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Pricing local emission exposure of road traffic

An agent-based approach

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Motivation

Costs Related to Exhaust Emissions

Related to Popuation / Activity Location Density

- Direct damages to human health (increased health costs, mortality, …)
- Indirect impacts on housing market (reduced property values, rents, …)
- Indirect impacts on quality of life, livability of the city
- Direct damages to building structure

- Indirect impacts from global warming (weather extremes)

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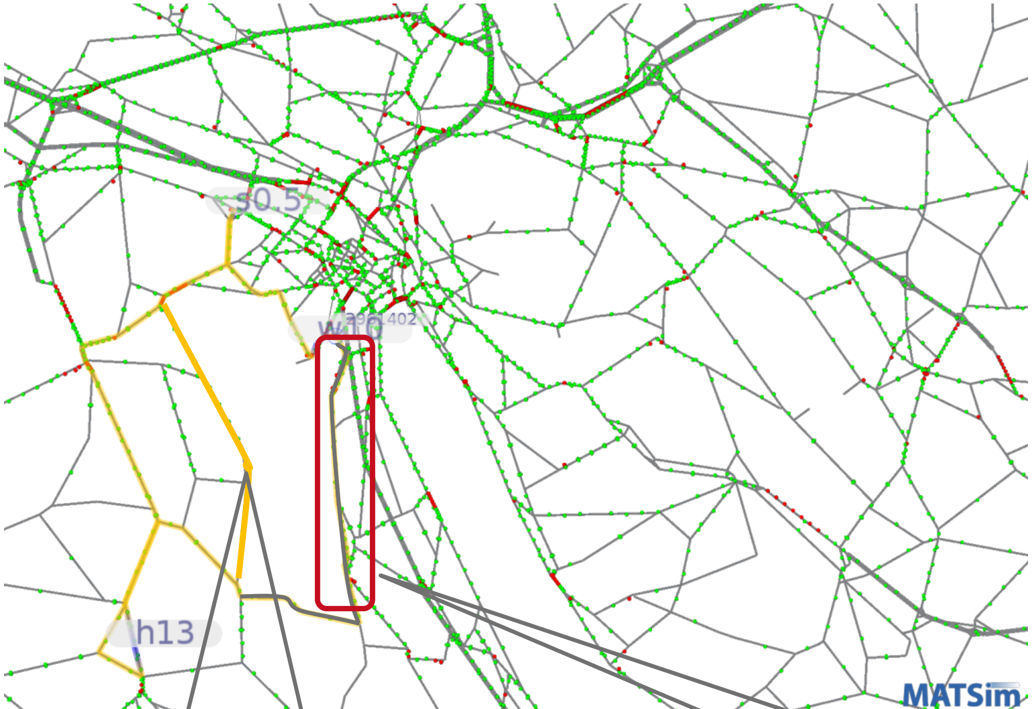
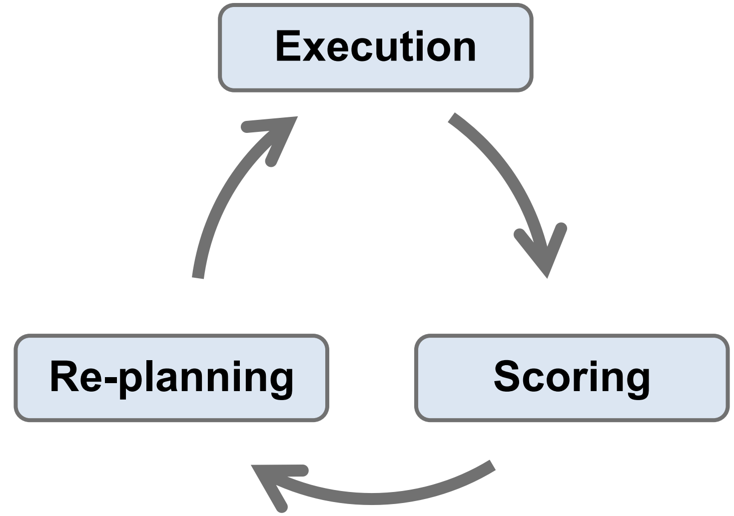
Optimal Pricing with MATSim





$$V_p = \sum_{i=1}^{n} V_{perf,i} + \sum_{i=1}^{n} V_{tr,i} = 100 utils$$

$$V_p = \sum_{i=1}^{n} V_{perf,i} + \sum_{i=1}^{n} V_{tr,i} = 97 utils$$

$$V_p = \sum_{i=1}^{n} V_{perf,i} + \sum_{i=1}^{n} V_{tr,i} = 90 utils$$

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Deriving Damage Cost Estimates of Exhaust Emissions

1. Modeling emission levels
2. Modeling dispersion and deriving air quality
3. Modeling exposure of individuals to air pollutant concentration
4. Applying concentration-response functions [numbers of cases for mortality, life years lost, hospital admissions, premature mortality, minor restricted activity days, work loss days, etc.]
5. Assigning monetary values to each of these cases

How to determine the “correct” price level iteratively?

Approach

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Modeling Emission Levels

Vehicle Type

- Engine Type
- Cubic Capacity
- European Emission Standard

Road Category

- Local Roads
- Collectors
- Arterials
- Freeways

Traffic State

- Freeflow
- ~~Heavy~~
- ~~Saturated~~
- Stop&Go

Activity time

Cold Emission Factors [g]

- Mass of Fuel
- CO_2
- PM

Warm Emission Factors [g/km]

- No_x
- CO
- SO_2
- NMHC
- HC
- …

HBEFA: Handbook on Emission Factors for Road Transport (see www.hbefa.net)
This is a non-exhaustive list of differentiations provided by HBEFA 3.1

Idea 1: Emission Toll (Independent of Exposure)

- Whenever a person leaves a road segment:
  - Calculate emissions (dependent on vehicle, traffic state, …)
  - Calculate emission costs (flat toll per [g])
  - Charge that person with the resulting individual toll

- Differentiated tolls are now part of the individual decision making process of every person

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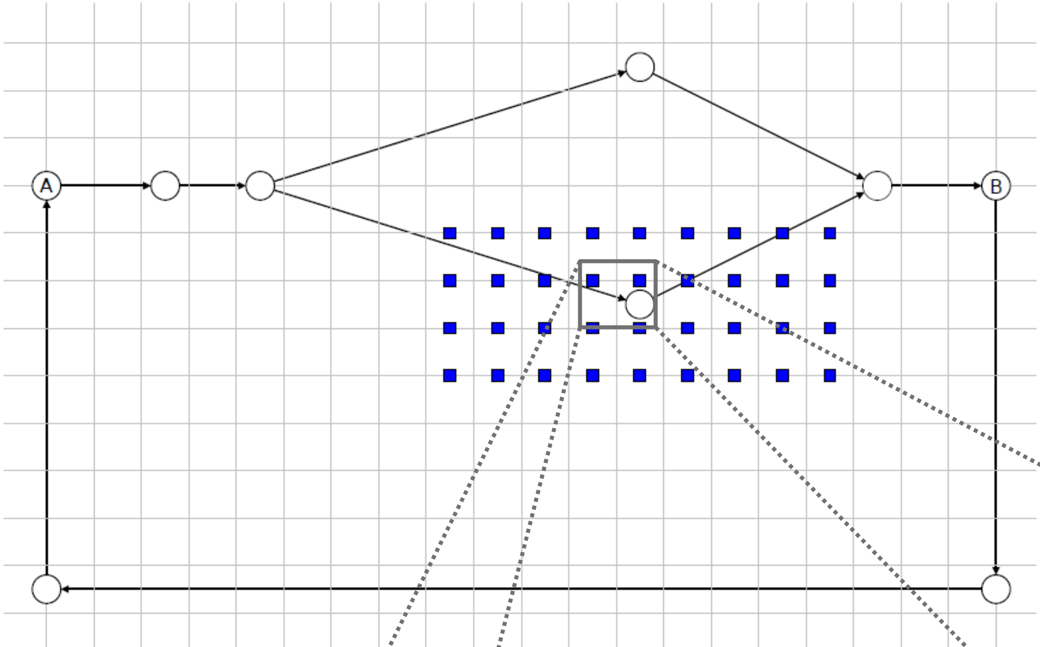
Idea 2: Exposure Toll (Dependent of Exposure)



$$c_{actual} = \quad_{average} \cdot \quad t_{average}$$

0.000 €	0.000 €	0.000 €	0.002 €	0.000 €	0.000 €	0.000 €
0.000 €	0.000 €	0.002 €	0.029 €	0.002 €	0.000 €	0.000 €
0.000 €	0.002 €	0.029 €	0.132 €	0.029 €	0.002 €	0.000 €
0.002 €	0.029 €	0.132 €	0.216 €	0.132 €	0.029 €	0.002 €
0.000 €	0.002 €	0.029 €	0.132 €	0.029 €	0.002 €	0.000 €
0.000 €	0.000 €	0.002 €	0.029 €	0.002 €	0.000 €	0.000 €
0.000 €	0.000 €	0.000 €	0.002 €	0.000 €	0.000 €	0.000 €

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Results:

Munich Metropolitan Area

Subpopulations and Choice Dimensions

- Subpopulations:
  - Urban travelers
  - Commuters
  - Reverse Commuters
  - Freight

- Choice dimensions:
  - Route choice
  - Mode choice (car vs public transit; other modes fixed)
  - Freight: only route choice

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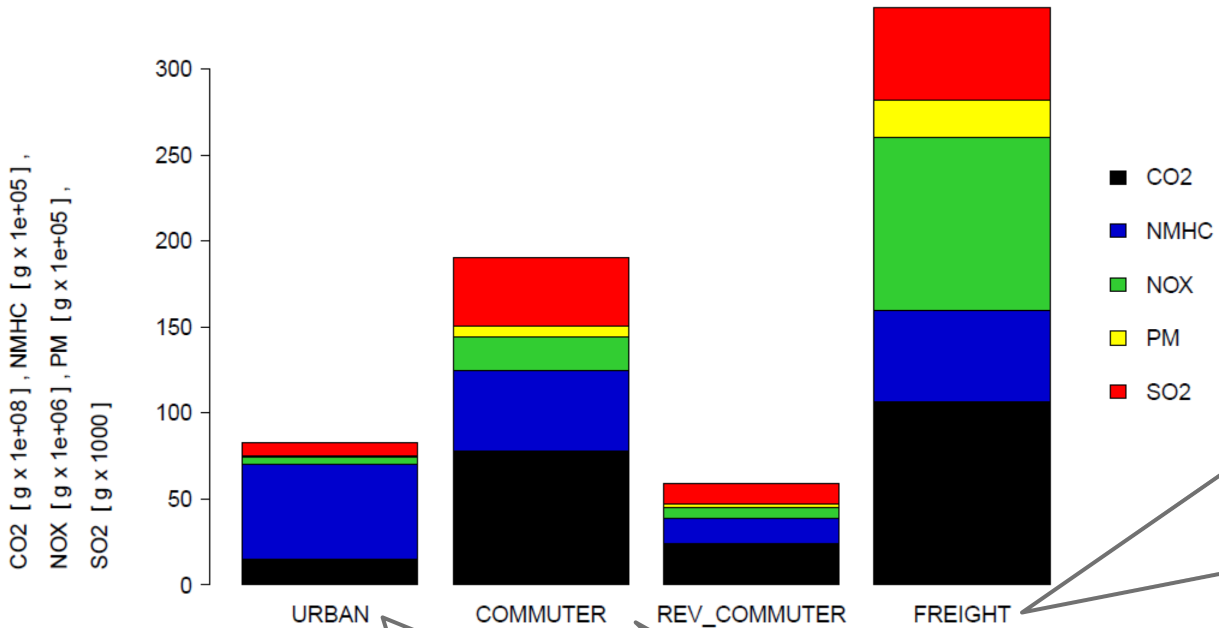
Base Case: Absolute Emissions by Subpopulation

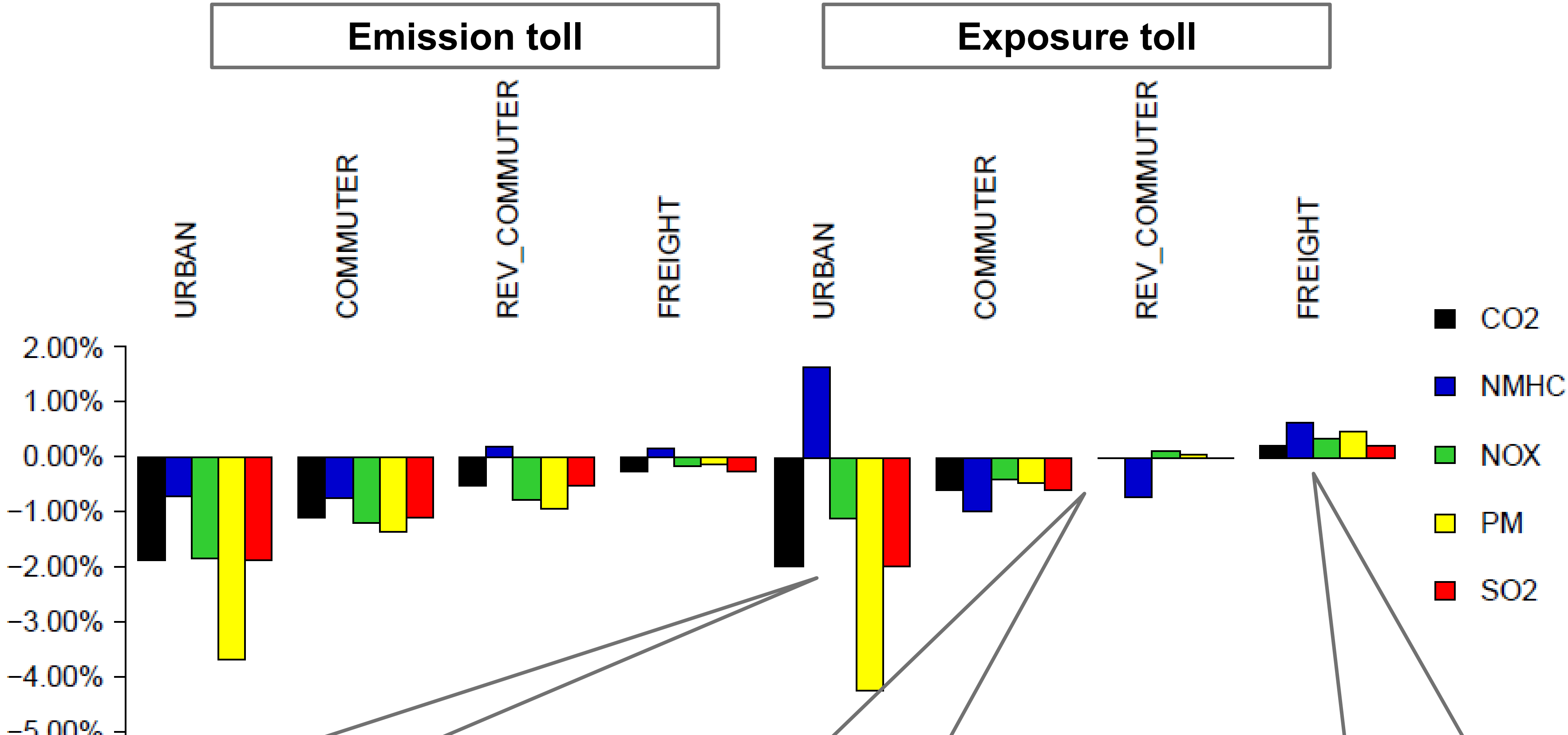


7.6% of total population
- Major part of total emissions
- PM and NOX over-proportionally high

68% of total population
- Relatively small part of total emissions
- NMHC over-proportionally high > cold starts!

14.6% and 9.8% of total population
- Commuters drive longer distances than rev. commuters…
- …and therefore emit more emissions

Changes in Relative Emissions by Subpopulation



- Similar impact on emission level
- Higher share of short trips with car (NMHC)

- Less emission reduction for commuters and rev. commuters

- Higher emission levels for freight

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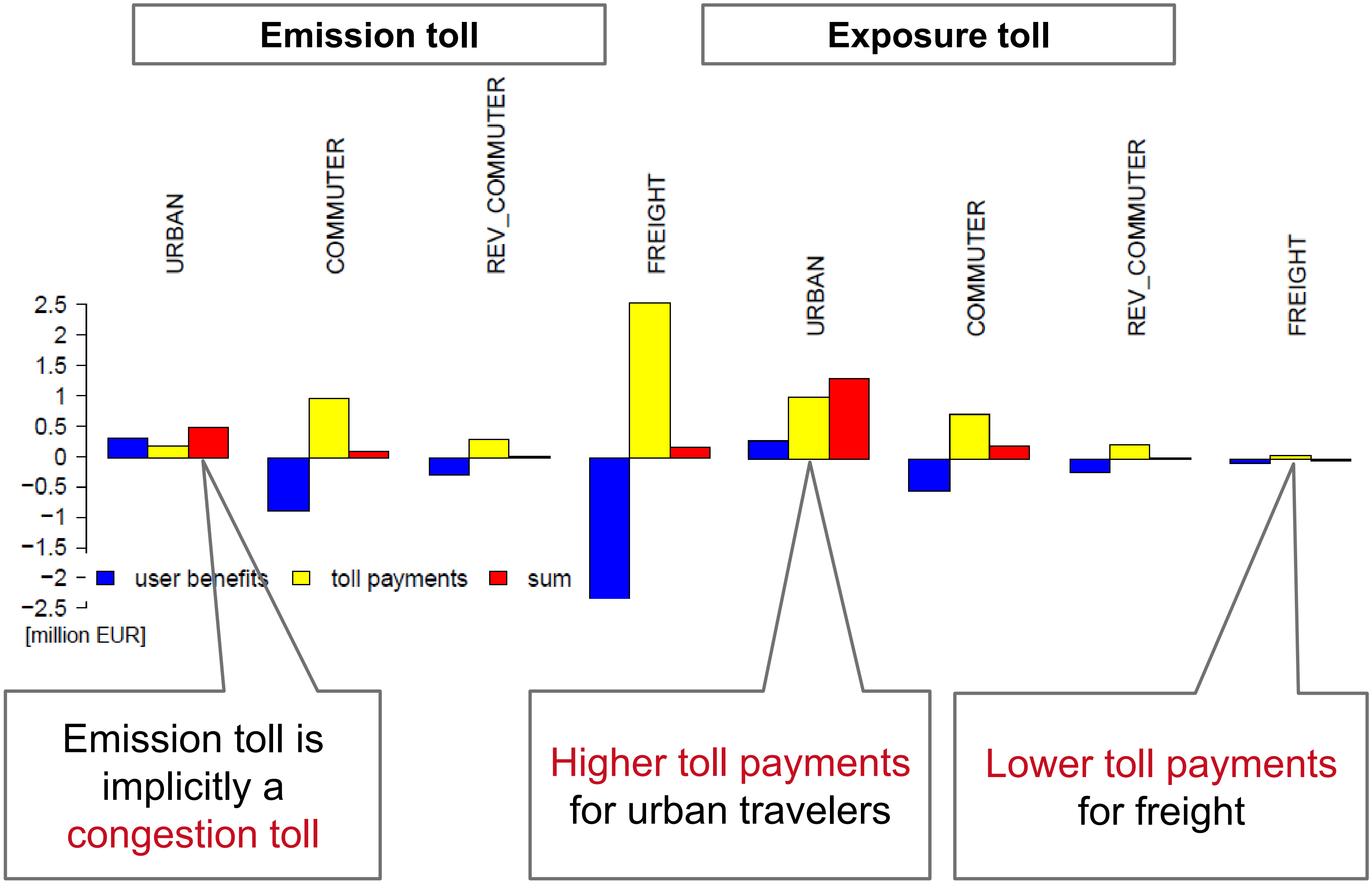
Absolute Changes in User Benefits by Subpopulation



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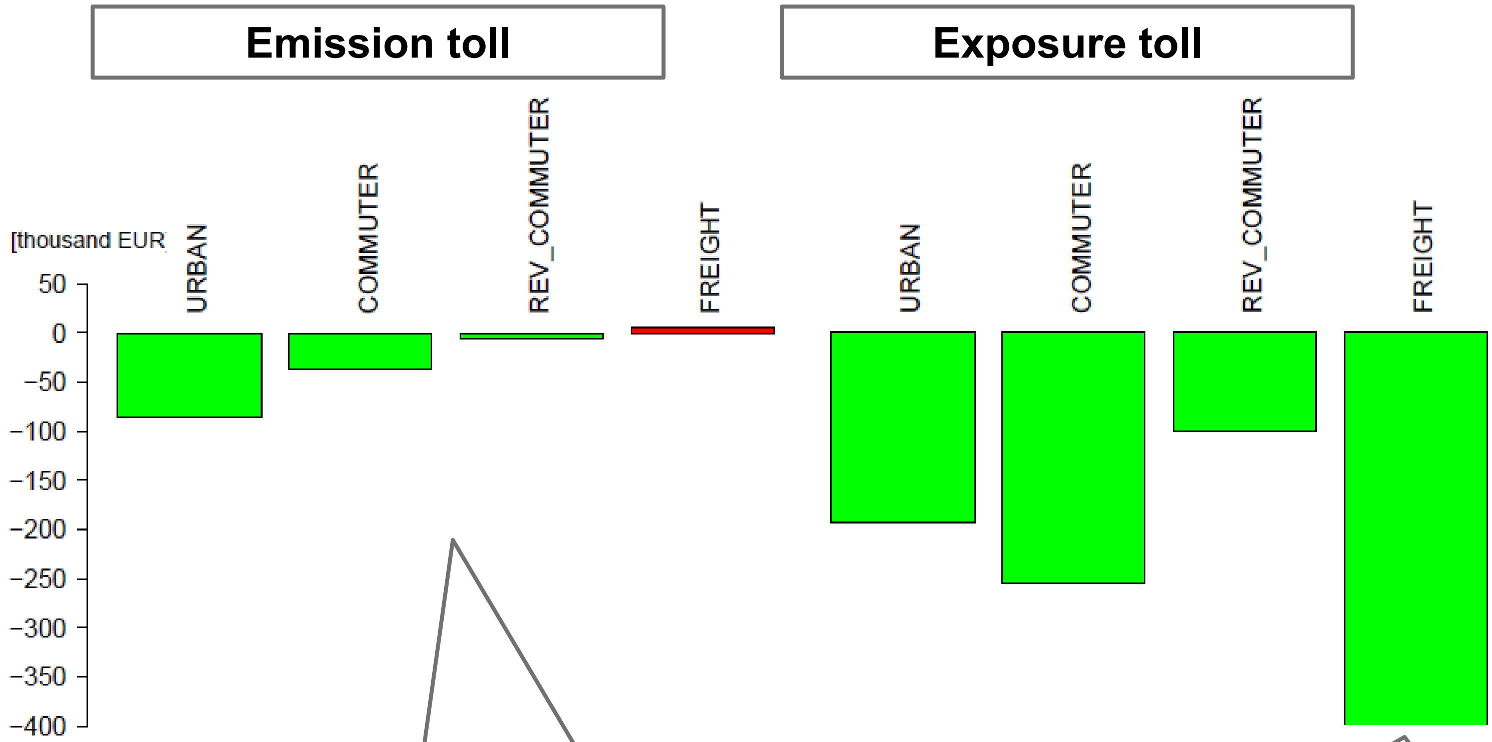
Absolute Changes in Exposure Costs by Subpopulation



A flat toll per [g] yields a reduction of emission externalities below damage cost optimum

Even though freight produces more emissions, exposure costs drop

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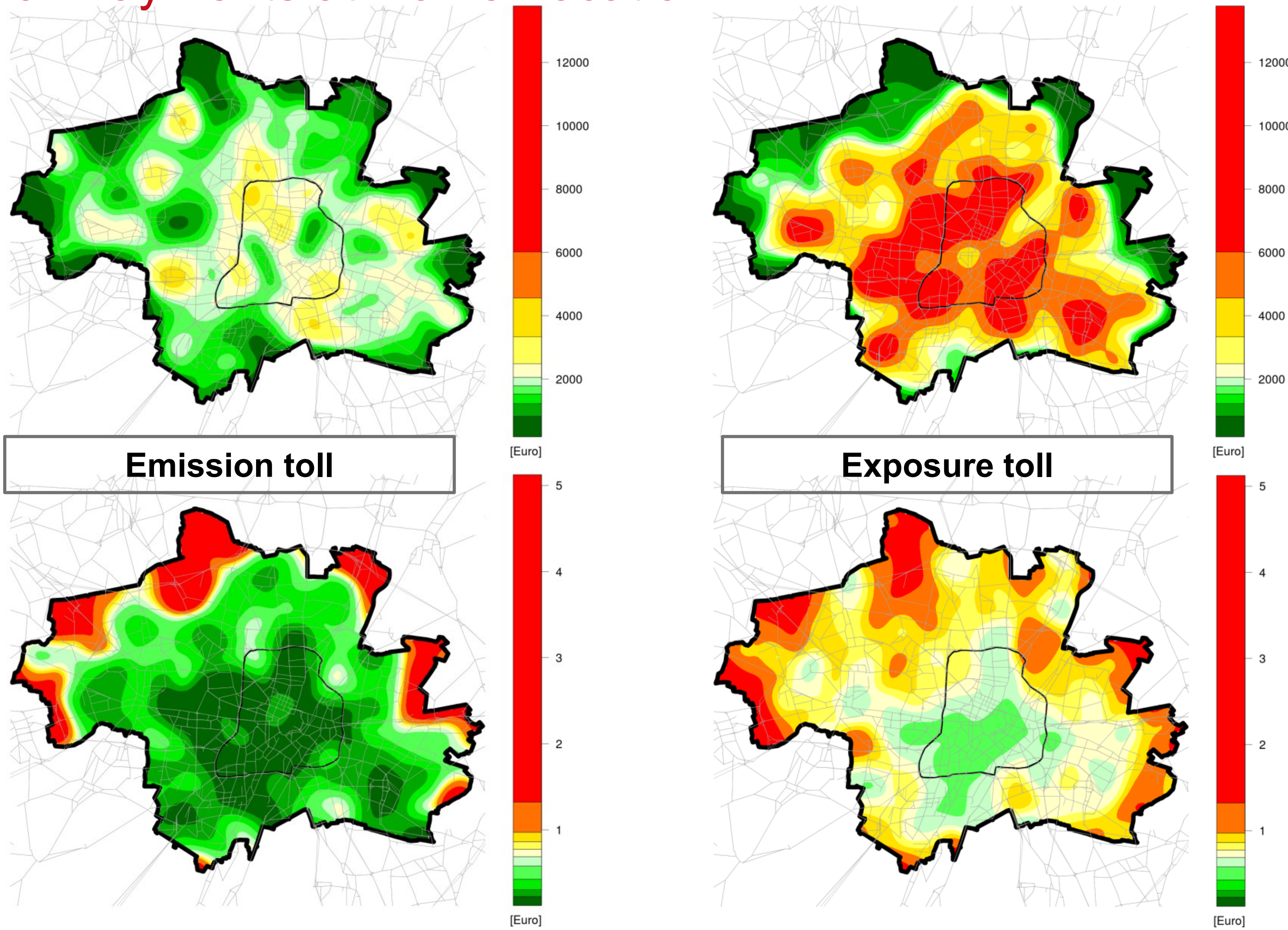
Toll Payments at Home Location



Summary

- Exposure should be accounted for; bottleneck is the air pollution concentration model > simplified approach
- Calculation of vehicle-specific, time-dependent tolls is possible for large-scale real-world scenarios
- Both, emission toll and exposure toll can be used as benchmark for evaluating real-world policies
- Emission toll (flat value per [g]) leads to only a small reduction in exposure costs
- Exposure toll will lead to less exposure costs, but can lead to more emissions [potential conflict: CO_2 vs local pollutants]
- MATSim allows for in-depth analysis (e.g. identifying areas with "environmentally friendly" vs "polluting" life styles

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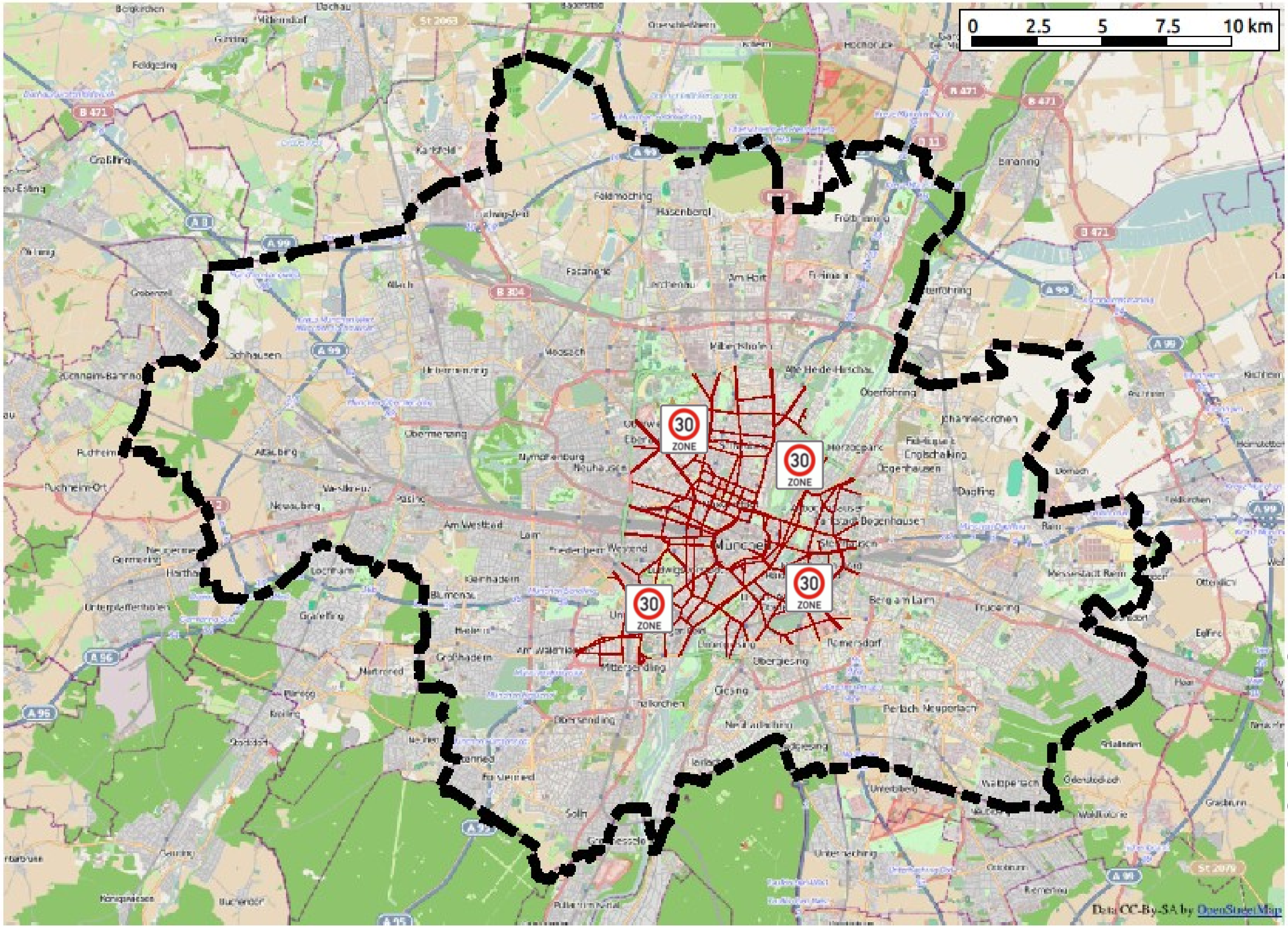
Thank you.

Evaluating a Speed Limitation in the Inner City



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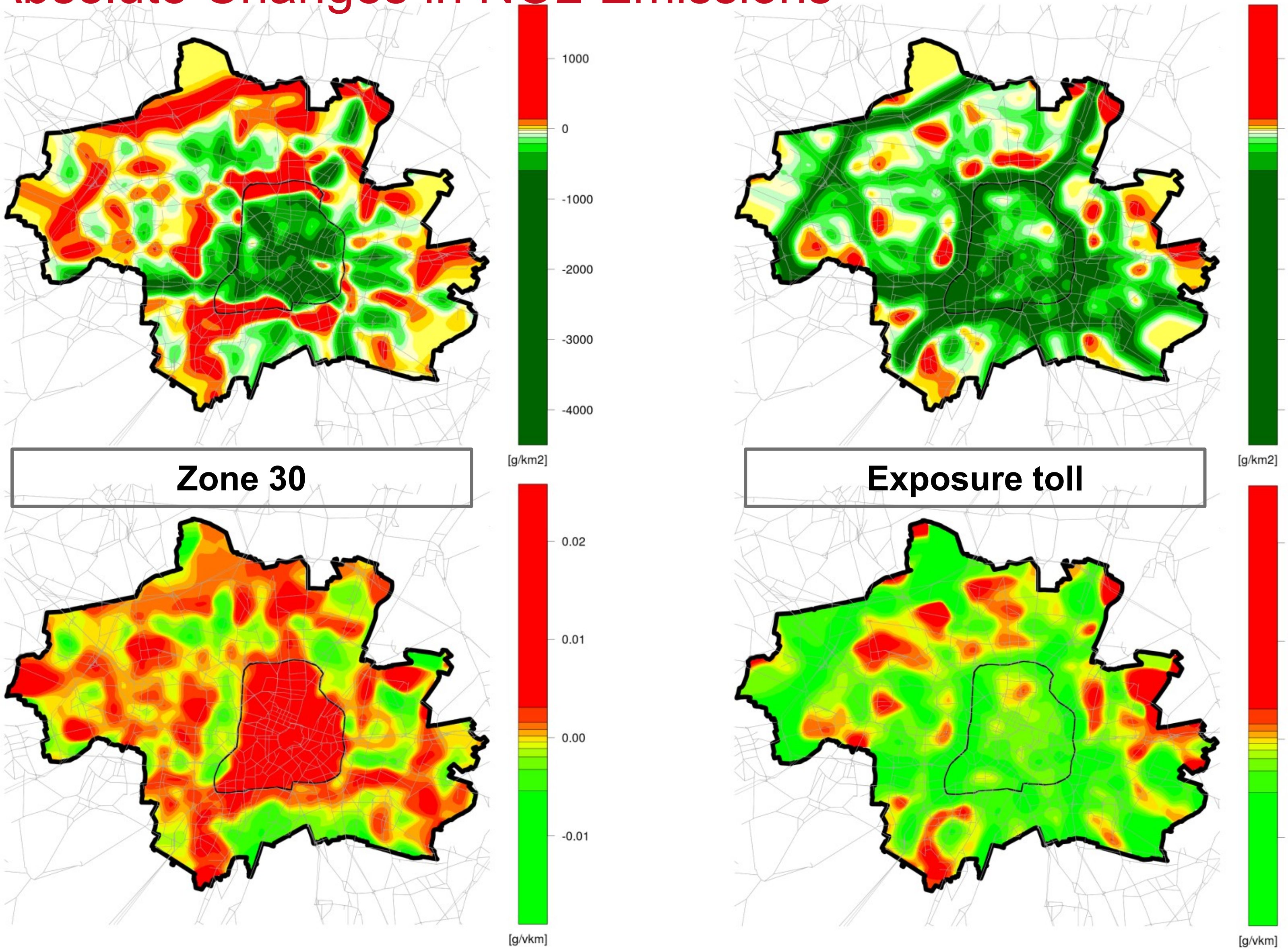
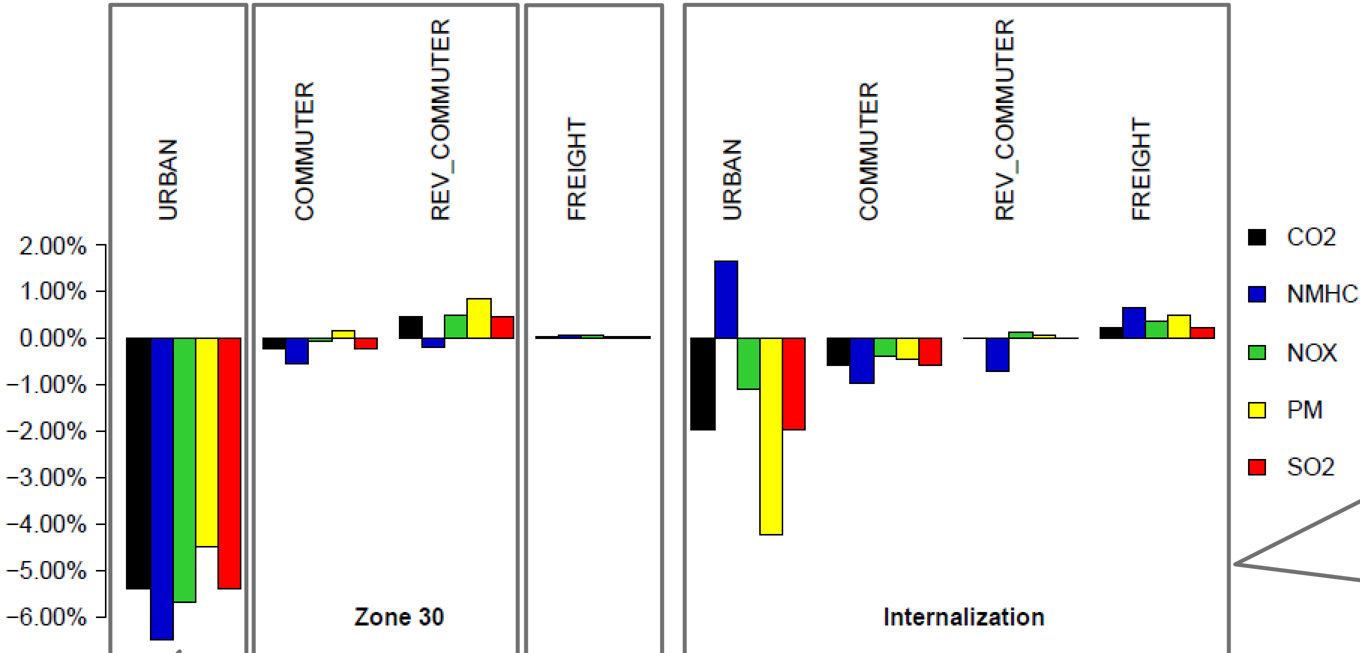
Absolute Changes in NO2 Emissions



Changes in Relative Emissions by Subpopulation



Benchmark: Optimal change in emission levels

Mode choice effect: Emission levels below the economic optimum

Re-route effect: Emission levels above the economic optimum

Re-route effect: Emission level still below the economic optimum

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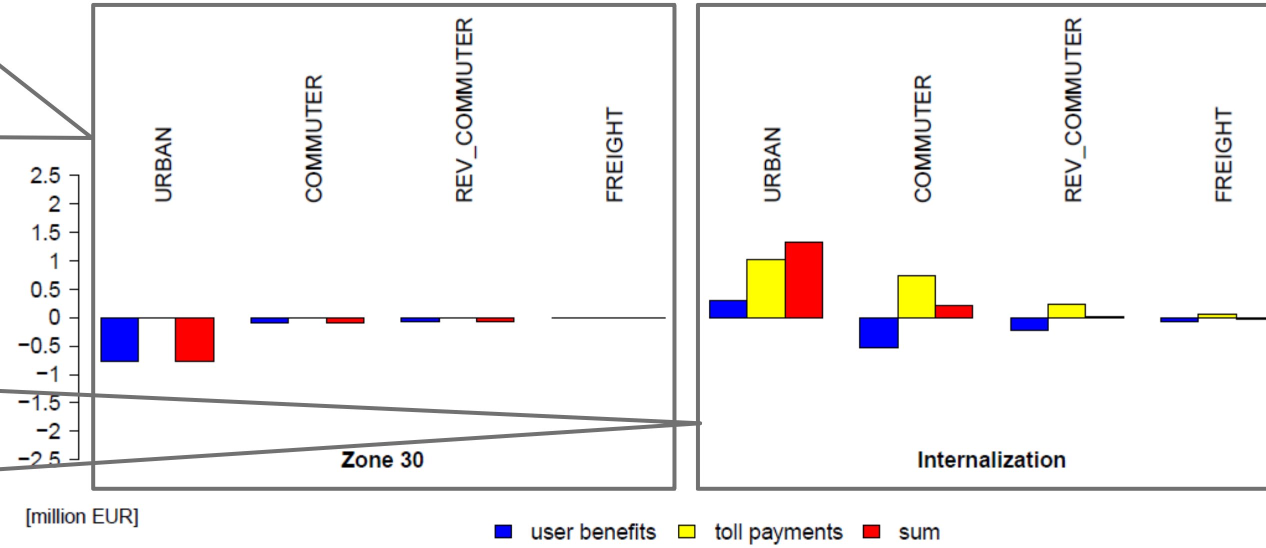
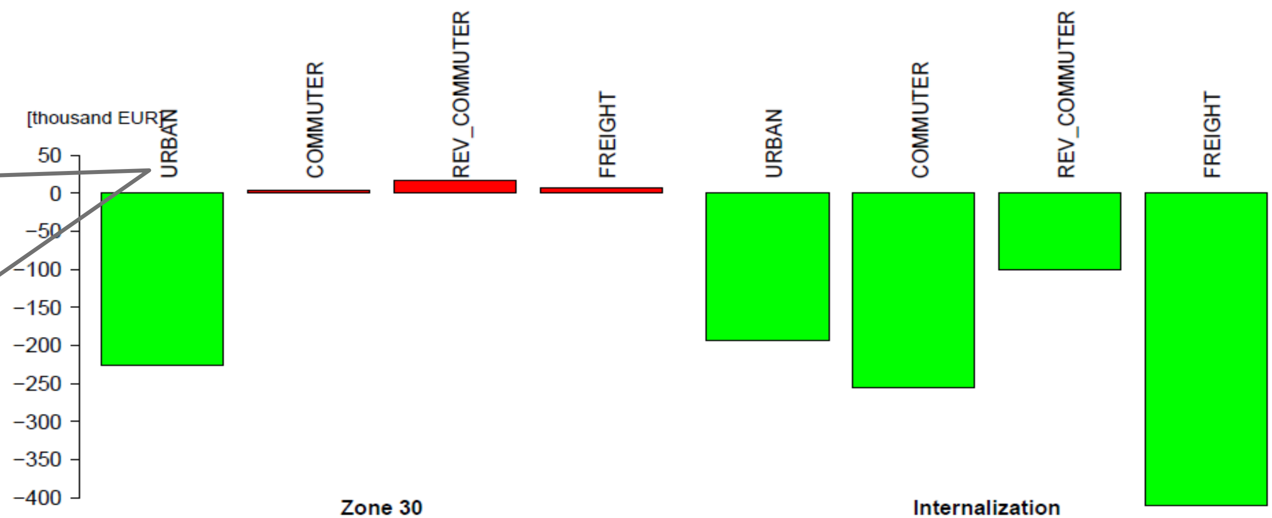
Absolute Changes in Benefits by Subpopulation

Loss in user benefit for all subpopulations



Net welfare gains: Emission toll is **implicitly a congestion toll**



Exposure costs: Zone 30 is an **effective strategy** for urban travelers, **ineffective** for other subpopulations

Backup

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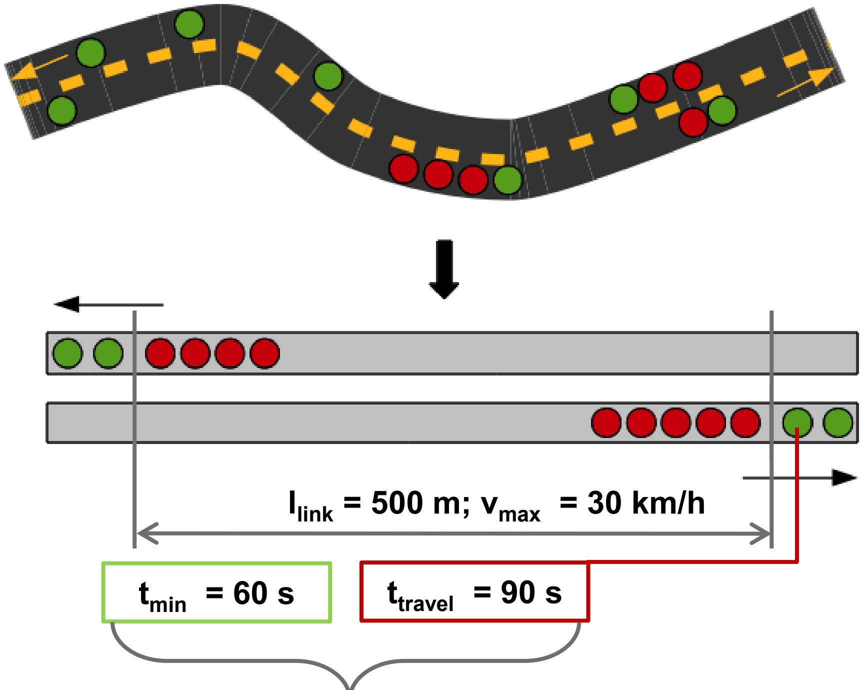
Emission Modeling Tool: Warm Emission Events



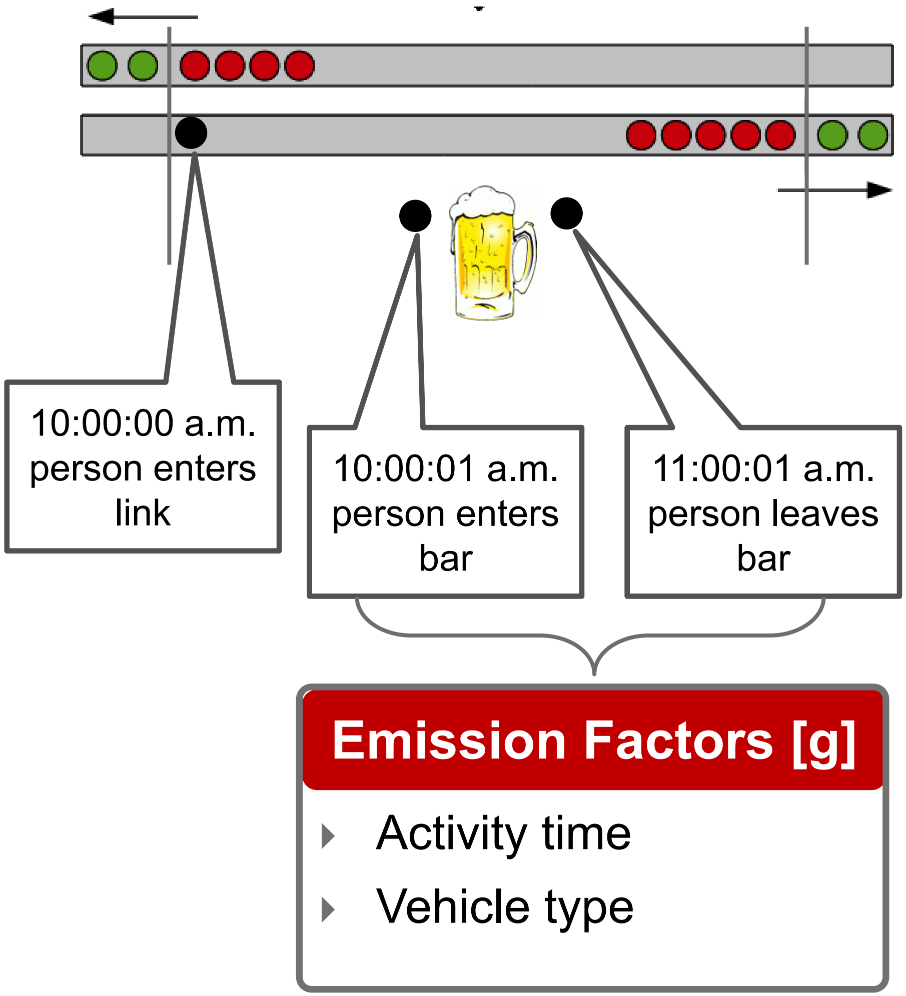
Traffic State

- Freeflow (60 s)
- ~~Heavy~~
- ~~Saturated~~
- Stop&Go (30 s)

$$x_{freeFlow} = l_{link} - x_{stopGo}$$

$$x_{stopGo} = (l_{link} \cdot v_{stopGo} \cdot (v_{max} - v_{avg})) / (v_{avg} \cdot (v_{max} - v_{stopGo}))$$

Emission Modeling Tool: Cold Emission Events



Behavioral Parameters

Table 5.1.: Estimated and adjusted utility parameters; resulting VTTS.

(a) Tirachini et al. (2014)

$\hat{\beta}_{tr,car}$	-0.96	$[\frac{utils}{h}]$
$\hat{\beta}_{tr,pt}$	-1.14	$[\frac{utils}{h}]$
$\hat{\beta}_{c}$	-0.062	$[\frac{utils}{AUD}]$
$\hat{\beta}_{perf}$	N/A	$[\frac{utils}{h}]$
$VTTS_{car}$	$+15.48$	$[\frac{AUD}{h}]$
$VTTS_{pt}$	$+18.39$	$[\frac{AUD}{h}]$

(b) MATSim

$\beta_{tr,car}$	-0.00	$[\frac{utils}{h}]$
$\beta_{tr,pt}$	-0.18	$[\frac{utils}{h}]$
β_{c}	-0.07949	$[\frac{utils}{EUR}]$
β_{perf}	$+0.96$	$[\frac{utils}{h}]$
$VTTS_{car}$	$+12.08$	$[\frac{EUR}{h}]$
$VTTS_{pt}$	$+14.34$	$[\frac{EUR}{h}]$

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Emission Cost Factors

Table 5.2.: Emission cost factors by emission type. Source: Maibach et al. (2008).

Emission type	Cost factor $[EUR/ton]$
CO_2	70
$NMHC$	1'700
NO_x	9'600
PM	384'500
SO_2	11'000

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Resulting Average Emission Cost Factors

Table 5.4.: Base case: resulting average emission cost factors by subpopulation [$EURct/km$].

Subpopulation	incl. CO_2	excl. CO_2
URBAN	2.71	1.20
COMMUTER	2.27	1.02
REV_COMMUTER	2.25	1.02
FREIGHT	14.51	10.29

For urban travelers, we find values close to those from the literature (e.g. Parry and Small, 2005: excl. CO2 approx. 1.23 EURct/km)

This needs to be investigated for Exposure Pricing!

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