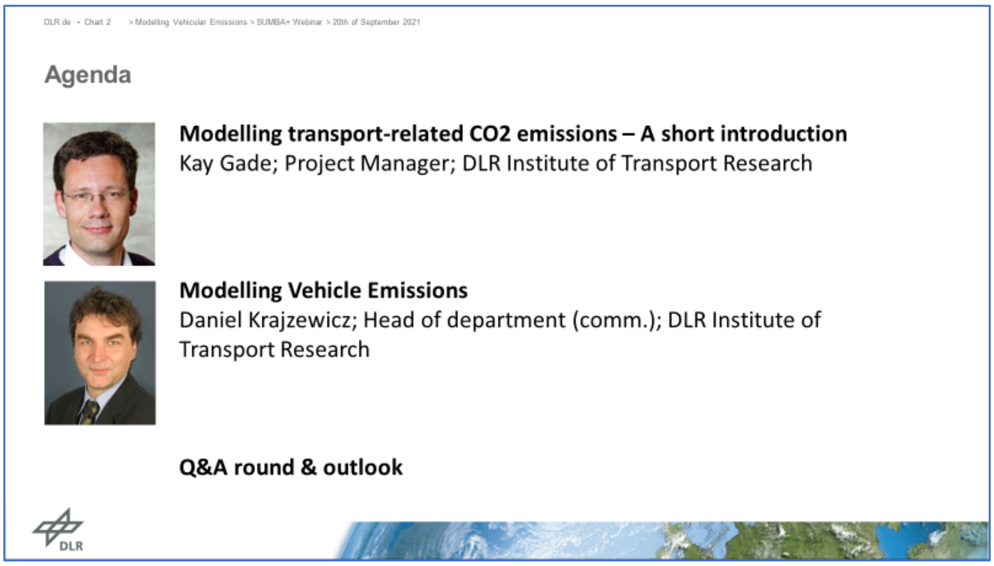
Sustainable Urban Mobility and Commuting in Baltic Cities

Webinar on Modelling CO2 emissions



DLR.de • Chart 1 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

SUMBA+
Webinar „Modelling transport-related CO$_2$ emissions“
Kay Gade; Project Manager
Daniel Krajzewicz; Head of department (comm)
DLR Institute of Transport Research
Department Mobility and Urban Development



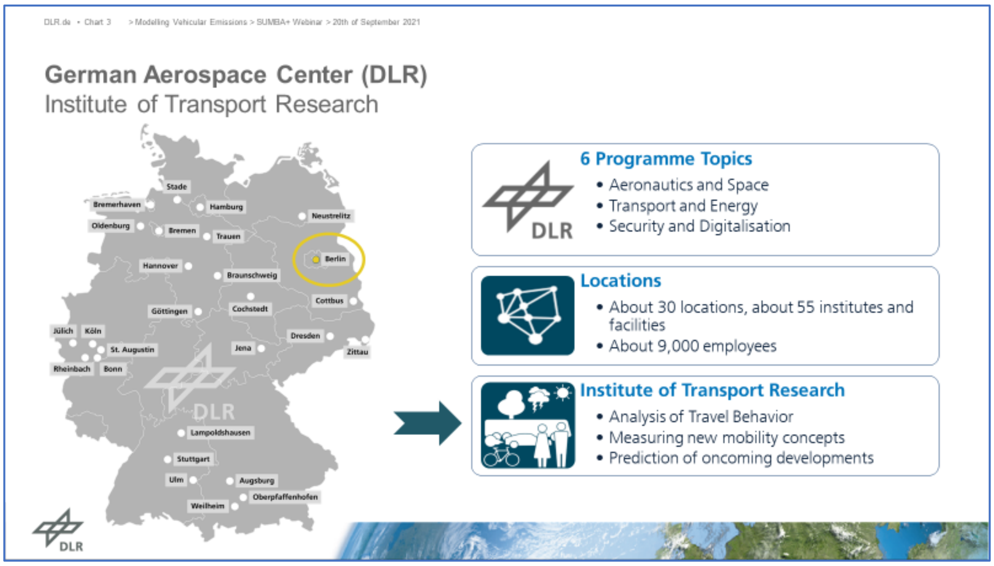
DLR.de • Chart 2 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Agenda

Modelling transport-related CO2 emissions – A short introduction
Kay Gade; Project Manager; DLR Institute of Transport Research

Modelling Vehicle Emissions
Daniel Krajzewicz; Head of department (comm.); DLR Institute of Transport Research

Q&A round & outlook



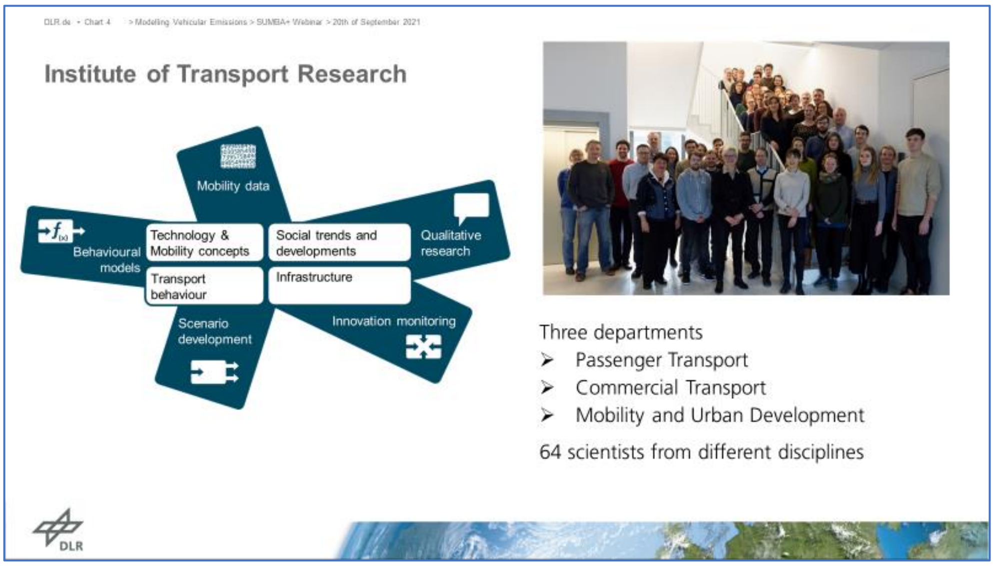
DLR.de • Chart 3 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

German Aerospace Center (DLR)
Institute of Transport Research

6 Programme Topics
- Aeronautics and Space
- Transport and Energy
- Security and Digitalisation

Locations
- About 30 locations, about 55 institutes and facilities
- About 9,000 employees

Institute of Transport Research
- Analysis of Travel Behavior
- Measuring new mobility concepts
- Prediction of oncoming developments



DLR.de • Chart 4 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Institute of Transport Research

Three departments
- Passenger Transport
- Commercial Transport
- Mobility and Urban Development

64 scientists from different disciplines

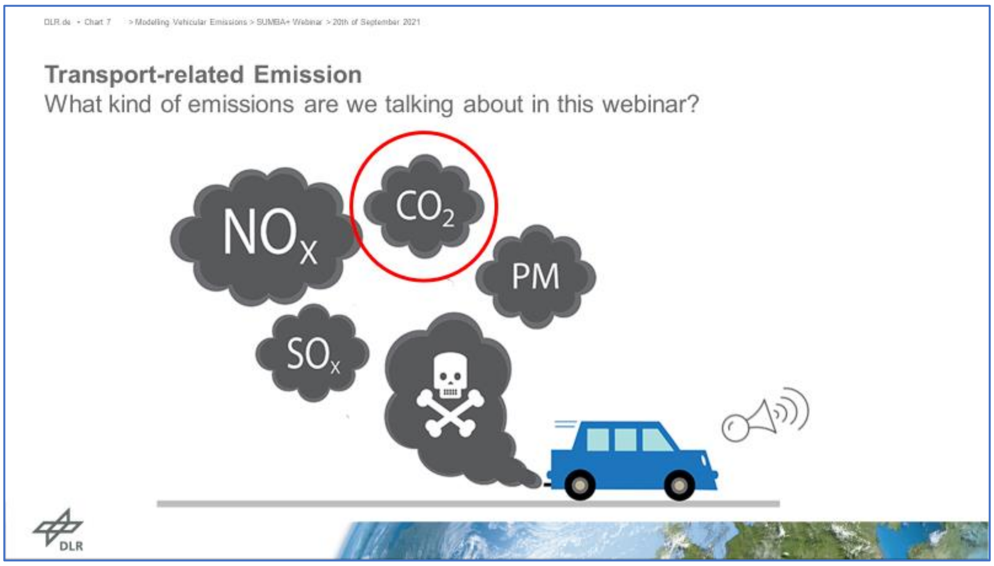
Transport related challenges

- Private car matters!
- Ongoing suburbanization
- PT not able to cope with new developments and customer needs
- Infrastructure for other transport modes and the combination is rarely developed

- Main aim: Development of tools that should help planners integrate intermodal solutions into urban mobility plans.

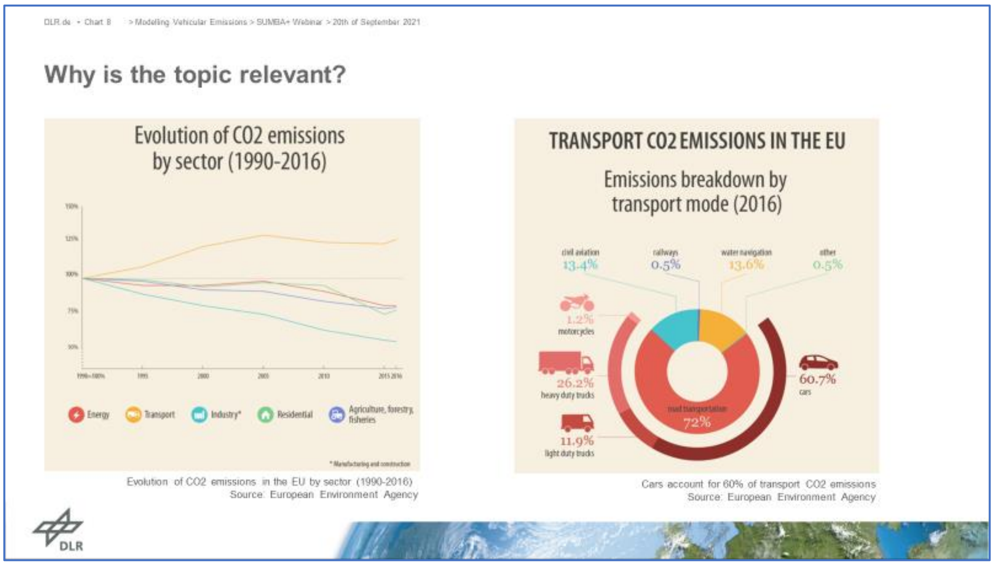
SUMBA +

- April 2021 – December 2021
- Continuation and further development of activities related to the main stage project
  - Driving implementation of commuting master plans in pilot regions forward
  - **Advancing modelling** to support the implementation of commuting master plans
  - Cycling library cookbook
  - Further development Intermodalyzer



DLR.de • Chart 7 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Transport-related Emission
What kind of emissions are we talking about in this webinar?

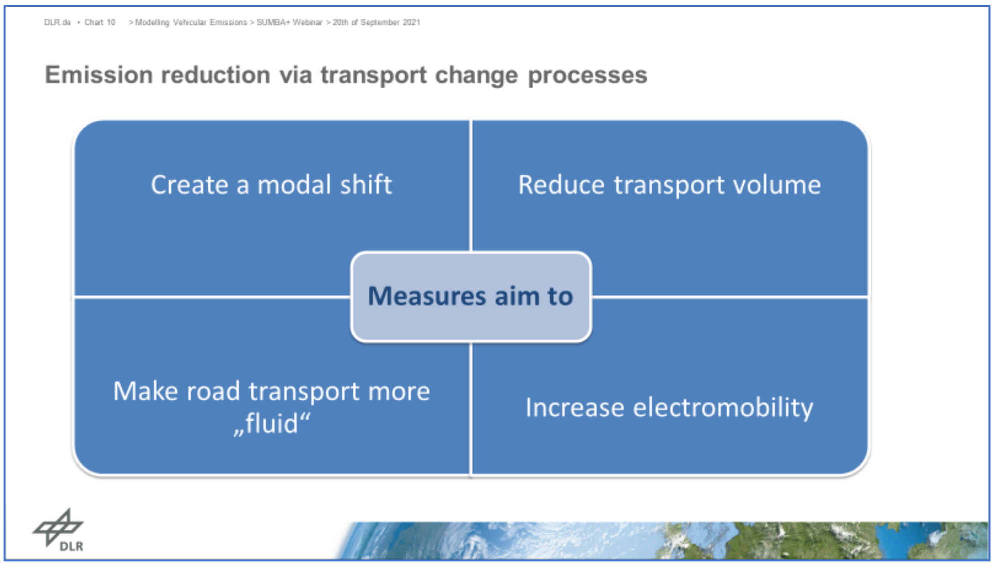


DLR.de • Chart 8 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Why is the topic relevant?

Evolution of CO2 emissions in the EU by sector (1990-2016)
Source: European Environment Agency

Cars account for 60% of transport CO2 emissions
Source: European Environment Agency



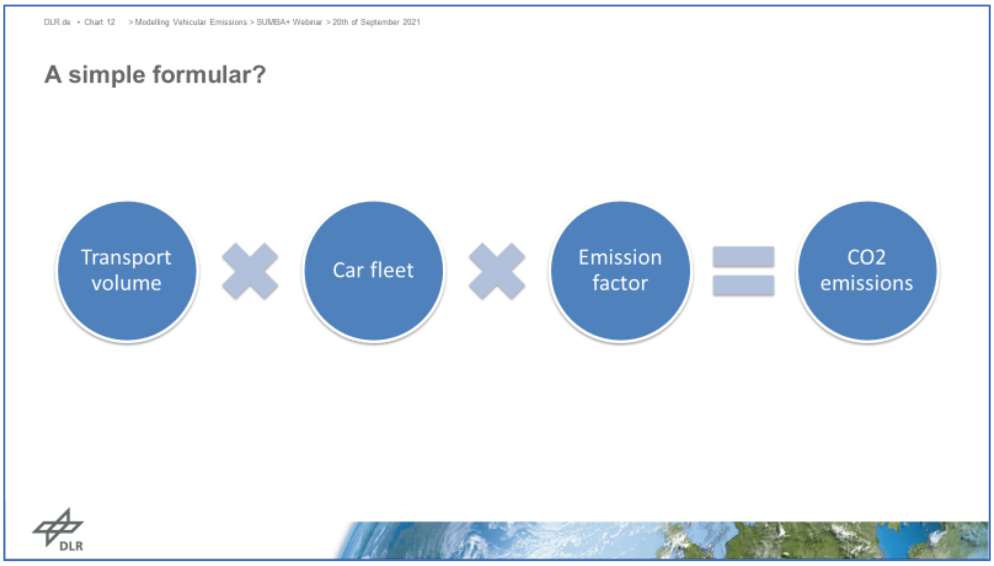
Emission reduction via transport change processes

Measures aim to

- Create a modal shift
- Reduce transport volume
- Make road transport more „fluid“
- Increase electromobility

Ambitions & context

- Goal of reducing emissions at the national level as well as in the cities
- Assessing different measurements for a sustainable urban transport
- Assessing CO2 emission reduction potential becomes more important

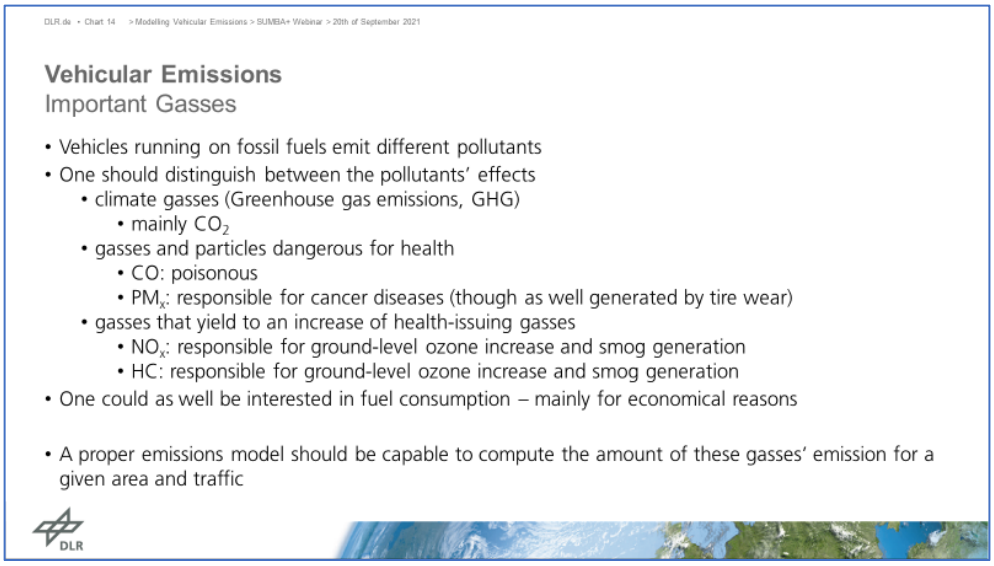


A simple formular?

Transport volume × Car fleet × Emission factor = CO2 emissions

Modelling Vehicular Emissions

SUMBA+ Workshop, 20th of September 2021
Institute of Transport Research, German Aerospace Center
Daniel Krajzewicz



Vehicular Emissions
Important Gasses

- Vehicles running on fossil fuels emit different pollutants
- One should distinguish between the pollutants' effects
  - climate gasses (Greenhouse gas emissions, GHG)
    - mainly CO_2
  - gasses and particles dangerous for health
    - CO: poisonous
    - PM_x: responsible for cancer diseases (though as well generated by tire wear)
  - gasses that yield to an increase of health-issuing gasses
    - NO_x: responsible for ground-level ozone increase and smog generation
    - HC: responsible for ground-level ozone increase and smog generation
- One could as well be interested in fuel consumption – mainly for economical reasons

- A proper emissions model should be capable to compute the amount of these gasses' emission for a given area and traffic

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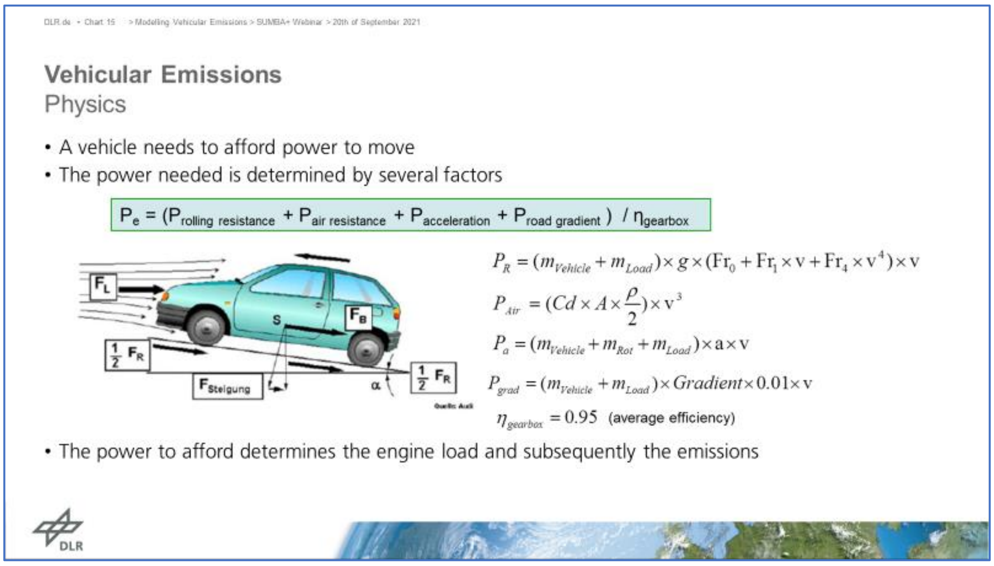


Vehicular Emissions
Physics

- A vehicle needs to afford power to move
- The power needed is determined by several factors

$$\boxed{P_e = (P_{\text{rolling resistance}} + P_{\text{air resistance}} + P_{\text{acceleration}} + P_{\text{road gradient}}) \; / \; \eta_{\text{gearbox}}}$$

$$P_R = (m_{Vehicle} + m_{Load}) \times g \times (\mathrm{Fr}_0 + \mathrm{Fr}_1 \times \mathrm{v} + \mathrm{Fr}_4 \times \mathrm{v}^4) \times \mathrm{v}$$

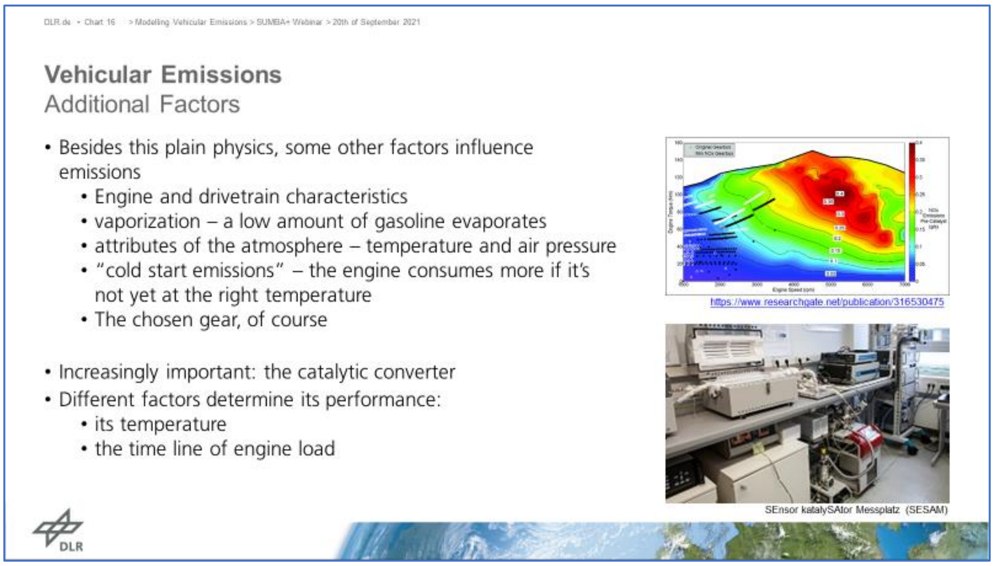
$$P_{Air} = (Cd \times A \times \frac{\rho}{2}) \times \mathrm{v}^3$$

$$P_a = (m_{Vehicle} + m_{Rot} + m_{Load}) \times \mathrm{a} \times \mathrm{v}$$

$$P_{grad} = (m_{Vehicle} + m_{Load}) \times Gradient \times 0.01 \times \mathrm{v}$$

$$\eta_{gearbox} = 0.95 \quad \text{(average efficiency)}$$

- The power to afford determines the engine load and subsequently the emissions



Vehicular Emissions
Additional Factors

- Besides this plain physics, some other factors influence emissions
    - Engine and drivetrain characteristics
    - vaporization – a low amount of gasoline evaporates
    - attributes of the atmosphere – temperature and air pressure
    - "cold start emissions" – the engine consumes more if it's not yet at the right temperature
    - The chosen gear, of course

- Increasingly important: the catalytic converter
- Different factors determine its performance:
    - its temperature
    - the time line of engine load

https://www.researchgate.net/publication/316530475

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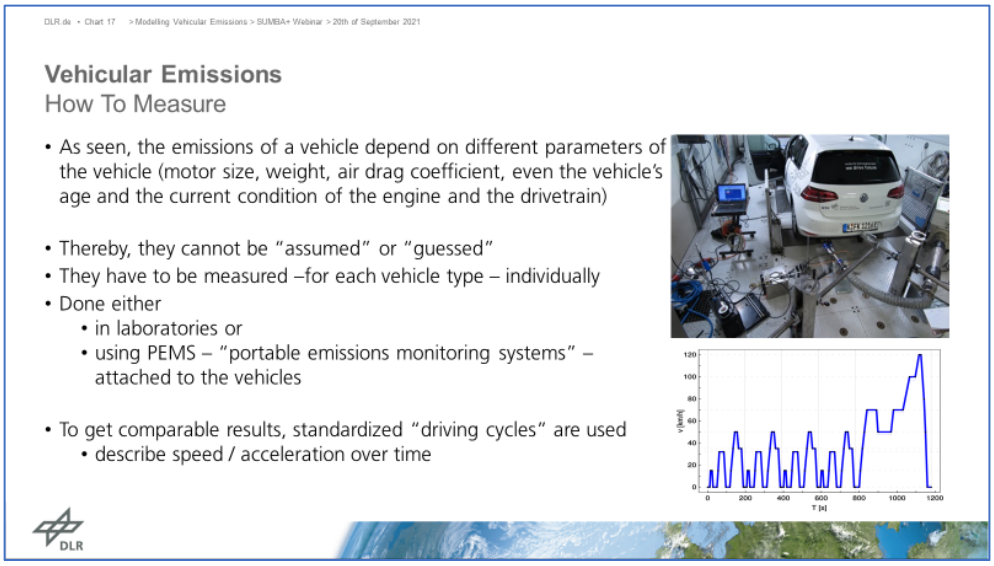
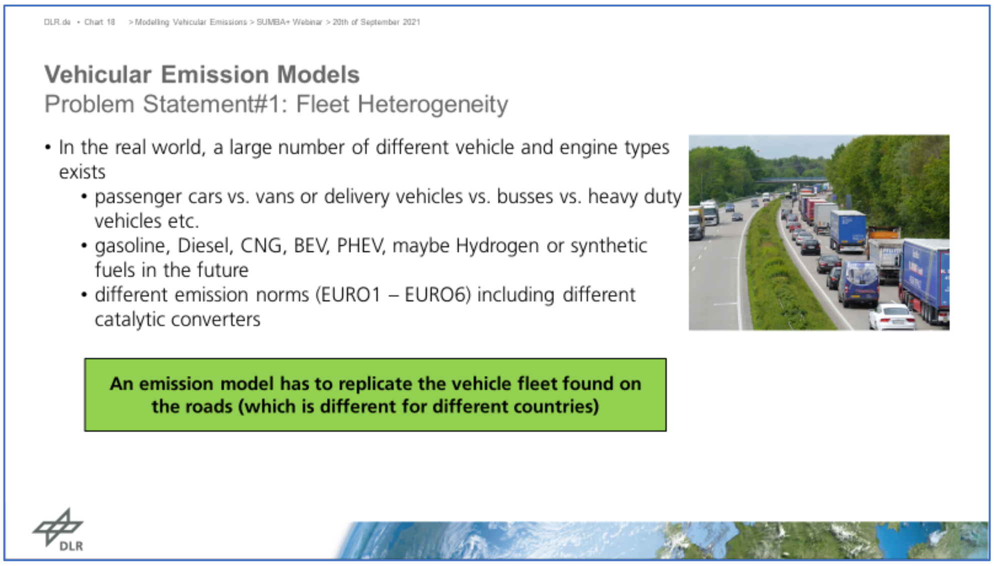


Vehicular Emissions
How To Measure

- As seen, the emissions of a vehicle depend on different parameters of the vehicle (motor size, weight, air drag coefficient, even the vehicle's age and the current condition of the engine and the drivetrain)

- Thereby, they cannot be "assumed" or "guessed"
- They have to be measured –for each vehicle type – individually
- Done either
    - in laboratories or
    - using PEMS – "portable emissions monitoring systems" – attached to the vehicles

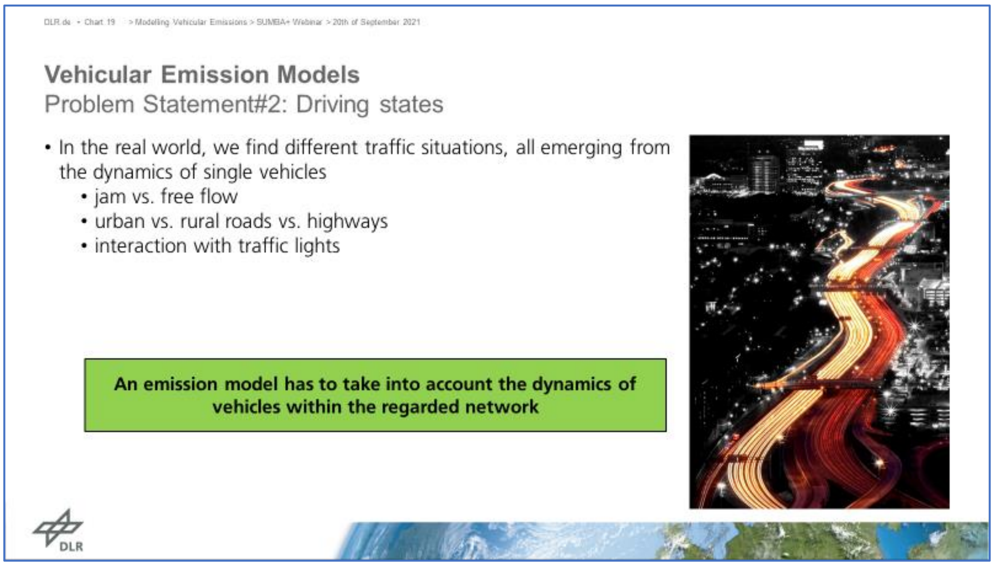
- To get comparable results, standardized "driving cycles" are used
    - describe speed / acceleration over time



Vehicular Emission Models
Problem Statement#1: Fleet Heterogeneity

- In the real world, a large number of different vehicle and engine types exists
    - passenger cars vs. vans or delivery vehicles vs. busses vs. heavy duty vehicles etc.
    - gasoline, Diesel, CNG, BEV, PHEV, maybe Hydrogen or synthetic fuels in the future
    - different emission norms (EURO1 – EURO6) including different catalytic converters

An emission model has to replicate the vehicle fleet found on the roads (which is different for different countries)

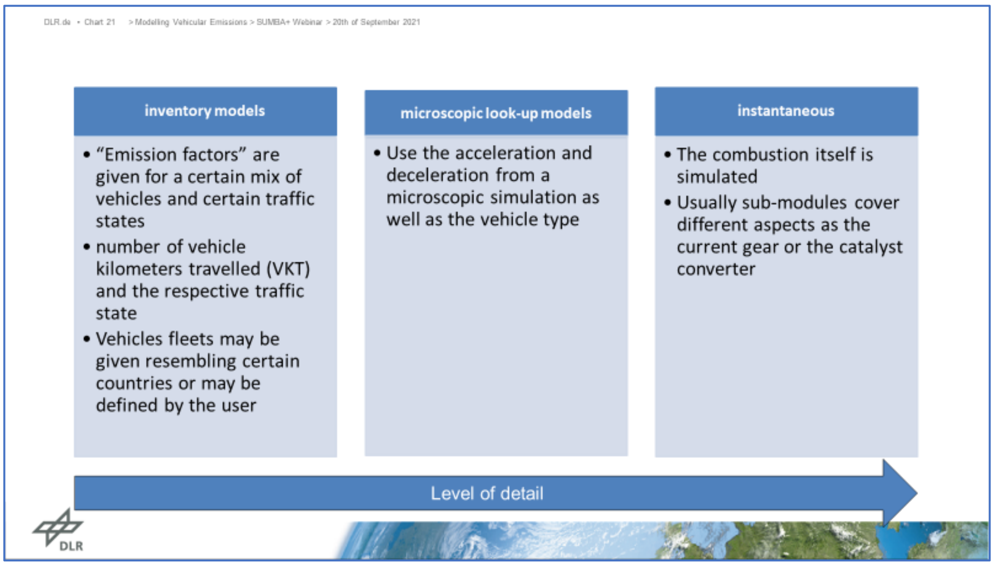


Vehicular Emission Models

Problem Statement#2: Driving states

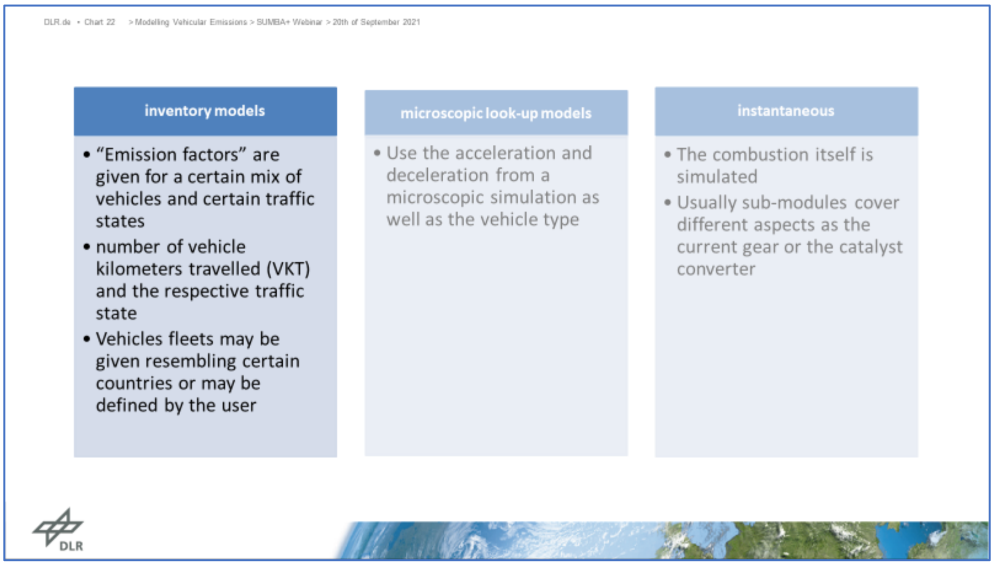
- In the real world, we find different traffic situations, all emerging from the dynamics of single vehicles
  - jam vs. free flow
  - urban vs. rural roads vs. highways
  - interaction with traffic lights

An emission model has to take into account the dynamics of vehicles within the regarded network



inventory models	microscopic look-up models	instantaneous
• “Emission factors” are given for a certain mix of vehicles and certain traffic states • number of vehicle kilometers travelled (VKT) and the respective traffic state • Vehicles fleets may be given resembling certain countries or may be defined by the user	• Use the acceleration and deceleration from a microscopic simulation as well as the vehicle type	• The combustion itself is simulated • Usually sub-modules cover different aspects as the current gear or the catalyst converter

Level of detail



inventory models	microscopic look-up models	instantaneous
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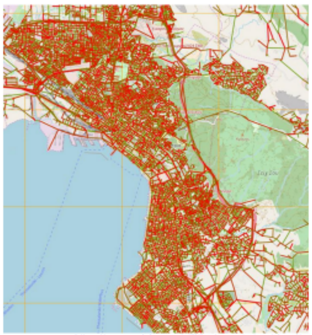
Inventory Models#1
COPERT - COmputer Programme to calculate Emissions from Road Transport

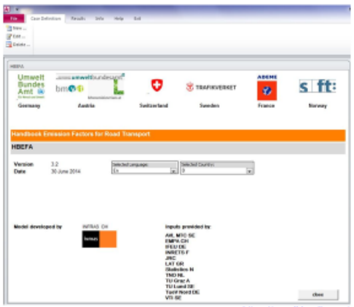
- Financed by the European Environment Agency (EEA)
- Part of the EMEP/CORINAIR Emission Inventory Guidebook
- Windows application, current version: COPERT 5 version 4.36
- Freeware, available at https://www.emisia.com/utilities/copert/
- Uses vehicle population, mileage, speed and other data such as ambient temperature
- Covers thermal stabilized engine operation ('hot' emissions), 'cold start' emissions, and non-exhaust emissions
- 24 passenger vehicle classes (6 different propulsion systems, four size classes each), 6 classes of light commercial vehicles, 30 heavy duty vehicle classes, 8 light vehicle classes



https://www.emisia.com/utilities/copert-street-level/

Inventory Models#2
HBEFA – Handbook of Emission Factors

- Financed by different European country agencies (Germany, Austria, Switzerland, Norway, France, …)
- Windows application, current version: HBEFA 4.1 with updates
- 250,- per license, available at https://hbefa.net/
- Uses fleet composition, traffic state,
- Covers thermal stabilized engine operation ('hot' emissions), 'cold start' emissions, and non-exhaust emissions
- Different vehicle classes (passenger, LDV, busses, HDV, motorcycles), different EURO emission norms
- Predefined vehicle fleets for different countries



Handbook Emission Factors for Road Transport

HBEFA

Version 3.2
Date 30 June 2014

Model developed by INFRAS CH

Inputs provided by:
AVL MTC SE
EMPA CH
IFEU DE
INRETS F
JRC
LAT GR
Statistics N
TNO NL
TU Graz A
TU Lund SE
TüV Nord DE
VTI SE

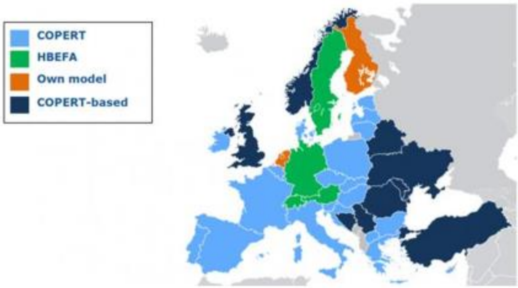
https://en.wikipedia.org/

Inventory Models#3
HBEFA – Handbook of Emission Factors

- COPERT and HBEFA are quite similar in features
- Difficult to decide on one
- The map of usage per country could help

- "COPERT-based" usually employs country-specific vehicle fleets

Vehicle emission models usage in Europe



inventory models	microscopic look-up models	instantaneous
• "Emission factors" are given for a certain mix of vehicles and certain traffic states • number of vehicle kilometers travelled (VKT) and the respective traffic state • Vehicles fleets may be given resembling certain countries or may be defined by the user	• Use the acceleration and deceleration from a microscopic simulation as well as the vehicle type	• The combustion itself is simulated • Usually sub-modules cover different aspects as the current gear or the catalyst converter

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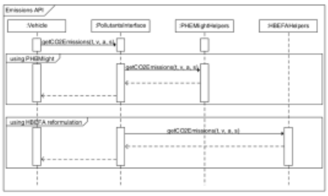
Derived Microscopic Emission Models#1
Features

- Usually directly implemented in microscopic simulations (PTV Vissim, SUMO)
- Most common method (for each vehicle)
  - get the speed and the acceleration computed in the last simulation step
  - use speed / acceleration and the vehicle's emission class to look up for the emissions

→very fast

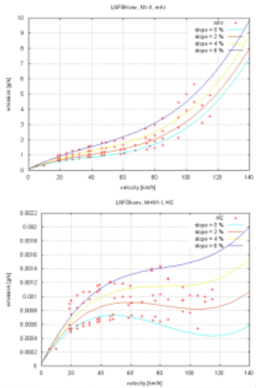
→Many possibilities to generate outputs
  - per vehicle (amount per trip)
  - per road or segment (emissions for each road)

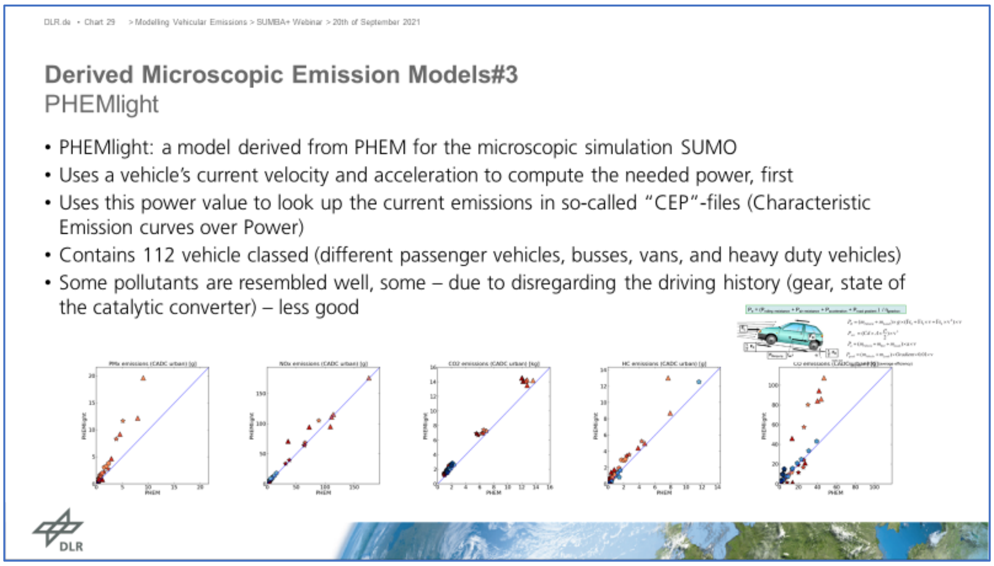


Derived Microscopic Emission Models#2
HBEFA-Derivation

- Using HBEFA version 3.1
- Free and included in SUMO

Some drawbacks
- Only some major classes were selected
- The dependency on acceleration had to be determined from the dependency on the slope of the road, given in HBEFA
- Not all pollutants' curves can be fit well to the used function





Derived Microscopic Emission Models#3
PHEMlight

- PHEMlight: a model derived from PHEM for the microscopic simulation SUMO
- Uses a vehicle's current velocity and acceleration to compute the needed power, first
- Uses this power value to look up the current emissions in so-called "CEP"-files (Characteristic Emission curves over Power)
- Contains 112 vehicle classed (different passenger vehicles, busses, vans, and heavy duty vehicles)
- Some pollutants are resembled well, some – due to disregarding the driving history (gear, state of the catalytic converter) – less good

---

inventory models	microscopic look-up models	instantaneous
• "Emission factors" are given for a certain mix of vehicles and certain traffic states • number of vehicle kilometers travelled (VKT) and the respective traffic state • Vehicles fleets may be given resembling certain countries or may be defined by the user	• Use the acceleration and deceleration from a microscopic simulation as well as the vehicle type	• The combustion itself is simulated • Usually sub-modules cover different aspects as the current gear or the catalyst converter

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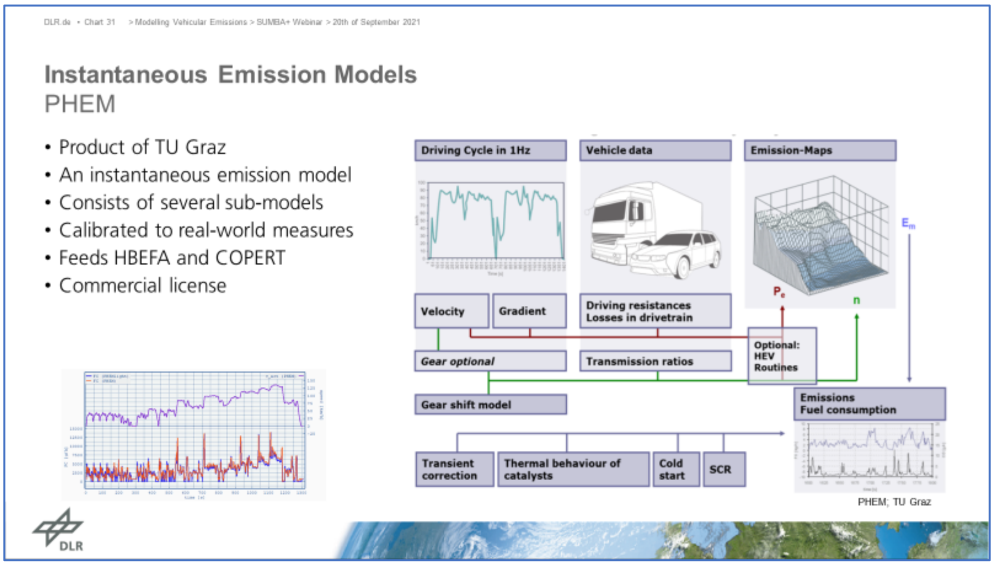


Instantaneous Emission Models
PHEM

- Product of TU Graz
- An instantaneous emission model
- Consists of several sub-models
- Calibrated to real-world measures
- Feeds HBEFA and COPERT
- Commercial license

PHEM; TU Graz

Evaluating Emission Models

- Difficult! Compare against what?
- First check: emission values for Brunswick (old HBEFA)

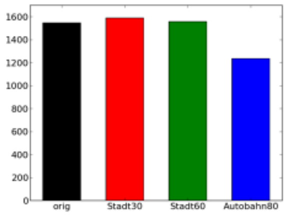
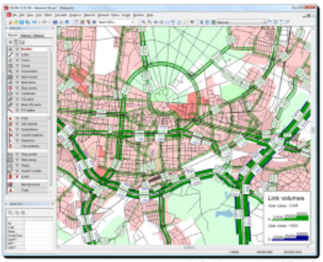


Abbildung 2.22: Treibhausgasemissionen des Gesamt-Verkehrs in 2008

- 521kt+126kt = 647kt p.a.; 647kt p.a./365 days ~= 1772 t
- 10 % error? Great, but: Same area? Same population? Who knows?

Applications for Models of Vehicular Emissions#1
Benchmarking Traffic Management Measures

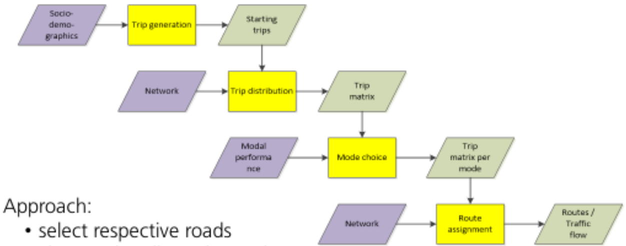
- Traffic management measures are usually evaluated on the level of complete cities – as they as well influence transit traffic
- Thereby, usually using macroscopic simulations
- Process
  - Build the base model, run it, compute emissions
  - Implement changes in the model, run it, compute emissions
  - Compute emissions
- Of course, one could think about an automatic optimization of the measure (but that's done very seldom)



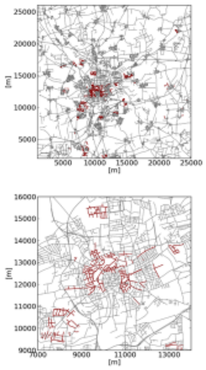
VISUM screenshot; PTV AG

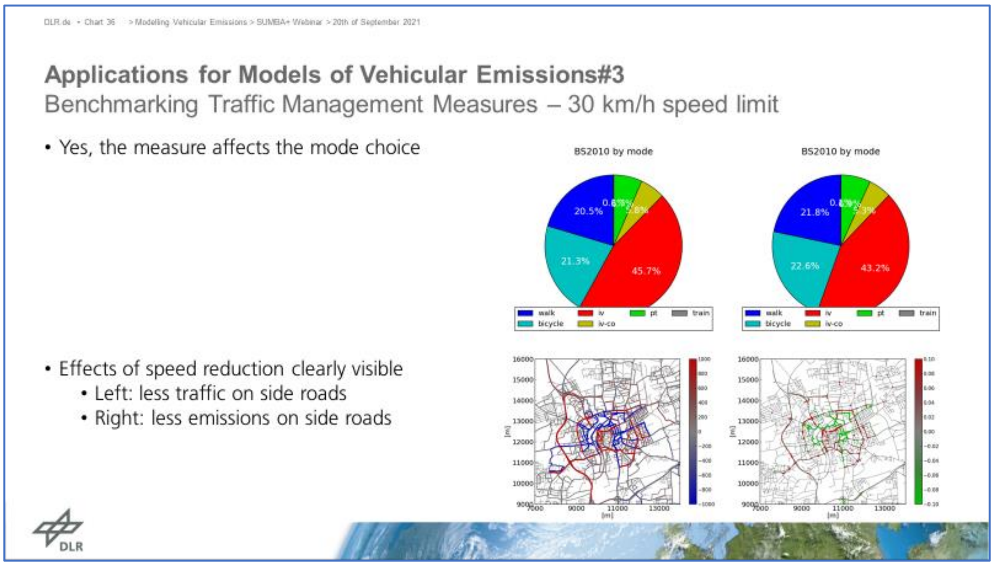
Applications for Models of Vehicular Emissions#2
Benchmarking Traffic Management Measures – 30 km/h speed limit

- Question: What happens if we change the allowed speed to 30km/h in side roads?



- Approach:
  - select respective roads
  - change the allowed speed
  - simulate (including assignment)



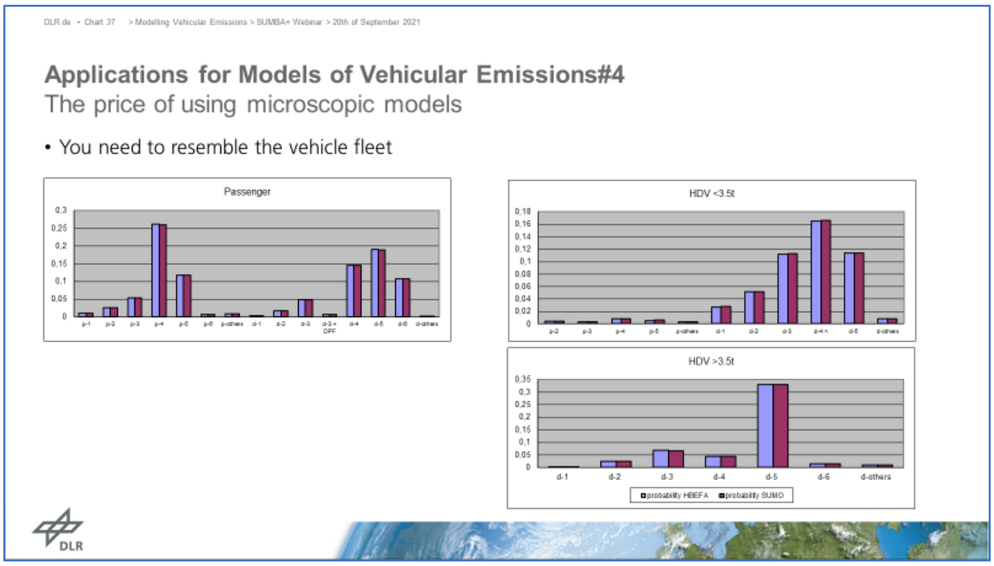


Applications for Models of Vehicular Emissions#3

Benchmarking Traffic Management Measures – 30 km/h speed limit

- Yes, the measure affects the mode choice

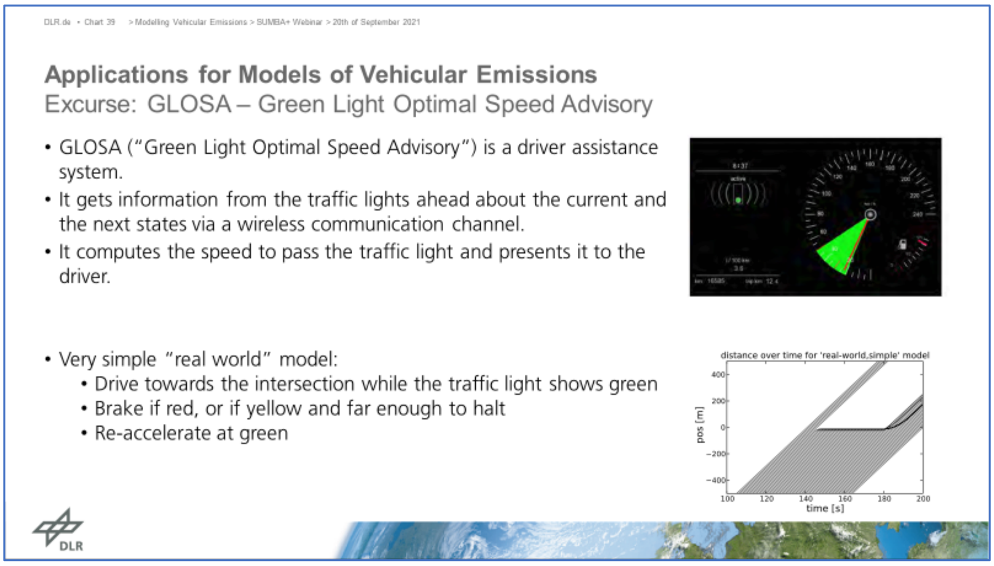
- Effects of speed reduction clearly visible
    - Left: less traffic on side roads
    - Right: less emissions on side roads



Applications for Models of Vehicular Emissions#4

The price of using microscopic models

- You need to resemble the vehicle fleet

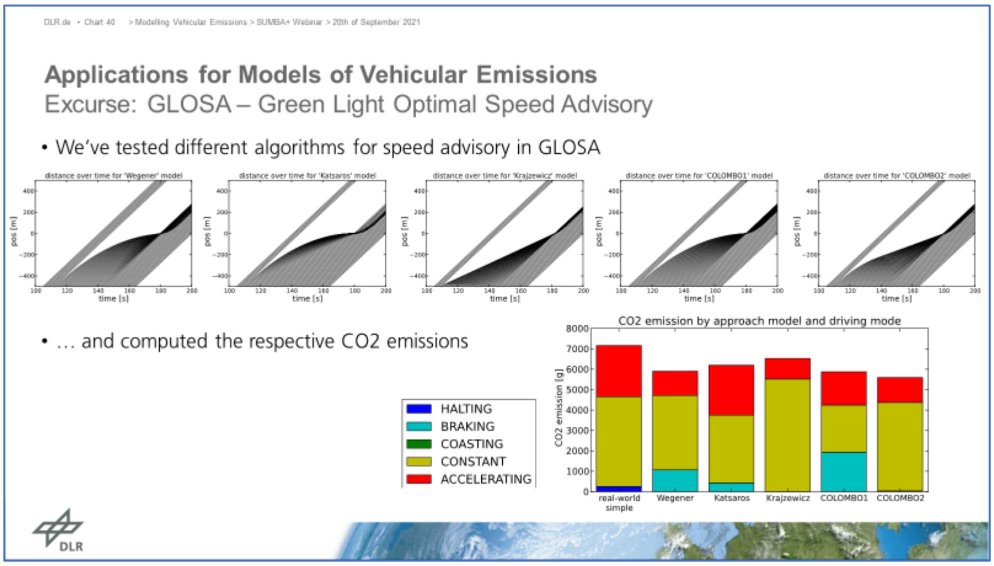


Applications for Models of Vehicular Emissions

Excurse: GLOSA – Green Light Optimal Speed Advisory

- GLOSA ("Green Light Optimal Speed Advisory") is a driver assistance system.
- It gets information from the traffic lights ahead about the current and the next states via a wireless communication channel.
- It computes the speed to pass the traffic light and presents it to the driver.

- Very simple "real world" model:
    - Drive towards the intersection while the traffic light shows green
    - Brake if red, or if yellow and far enough to halt
    - Re-accelerate at green



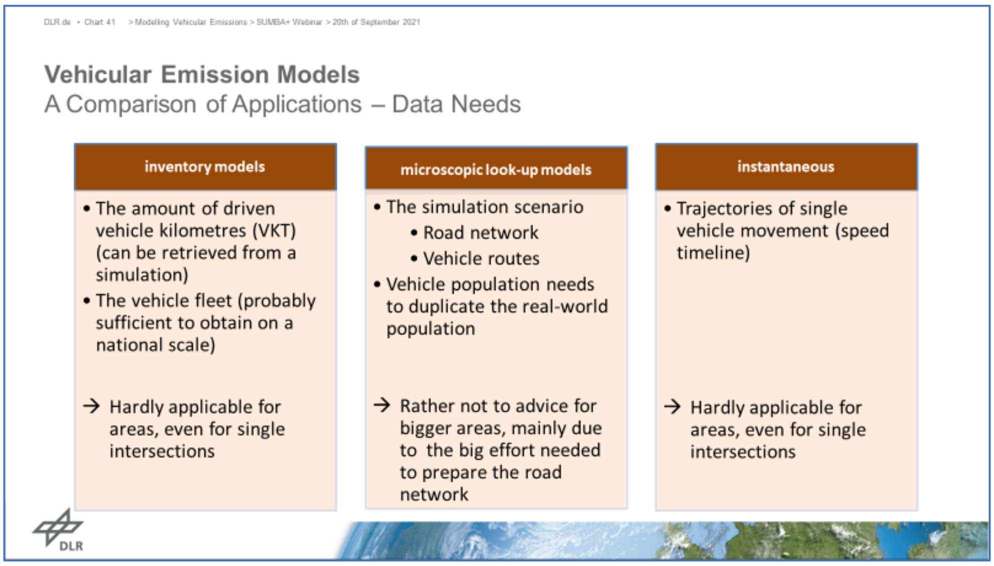
DLR.de • Chart 40 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Applications for Models of Vehicular Emissions

Excurse: GLOSA – Green Light Optimal Speed Advisory

- We've tested different algorithms for speed advisory in GLOSA

- … and computed the respective CO2 emissions



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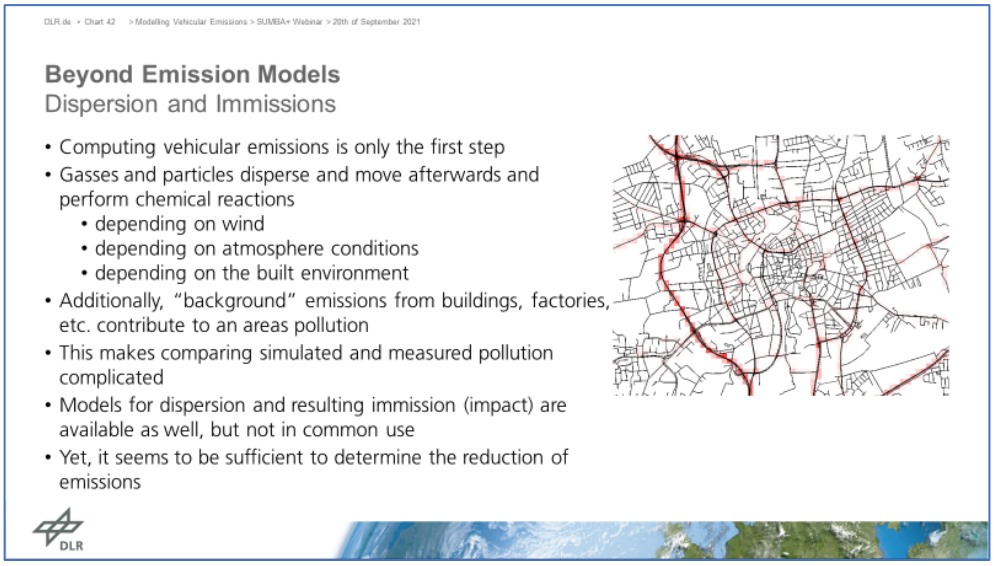
Vehicular Emission Models

A Comparison of Applications – Data Needs

inventory models	microscopic look-up models	instantaneous

• The amount of driven vehicle kilometres (VKT) (can be retrieved from a simulation)
• The vehicle fleet (probably sufficient to obtain on a national scale)
	• The simulation scenario
	  • Road network
	  • Vehicle routes
	• Vehicle population needs to duplicate the real-world population
		• Trajectories of single vehicle movement (speed timeline)

→ Hardly applicable for areas, even for single intersections	→ Rather not to advice for bigger areas, mainly due to the big effort needed to prepare the road network	→ Hardly applicable for areas, even for single intersections



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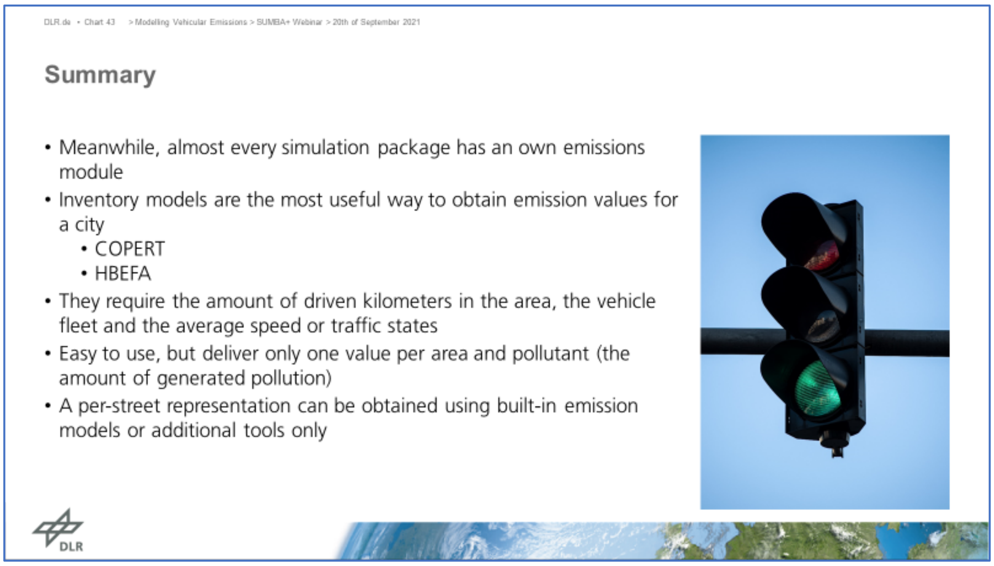
Beyond Emission Models

Dispersion and Immissions

- Computing vehicular emissions is only the first step
- Gasses and particles disperse and move afterwards and perform chemical reactions
  - depending on wind
  - depending on atmosphere conditions
  - depending on the built environment
- Additionally, "background" emissions from buildings, factories, etc. contribute to an areas pollution
- This makes comparing simulated and measured pollution complicated
- Models for dispersion and resulting immission (impact) are available as well, but not in common use
- Yet, it seems to be sufficient to determine the reduction of emissions



DLR.de • Chart 43 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Summary

- Meanwhile, almost every simulation package has an own emissions module
- Inventory models are the most useful way to obtain emission values for a city
    - COPERT
    - HBEFA
- They require the amount of driven kilometers in the area, the vehicle fleet and the average speed or traffic states
- Easy to use, but deliver only one value per area and pollutant (the amount of generated pollution)
- A per-street representation can be obtained using built-in emission models or additional tools only

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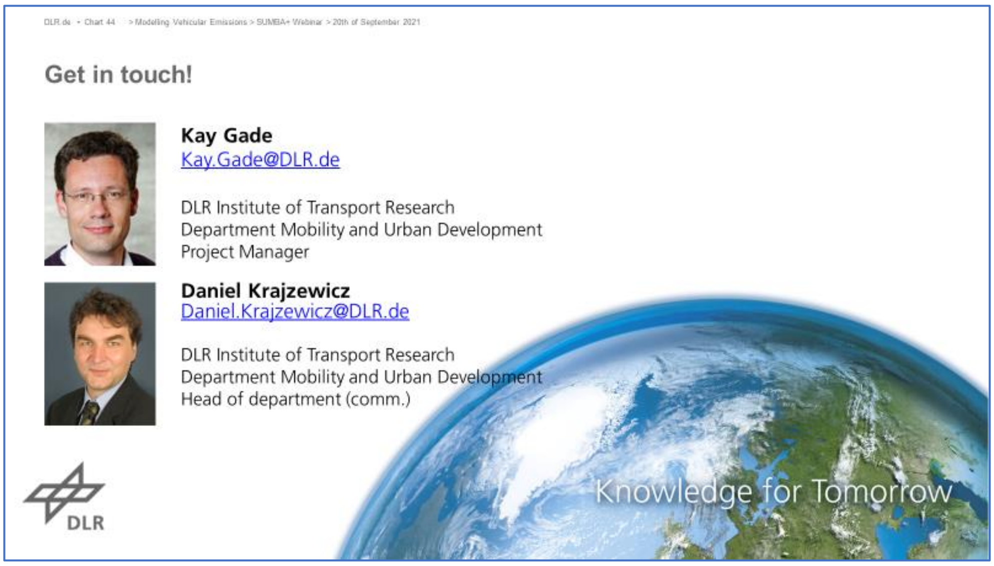

DLR.de • Chart 44 > Modelling Vehicular Emissions > SUMBA+ Webinar > 20th of September 2021

Get in touch!

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Head of department (comm.)

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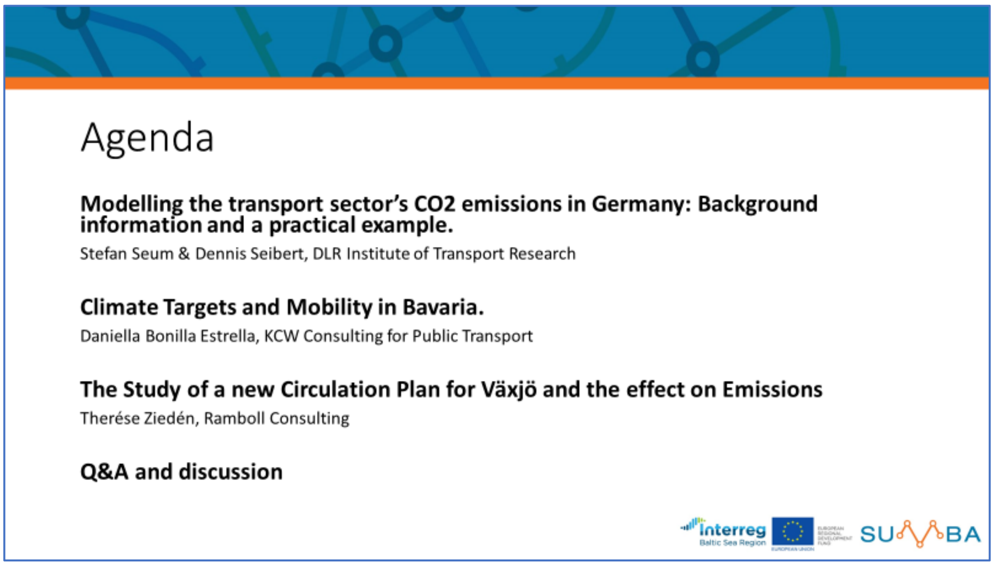
Knowledge for Tomorrow

Sustainable Urban Mobility and Commuting in Baltic Cities

2nd Webinar on Modelling CO2 emissions



Agenda

Modelling the transport sector's CO2 emissions in Germany: Background information and a practical example.

Stefan Seum & Dennis Seibert, DLR Institute of Transport Research

Climate Targets and Mobility in Bavaria.

Daniella Bonilla Estrella, KCW Consulting for Public Transport

The Study of a new Circulation Plan for Växjö and the effect on Emissions

Therése Ziedén, Ramboll Consulting

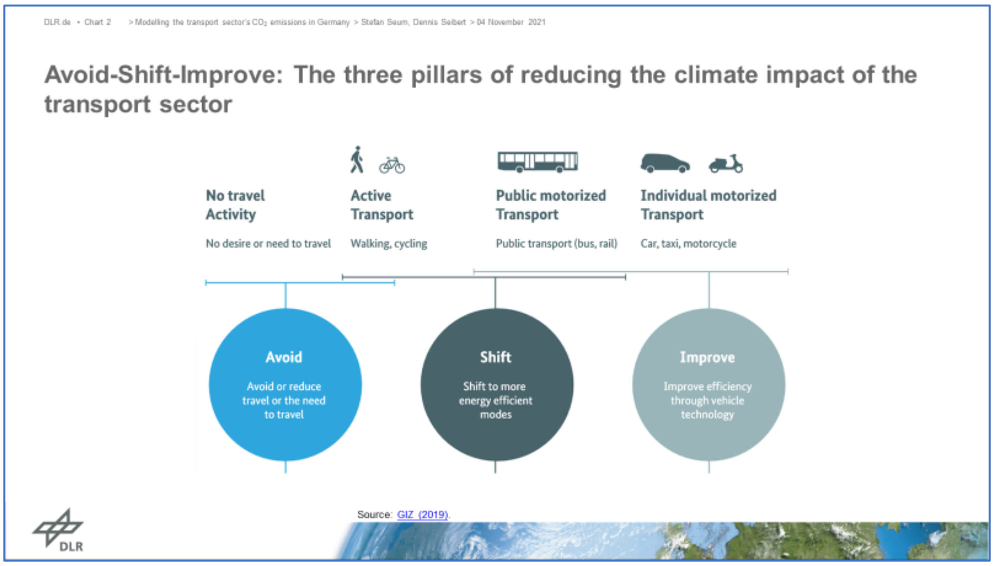
Q&A and discussion

DLR.de • Chart 1

Modelling the transport sector's CO_2 emissions in Germany: Background information and a practical example

Stefan Seum, Dennis Seibert

SUMBA+ Webinars
04 November 2021



Avoid-Shift-Improve: The three pillars of reducing the climate impact of the transport sector

No travel Activity
No desire or need to travel

Active Transport
Walking, cycling

Public motorized Transport
Public transport (bus, rail)

Individual motorized Transport
Car, taxi, motorcycle

Avoid
Avoid or reduce travel or the need to travel

Shift
Shift to more energy efficient modes

Improve
Improve efficiency through vehicle technology

Source: GIZ (2019).

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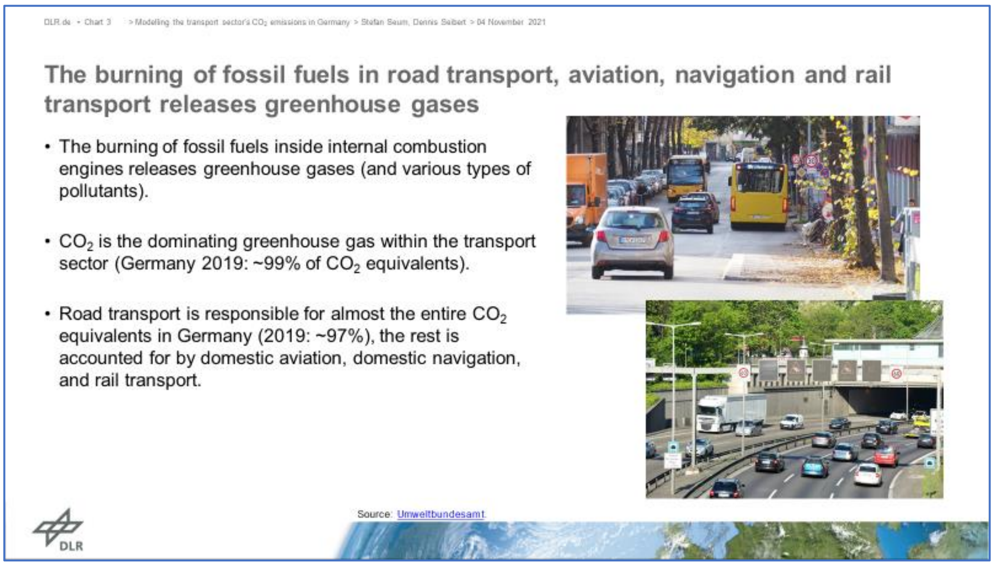

The burning of fossil fuels in road transport, aviation, navigation and rail transport releases greenhouse gases

- The burning of fossil fuels inside internal combustion engines releases greenhouse gases (and various types of pollutants).
- CO_2 is the dominating greenhouse gas within the transport sector (Germany 2019: ~99% of CO_2 equivalents).
- Road transport is responsible for almost the entire CO_2 equivalents in Germany (2019: ~97%), the rest is accounted for by domestic aviation, domestic navigation, and rail transport.

Source: Umweltbundesamt.

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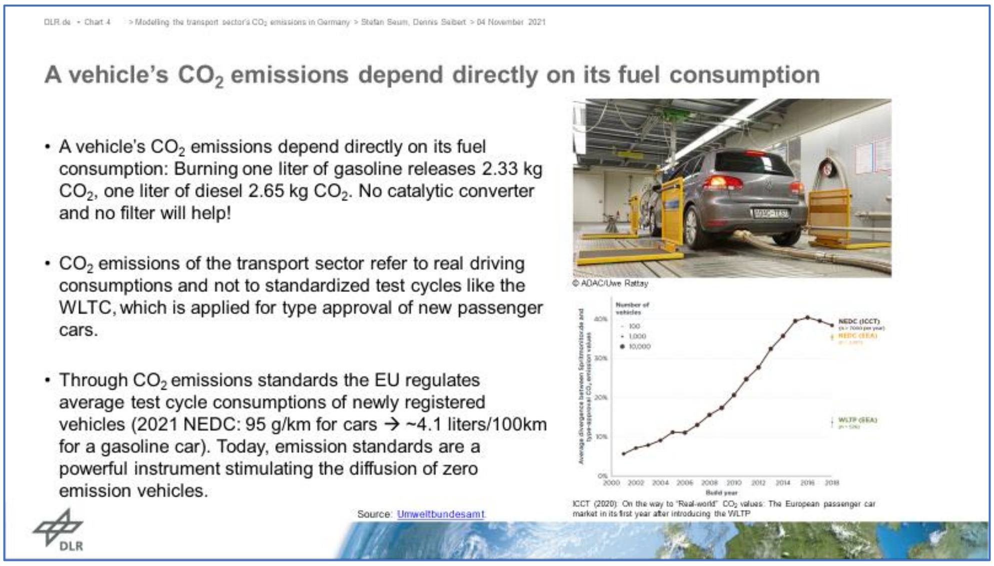

A vehicle's CO_2 emissions depend directly on its fuel consumption

- A vehicle's CO_2 emissions depend directly on its fuel consumption: Burning one liter of gasoline releases 2.33 kg CO_2, one liter of diesel 2.65 kg CO_2. No catalytic converter and no filter will help!
- CO_2 emissions of the transport sector refer to real driving consumptions and not to standardized test cycles like the WLTC, which is applied for type approval of new passenger cars.
- Through CO_2 emissions standards the EU regulates average test cycle consumptions of newly registered vehicles (2021 NEDC: 95 g/km for cars → ~4.1 liters/100km for a gasoline car). Today, emission standards are a powerful instrument stimulating the diffusion of zero emission vehicles.

© ADAC/Uwe Rattay

ICCT (2020): On the way to "Real-world" CO_2 values: The European passenger car market in its first year after introducing the WLTP

Source: Umweltbundesamt.

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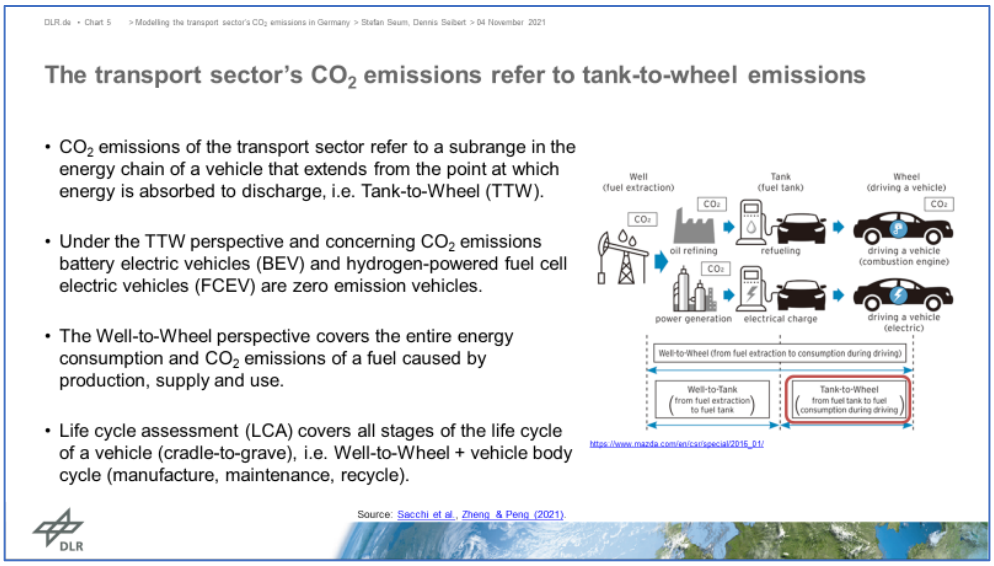
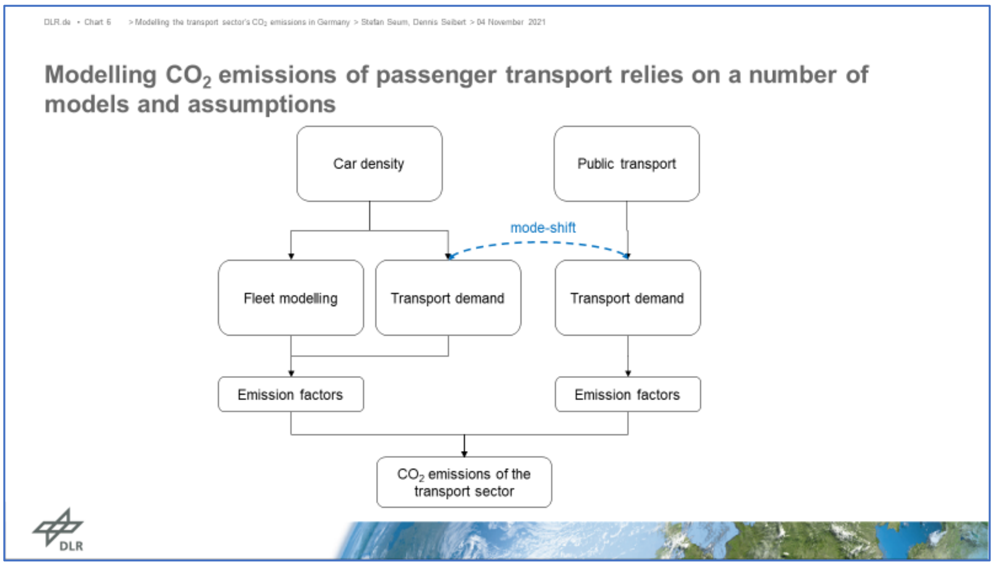


The transport sector's CO_2 emissions refer to tank-to-wheel emissions

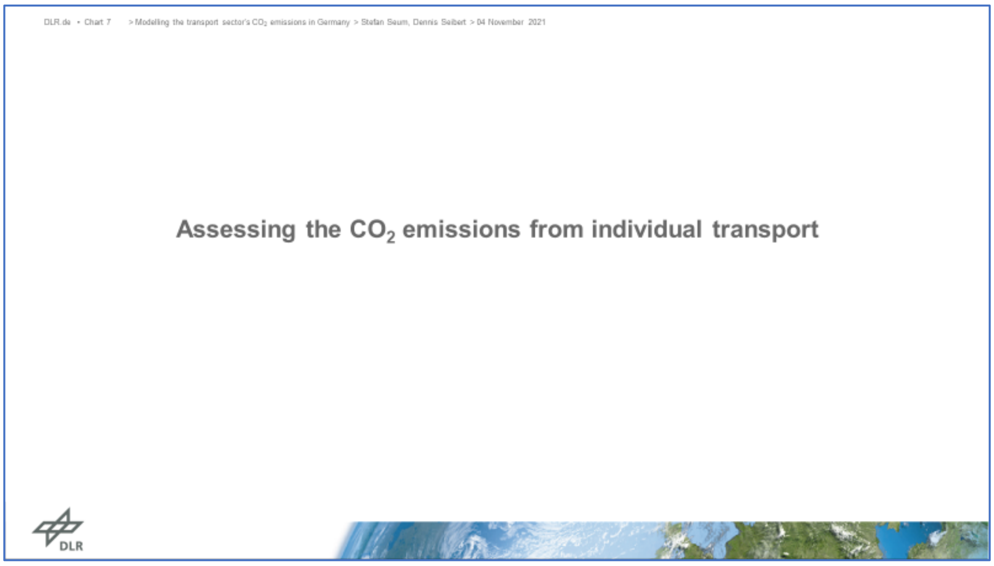
- CO_2 emissions of the transport sector refer to a subrange in the energy chain of a vehicle that extends from the point at which energy is absorbed to discharge, i.e. Tank-to-Wheel (TTW).
- Under the TTW perspective and concerning CO_2 emissions battery electric vehicles (BEV) and hydrogen-powered fuel cell electric vehicles (FCEV) are zero emission vehicles.
- The Well-to-Wheel perspective covers the entire energy consumption and CO_2 emissions of a fuel caused by production, supply and use.
- Life cycle assessment (LCA) covers all stages of the life cycle of a vehicle (cradle-to-grave), i.e. Well-to-Wheel + vehicle body cycle (manufacture, maintenance, recycle).

https://www.mazda.com/en/csr/special/2016_01/

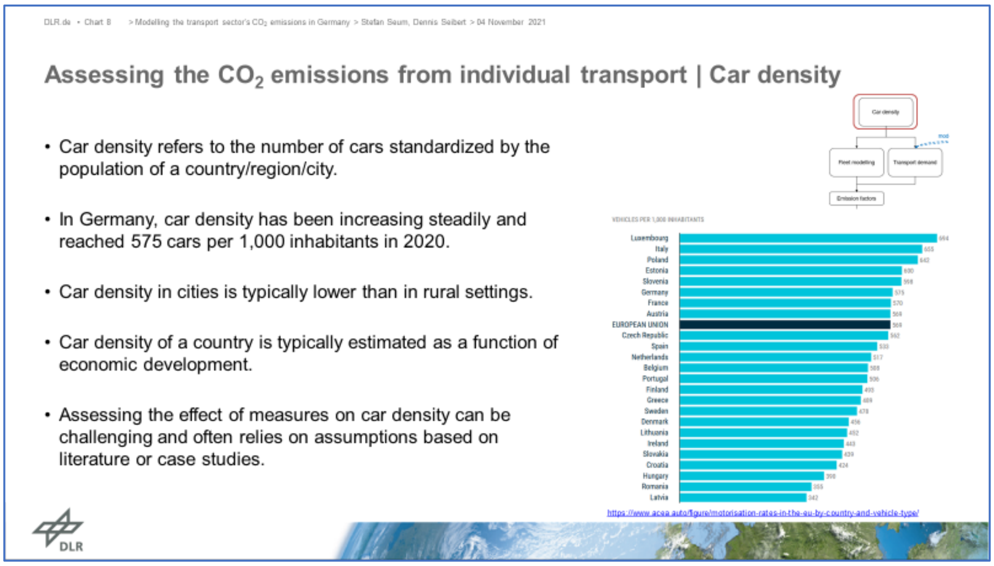
Source: Sacchi et al., Zheng & Peng (2021).



Modelling CO_2 emissions of passenger transport relies on a number of models and assumptions



Assessing the CO_2 emissions from individual transport

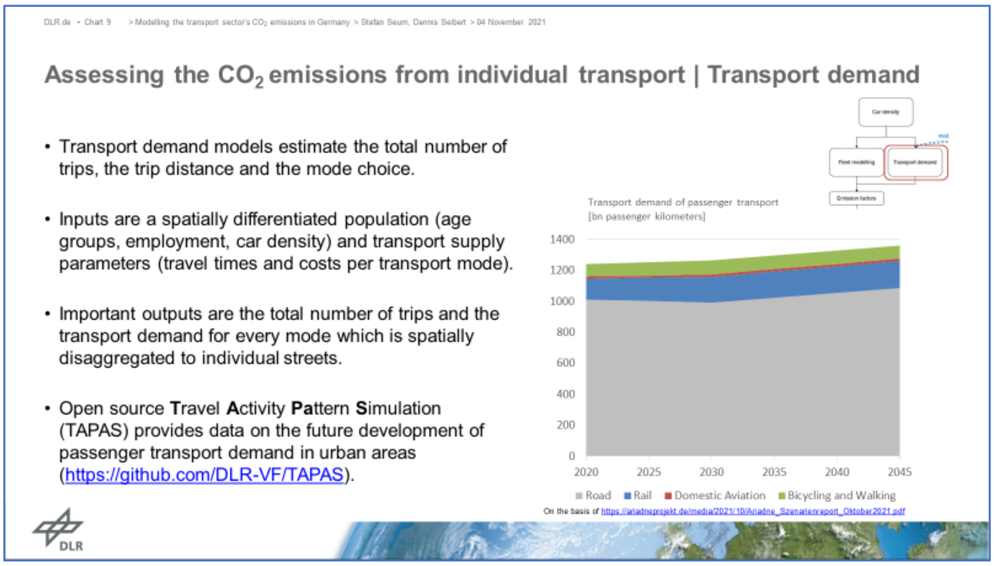


DLR.de • Chart 8 > Modelling the transport sector's CO_2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Assessing the CO_2 emissions from individual transport | Car density

- Car density refers to the number of cars standardized by the population of a country/region/city.
- In Germany, car density has been increasing steadily and reached 575 cars per 1,000 inhabitants in 2020.
- Car density in cities is typically lower than in rural settings.
- Car density of a country is typically estimated as a function of economic development.
- Assessing the effect of measures on car density can be challenging and often relies on assumptions based on literature or case studies.

https://www.acea.auto/figure/motorisation-rates-in-the-eu-by-country-and-vehicle-type/

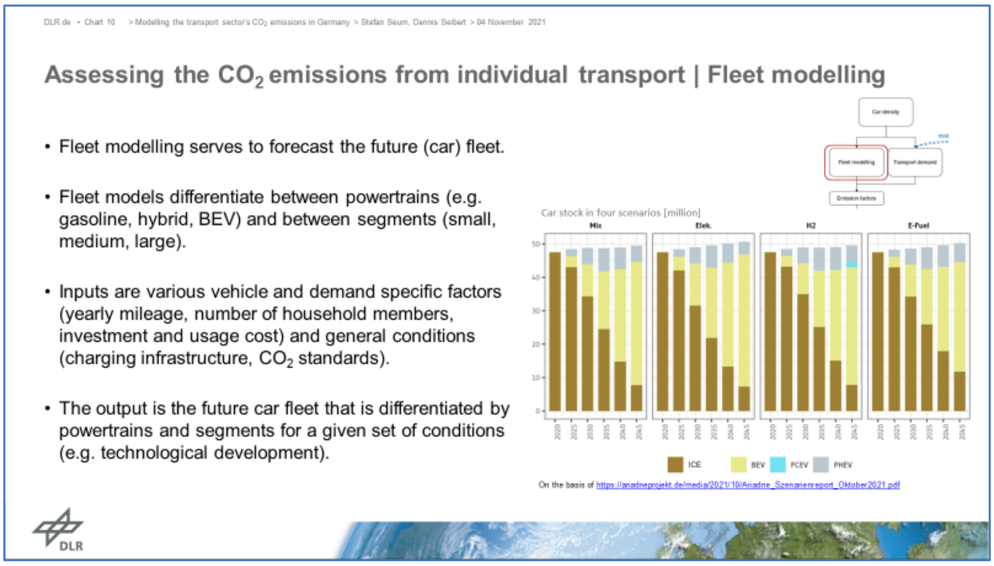


DLR.de • Chart 9 > Modelling the transport sector's CO_2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Assessing the CO_2 emissions from individual transport | Transport demand

- Transport demand models estimate the total number of trips, the trip distance and the mode choice.
- Inputs are a spatially differentiated population (age groups, employment, car density) and transport supply parameters (travel times and costs per transport mode).
- Important outputs are the total number of trips and the transport demand for every mode which is spatially disaggregated to individual streets.
- Open source **T**ravel **A**ctivity **Pa**ttern **S**imulation (TAPAS) provides data on the future development of passenger transport demand in urban areas (https://github.com/DLR-VF/TAPAS).

On the basis of https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021.pdf

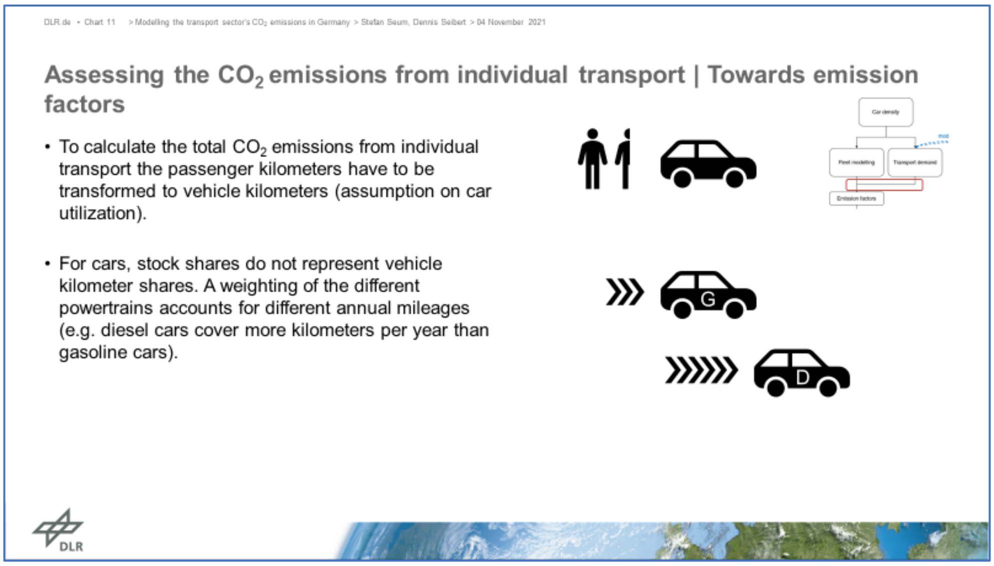


DLR.de • Chart 10 > Modelling the transport sector's CO_2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Assessing the CO_2 emissions from individual transport | Fleet modelling

- Fleet modelling serves to forecast the future (car) fleet.
- Fleet models differentiate between powertrains (e.g. gasoline, hybrid, BEV) and between segments (small, medium, large).
- Inputs are various vehicle and demand specific factors (yearly mileage, number of household members, investment and usage cost) and general conditions (charging infrastructure, CO_2 standards).
- The output is the future car fleet that is differentiated by powertrains and segments for a given set of conditions (e.g. technological development).

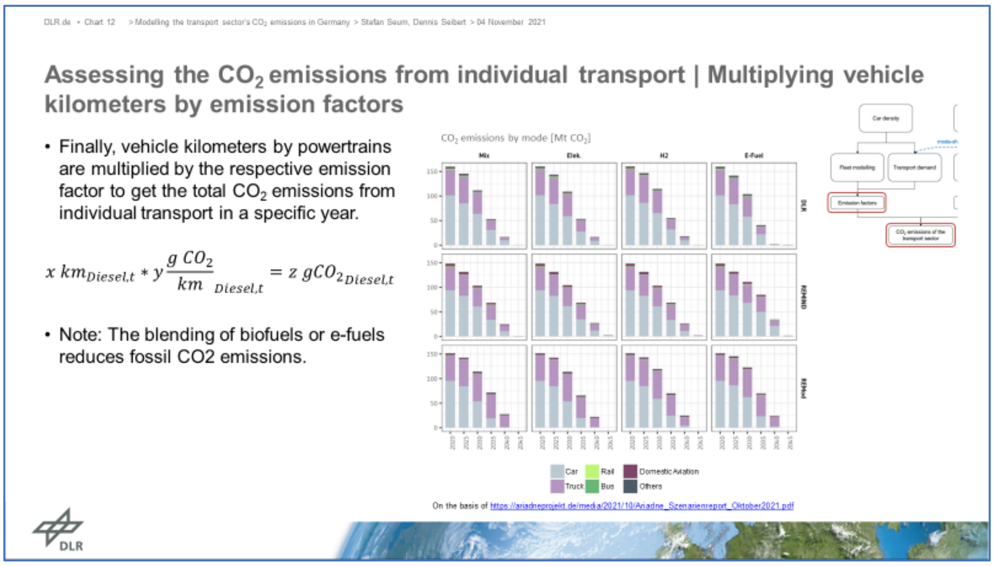
On the basis of https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021.pdf



Assessing the CO_2 emissions from individual transport | Towards emission factors

- To calculate the total CO_2 emissions from individual transport the passenger kilometers have to be transformed to vehicle kilometers (assumption on car utilization).

- For cars, stock shares do not represent vehicle kilometer shares. A weighting of the different powertrains accounts for different annual mileages (e.g. diesel cars cover more kilometers per year than gasoline cars).



Assessing the CO_2 emissions from individual transport | Multiplying vehicle kilometers by emission factors

- Finally, vehicle kilometers by powertrains are multiplied by the respective emission factor to get the total CO_2 emissions from individual transport in a specific year.

$$x\,km_{Diesel,t} * y\,\frac{g\,CO_2}{km}_{Diesel,t} = z\,gCO_{2_{Diesel,t}}$$

- Note: The blending of biofuels or e-fuels reduces fossil CO2 emissions.

On the basis of https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021.pdf

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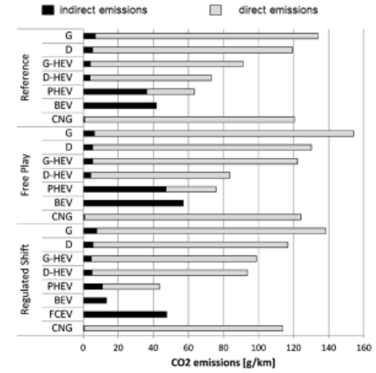
Experience from using HBEFA emission database for passenger cars

DLR

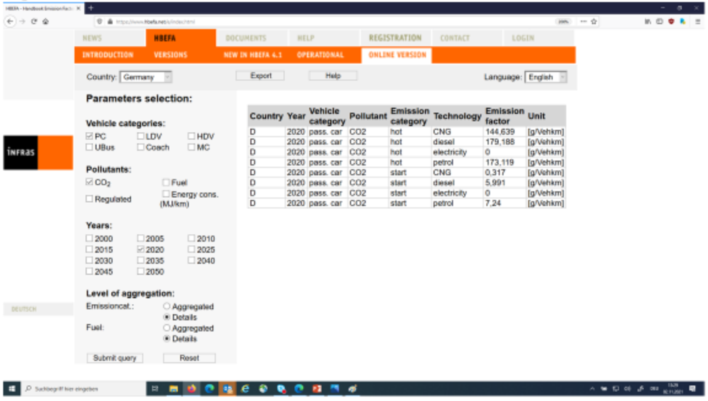
What are emission factors and what are they for?

- Emission factors mainly relate to concentrations in exhaust streams for regulated pollutants (NOx, PM, CO, HC)
- CO_2 is not considered an air pollutant, but a strong and long lasting climate gas
- For vehicles, emission factors are the concentration of a gas in the exhaust stream per unit:
  - Vehicle kilometer
  - Passenger / Tonne kilometer
- Furthermore important are:
  - direct emissions (tailpipe)
  - indirect emissions (upstream, life-cycle emissions)
  - hot emissions (hot driving emissions)
  - cold-start emissions (additional emissions until engine is warm)



Seum et al. (2020) Extended emission factors for future automotive propulsion in Germany considering fleet composition, new technologies and emissions from energy supplies. In: Atmospheric Environment 233 (2020) 117568

HBEFA online allows for an easy access to general emission factors for passenger cars, vans, lorries and busses



Country: Germany

Language: English

Parameters selection:

Vehicle categories:
☑ PC ☐ LDV ☐ HDV
☐ UBus ☐ Coach ☐ MC

Pollutants:
☑ CO_2 ☐ Fuel
☐ Regulated ☐ Energy cons. (MJ/km)

Years:
☐ 2000 ☐ 2005 ☐ 2010
☐ 2015 ☑ 2020 ☐ 2025
☐ 2030 ☐ 2035 ☐ 2040
☐ 2045 ☐ 2050

Level of aggregation:
Emissioncat.: ○ Aggregated ● Details
Fuel: ○ Aggregated ● Details

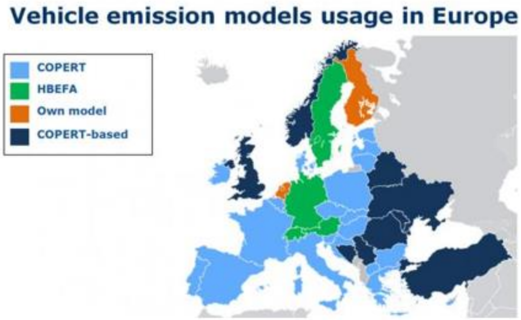
Country	Year	Vehicle category	Pollutant	Emission category	Technology	Emission factor	Unit
D	2020	pass. car	CO2	hot	CNG	144,639	[g/Vehkm]
D	2020	pass. car	CO2	hot	diesel	179,188	[g/Vehkm]
D	2020	pass. car	CO2	hot	electricity	0	[g/Vehkm]
D	2020	pass. car	CO2	hot	petrol	173,119	[g/Vehkm]
D	2020	pass. car	CO2	start	CNG	0,317	[g/Vehkm]
D	2020	pass. car	CO2	start	diesel	5,991	[g/Vehkm]
D	2020	pass. car	CO2	start	electricity	0	[g/Vehkm]
D	2020	pass. car	CO2	start	petrol	7,24	[g/Vehkm]

Inventory Models#3

HBEFA – Handbook of Emission Factors

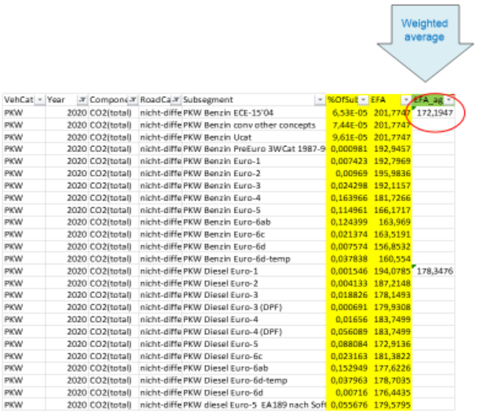
- COPERT and HBEFA are quite similar in features
- HBEFA allows easier access to data
- Norway and France and EC JRC now also support the use of HBEFA
- Both providing "real-world" emission factors
- For some nations uncertainties in fleet composition

=> Notice: COPERT and HBEFA stem from the same original data harmonization (ERMES European Research on Mobile Emission Sources)



Extracting data for customized passenger car fleets

- HBEFA provides data that allow customizing to your fleet
- Important features are:
  - three road types (urban, sub-urban and highway)
  - Technological subsegments (fuel, EURO class)
  - Bio-fuel share considered or not (CO2)
  - Energy consumed fossil and electricity
  - Cold-start emissions
  - and many more (traffic situation, gradient etc.)
- Before compiling data, one need to decide what features are relevant and how to use them, e.g.:
  - do I need road-type differentiation?
  - will I modify bio-fuel content?
  - will I modify fleet composition?
- **Percent of Subsegment is key for customization!**


Weighted average

VehCat	Year	Compone	RoadCa	Subsegment	%OfSub	EFA	EFA_ag
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin ECE-15'04	6,53E-05	201,7747	172,1947
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin conv other concepts	7,44E-05	201,7747	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Ucat	9,61E-05	201,7747	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin PreEuro 3WCat 1987-9	0,000981	192,9457	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-1	0,007423	192,7969	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-2	0,00969	195,9836	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-3	0,024298	192,1157	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-4	0,163966	181,7266	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-5	0,114961	166,1717	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6ab	0,124399	163,969	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6c	0,021374	163,5191	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6d	0,007574	156,8532	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6d-temp	0,037838	160,554	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-1	0,001546	194,0785	178,3476
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-2	0,004133	187,2148	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-3	0,018826	178,1493	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-3 (DPF)	0,000691	179,9308	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-4	0,01656	183,7499	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-4 (DPF)	0,056089	183,7499	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-5	0,088084	172,9136	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6c	0,023163	181,3822	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6ab	0,152949	177,6226	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6d-temp	0,037963	178,7035	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6d	0,00716	176,4435	
PKW	2020	CO2(total)	nicht-diffe	PKW diesel Euro-5 EA189 nach Soft	0,055676	179,5795	

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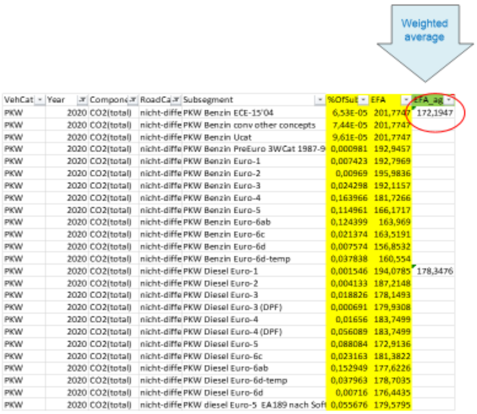

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PKW	2020	CO2(total)	nicht-diffe	PKW diesel Euro-5 EA189 nach Soft	0,055676	179,5795	

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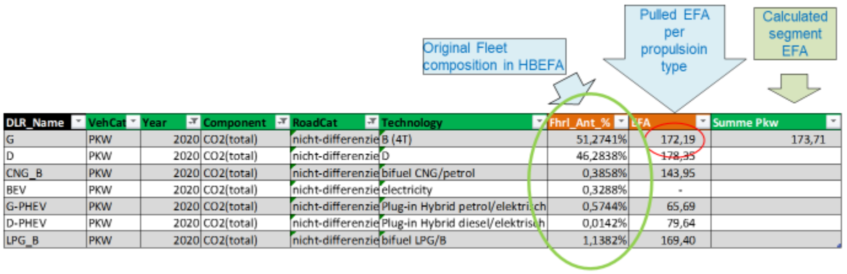
Example of an extract from HBEFA, ready to be customized


Original Fleet composition in HBEFA

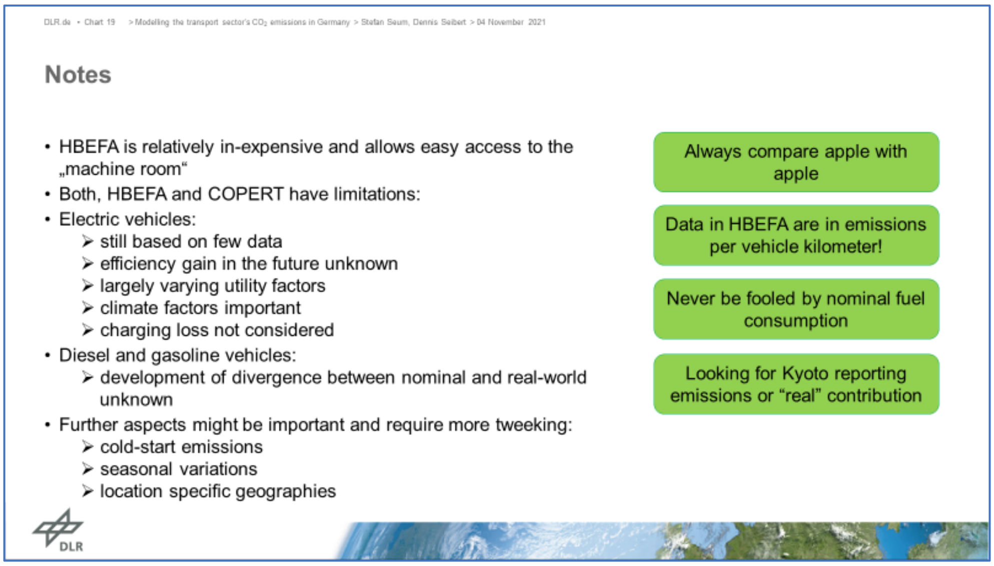
Pulled EFA per propulsioin type

Calculated segment EFA

DLR_Name	VehCat	Year	Component	RoadCat	Technology	Fhrl_Ant_%	EFA	Summe Pkw
G	PKW	2020	CO2(total)	nicht-differenzie	B (4T)	51,2741%	172,19	173,71
D	PKW	2020	CO2(total)	nicht-differenzie	D	46,2838%	178,35	
CNG_B	PKW	2020	CO2(total)	nicht-differenzie	bifuel CNG/petrol	0,3858%	143,95	
BEV	PKW	2020	CO2(total)	nicht-differenzie	electricity	0,3288%	-	
G-PHEV	PKW	2020	CO2(total)	nicht-differenzie	Plug-in Hybrid petrol/elektrisch	0,5744%	65,69	
D-PHEV	PKW	2020	CO2(total)	nicht-differenzie	Plug-in Hybrid diesel/elektrisch	0,0142%	79,64	
LPG_B	PKW	2020	CO2(total)	nicht-differenzie	bifuel LPG/B	1,1382%	169,40	

The fleet composition can now be altered according to the demand, e.g. scenarios, locally specific compositions etc.

DLR



Notes

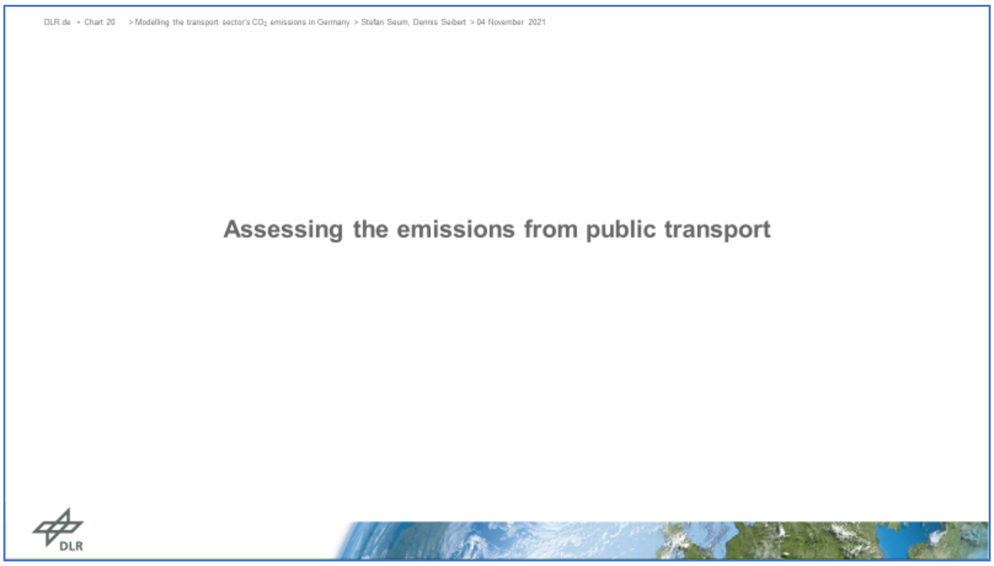
- HBEFA is relatively in-expensive and allows easy access to the „machine room"
- Both, HBEFA and COPERT have limitations:
- Electric vehicles:
  - ➢ still based on few data
  - ➢ efficiency gain in the future unknown
  - ➢ largely varying utility factors
  - ➢ climate factors important
  - ➢ charging loss not considered
- Diesel and gasoline vehicles:
  - ➢ development of divergence between nominal and real-world unknown
- Further aspects might be important and require more tweeking:
  - ➢ cold-start emissions
  - ➢ seasonal variations
  - ➢ location specific geographies

Always compare apple with apple

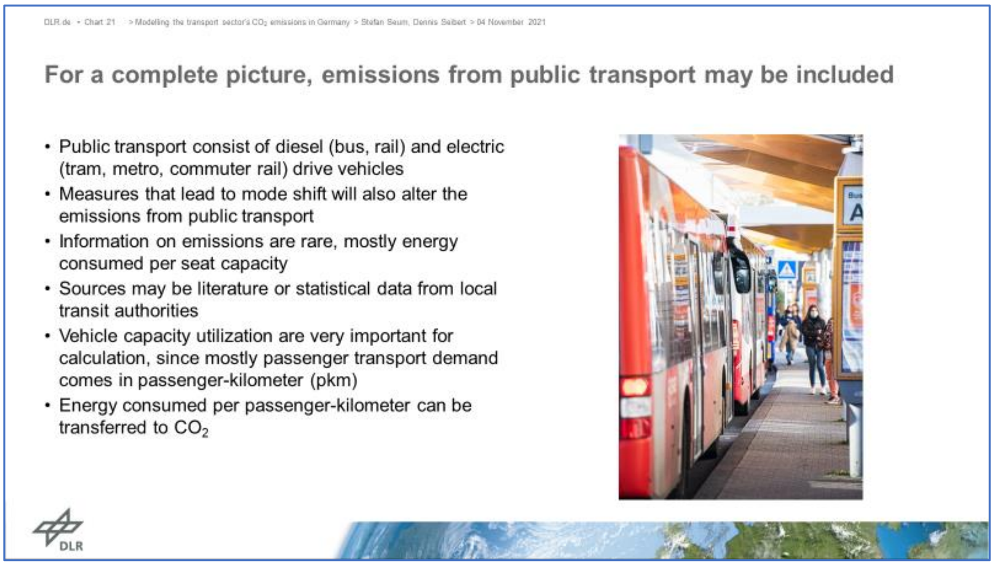
Data in HBEFA are in emissions per vehicle kilometer!

Never be fooled by nominal fuel consumption

Looking for Kyoto reporting emissions or "real" contribution

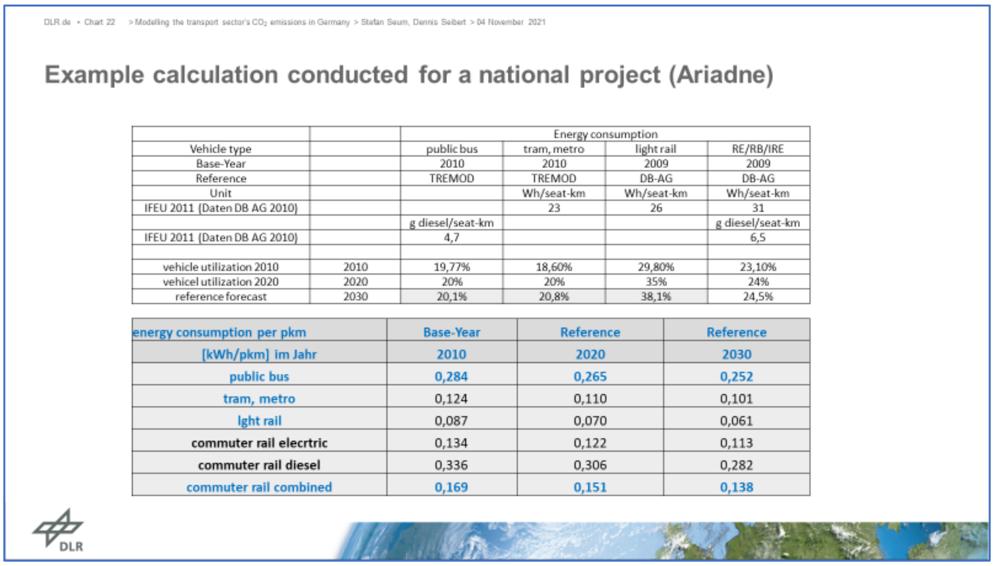


Assessing the emissions from public transport



For a complete picture, emissions from public transport may be included

- Public transport consist of diesel (bus, rail) and electric (tram, metro, commuter rail) drive vehicles
- Measures that lead to mode shift will also alter the emissions from public transport
- Information on emissions are rare, mostly energy consumed per seat capacity
- Sources may be literature or statistical data from local transit authorities
- Vehicle capacity utilization are very important for calculation, since mostly passenger transport demand comes in passenger-kilometer (pkm)
- Energy consumed per passenger-kilometer can be transferred to CO_2



Example calculation conducted for a national project (Ariadne)

		Energy consumption			
Vehicle type		public bus	tram, metro	light rail	RE/RB/IRE
Base-Year		2010	2010	2009	2009
Reference		TREMOD	TREMOD	DB-AG	DB-AG
Unit			Wh/seat-km	Wh/seat-km	Wh/seat-km
IFEU 2011 (Daten DB AG 2010)			23	26	31
		g diesel/seat-km			g diesel/seat-km
IFEU 2011 (Daten DB AG 2010)		4,7			6,5
vehicle utilization 2010	2010	19,77%	18,60%	29,80%	23,10%
vehicel utilization 2020	2020	20%	20%	35%	24%
reference forecast	2030	20,1%	20,8%	38,1%	24,5%

energy consumption per pkm	Base-Year	Reference	Reference
[kWh/pkm] im Jahr	2010	2020	2030
public bus	0,284	0,265	0,252
tram, metro	0,124	0,110	0,101
lght rail	0,087	0,070	0,061
commuter rail elecrtric	0,134	0,122	0,113
commuter rail diesel	0,336	0,306	0,282
commuter rail combined	0,169	0,151	0,138

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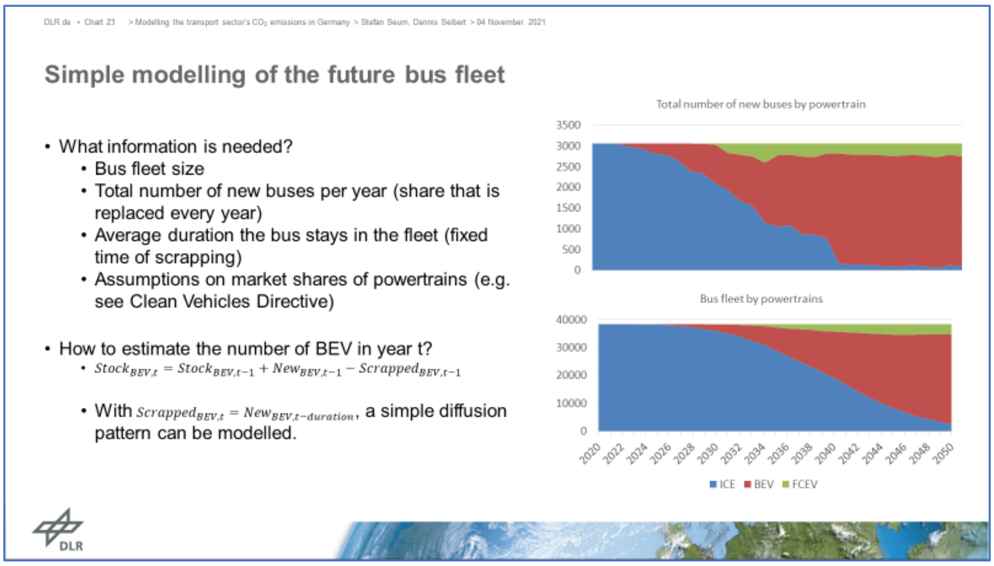
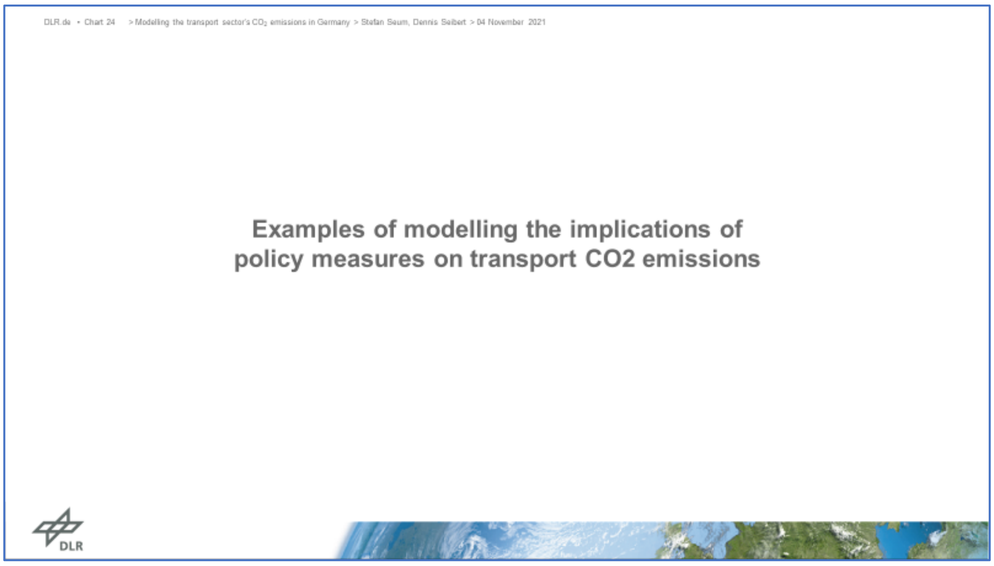


Simple modelling of the future bus fleet

- What information is needed?
  - Bus fleet size
  - Total number of new buses per year (share that is replaced every year)
  - Average duration the bus stays in the fleet (fixed time of scrapping)
  - Assumptions on market shares of powertrains (e.g. see Clean Vehicles Directive)

- How to estimate the number of BEV in year t?
  - $Stock_{BEV,t} = Stock_{BEV,t-1} + New_{BEV,t-1} - Scrapped_{BEV,t-1}$
  - With $Scrapped_{BEV,t} = New_{BEV,t-duration}$, a simple diffusion pattern can be modelled.



Examples of modelling the implications of policy measures on transport CO2 emissions

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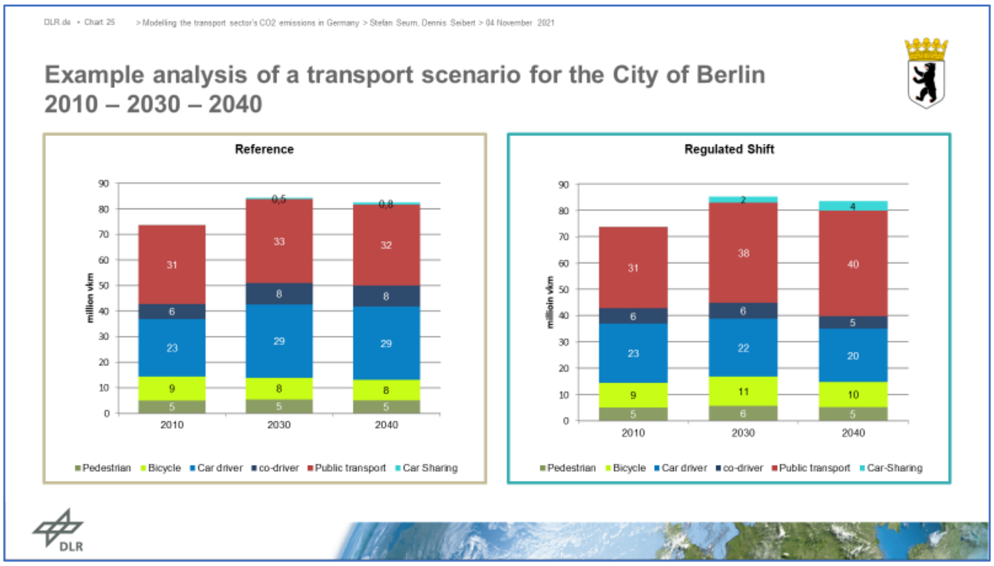
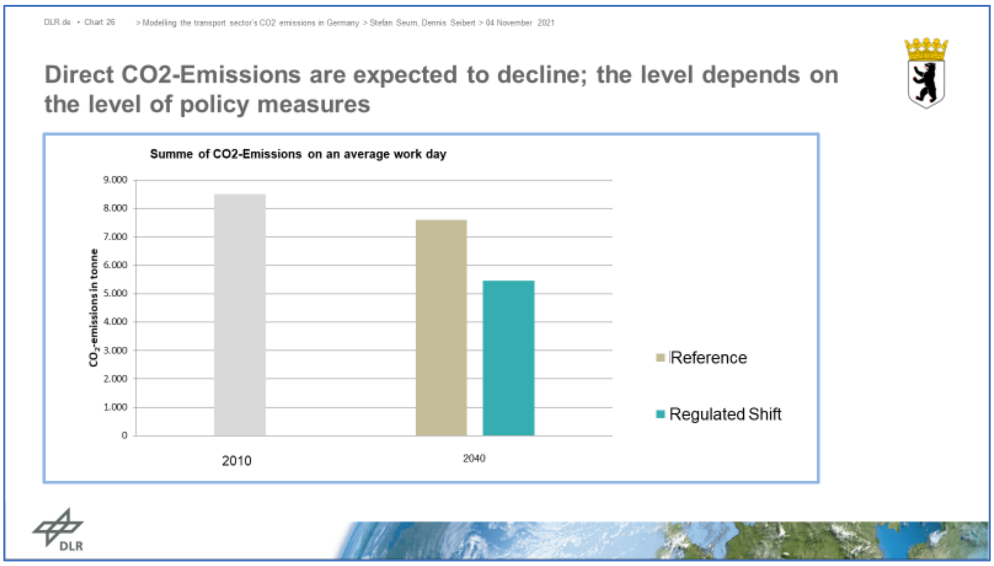


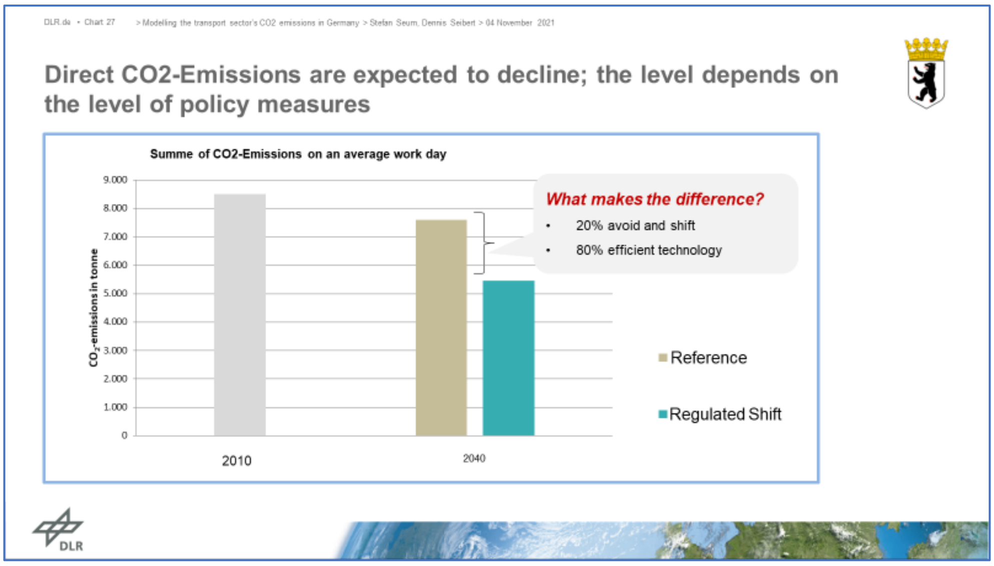
DLR.de • Chart 25 > Modelling the transport sector's CO2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Example analysis of a transport scenario for the City of Berlin 2010 – 2030 – 2040



DLR.de • Chart 26 > Modelling the transport sector's CO2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Direct CO2-Emissions are expected to decline; the level depends on the level of policy measures

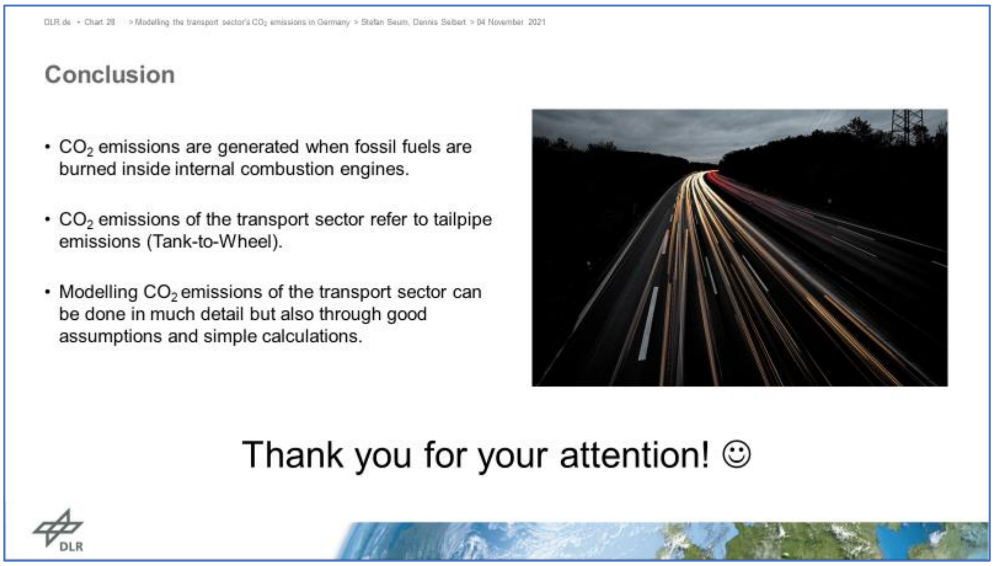


DLR.de • Chart 27 > Modelling the transport sector's CO2 emissions in Germany > Stefan Seum, Dennis Seibert > 04 November 2021

Direct CO2-Emissions are expected to decline; the level depends on the level of policy measures

What makes the difference?

- 20% avoid and shift
- 80% efficient technology



Conclusion

- CO$_2$ emissions are generated when fossil fuels are burned inside internal combustion engines.
- CO$_2$ emissions of the transport sector refer to tailpipe emissions (Tank-to-Wheel).
- Modelling CO$_2$ emissions of the transport sector can be done in much detail but also through good assumptions and simple calculations.

Thank you for your attention! ☺

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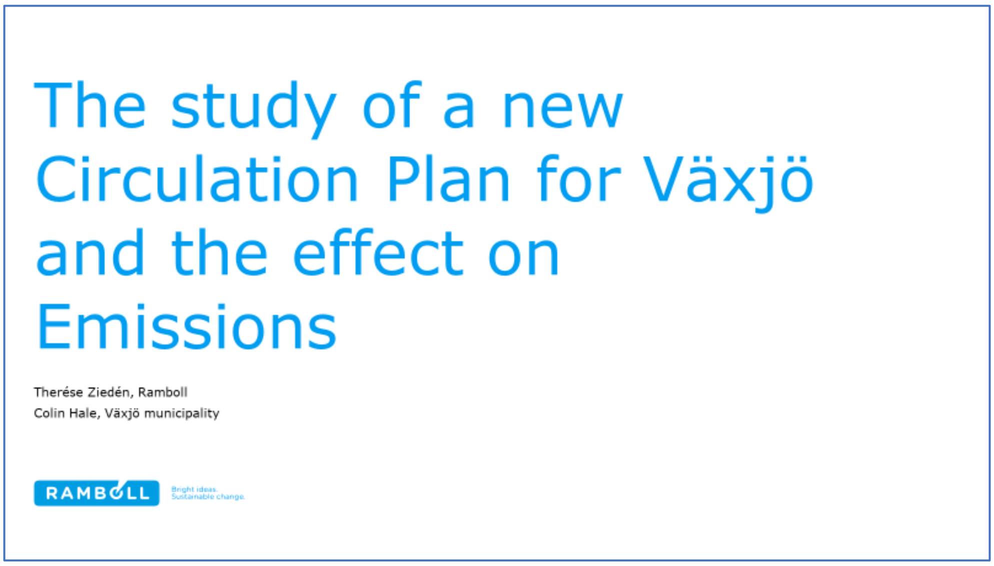
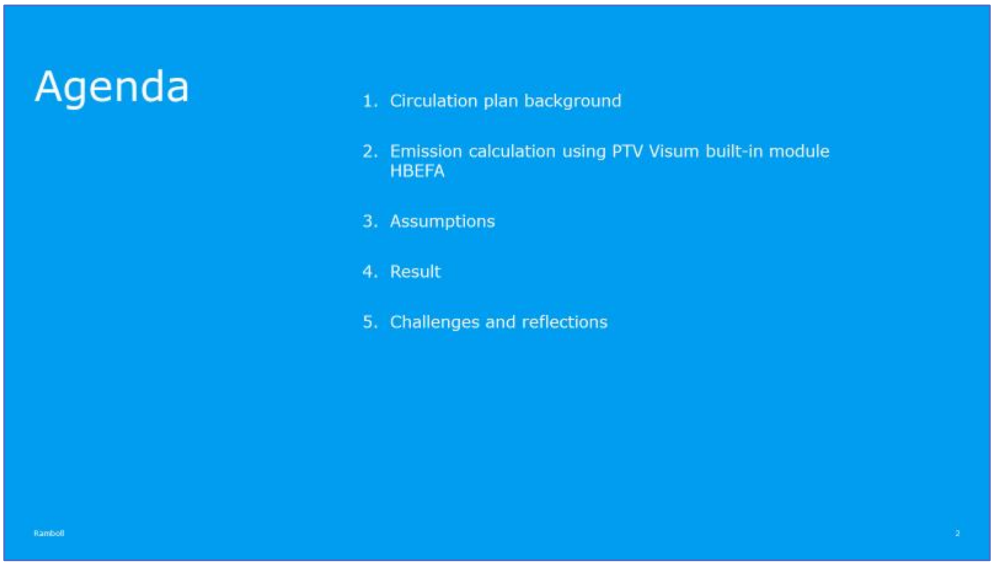


The study of a new Circulation Plan for Växjö and the effect on Emissions

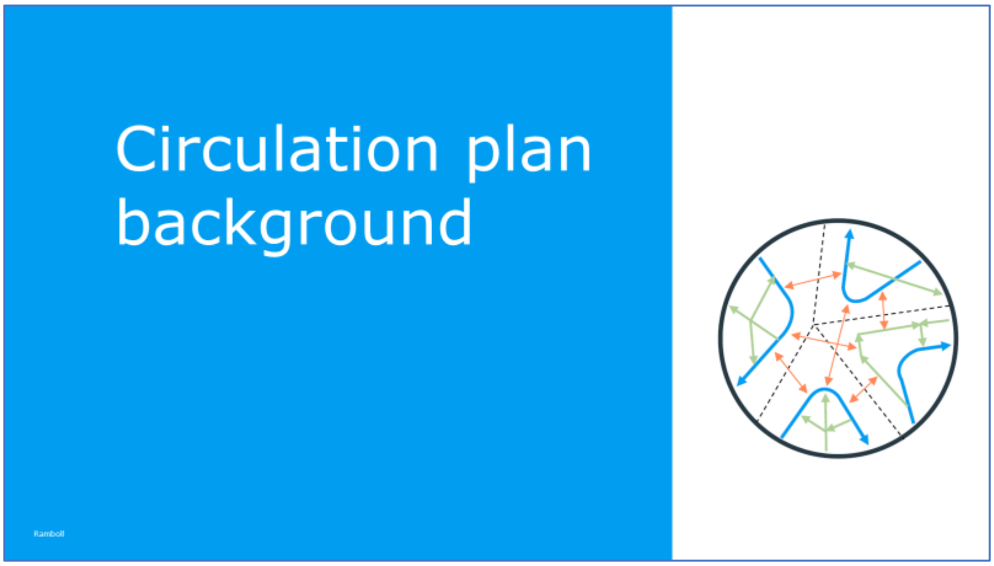
Therése Ziedén, Ramboll
Colin Hale, Växjö municipality

RAMBOLL Bright ideas. Sustainable change.

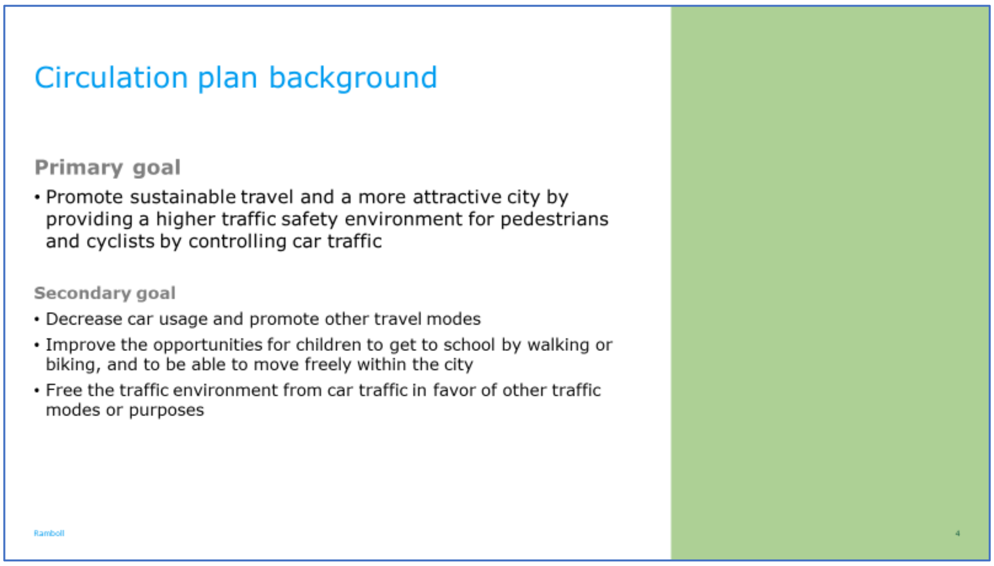


Agenda

1. Circulation plan background
2. Emission calculation using PTV Visum built-in module HBEFA
3. Assumptions
4. Result
5. Challenges and reflections



Circulation plan background



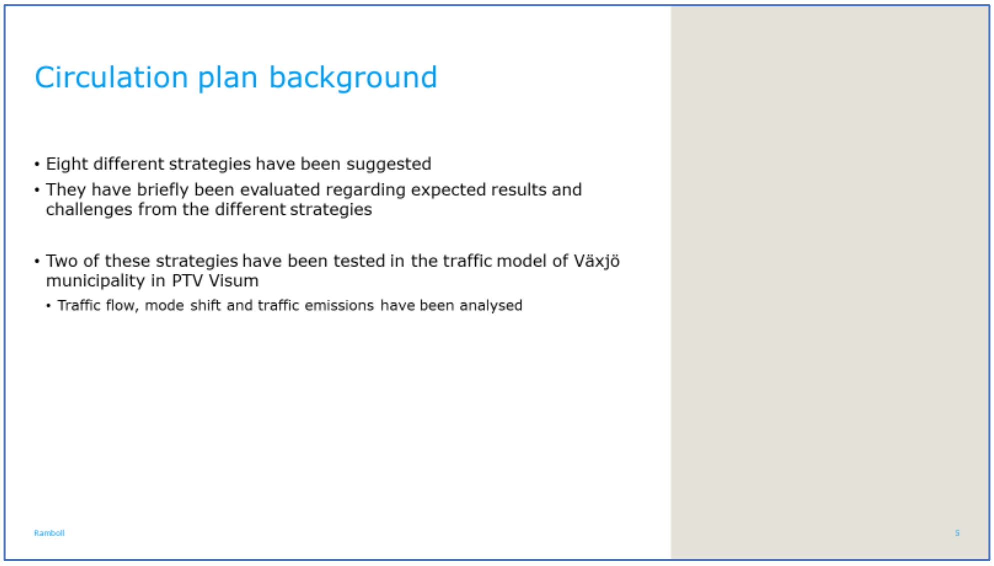
Circulation plan background

Primary goal

- Promote sustainable travel and a more attractive city by providing a higher traffic safety environment for pedestrians and cyclists by controlling car traffic

Secondary goal

- Decrease car usage and promote other travel modes
- Improve the opportunities for children to get to school by walking or biking, and to be able to move freely within the city
- Free the traffic environment from car traffic in favor of other traffic modes or purposes



Circulation plan background

- Eight different strategies have been suggested
- They have briefly been evaluated regarding expected results and challenges from the different strategies

- Two of these strategies have been tested in the traffic model of Växjö municipality in PTV Visum
  - Traffic flow, mode shift and traffic emissions have been analysed

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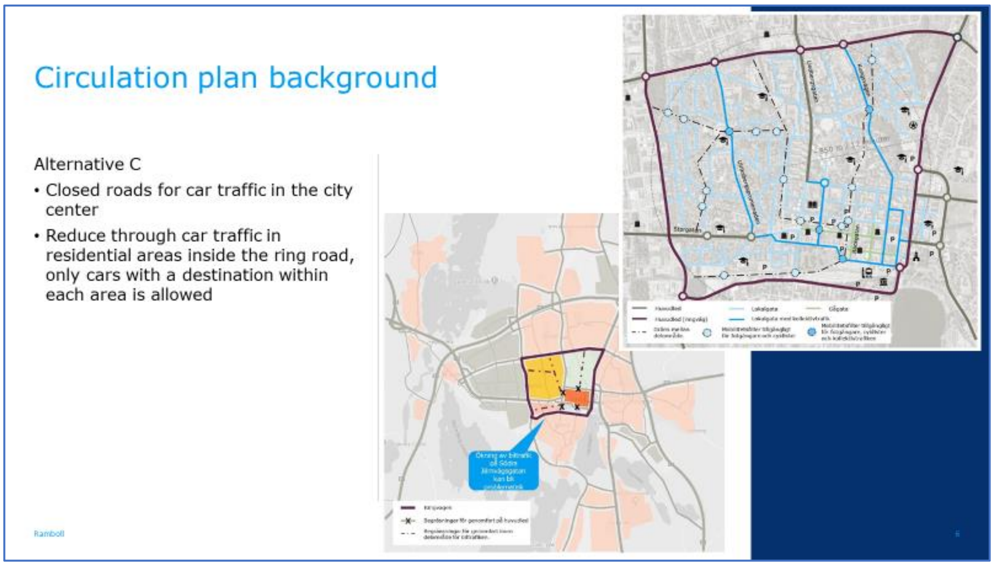
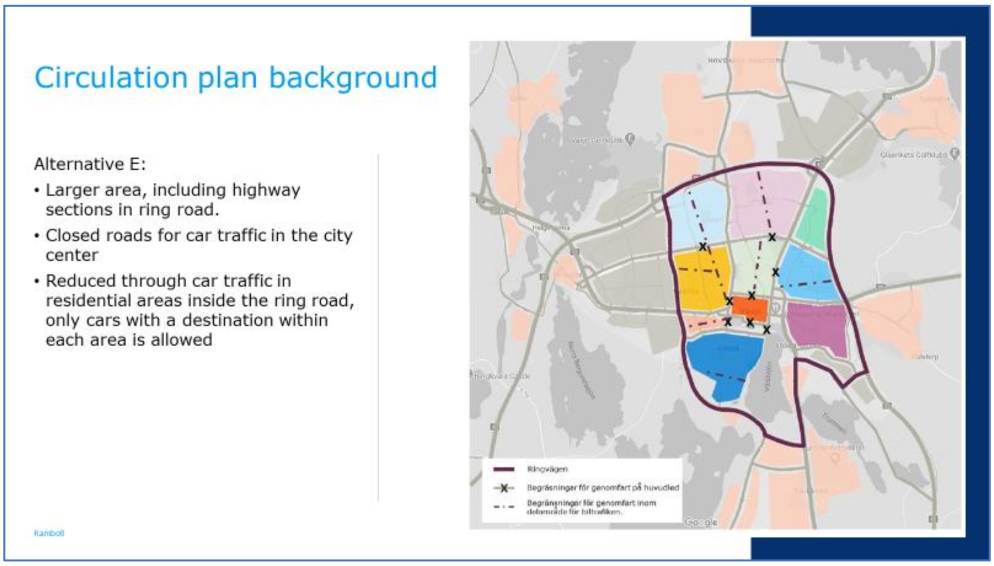


Circulation plan background

Alternative C

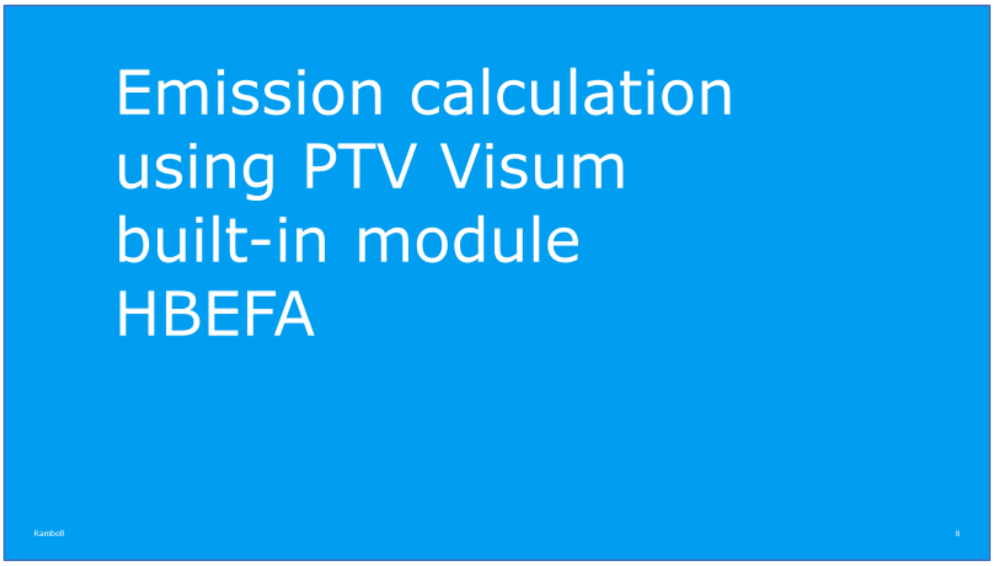
- Closed roads for car traffic in the city center
- Reduce through car traffic in residential areas inside the ring road, only cars with a destination within each area is allowed



Circulation plan background

Alternative E:

- Larger area, including highway sections in ring road.
- Closed roads for car traffic in the city center
- Reduced through car traffic in residential areas inside the ring road, only cars with a destination within each area is allowed



Emission calculation using PTV Visum built-in module HBEFA

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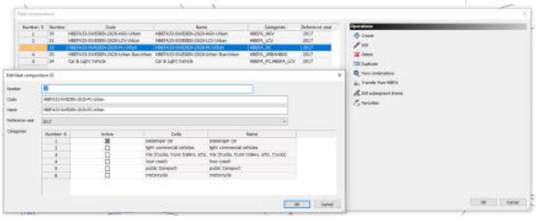
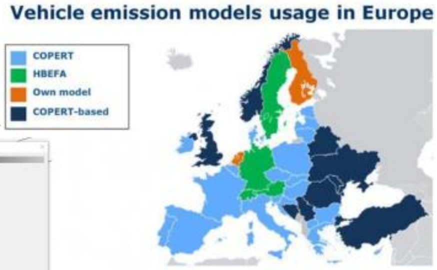
SUMBA

Emission calculation using Visum HBEFA module

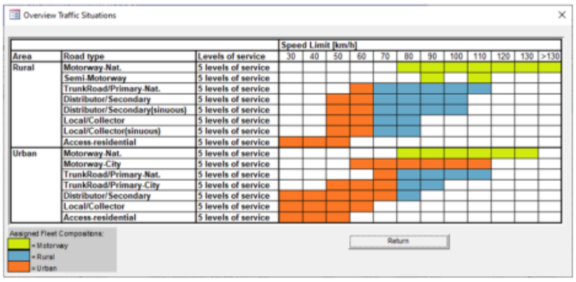
- Emission factors, fleet compositions etc are per-built and available in Visum for Germany, Sweden, Norway, Austria, France, Switzerland
- 6 different motor vehicles are available, each divided into different vehicle types
- These can be combined to fit the demand segments already used in the model





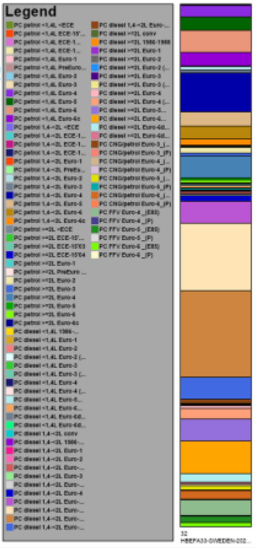
Emission calculation using Visum HBEFA module

- The road network has to be classified according to Visums built-in HBEFA link types
  - There are 15 different link types available
- The default Swedish fleet compositions have been used for reference year 2017
  - The fleet composition for PC is a combination of 129 different vehicle types



			Speed Limit [km/h]											
Area	Road type	Levels of service	30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway-Nat.	5 levels of service						🟨	🟨	🟨	🟨	🟨	🟨	🟨
	Semi-Motorway	5 levels of service							🟨		🟨			
	TrunkRoad/Primary-Nat.	5 levels of service				🟧	🟦	🟦	🟦	🟦	🟦			
	Distributor/Secondary	5 levels of service			🟧	🟧	🟦	🟦	🟦	🟦				
	Distributor/Secondary(sinuous)	5 levels of service			🟧	🟧	🟦	🟦	🟦	🟦				
	Local/Collector	5 levels of service			🟧	🟧	🟦	🟦						
	Local/Collector(sinuous)	5 levels of service			🟧	🟧	🟦	🟦						
	Access-residential	5 levels of service	🟧	🟧	🟧									
Urban	Motorway-Nat.	5 levels of service						🟨	🟨	🟨	🟨	🟨	🟨	
	Motorway-City	5 levels of service				🟧	🟧	🟧	🟧	🟧	🟧			
	TrunkRoad/Primary-Nat.	5 levels of service					🟧	🟦	🟦	🟦	🟦			
	TrunkRoad/Primary-City	5 levels of service			🟧	🟧	🟧	🟦	🟦					
	Distributor/Secondary	5 levels of service	🟧	🟧	🟧	🟧	🟧	🟦						
	Local/Collector	5 levels of service	🟧	🟧	🟧	🟧								
	Access-residential	5 levels of service	🟧	🟧	🟧									

Assigned Fleet Compositions:
🟨 = Motorway
🟦 = Rural
🟧 = Urban



Emission calculation using Visum module

- 11 different HBEFA link types have been used in the city of Växjö model
- The classification is based on the link types used in the model - which is based on the Swedish Transport Administration's road type classes

Interreg
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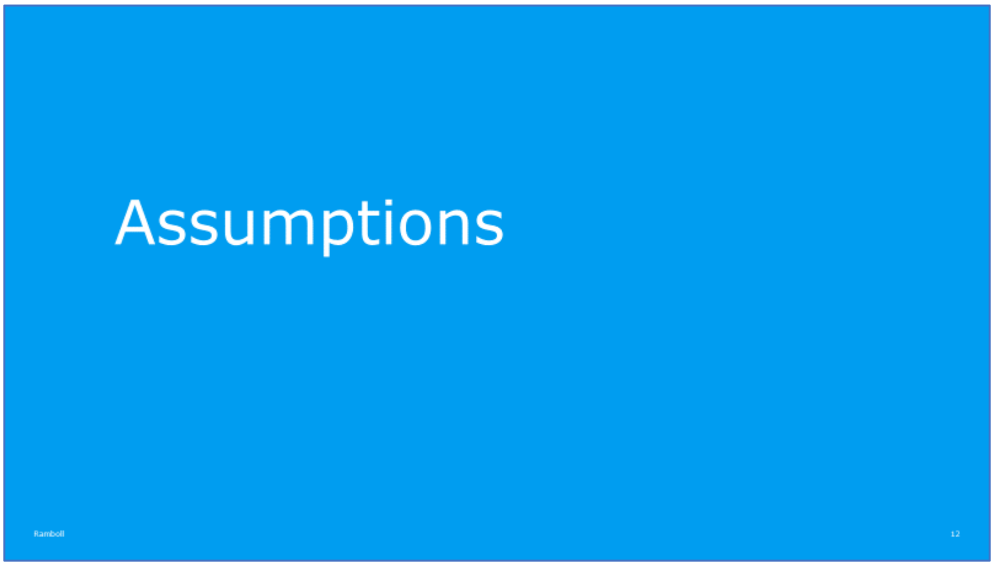
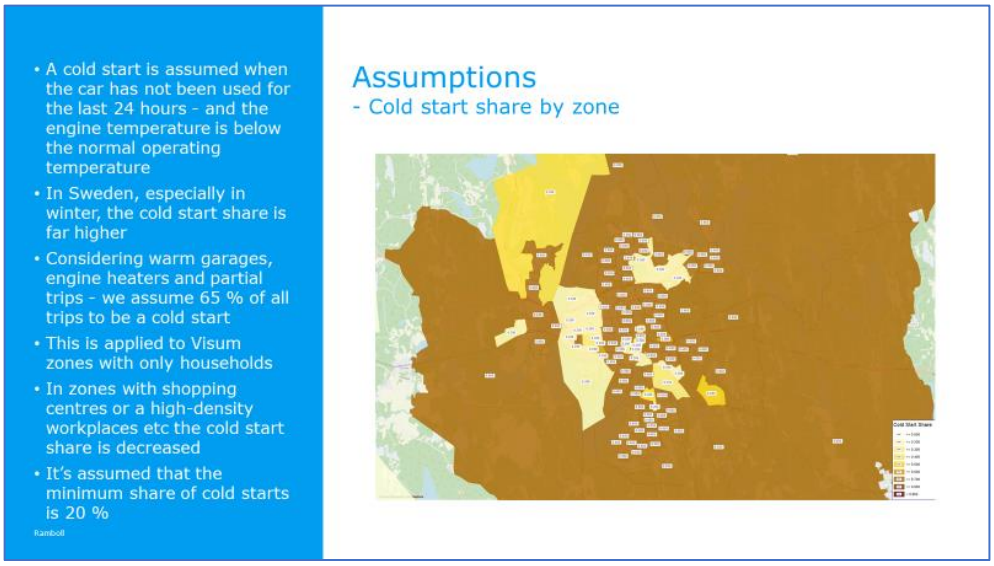


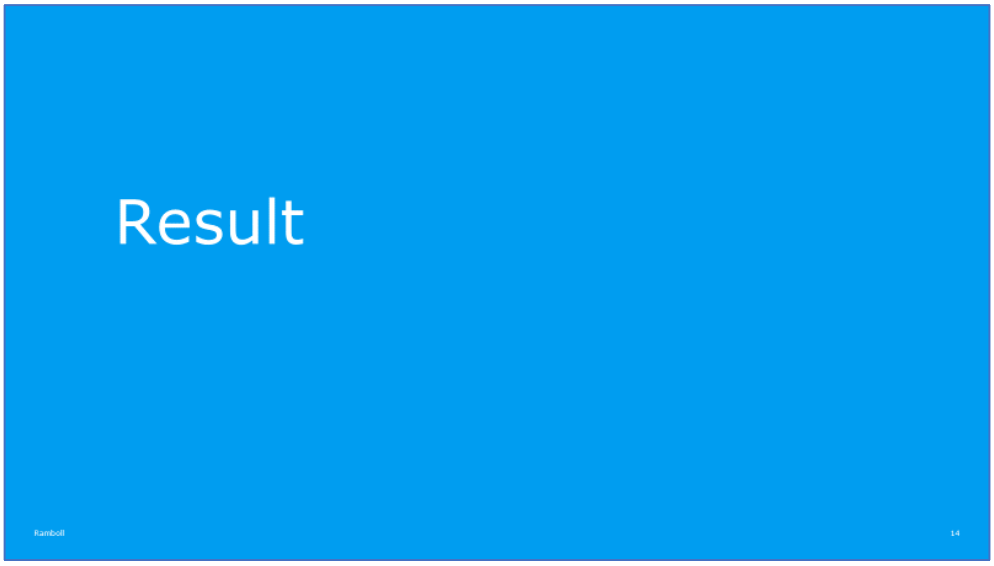
Assumptions



- A cold start is assumed when the car has not been used for the last 24 hours - and the engine temperature is below the normal operating temperature
- In Sweden, especially in winter, the cold start share is far higher
- Considering warm garages, engine heaters and partial trips - we assume 65 % of all trips to be a cold start
- This is applied to Visum zones with only households
- In zones with shopping centres or a high-density workplaces etc the cold start share is decreased
- It's assumed that the minimum share of cold starts is 20 %

Assumptions

- Cold start share by zone



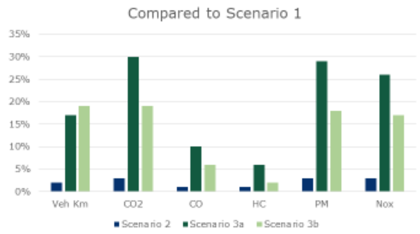
Result

Scenarios analysed

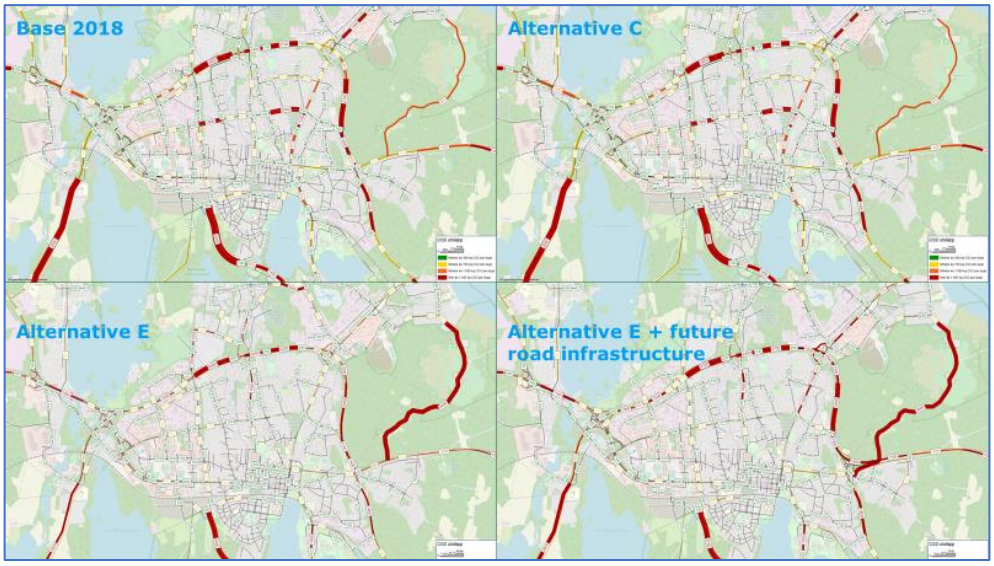
1. Base 2018
2. Alternative C with today's infrastructure
3. Alternative E
   a) with today's road infrastructure
   b) with a future road infrastructure

All scenarios are using the same demography

Result Emission calculations


Compared to Scenario 1

	Scenario 1 (Base 2018)	Scenario 2 (Alt C)	Scenario 3a (Alt E)	Scenario 3b (alt E+)
Vehicle km	1 284 349 km	1 314 189 km (+2%)	1 503 609 km (+17%)	1 526 495 km (+19%)
CO2	148 912 kg	153 758 kg (+3%)	193 442 kg (+30%)	177 802 kg (+19%)
CO	452 kg	458 kg (+1%)	497 kg (+10%)	480 kg (+6%)
HC	70.07 kg	70.44 kg (+1%)	74.04 kg (+6%)	71.76 kg (+2%)
PM	3.47 kg	3.58 kg (+3%)	4.48 kg (+29%)	4.11 kg (+18%)
NOx	409 kg	421 kg (+3%)	517 kg (+26%)	480 kg (+17%)



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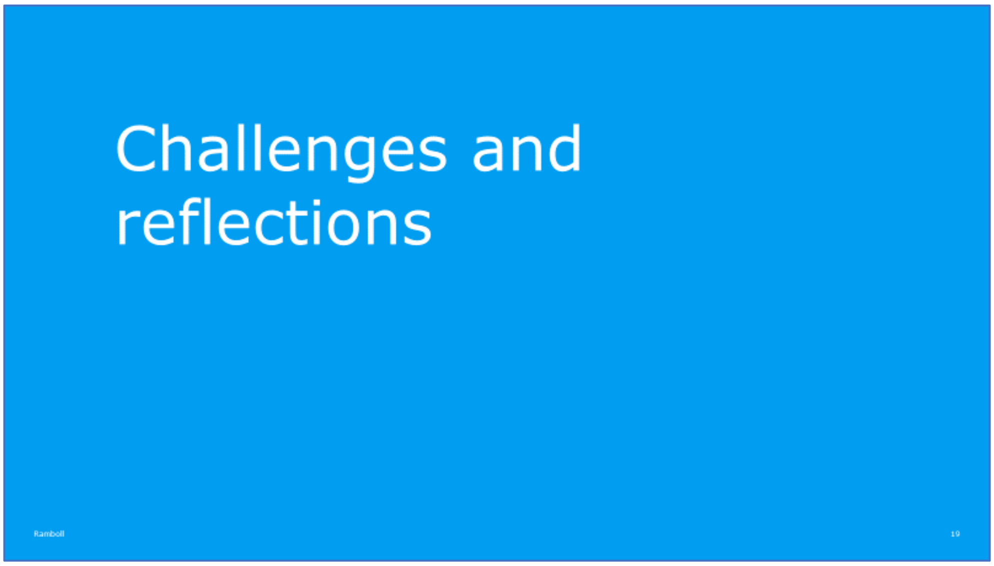
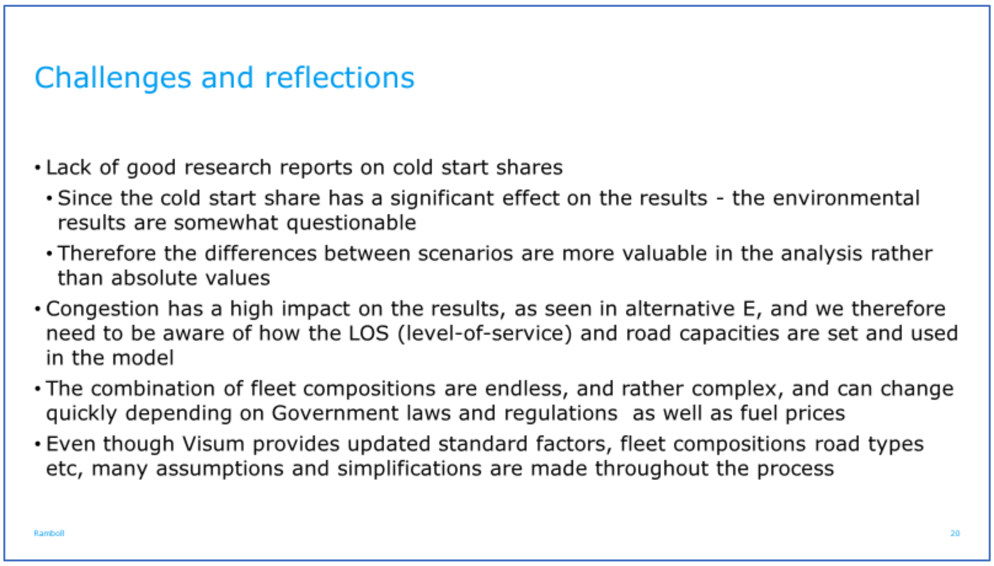


Challenges and reflections



Challenges and reflections

- Lack of good research reports on cold start shares
  - Since the cold start share has a significant effect on the results - the environmental results are somewhat questionable
  - Therefore the differences between scenarios are more valuable in the analysis rather than absolute values
- Congestion has a high impact on the results, as seen in alternative E, and we therefore need to be aware of how the LOS (level-of-service) and road capacities are set and used in the model
- The combination of fleet compositions are endless, and rather complex, and can change quickly depending on Government laws and regulations as well as fuel prices
- Even though Visum provides updated standard factors, fleet compositions road types etc, many assumptions and simplifications are made throughout the process

Thank you!

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Therese.zieden@ramboll.se

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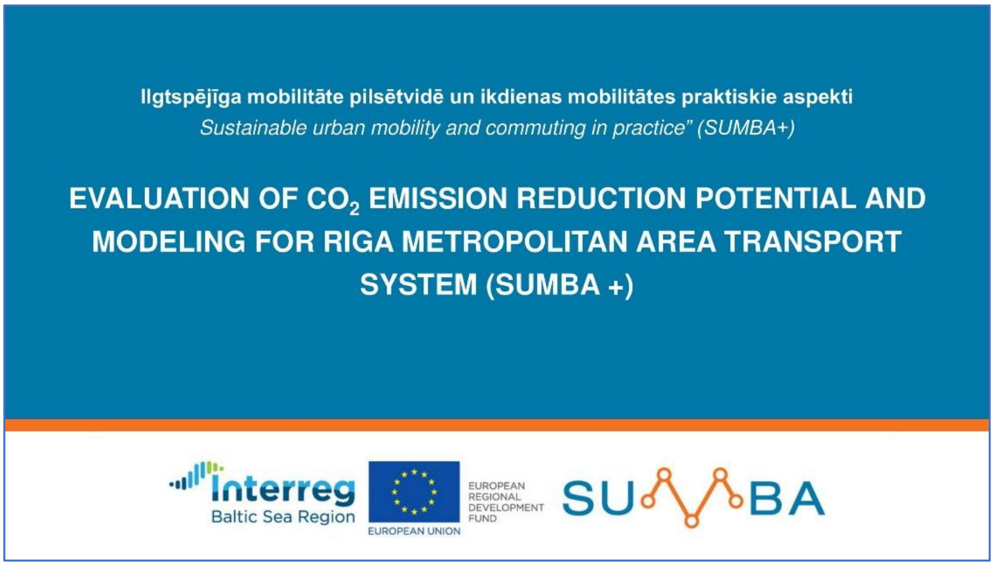
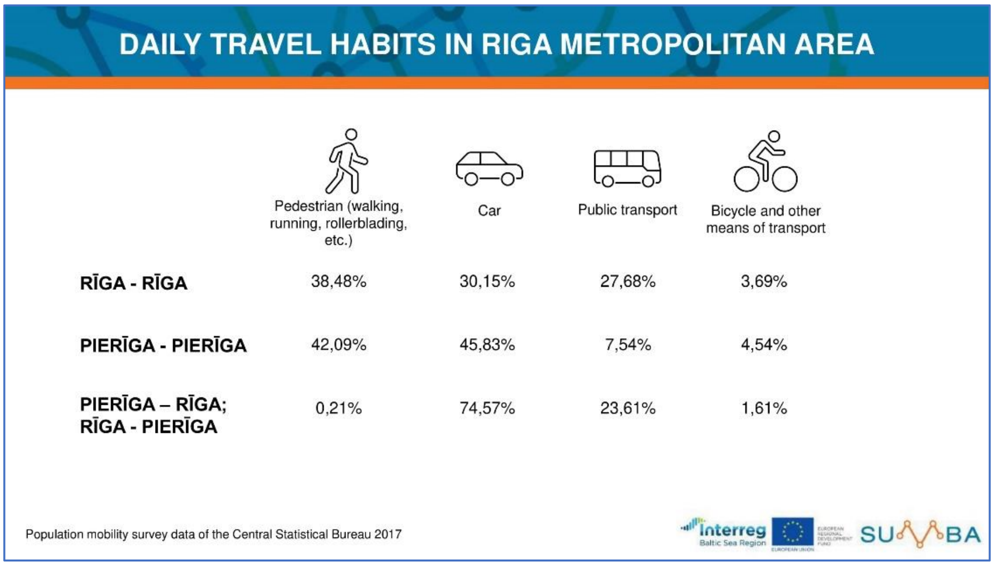
ANNEX II: SLIDES OF THE PRESENTATION OF RESULTS FOR THE RIGA METROPOLITAN AREA



Ilgtspējīga mobilitāte pilsētvidē un ikdienas mobilitātes praktiskie aspekti

Sustainable urban mobility and commuting in practice" (SUMBA+)

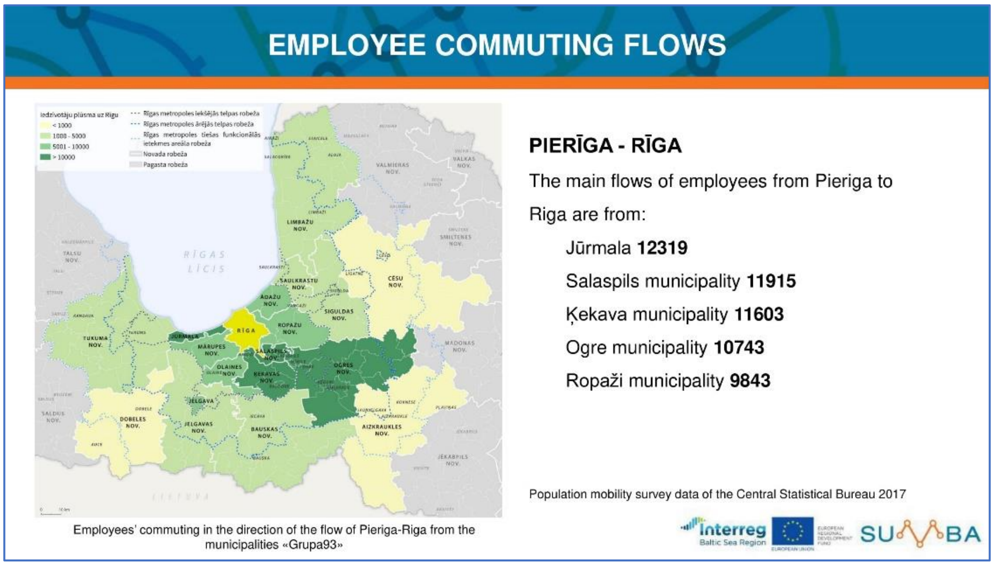
EVALUATION OF CO_2 EMISSION REDUCTION POTENTIAL AND MODELING FOR RIGA METROPOLITAN AREA TRANSPORT SYSTEM (SUMBA +)



DAILY TRAVEL HABITS IN RIGA METROPOLITAN AREA

	Pedestrian (walking, running, rollerblading, etc.)	Car	Public transport	Bicycle and other means of transport
RĪGA - RĪGA	38,48%	30,15%	27,68%	3,69%
PIERĪGA - PIERĪGA	42,09%	45,83%	7,54%	4,54%
PIERĪGA – RĪGA; RĪGA - PIERĪGA	0,21%	74,57%	23,61%	1,61%

Population mobility survey data of the Central Statistical Bureau 2017



EMPLOYEE COMMUTING FLOWS

Employees' commuting in the direction of the flow of Pieriga-Riga from the municipalities «Grupa93»

PIERĪGA - RĪGA

The main flows of employees from Pieriga to Riga are from:

Jūrmala **12319**
Salaspils municipality **11915**
Ķekava municipality **11603**
Ogre municipality **10743**
Ropaži municipality **9843**

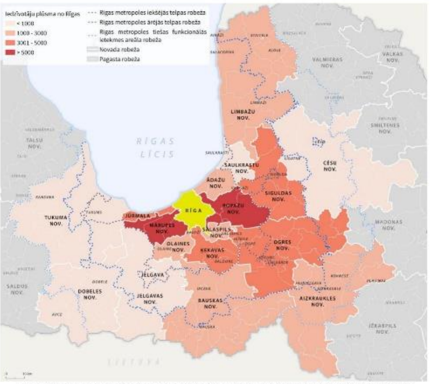
Population mobility survey data of the Central Statistical Bureau 2017

EMPLOYEE COMMUTING FLOWS

RĪGA - PIERĪGA

The largest number of employees' commuting from Riga to work in the municipalities of Pieriga are to:

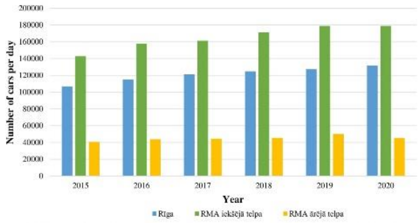
Mārupe municipality **10551**
Ropaži municipality **5334**
Ķekava municipality **4501**
Sigulda municipality **4001**
Ogre municipality **3630**



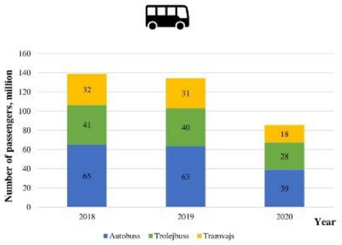
Employees' commuting in the direction of the flow of Riga-Pieriga to the municipalities «Grupa93»

Population mobility survey data of the Central Statistical Bureau 2017

TRAFFIC INTENSITY AND PASSENGERS TRANSPORTED BY 'RIGAS SATIKSME'



Daily number of passenger cars on the main national roads during the period 2015-2020 («Grupa93» calculations, LVC data)

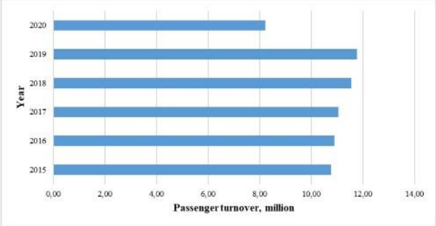


Number of passengers transported by Rigas Satiksme Ltd. for 2018-2020 («Grupa93» calculations according to data from "Rigas Satiksme")

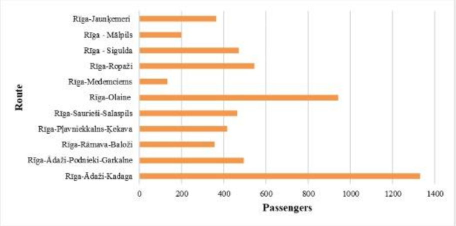
The number of passengers transported by Rigas Satiksme Ltd. has a tendency to fall, which has been significantly affected by the Covid-19 pandemic. In 2020, compared to 2019, the number of passengers transported **decreased by 36.38% to 85.5 million passengers.**

ANALYSIS OF THE DATA OF THE ROAD TRANSPORT DIRECTORATE AS "PASSENGER TRAIN" AND VSIA ATD

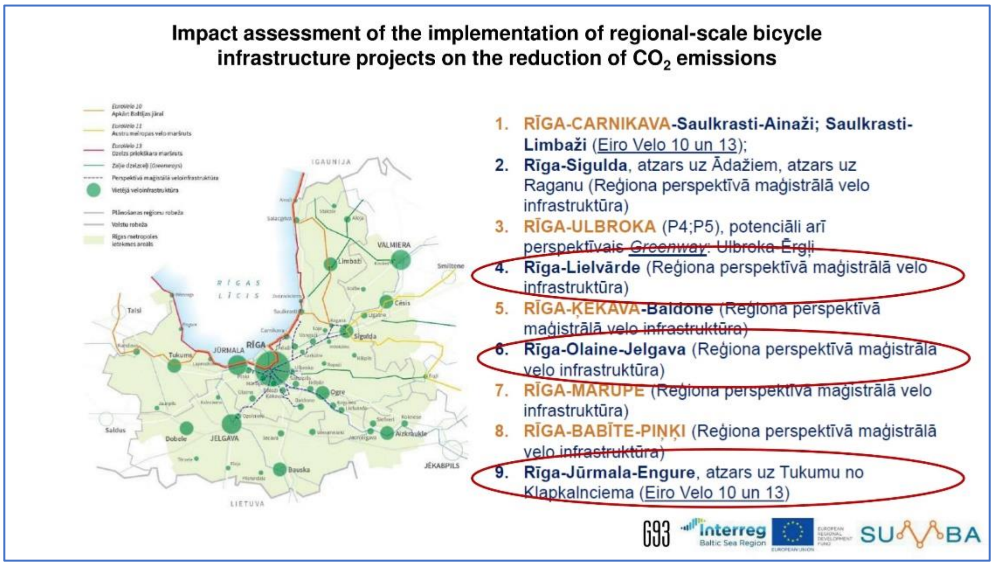
In 2019, passenger turnover at the Riga passenger railway station was the highest, reaching 11.77 million passengers per year. In 2020, there is a drop in turnover to 8.2 million passengers per year.



Number of passenger train trips per year for the period 2015-2020 (Source: AS "Pasazieru Vilciens")

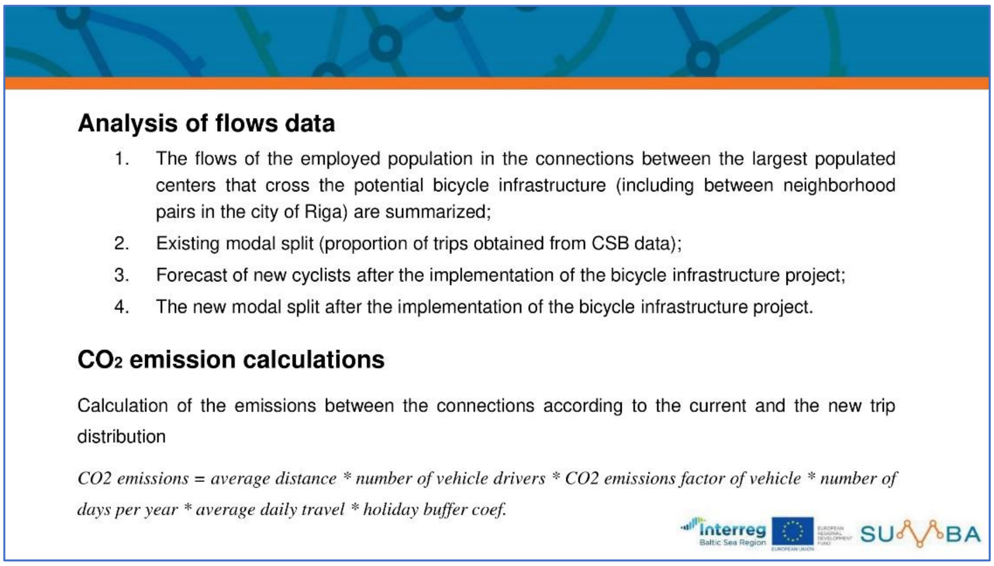


Average number of passengers entering the routes in Pieriga (Source: VSIA ATD)



Impact assessment of the implementation of regional-scale bicycle infrastructure projects on the reduction of CO_2 emissions

1. **RĪGA-CARNIKAVA-Saulkrasti-Ainaži; Saulkrasti-Limbaži** (Eiro Velo 10 un 13);
2. **Rīga-Sigulda**, atzars uz Ādažiem, atzars uz Raganu (Reģiona perspektīvā maģistrālā velo infrastruktūra)
3. **RĪGA-ULBROKA** (P4;P5), potenciāli arī perspektīvais *Greenway*: Ulbroka-Ērgļi
4. **Rīga-Lielvārde** (Reģiona perspektīvā maģistrālā velo infrastruktūra)
5. **RĪGA-ĶEKAVA-Baldone** (Reģiona perspektīvā maģistrālā velo infrastruktūra)
6. **Rīga-Olaine-Jelgava** (Reģiona perspektīvā maģistrāla velo infrastruktūra)
7. **RĪGA-MARUPE** (Reģiona perspektīvā maģistrālā velo infrastruktūra)
8. **RĪGA-BABĪTE-PIŅĶI** (Reģiona perspektīvā maģistrālā velo infrastruktūra)
9. **Rīga-Jūrmala-Engure**, atzars uz Tukumu no Klapkalnciema (Eiro Velo 10 un 13)



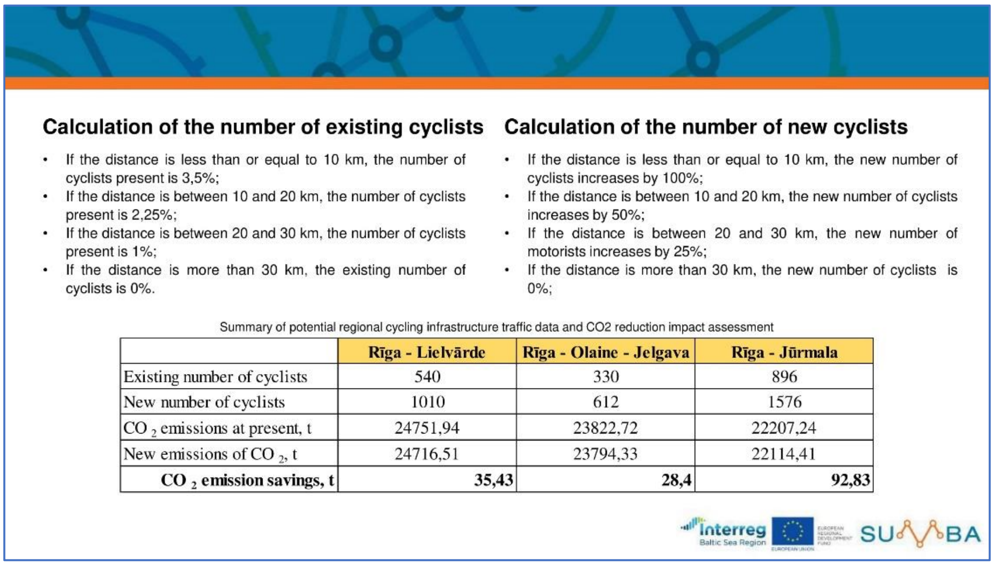
Analysis of flows data

1. The flows of the employed population in the connections between the largest populated centers that cross the potential bicycle infrastructure (including between neighborhood pairs in the city of Riga) are summarized;
2. Existing modal split (proportion of trips obtained from CSB data);
3. Forecast of new cyclists after the implementation of the bicycle infrastructure project;
4. The new modal split after the implementation of the bicycle infrastructure project.

CO_2 emission calculations

Calculation of the emissions between the connections according to the current and the new trip distribution

*CO2 emissions = average distance * number of vehicle drivers * CO2 emissions factor of vehicle * number of days per year * average daily travel * holiday buffer coef.*



Calculation of the number of existing cyclists

- If the distance is less than or equal to 10 km, the number of cyclists present is 3,5%;
- If the distance is between 10 and 20 km, the number of cyclists present is 2,25%;
- If the distance is between 20 and 30 km, the number of cyclists present is 1%;
- If the distance is more than 30 km, the existing number of cyclists is 0%.

Calculation of the number of new cyclists

- If the distance is less than or equal to 10 km, the new number of cyclists increases by 100%;
- If the distance is between 10 and 20 km, the new number of cyclists increases by 50%;
- If the distance is between 20 and 30 km, the new number of motorists increases by 25%;
- If the distance is more than 30 km, the new number of cyclists is 0%;

Summary of potential regional cycling infrastructure traffic data and CO2 reduction impact assessment

	Rīga - Lielvārde	**Rīga - Olaine - Jelgava**	**Rīga - Jūrmala**
Existing number of cyclists	540	330	896
New number of cyclists	1010	612	1576
CO_2 emissions at present, t	24751,94	23822,72	22207,24
New emissions of CO_2, t	24716,51	23794,33	22114,41
CO_2 emission savings, t	**35,43**	**28,4**	**92,83**

Impact assessment of the implementation of mobility point projects on CO_2 reduction

Population within a 1 km radius

- Population within a 1 km radius around the mobility point (of which 80.5% mobile);
- Existing modal distribution and calculation of CO2 emissions (PKM * CO2 emissions factor * number of days per year);
- The new distribution of journeys where a person switches from a private car to a sharing service at a mobility point;
- The new modal distribution and calculation of CO2 emissions.

Holiday trips

- Basic data on visits to tourist sites from TIC;
- Population in the reach areas of stations with different modes of transport (50 min. on the way and to the station, 10 min. to the destination);
- Distribution of trips before and after the realization of the mobility point;
- CO2 emissions before and after the realization of the mobility point.

Employee commuting

- Employee commuting flows in connections between densely populated areas near the mobility point and Riga;
- Number of journeys by car at present;
- Number of trips to switch to a train (90%) and an intercity bus (10%) (demand for supply);
- CO2 emissions before and after switching to the mobility point.

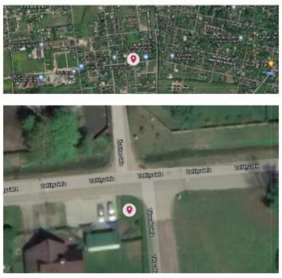
Indicative calculations of service capacity depending on the area were made for each mobility point.

Impact assessment of the implementation of mobility point projects on CO_2 reduction

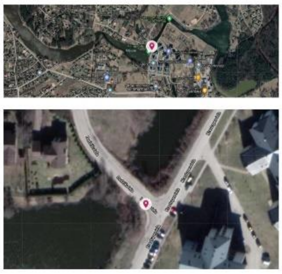
MICROMOBILITY POINTS

Mandatory functions - Bike and Car Sharing Services

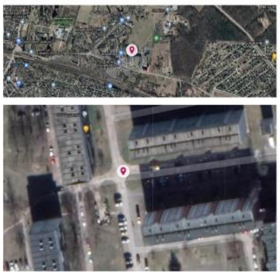
Data: Population within a 1 km radius



MĀRUPE



KRASTUPES STREET
(ĀDAŽI)



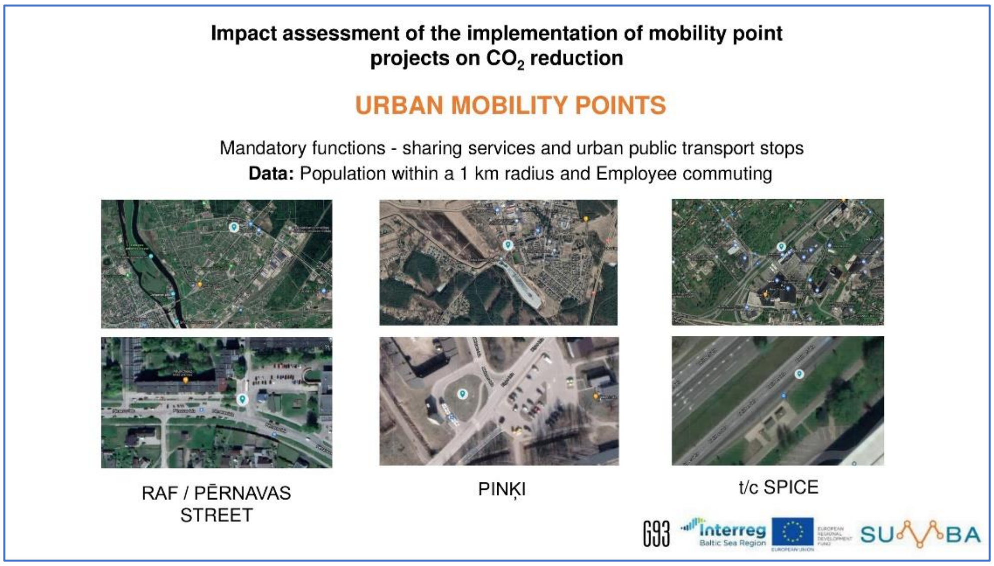
SALASPILS

Reduction in the number of trips when no car is available at any moment	**5%**	**1,9**
Number of trips where a car is needed	50%	0,95
From trips where the car is needed, how many **private cars** will be used	50%	0,475
From trips where the car is needed, how many **sharing vehicles** will be used	50%	0,475
From trips where no car is needed, how much **public transport** will be used	90%	0,855
From trips where there is no need for a car, how many will use **a bicycle**	10%	0,095

New distribution of trips when a person switches from a private car to sharing services at a mobility point.

Impact of the realisation of a micromobility point on annual CO2 emissions reductions

	SALASPILS				KRASTUPES STREET				MĀRUPE			
	CO_2 emissions prior to the realisation of the mobility point, t	%	CO_2 emissions following the realisation of the mobility point, t	%	CO_2 emissions prior to the realisation of the mobility point, t	%	CO_2 emissions following the realisation of the mobility point, t	%	CO_2 emissions prior to the realisation of the mobility point, t	%	CO_2 emissions following the realisation of the mobility point, t	%
Car	1873,73	97,95	1775,36	97,48	1363,51	97,95	1291,92	97,48	1747,51	97,95	1655,77	97,48
Private	-	-	1730,85	95,03	-	-	1259,54	95,03	-	-	1614,26	95,03
Sharing	-	-	13,36	0,73	-	-	9,72	0,73	-	-	12,46	0,73
PT	39,12	2,05	45,96	2,52	28,47	2,05	33,44	2,52	36,48	2,05	42,86	2,52
With bicycle	0	0	0	0	0	0	0	0	0	0	0	0
Walking	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	**1912,84**		**1821,31**		**1391,97**		**1325,36**		**1784**		**1698,63**	



Impact assessment of the implementation of mobility point projects on CO_2 reduction

URBAN MOBILITY POINTS

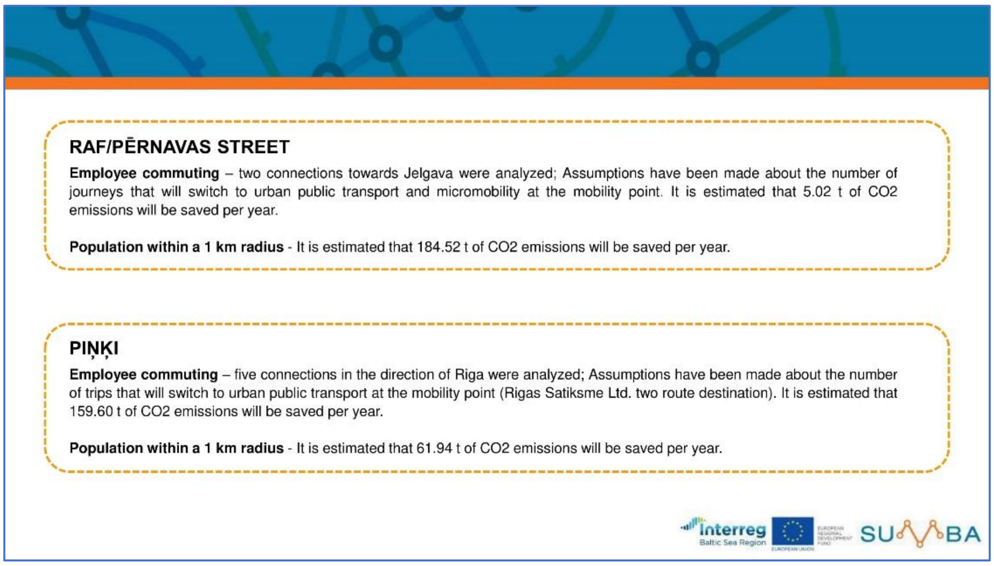
Mandatory functions - sharing services and urban public transport stops

Data: Population within a 1 km radius and Employee commuting

RAF / PĒRNAVAS STREET

PIŅĶI

t/c SPICE



RAF/PĒRNAVAS STREET

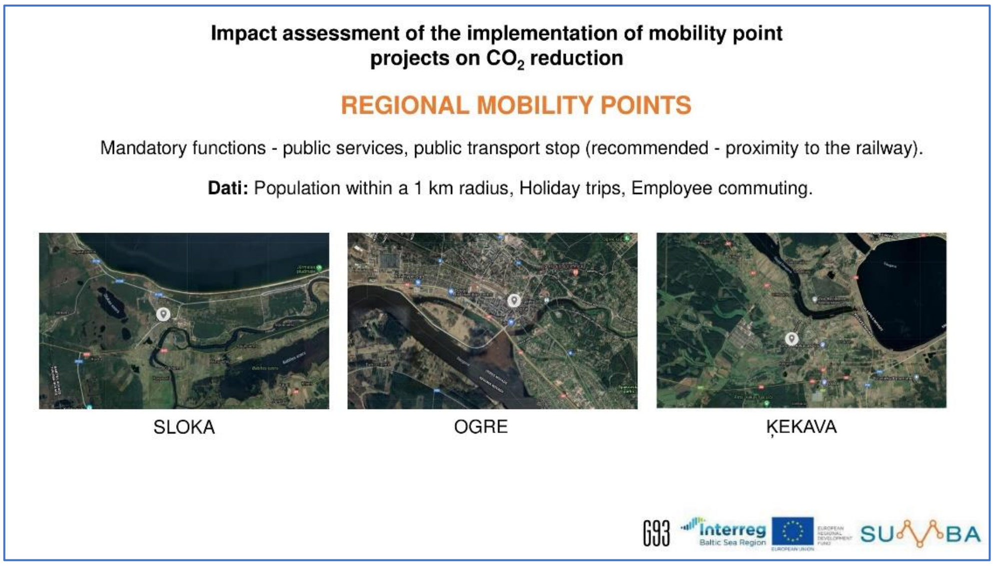
Employee commuting – two connections towards Jelgava were analyzed; Assumptions have been made about the number of journeys that will switch to urban public transport and micromobility at the mobility point. It is estimated that 5.02 t of CO2 emissions will be saved per year.

Population within a 1 km radius - It is estimated that 184.52 t of CO2 emissions will be saved per year.

PIŅĶI

Employee commuting – five connections in the direction of Riga were analyzed; Assumptions have been made about the number of trips that will switch to urban public transport at the mobility point (Rigas Satiksme Ltd. two route destination). It is estimated that 159.60 t of CO2 emissions will be saved per year.

Population within a 1 km radius - It is estimated that 61.94 t of CO2 emissions will be saved per year.



Impact assessment of the implementation of mobility point projects on CO_2 reduction

REGIONAL MOBILITY POINTS

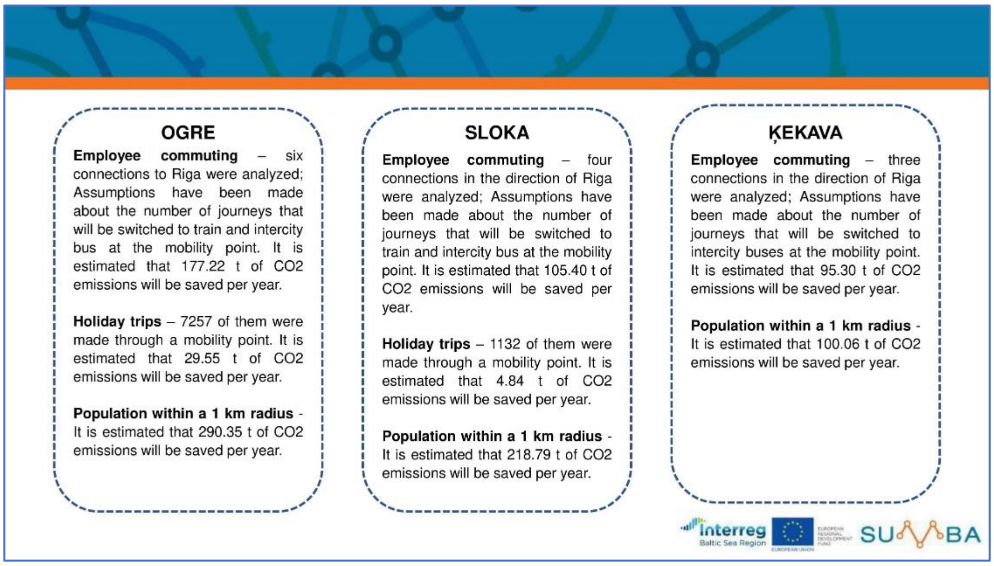
Mandatory functions - public services, public transport stop (recommended - proximity to the railway).

Dati: Population within a 1 km radius, Holiday trips, Employee commuting.

SLOKA

OGRE

ĶEKAVA



OGRE

Employee commuting – six connections to Riga were analyzed; Assumptions have been made about the number of journeys that will be switched to train and intercity bus at the mobility point. It is estimated that 177.22 t of CO2 emissions will be saved per year.

Holiday trips – 7257 of them were made through a mobility point. It is estimated that 29.55 t of CO2 emissions will be saved per year.

Population within a 1 km radius - It is estimated that 290.35 t of CO2 emissions will be saved per year.

SLOKA

Employee commuting – four connections in the direction of Riga were analyzed; Assumptions have been made about the number of journeys that will be switched to train and intercity bus at the mobility point. It is estimated that 105.40 t of CO2 emissions will be saved per year.

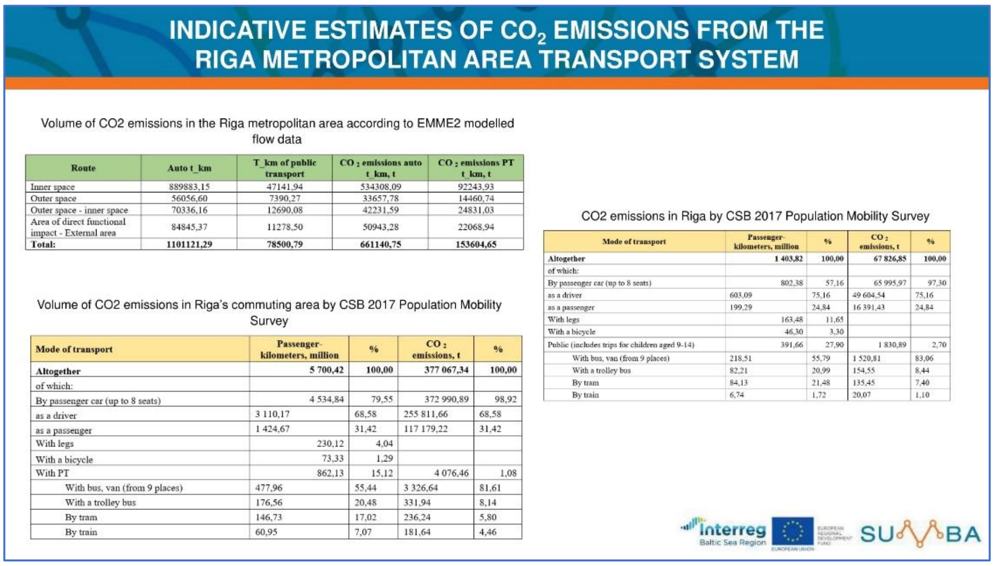
Holiday trips – 1132 of them were made through a mobility point. It is estimated that 4.84 t of CO2 emissions will be saved per year.

Population within a 1 km radius - It is estimated that 218.79 t of CO2 emissions will be saved per year.

ĶEKAVA

Employee commuting – three connections in the direction of Riga were analyzed; Assumptions have been made about the number of journeys that will be switched to intercity buses at the mobility point. It is estimated that 95.30 t of CO2 emissions will be saved per year.

Population within a 1 km radius - It is estimated that 100.06 t of CO2 emissions will be saved per year.



INDICATIVE ESTIMATES OF CO_2 EMISSIONS FROM THE RIGA METROPOLITAN AREA TRANSPORT SYSTEM

Volume of CO2 emissions in the Riga metropolitan area according to EMME2 modelled flow data

Route	Auto t_km	T_km of public transport	CO_2 emissions auto t_km, t	CO_2 emissions PT t_km, t
Inner space	889883,15	47141,94	534308,09	92243,93
Outer space	56056,60	7390,27	33657,78	14460,74
Outer space - inner space	70336,16	12690,08	42231,59	24831,03
Area of direct functional impact - External area	84845,37	11278,50	50943,28	22068,94
Total:	**1101121,29**	**78500,79**	**661140,75**	**153604,65**

Volume of CO2 emissions in Riga's commuting area by CSB 2017 Population Mobility Survey

Mode of transport	Passenger-kilometers, million	%	CO_2 emissions, t	%
Altogether	**5 700,42**	**100,00**	**377 067,34**	**100,00**
of which:				
By passenger car (up to 8 seats)	4 534,84	79,55	372 990,89	98,92
as a driver	3 110,17	68,58	255 811,66	68,58
as a passenger	1 424,67	31,42	117 179,22	31,42
With legs	230,12	4,04		
With a bicycle	73,33	1,29		
With PT	862,13	15,12	4 076,46	1,08
With bus, van (from 9 places)	477,96	55,44	3 326,64	81,61
With a trolley bus	176,56	20,48	331,94	8,14
By tram	146,73	17,02	236,24	5,80
By train	60,95	7,07	181,64	4,46

CO2 emissions in Riga by CSB 2017 Population Mobility Survey

Mode of transport	Passenger-kilometers, million	%	CO_2 emissions, t	%
Altogether	**1 403,82**	**100,00**	**67 826,85**	**100,00**
of which:				
By passenger car (up to 8 seats)	802,38	57,16	65 995,97	97,30
as a driver	603,09	75,16	49 604,54	75,16
as a passenger	199,29	24,84	16 391,43	24,84
With legs	163,48	11,65		
With a bicycle	46,30	3,30		
Public (includes trips for children aged 9-14)	391,66	27,90	1 830,89	2,70
With bus, van (from 9 places)	218,51	55,79	1 520,81	83,06
With a trolley bus	82,21	20,99	154,55	8,44
By tram	84,13	21,48	135,45	7,40
By train	6,74	1,72	20,07	1,10

Thank you for your attention!