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

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

German Aerospace Center (DLR)
Institute of Transport Research

6 Programme Topics

- Aeronautics and Space
- Transport and Energy
- Security and Digitalisation

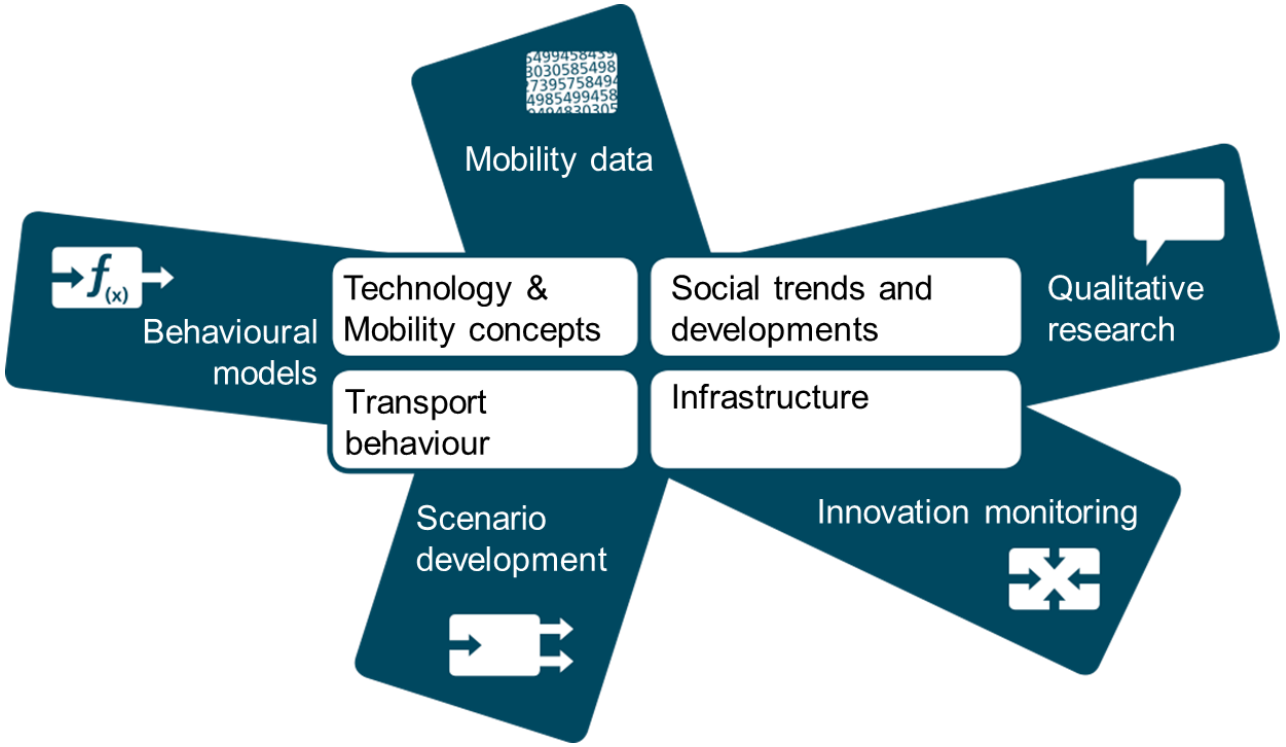
Locations

- 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

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.

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
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- 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

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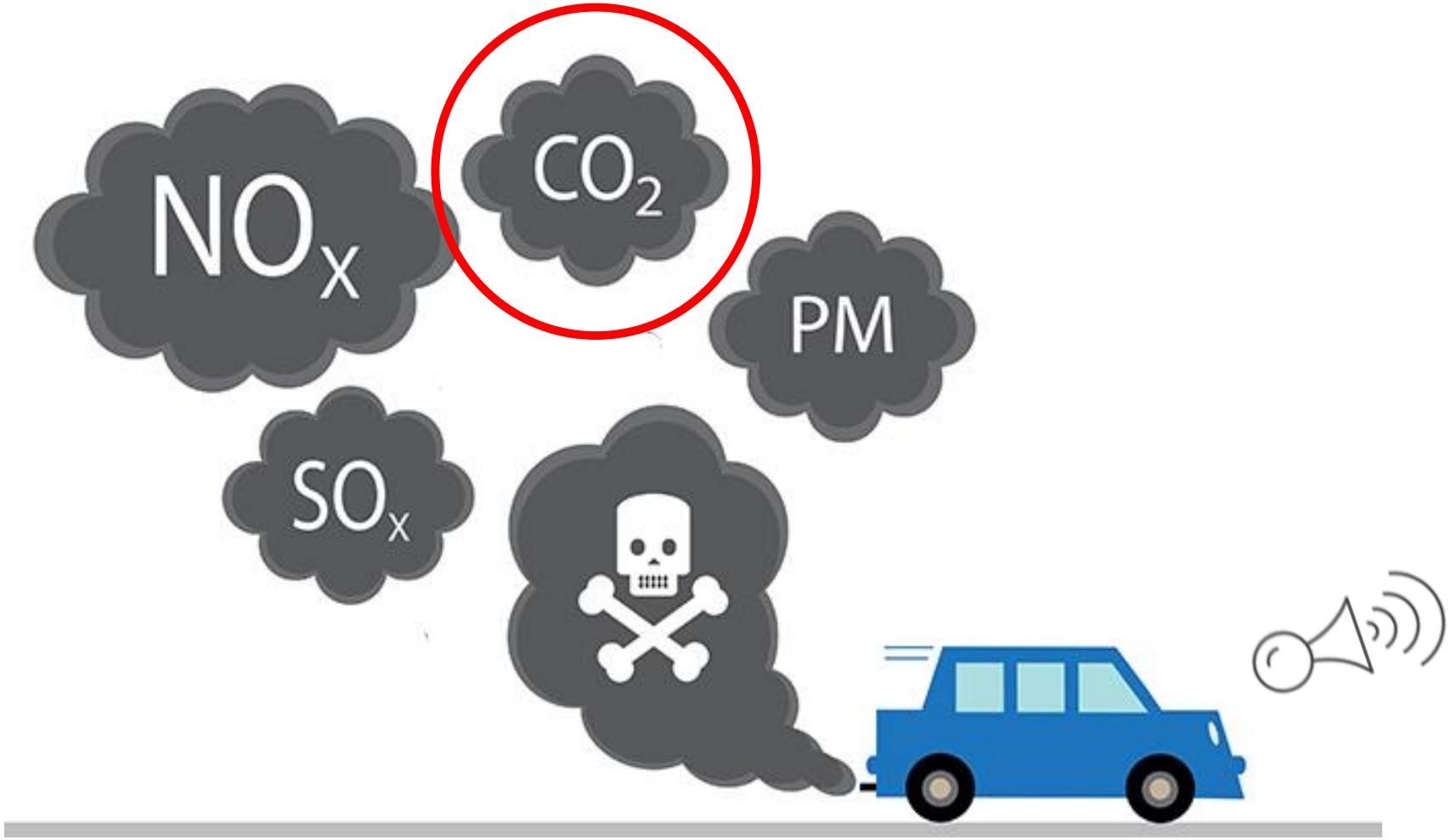
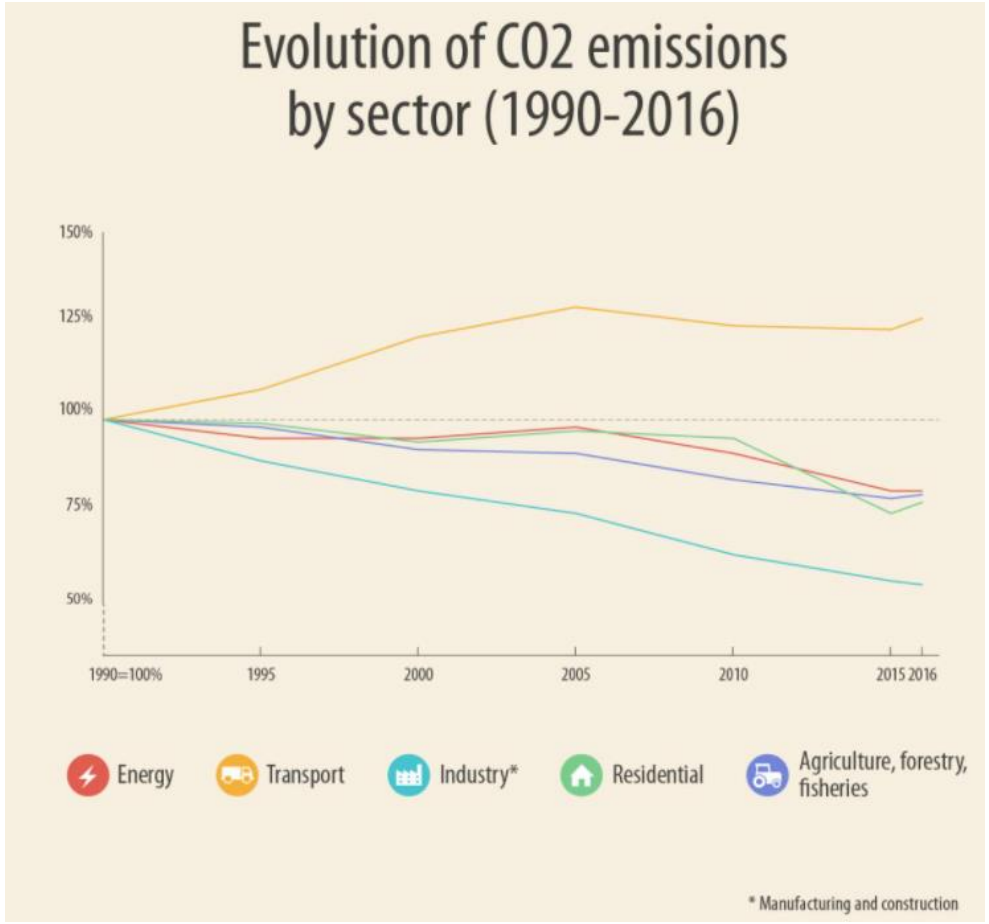
Transport-related Emission

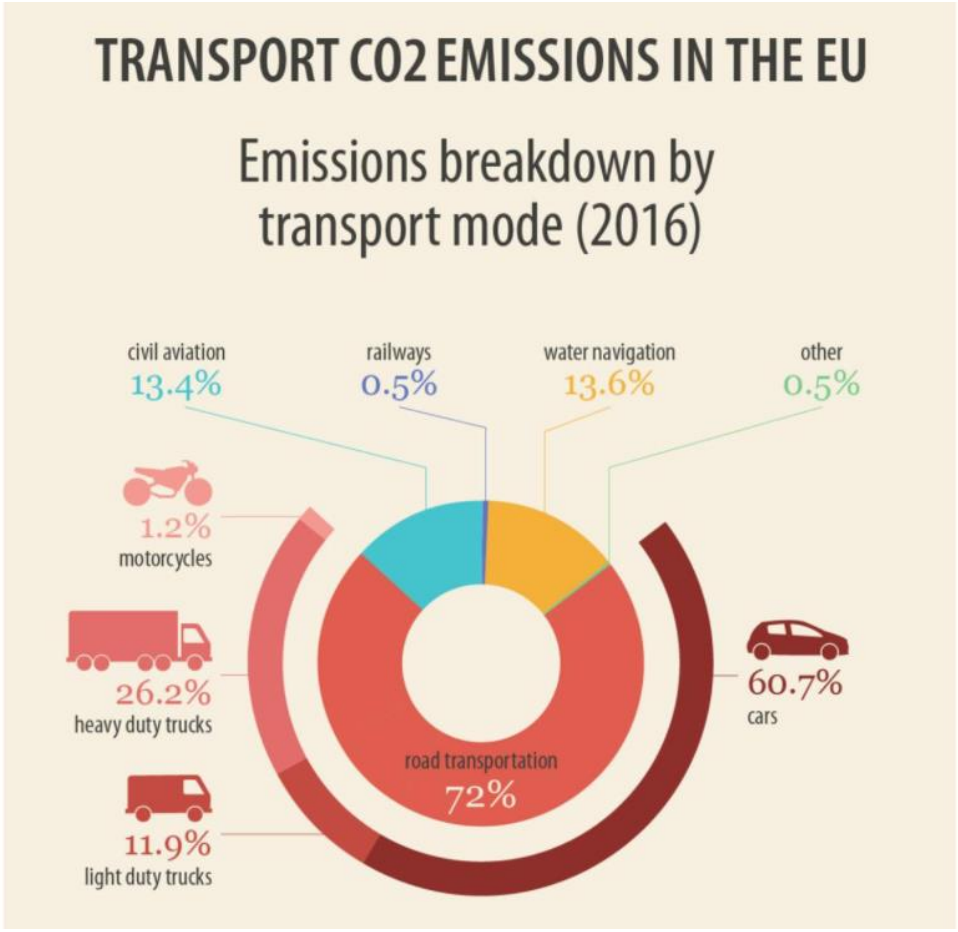
What kind of emissions are we talking about in this webinar?



Why is the topic relevant?

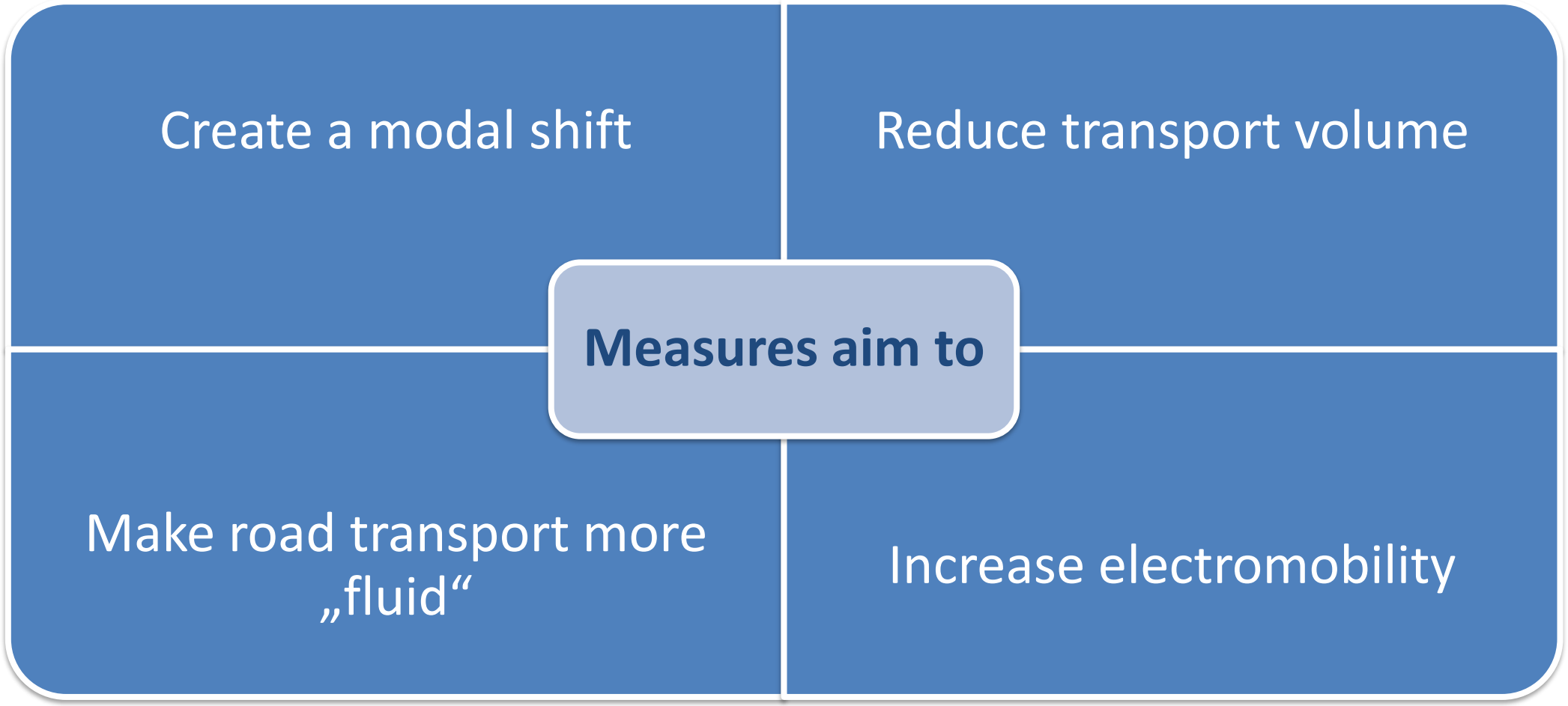


Evolution of CO2 emissions in the EU by sector (1990-2016)
Source: European Environment Agency



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

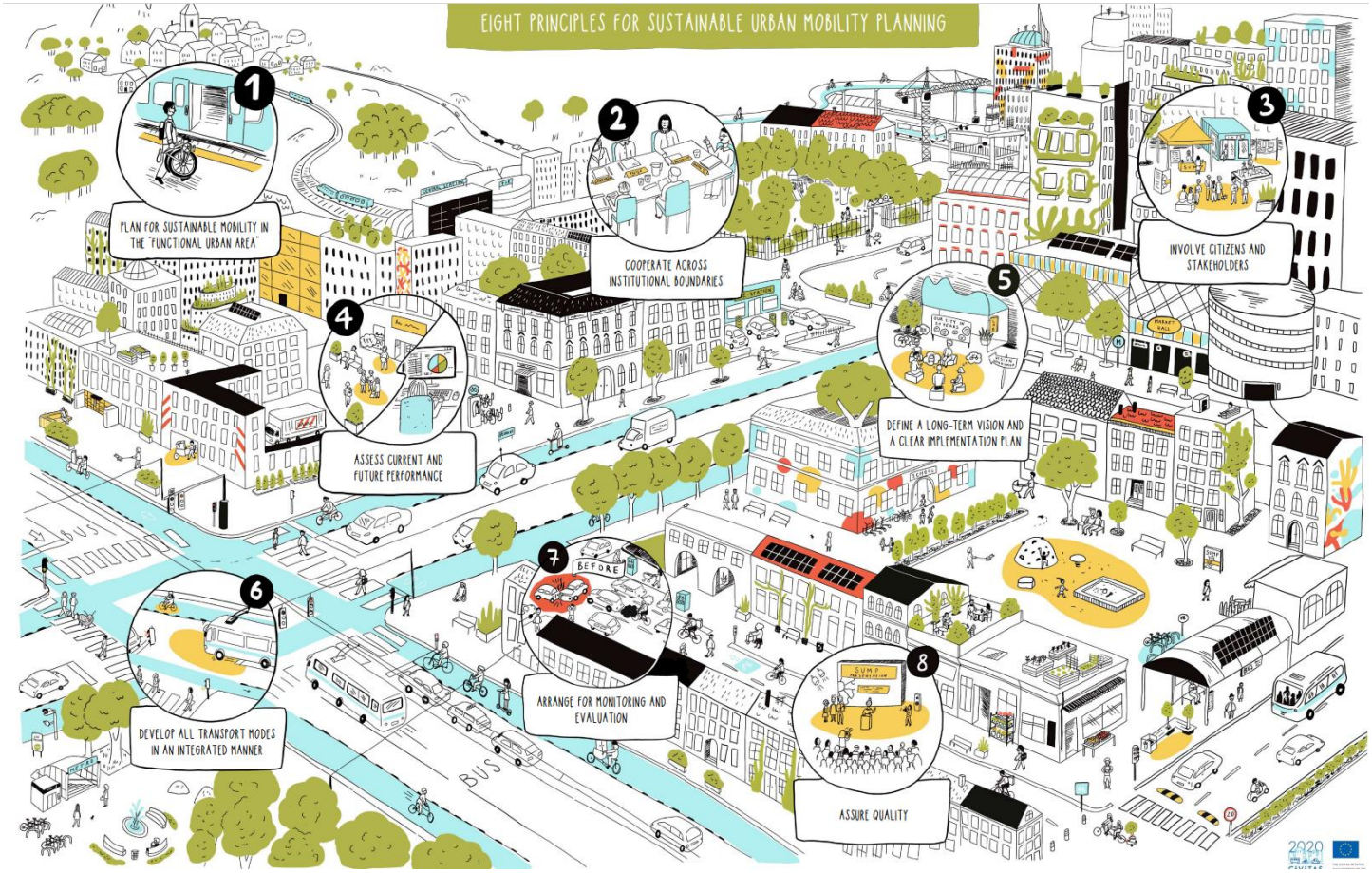
Emission reduction via transport change processes



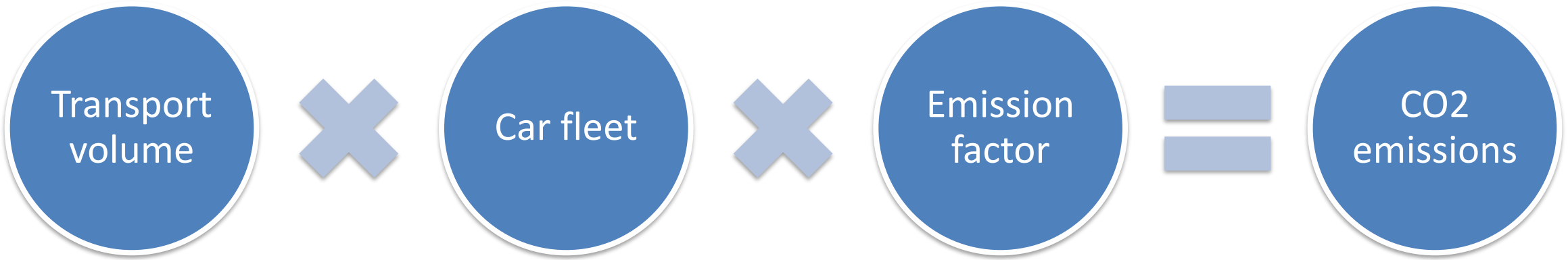
Ambitions & context

- 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?



Modelling Vehicular Emissions

SUMBA+ Workshop, 20th of September 2021

Institute of Transport Research, German Aerospace Center
Daniel Krajzewicz

Vehicular Emissions
Important Gasses

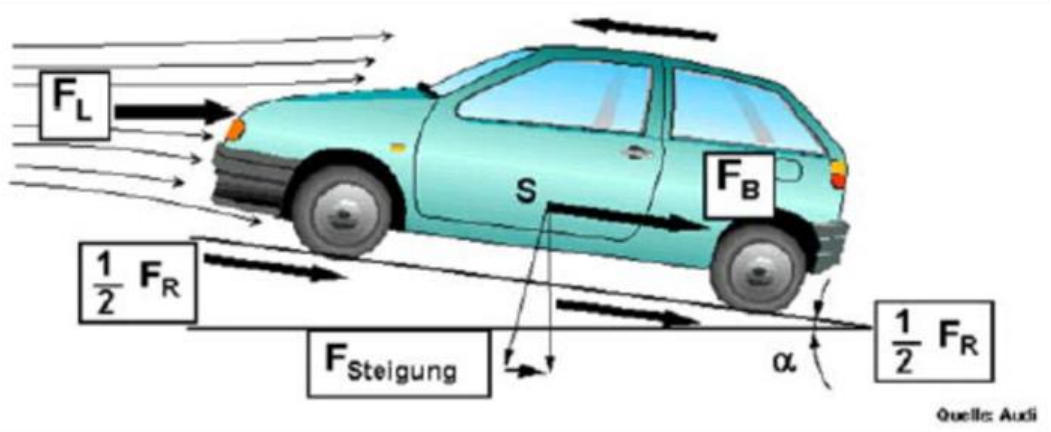
- Vehicles running on fossil fuels emit different pollutants
- One should distinguish between the pollutants' effects
  - climate gasses (Greenhouse gas emissions, GHG)
    - mainly CO_2
  - gasses and particles dangerous for health
    - CO: poisonous
    - PM_x: responsible for cancer diseases (though 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

Vehicular Emissions
Physics

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

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



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

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

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

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

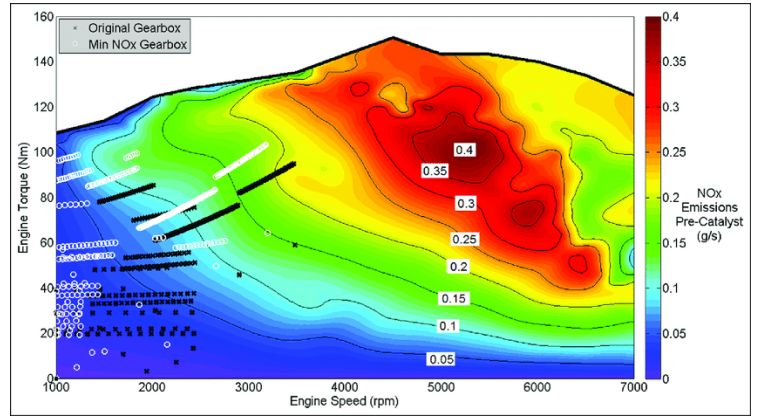
$$\eta_{gearbox} = 0.95 \quad \text{(average efficiency)}$$

- 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

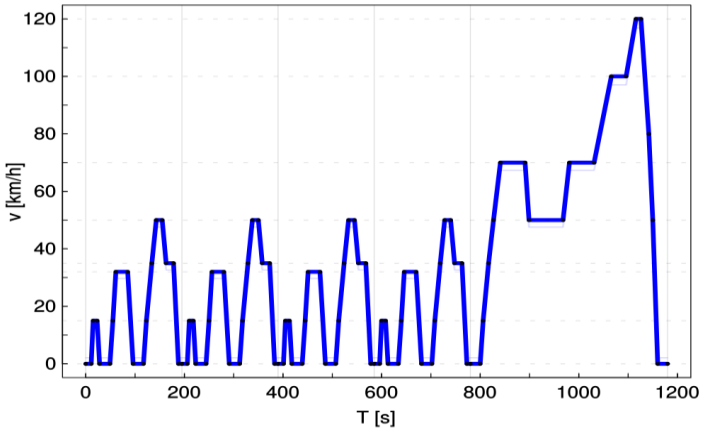
SEnsor katalySAtor Messplatz (SESAM)

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

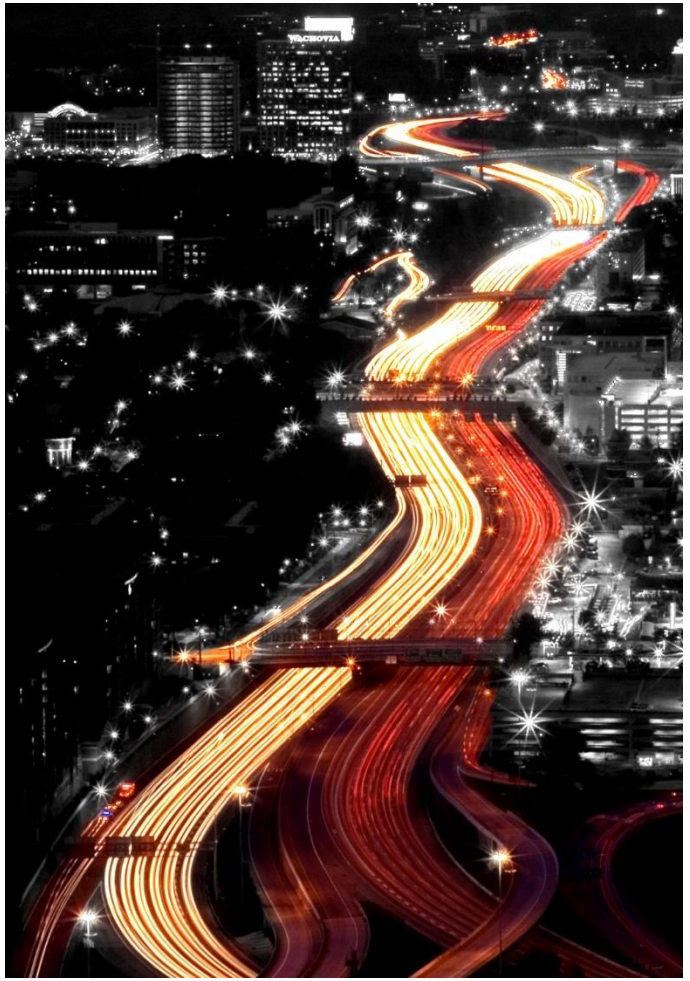
- In the real world, a large number of different vehicle and engine types exists
  - passenger cars vs. vans or delivery vehicles vs. busses vs. heavy duty vehicles etc.
  - gasoline, Diesel, CNG, BEV, PHEV, maybe Hydrogen or synthetic fuels in the future
  - different emission norms (EURO1 – EURO6)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

- “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

microscopic look-up models

- Use the acceleration and deceleration from a microscopic simulation as well as the vehicle type

instantaneous

- The combustion itself is simulated
- Usually sub-modules cover different aspects as the current gear or the catalyst converter

Level of detail

inventory models

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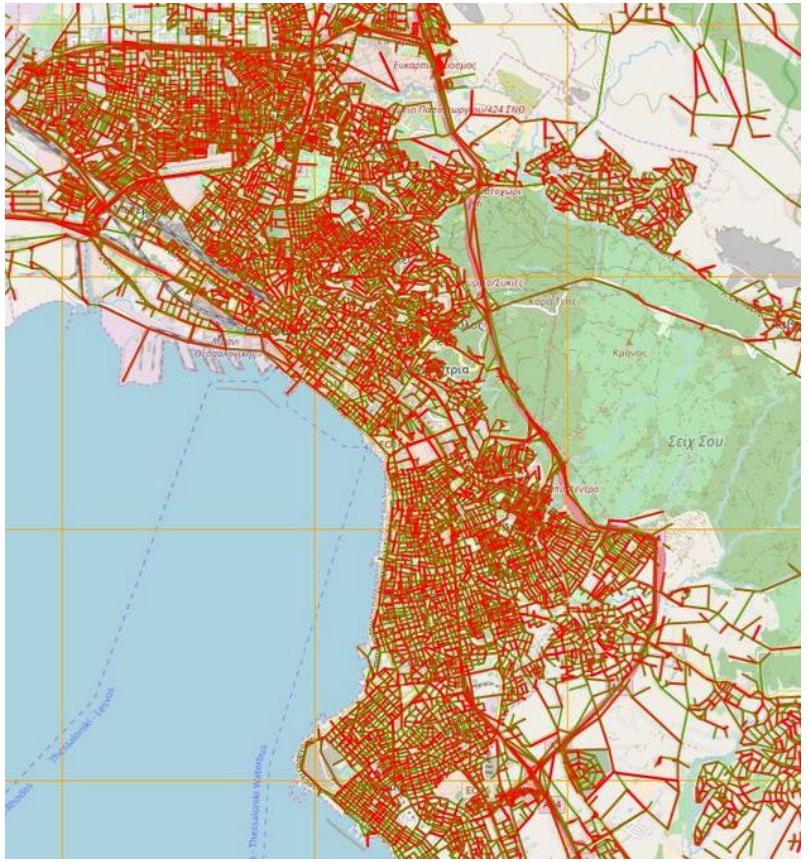
Inventory Models#1

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

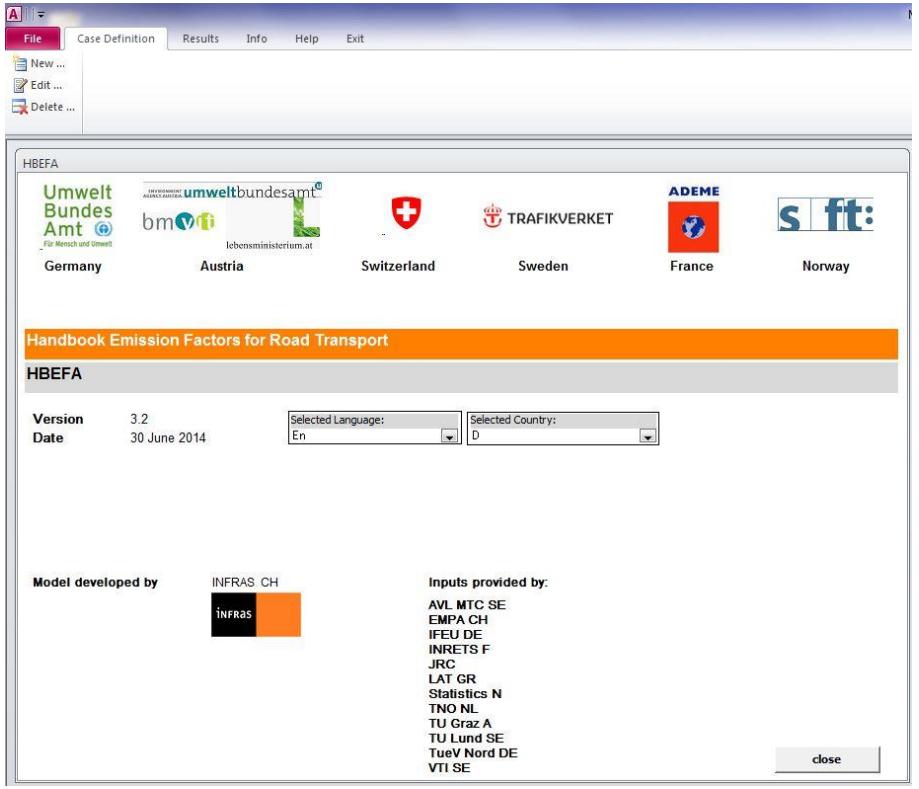


https://www.emisia.com/utilities/copert-street-level/

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



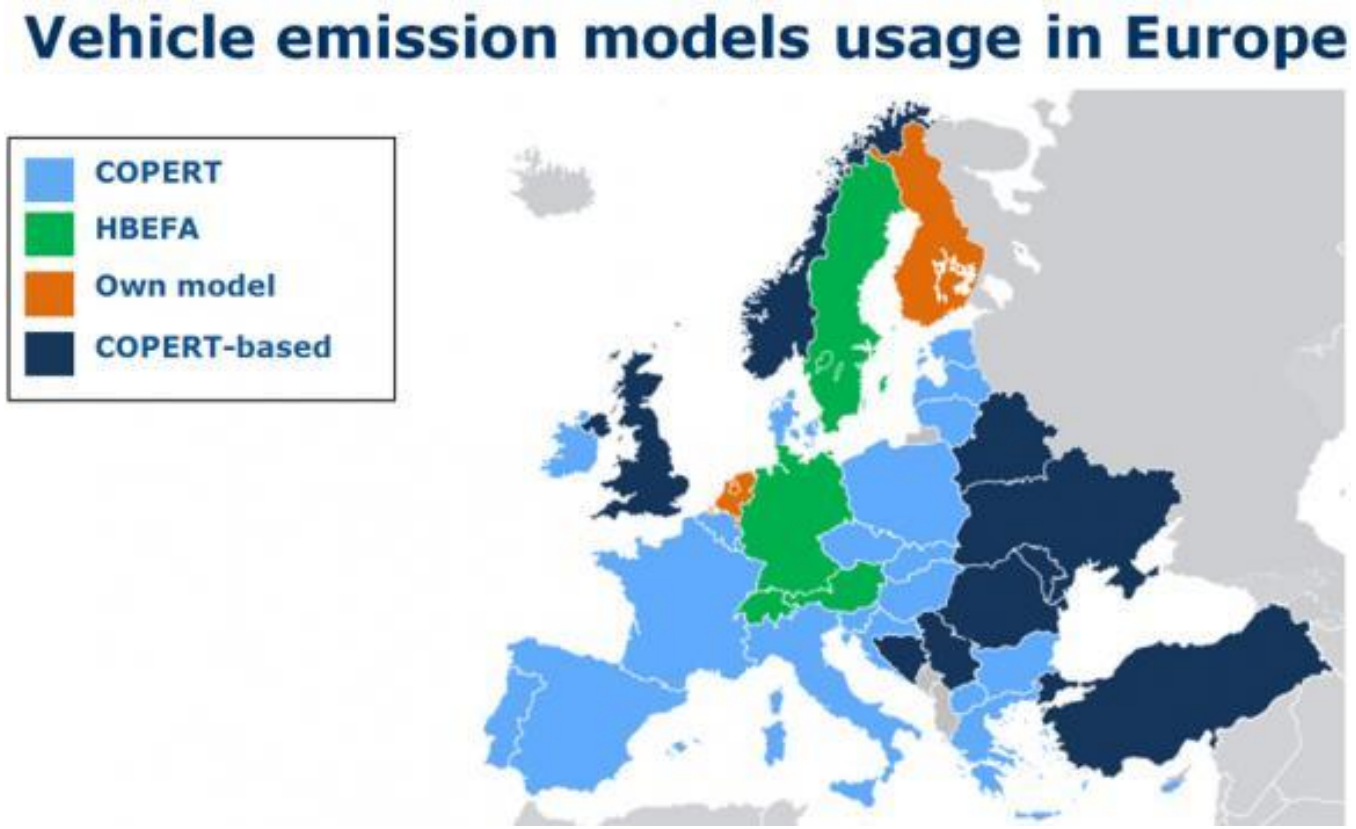
https://en.wikipedia.org/

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



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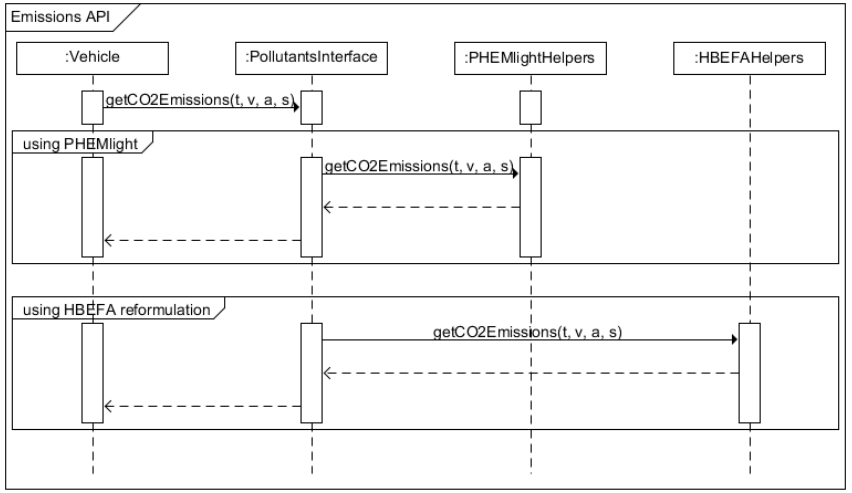
Derived Microscopic Emission Models#1
Features

- 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)

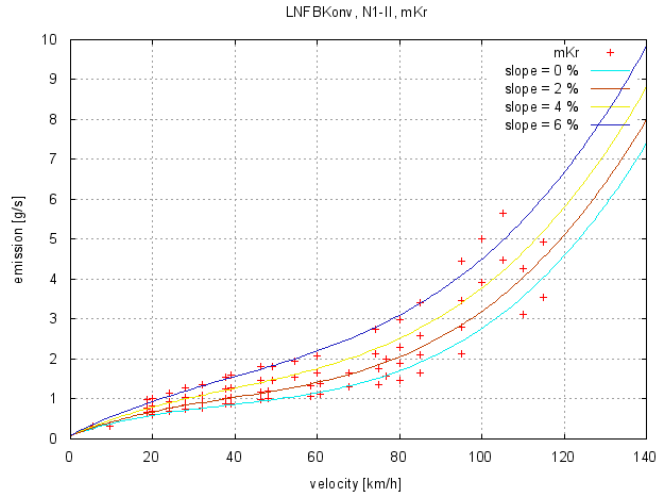


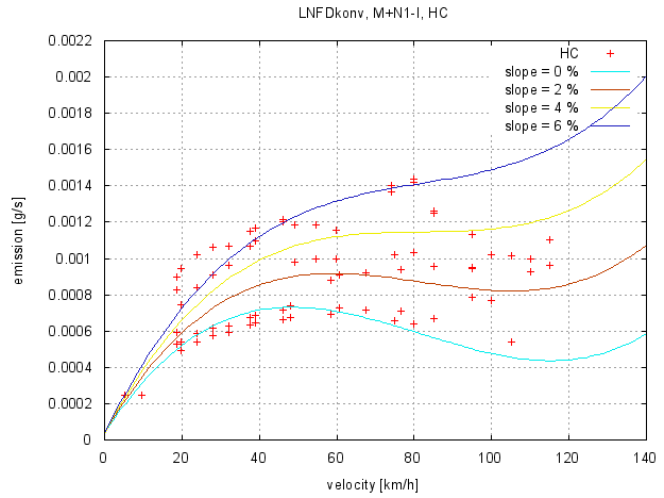
Derived Microscopic Emission Models#2
HBEFA-Derivation

- 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

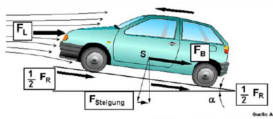




Derived Microscopic Emission Models#3
PHEMlight

- 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

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



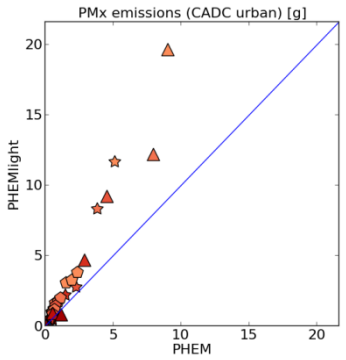
$P_R = (m_{Vehicle} + m_{Load}) \times g \times (Fr_0 + Fr_1 \times v + Fr_4 \times v^4) \times v$

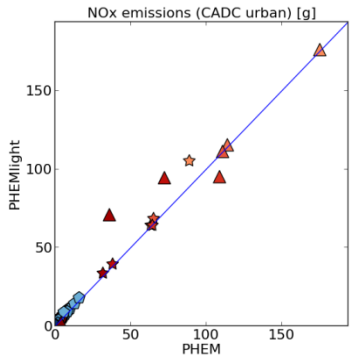
$P_{Air} = (Cd \times A \times \frac{\rho}{2}) \times v^3$

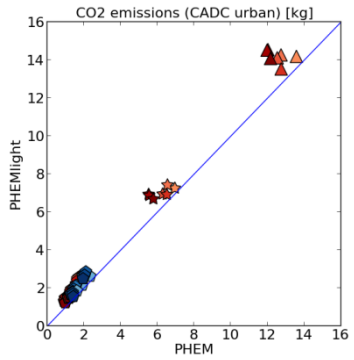
$P_a = (m_{Vehicle} + m_{Rot} + m_{Load}) \times a \times v$

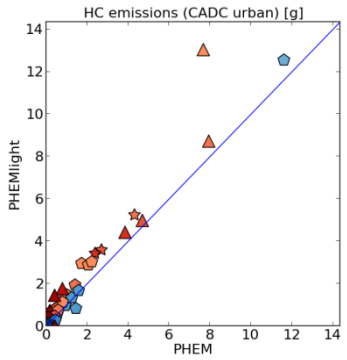
$P_{grad} = (m_{Vehicle} + m_{Load}) \times Gradient \times 0.01 \times v$

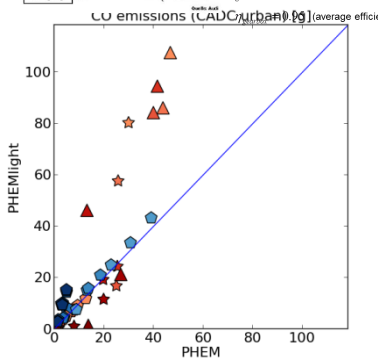
$P_{Motor} = P_e / \eta_{Motor}$ (average efficiency)











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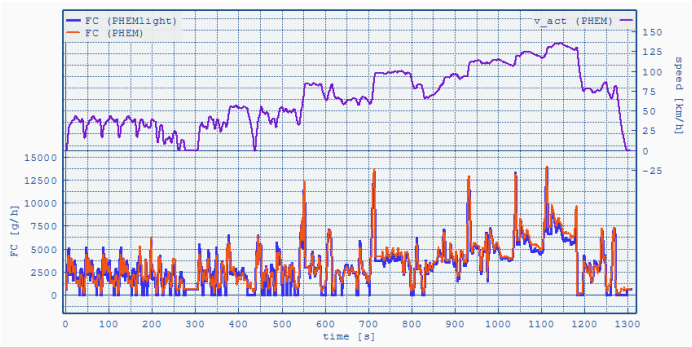
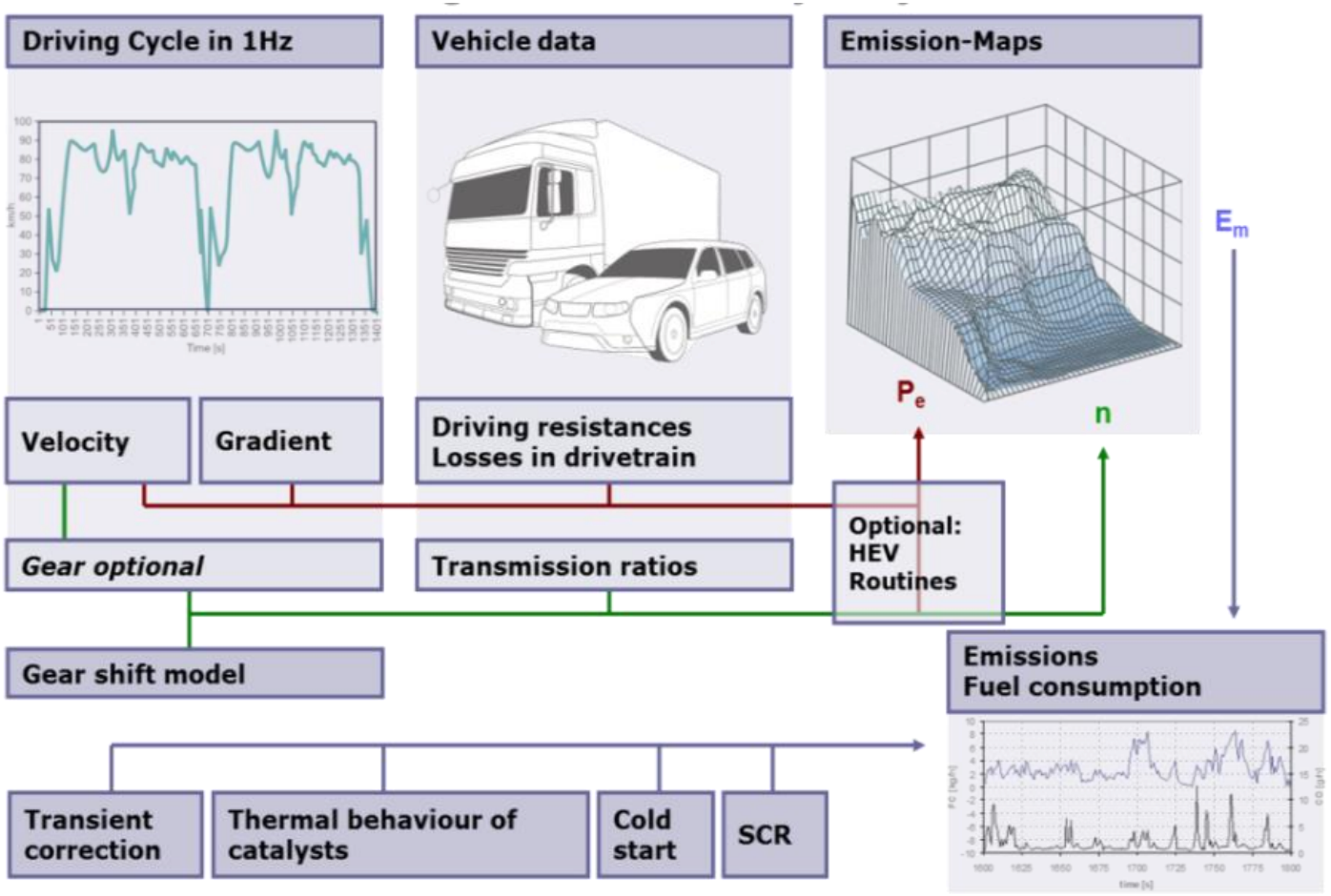
Instantaneous Emission Models
PHEM

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

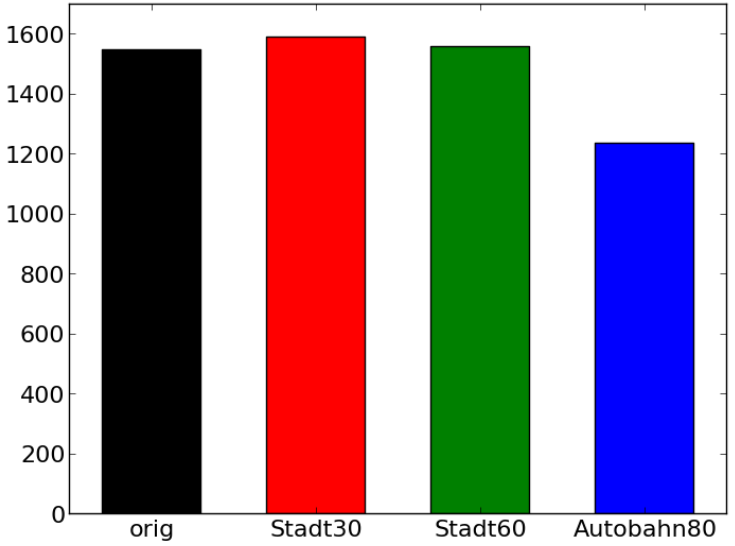




PHEM; TU Graz

Evaluating Emission Models

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



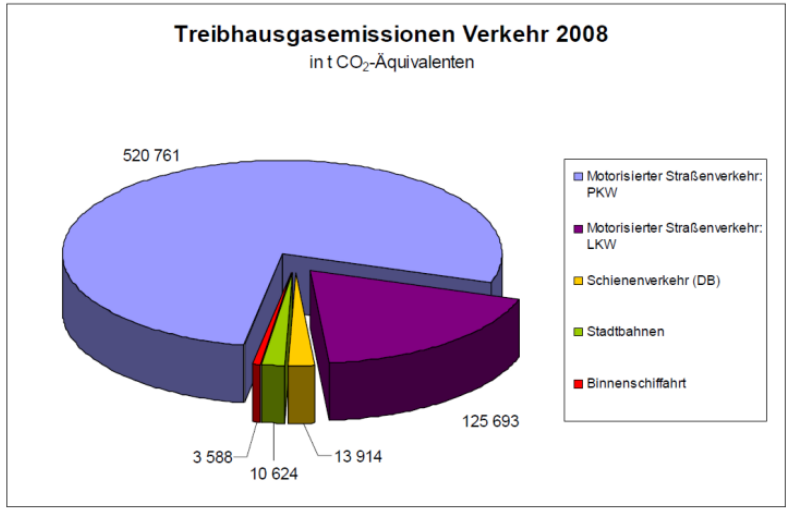
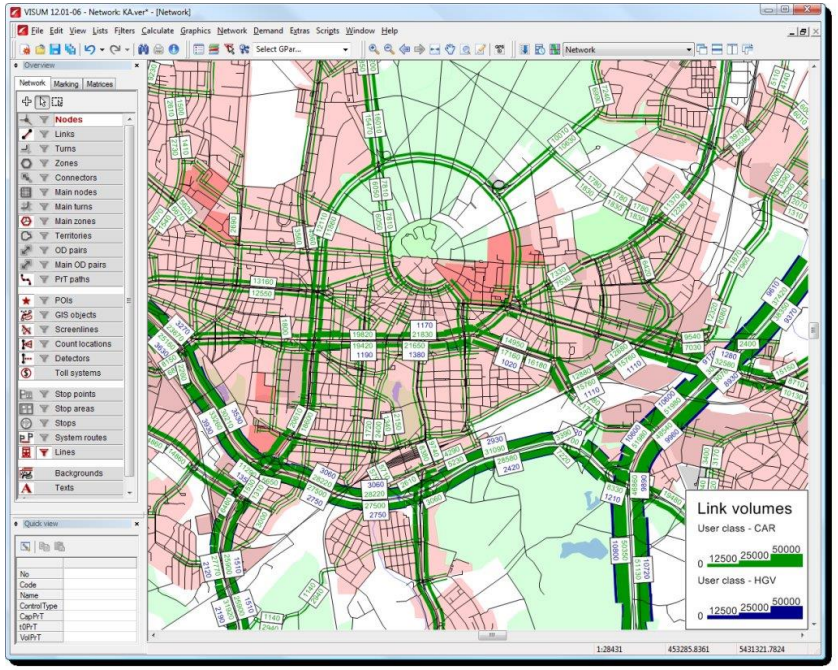


Abbildung 2.22: Treibhausgasemissionen des Gesamt-Verkehrs in 2008

- 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)

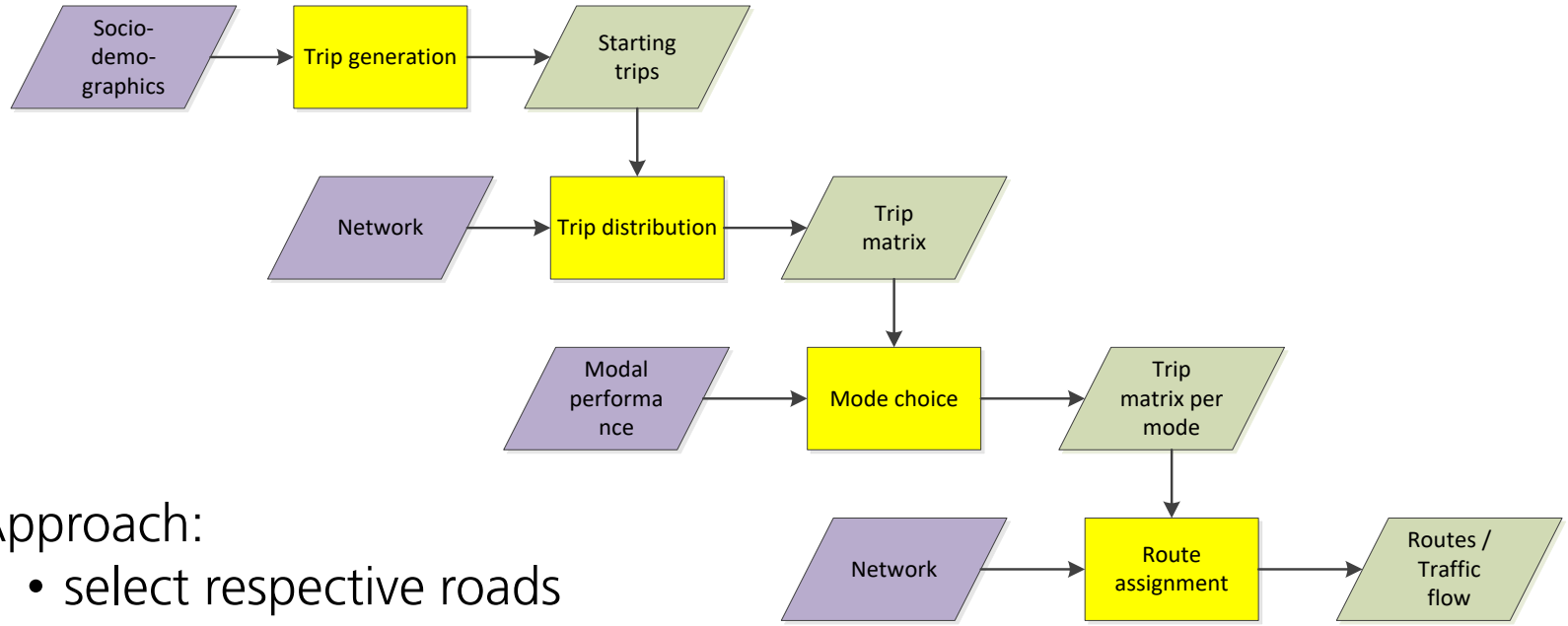


VISUM screenshot; PTV AG

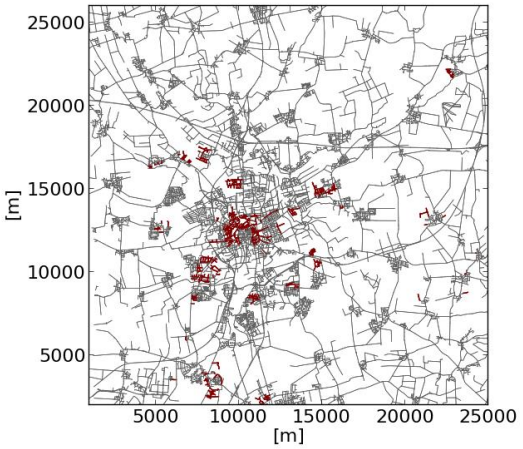
Applications for Models of Vehicular Emissions#2

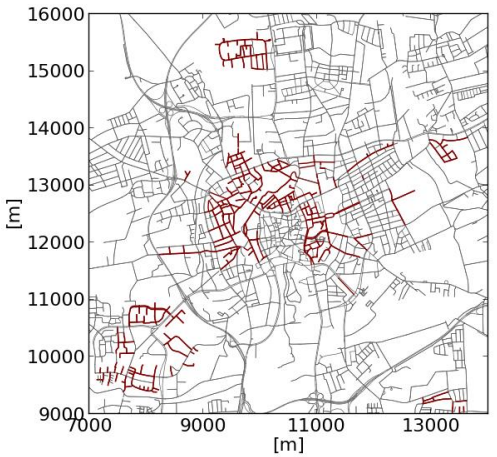
Benchmarking Traffic Management Measures – 30 km/h speed limit

- 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)

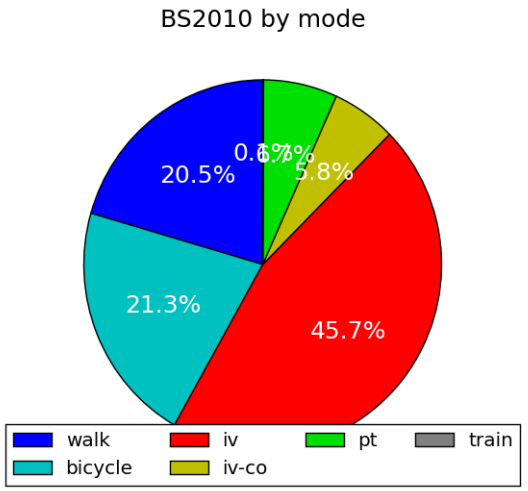


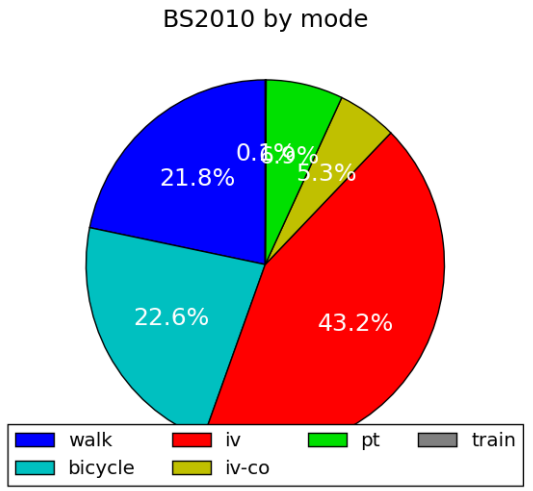


Applications for Models of Vehicular Emissions#3

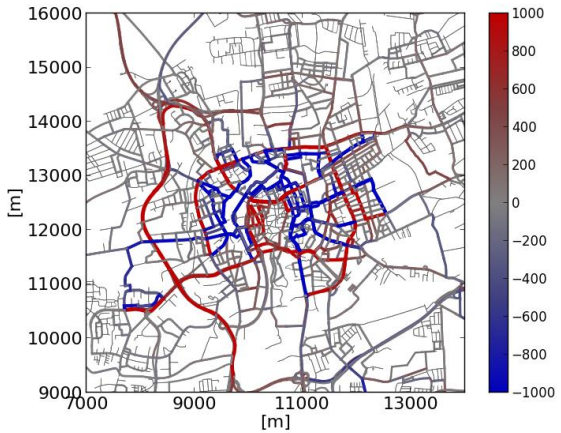
Benchmarking Traffic Management Measures – 30 km/h speed limit

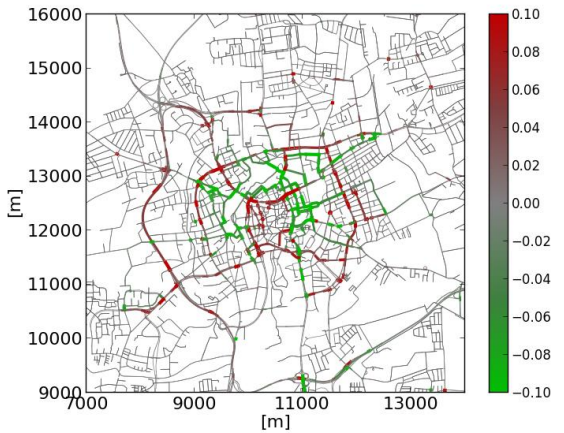
- Yes, the measure affects the mode choice





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

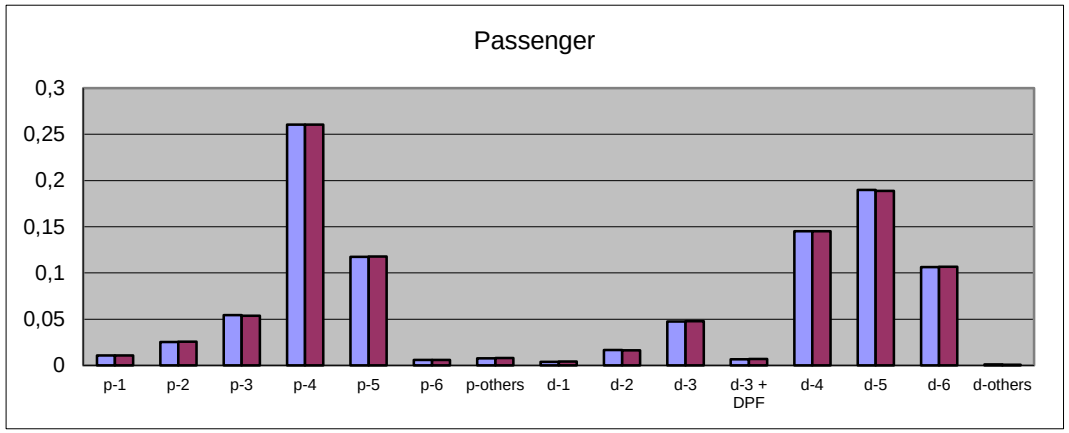


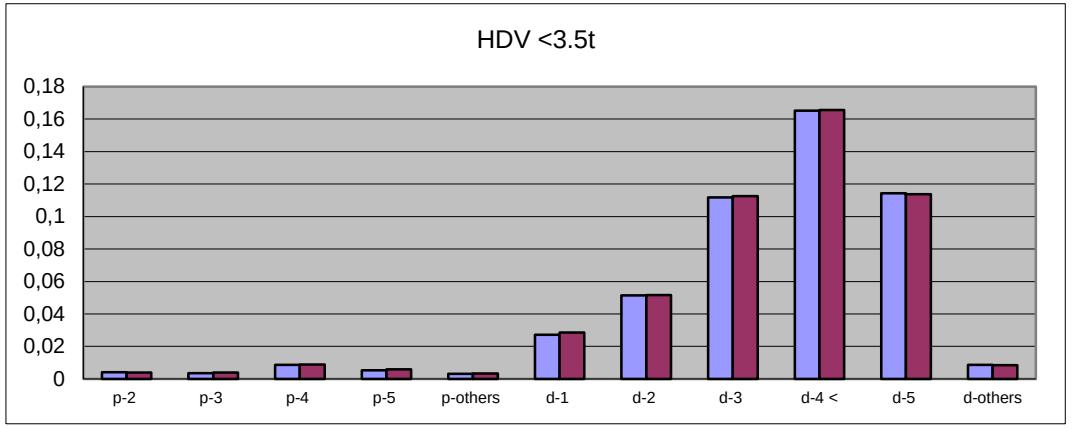


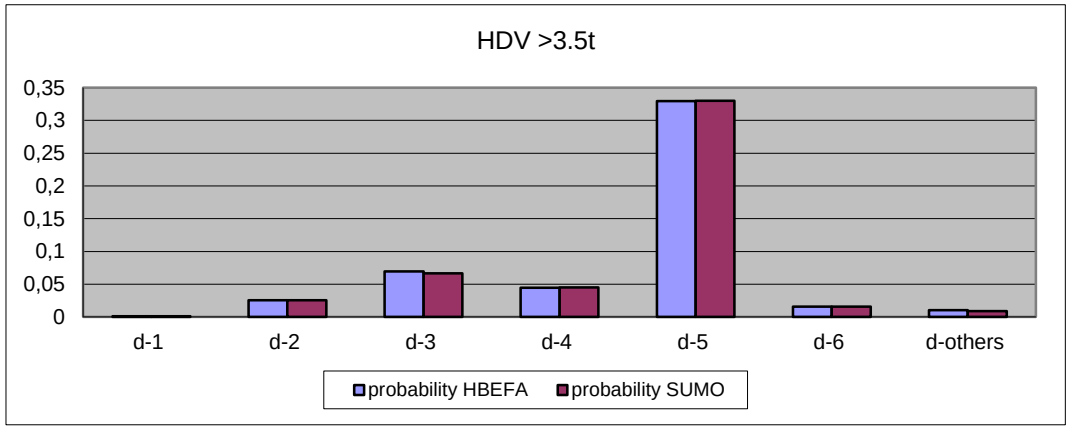
Applications for Models of Vehicular Emissions#4

The price of using microscopic models

- You need to resemble the vehicle fleet





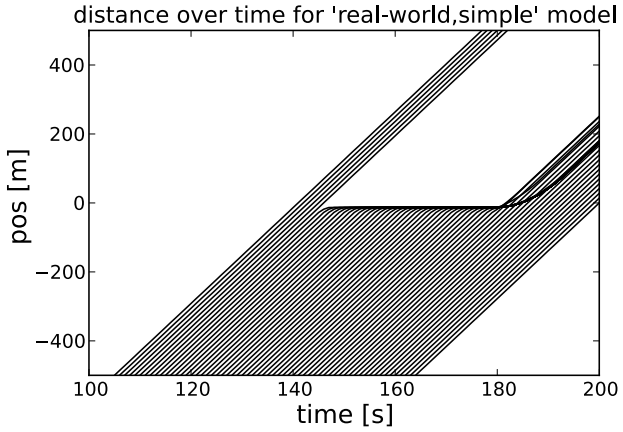


Applications for Models of Vehicular Emissions

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.

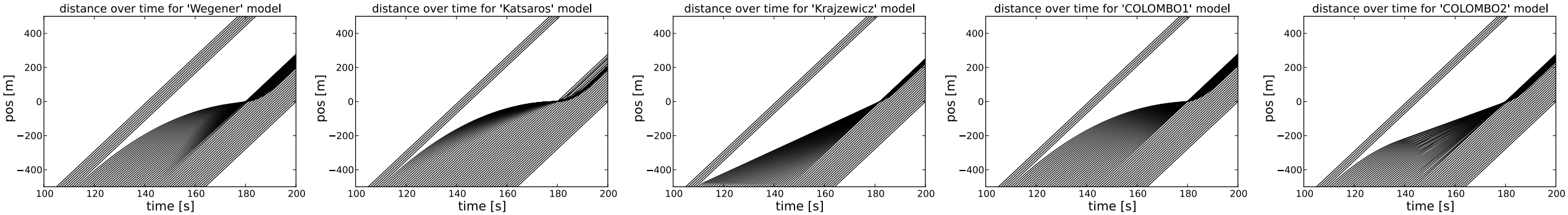
- Very simple "real world" model:
  - Drive towards the intersection while the traffic light shows green
  - Brake if red, or if yellow and far enough to halt
  - Re-accelerate at green



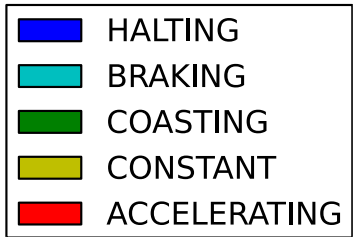
Applications for Models of Vehicular Emissions

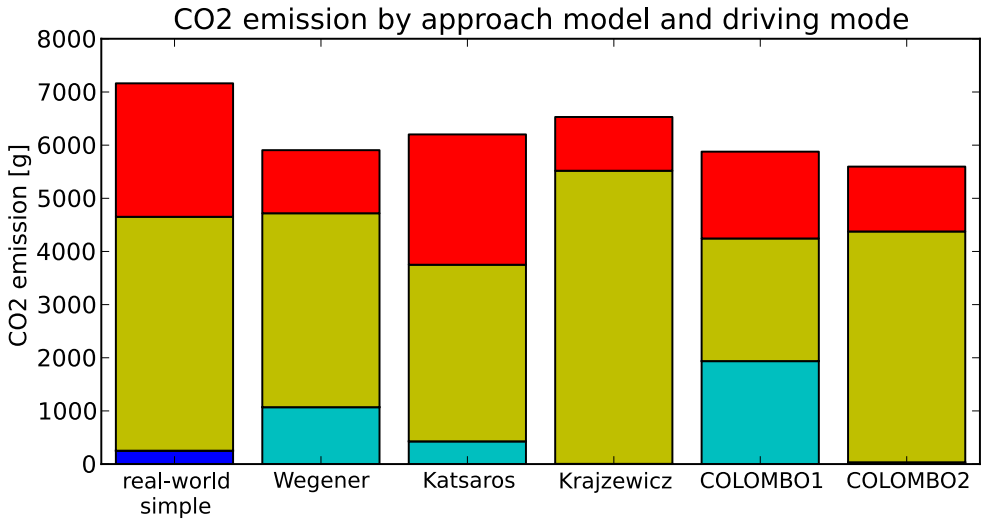
Excurse: GLOSA – Green Light Optimal Speed Advisory

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



- … and computed the respective CO2 emissions





Vehicular Emission Models

A Comparison of Applications – Data Needs

inventory models

- The amount of driven vehicle kilometres (VKT) (can be retrieved from a simulation)
- The vehicle fleet (probably sufficient to obtain on a national scale)

→ Hardly applicable for areas, even for single intersections

microscopic look-up models

- The simulation scenario
  - Road network
  - Vehicle routes
- Vehicle population needs to duplicate the real-world population

→ Rather not to advice for bigger areas, mainly due to the big effort needed to prepare the road network

instantaneous

- Trajectories of single vehicle movement (speed timeline)

→ Hardly applicable for areas, even for single intersections

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

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

Get in touch!

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