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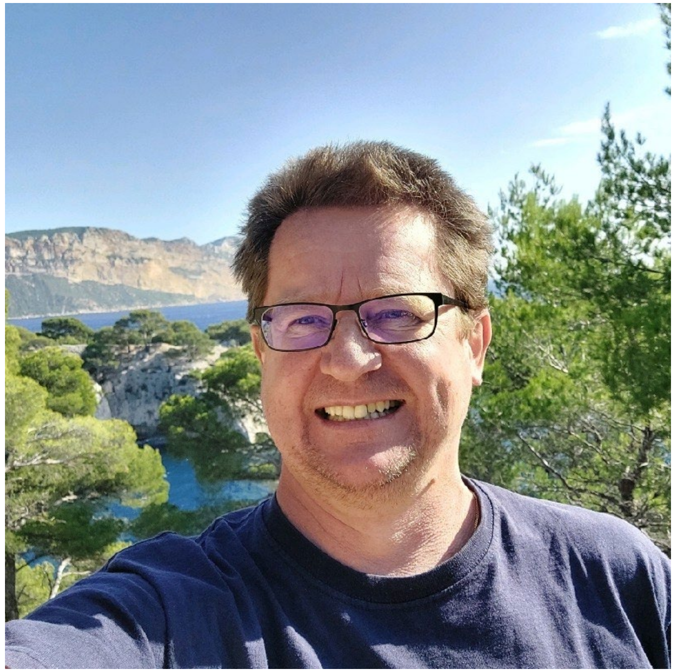
MINIMUM-COST FAST CHARGING INFRASTRUCTURE

PLANNING FOR ELECTRIC PASSENGER CARS ALONG HIGHWAYS

TEAM



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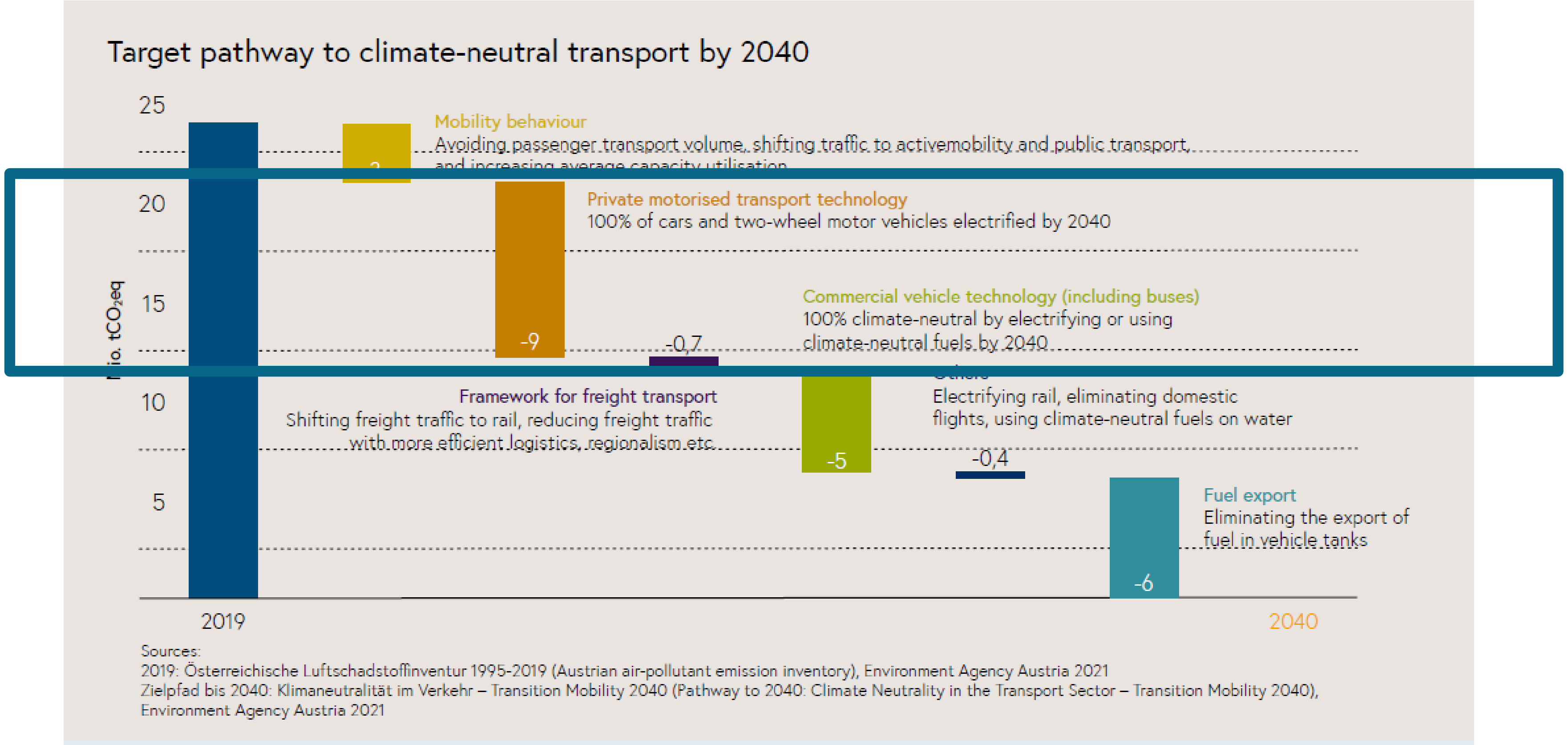
OVERVIEW ON AUSTRIA‘S TRANSPORT DECARBONIZATION GOALS



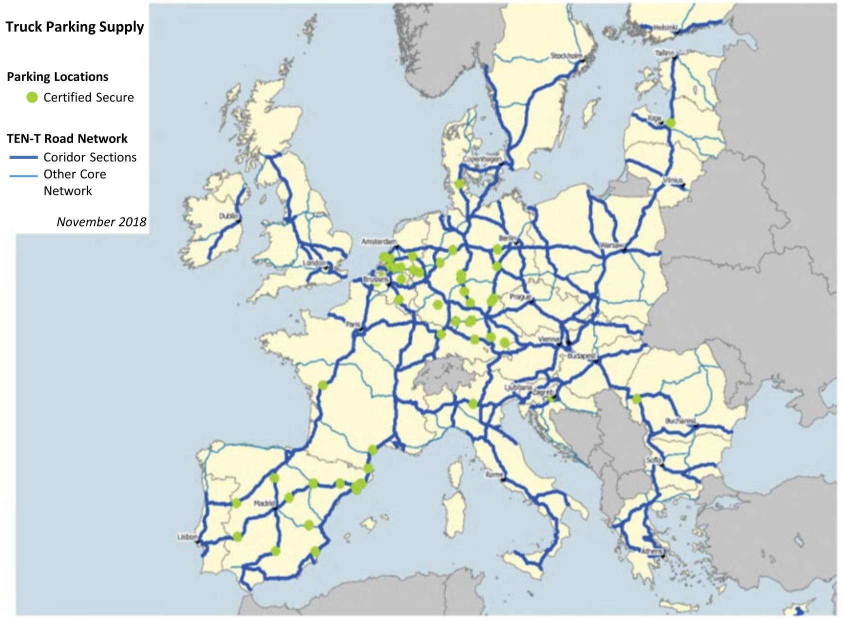
Target pathway to climate-neutral transport by 2040

Sources:
2019: Österreichische Luftschadstoffinventur 1995-2019 (Austrian air-pollutant emission inventory), Environment Agency Austria 2021
Zielpfad bis 2040: Klimaneutralität im Verkehr – Transition Mobility 2040 (Pathway to 2040: Climate Neutrality in the Transport Sector – Transition Mobility 2040), Environment Agency Austria 2021

https://www.bmk.gv.at/en/topics/mobility/mobilitymasterplan2030.html, last access Nov 21st, 2022

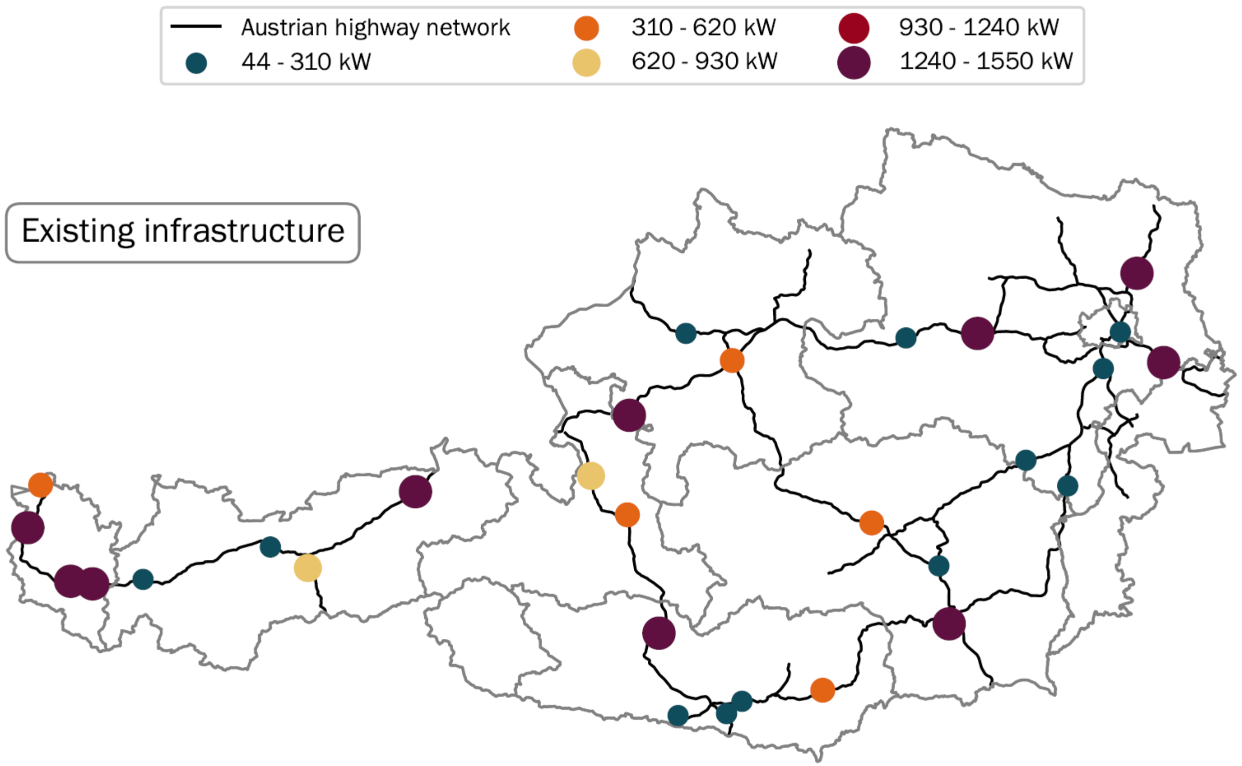
FAST-CHARGING ALONG HIGHWAYS

- Dense fast-charging infrastructure network is **motivating large-scale adoption** of electric vehicles
- Allocation of fast-charging infrastructure *along high-level road networks*
- „Fit for 55“: densification of fast-charging infrastructure along TEN-T network



https://op.europa.eu/webpub/eca/special-reports/core-road-network-9-2020/en/, last access: September 12th, 2022

FAST CHARGING CAPACITIES ALONG THE AUSTRIAN HIGHWAY NETWORK



	Existing infrastructure
Nb. charging stations	31
Nb. charging points with $\hat{P}_{CP} = 44kW$ (AC)	8
Nb. charging points with $\hat{P}_{CP} = 50kW$ (DC)	72
Nb. charging points with $\hat{P}_{CP} = 75kW$ (DC)	4
Nb. charging points with $\hat{P}_{CP} = 150kW$ (DC)	22
Nb. charging points with $\hat{P}_{CP} = 350kW$ (DC)	40
Total capacity (MW)	20.1

Status: January 2022

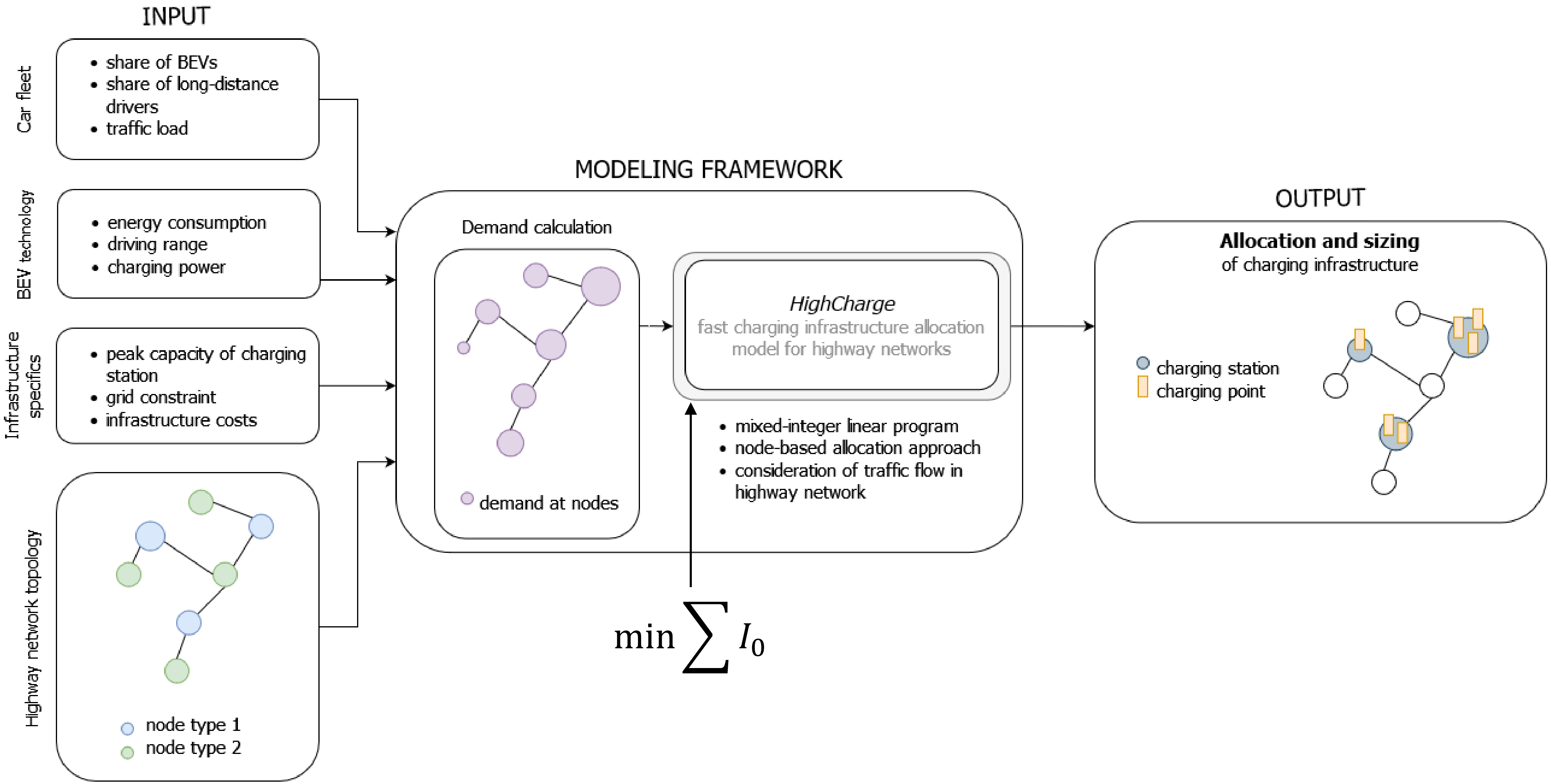
Data on current fast-charging infrastructure along Austrian highway network: https://www.asfinag.at/en/parking-resting/looking-for-resting-places/

RESEARCH QUESTIONS

- What are the **future requirements** for the expansion of the existing fast-charging infrastructure?
- How are these requirements affected by **share of BEVs** in the passenger car fleet, **future modal split** and **technological developments**?

- Development of **allocation** model with consideration of traffic flow
- **Quantification** of future fast-charging infrastructure expansion
- Observance of effects by different input parameters by the means of sensitivity analysis

CHARGING STATION ALLOCATION MODEL



INPUT

Car fleet
- share of BEVs
- share of long-distance drivers
- traffic load

BEV technology
- energy consumption
- driving range
- charging power

Infrastructure specifics
- peak capacity of charging station
- grid constraint
- infrastructure costs

Highway network topology

● node type 1
● node type 2

MODELING FRAMEWORK

Demand calculation

● demand at nodes

HighCharge
fast charging infrastructure allocation model for highway networks

- mixed-integer linear program
- node-based allocation approach
- consideration of traffic flow in highway network

$$\min \sum I_0$$

OUTPUT

Allocation and sizing
of charging infrastructure

● charging station
▯ charging point

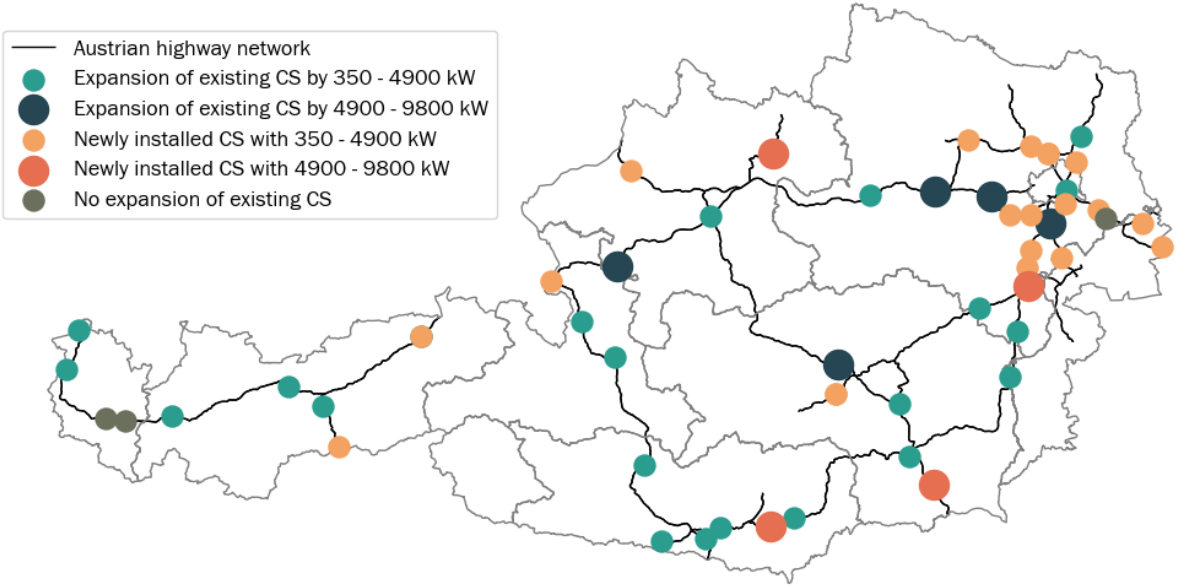
RESULTS: REQUIRED EXPANSION FOR 2030

Projections for 2030:

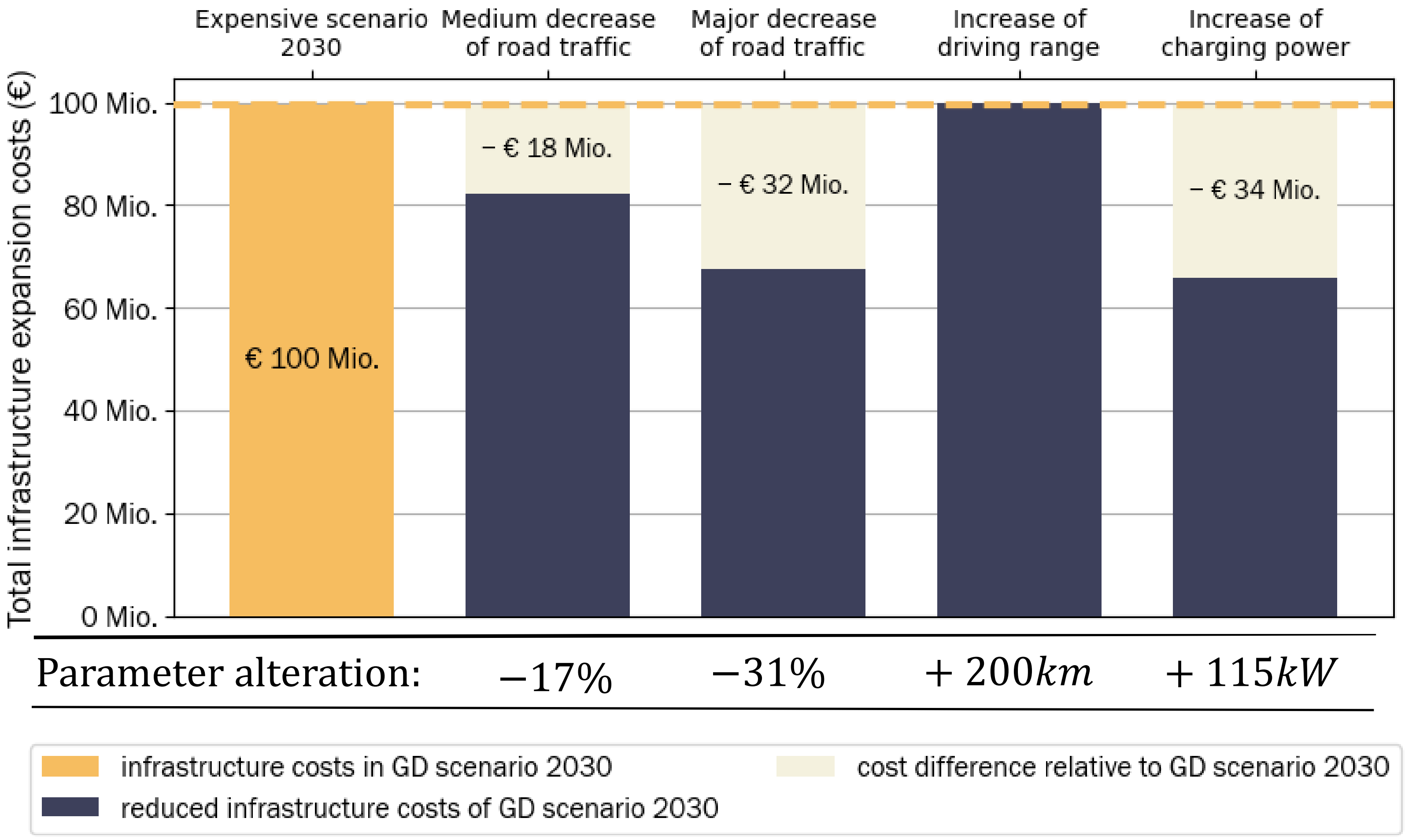
share of BEVs	share of today's traffic load	BEV driving range	BEV charging power	charging pole peak power	costs of charging pole
27 – 33%	69 – 100%	450 – 800km	200 – 315kW	350kW	€ 120,000

Results:

+ Installed charging capacity	146 – 270MW
+ Charging stations	24 – 27
Specific costs per kW	€/kW 370
Specific costs per BEV	€/BEV 39 - 72
Costs of expansion	€ 54 - 100 Mio.

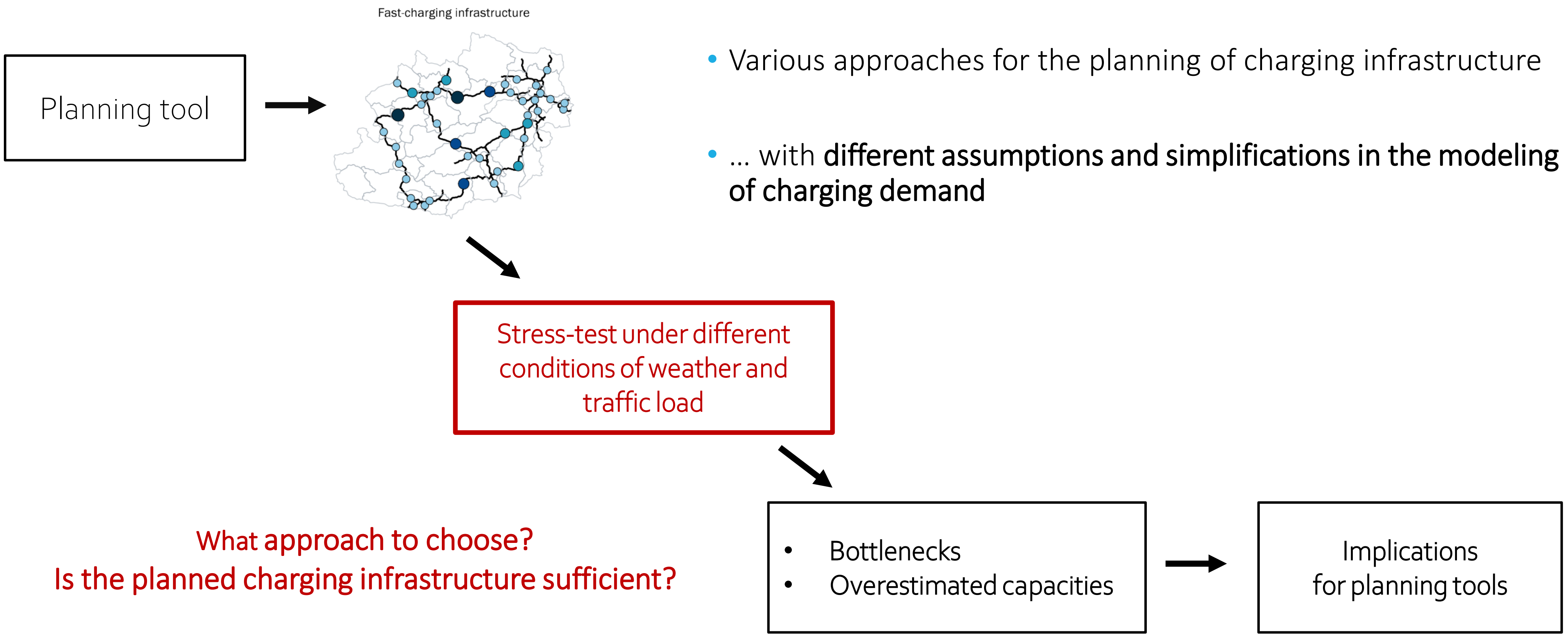


RESULTS: COST-REDUCTION POTENTIALS



Parameter alteration: -17% -31% $+200km$ $+115kW$

THERE'S A VARIETY OF PLANNING TOOLS …



Planning tool

Fast-charging infrastructure

Stress-test under different conditions of weather and traffic load

- Bottlenecks
- Overestimated capacities

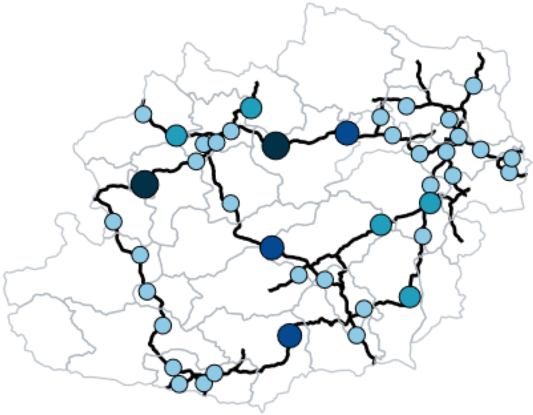
Implications for planning tools

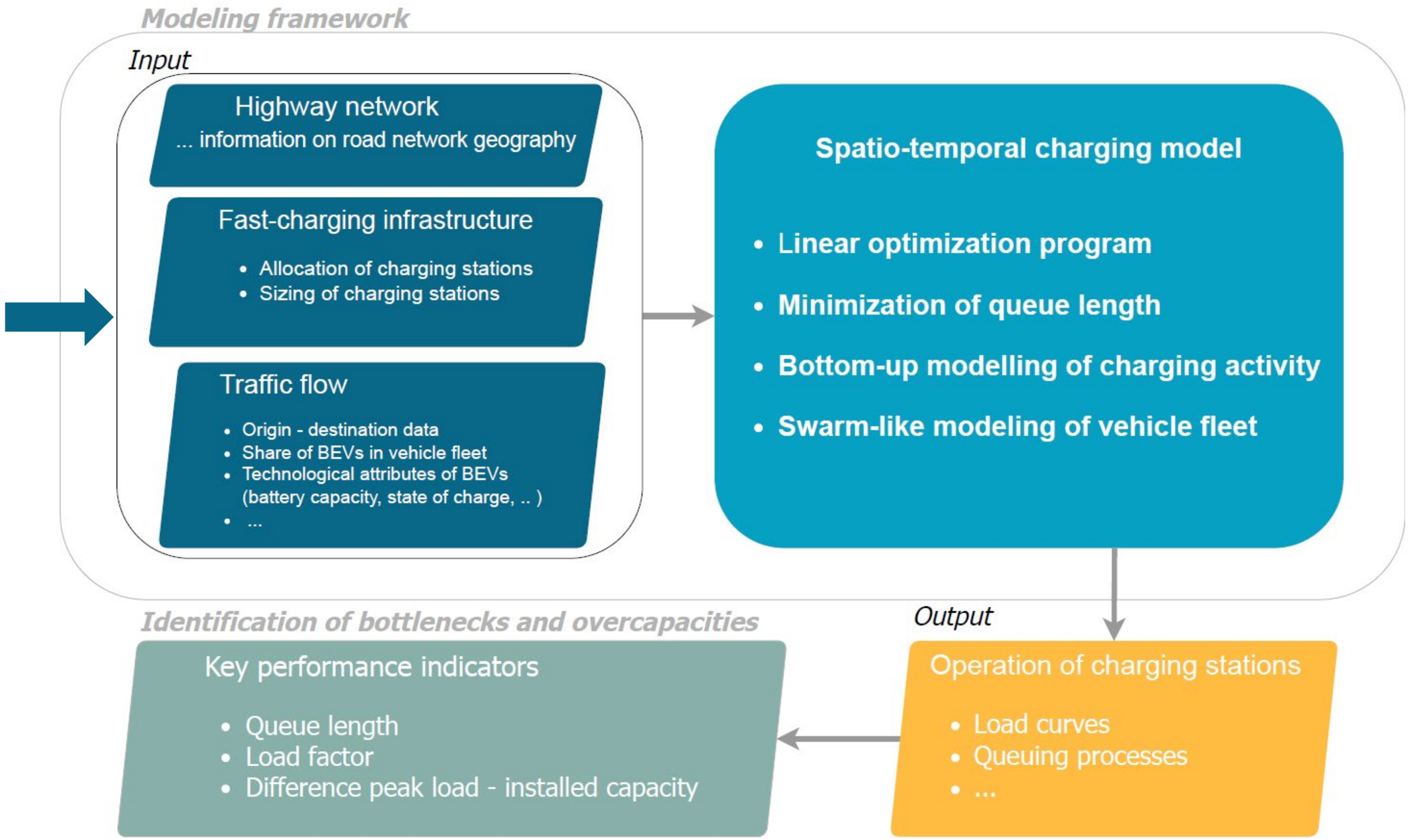
- Various approaches for the planning of charging infrastructure
- … with **different assumptions and simplifications in the modeling of charging demand**

What **approach to choose?**
Is the planned charging infrastructure sufficient?

SPATIO-TEMPORAL CHARGING MODEL

Fast-charging infrastructure





Modeling framework

Input

Highway network

... information on road network geography

Fast-charging infrastructure

- Allocation of charging stations
- Sizing of charging stations

Traffic flow

- Origin - destination data
- Share of BEVs in vehicle fleet
- Technological attributes of BEVs (battery capacity, state of charge, ..)
- ...

Spatio-temporal charging model

- **Linear optimization program**
- **Minimization of queue length**
- **Bottom-up modelling of charging activity**
- **Swarm-like modeling of vehicle fleet**

Output

Operation of charging stations

- Load curves
- Queuing processes
- ...

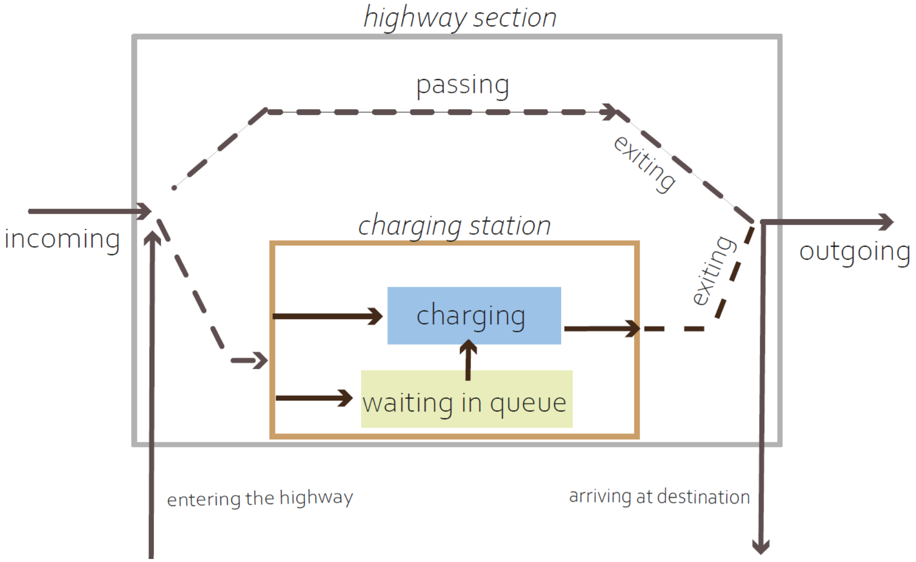
Identification of bottlenecks and overcapacities

Key performance indicators

- Queue length
- Load factor
- Difference peak load - installed capacity

SPATIO-TEMPORAL CHARGING MODEL II

Objective Function: $min_x \sum_f \sum_c \sum_t n_{f,c}^{queue,t}$



Two information layers:

→ Number of vehicles n

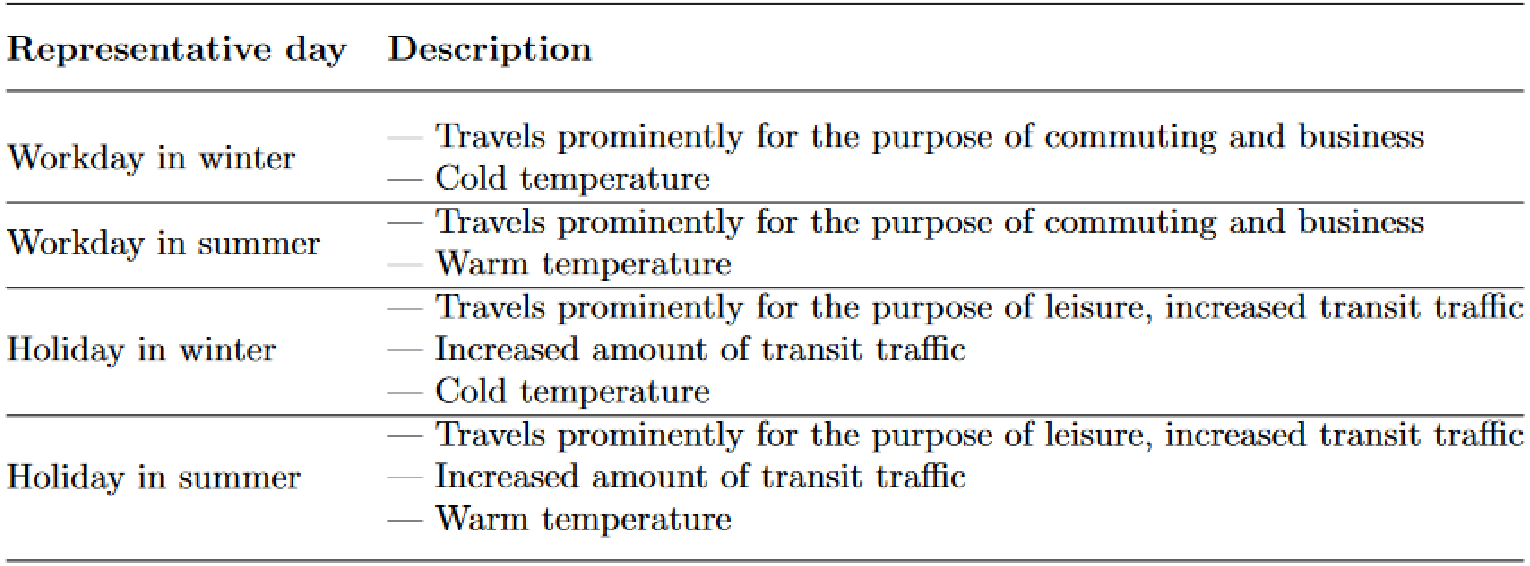
→ Accumulated state of charge Q

$$Q_{f,c}^{*,t} \geq n_{f,c}^{*,t} * SOC^{min} * Cap_f^{BEV}$$
$$Q_{f,c}^{*,t} \leq n_{f,c}^{*,t} * SOC^{max} * Cap_f^{BEV}$$

t … timestep
c … highway section
f … fleet

SOC^{min} … minimum SOC (%)
SOC^{max} … maximum SOC (%)
Cap_f^{BEV} … battery capacity (kWh)

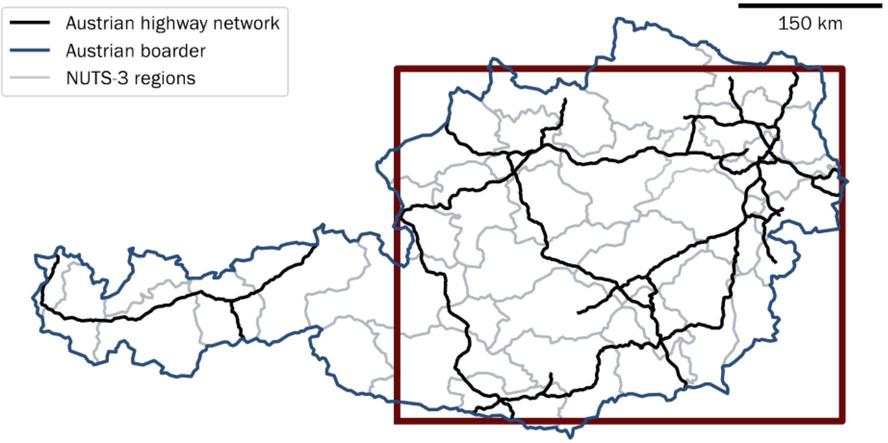
REPRESENTATIVE DAYS



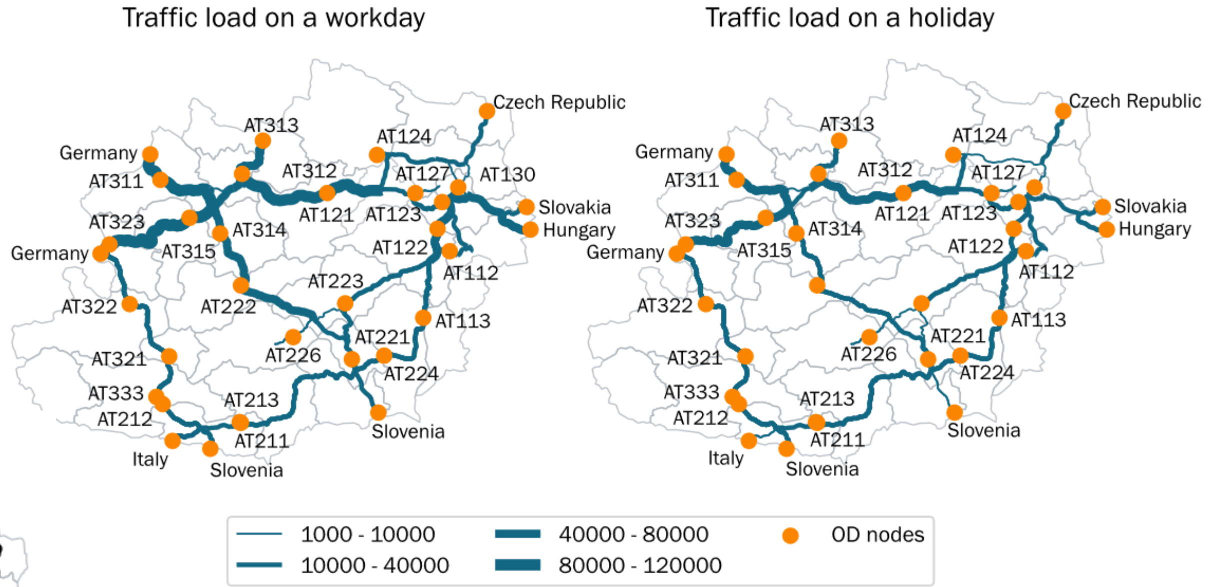
Representative day	**Description**
Workday in winter	— Travels prominently for the purpose of commuting and business — Cold temperature
Workday in summer	— Travels prominently for the purpose of commuting and business — Warm temperature
Holiday in winter	— Travels prominently for the purpose of leisure, increased transit traffic — Increased amount of transit traffic — Cold temperature
Holiday in summer	— Travels prominently for the purpose of leisure, increased transit traffic — Increased amount of transit traffic — Warm temperature

TEST-BED: AUSTRIAN HIGHWAY NETWORK 2030

Test-bed

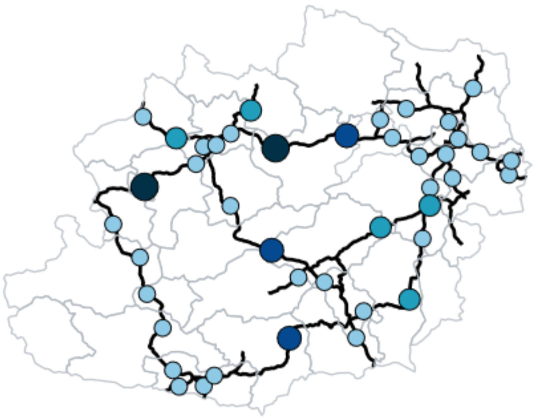


Origin-Destination nodes



Charging infrastructure

Fast-charging infrastructure



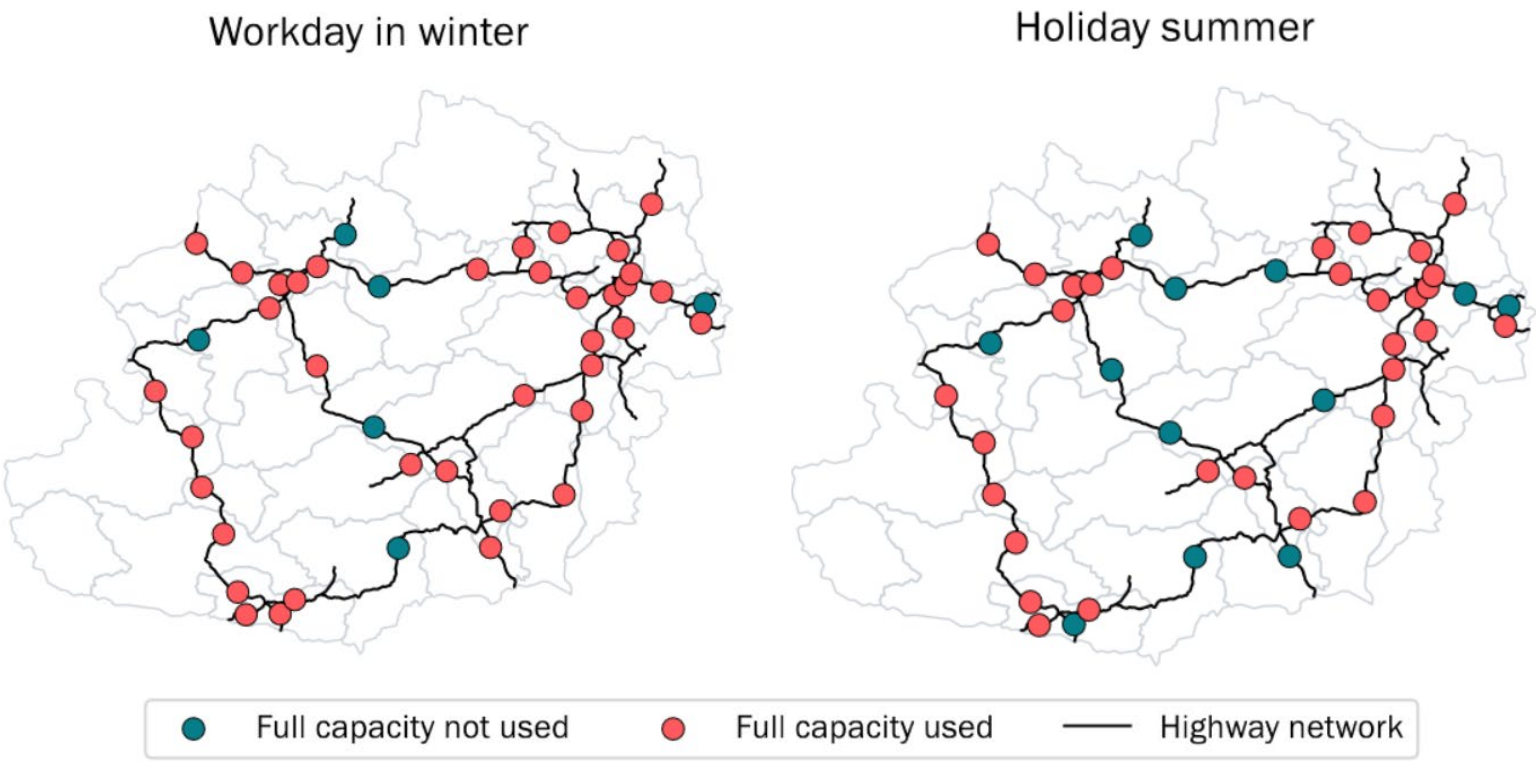
Antonia Golab, Sebastian Zwickl-Bernhard, and Hans Auer. *Minimum-cost fast-charging infrastructure planning for electric vehicles along the austrian high-level road network*. Energies, 15(6), 2022. ISSN 1996-1073.

BOTTLENECKS AND OVERCAPACITIES

Objective Function value:

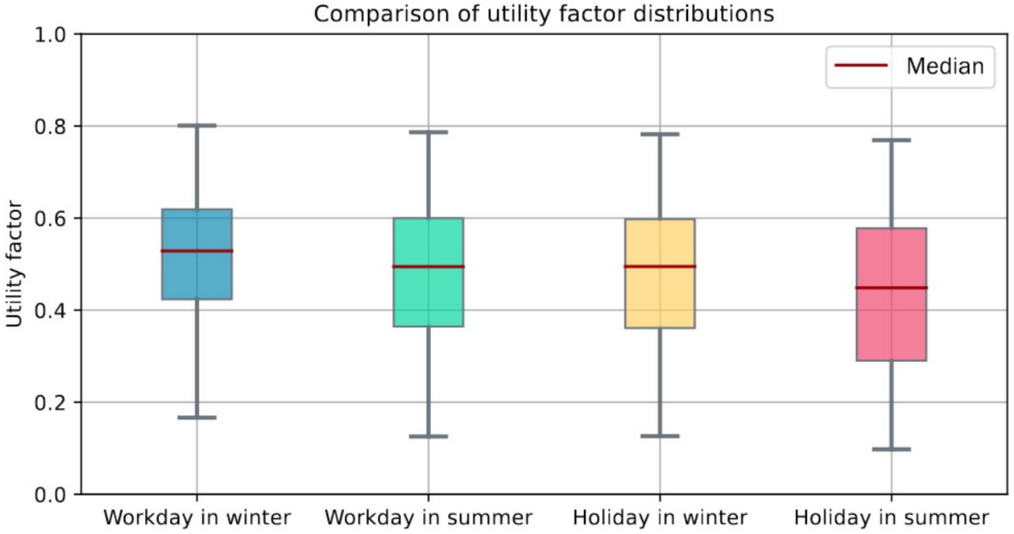
$$\sum_{t,c,f} n_{f,c}^{queue,t} = 0$$

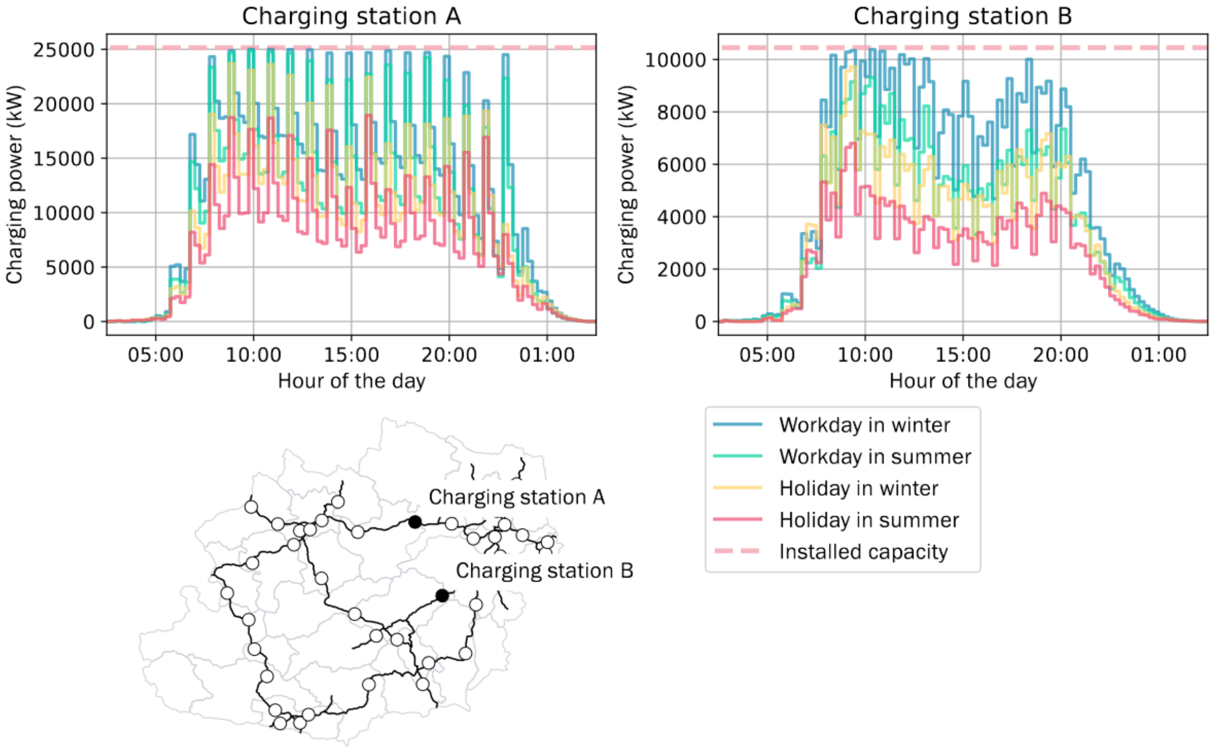
$$\overline{SOC}_f^{exit} \approx 30\%$$


Workday in winter

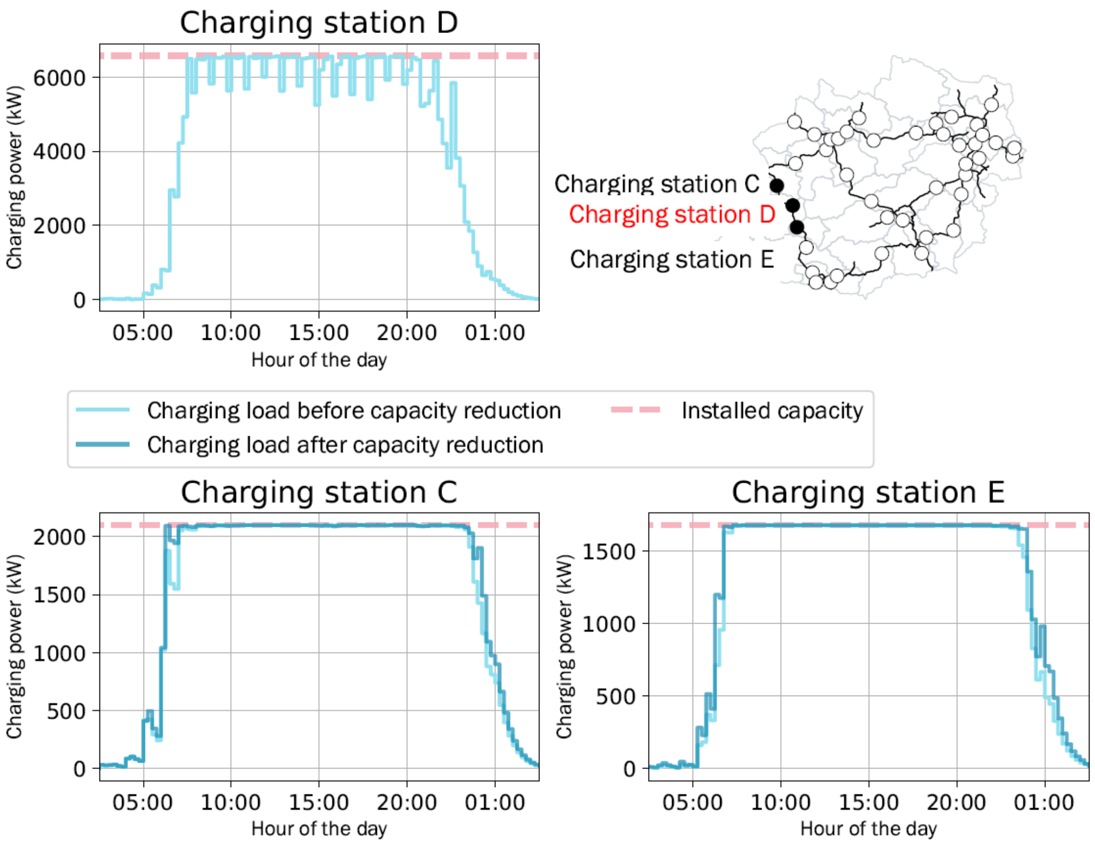
Holiday summer

VARIATIONS IN CHARGING INFRASTRUCTURE UTILIZATION





WHAT HAPPENS IN THE CASE OF A CHARGING STATION OUTAGE?



- Load curve of adjacent charging stations is not changing significantly
- Charging demand is covered elsewhere within the network

→ Implications for **overestimated charging capacities** within the network

→ Hint at cost-saving potential of application of **coordinated charging** along highway

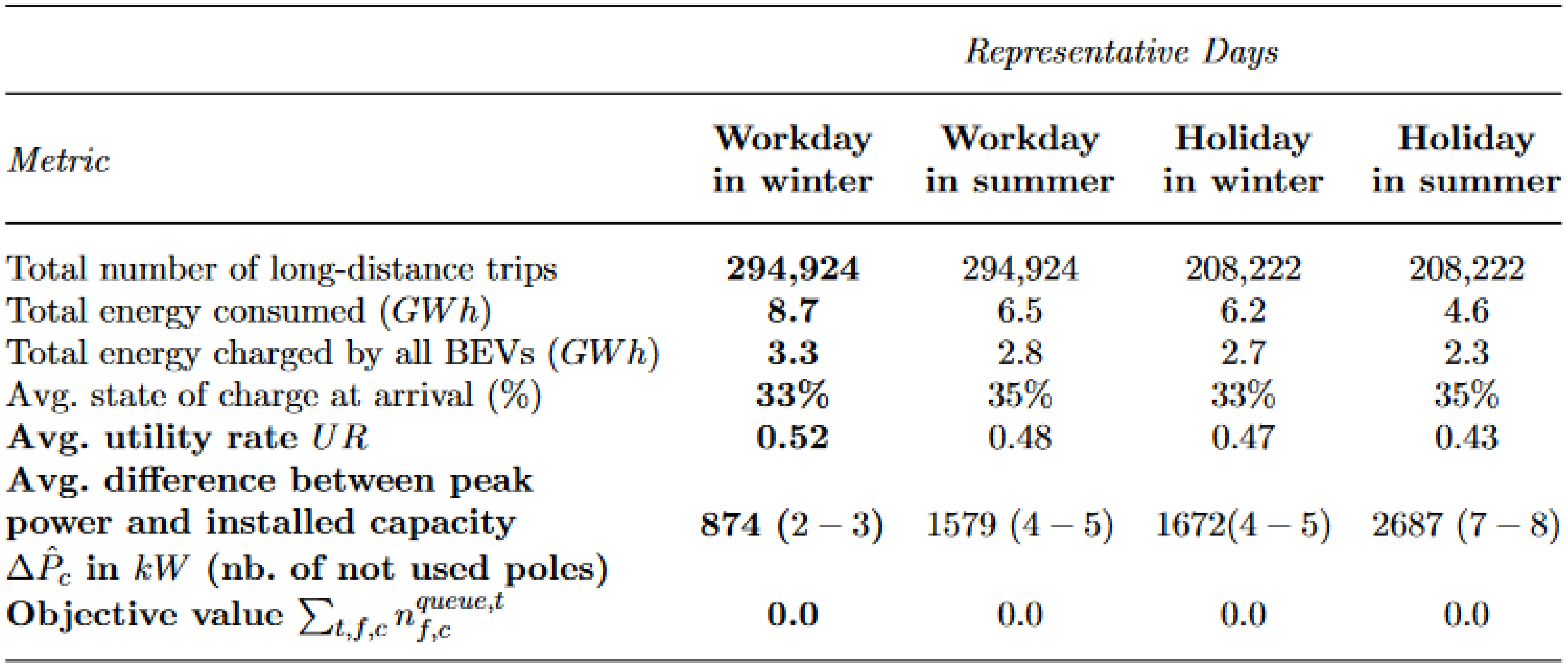
SUMMARY & CONCLUSION

- **Cost reduction potentials** in investments in future charging infrastructure:
    - investments in technological development (improving efficiency in charging)
    - Reduction in charging demand through reduction in road traffic load

- **Essential features of planning tools** for highway charging infrastructure
    - O-D nodes: Where do they come from? Where do they go?
    - Temporal distribution of charging activity throughout the day
        - Coverage of peak demand
        - Utilization factor
- Future work: introducing **randomness of user choices** (no coordinated charging)

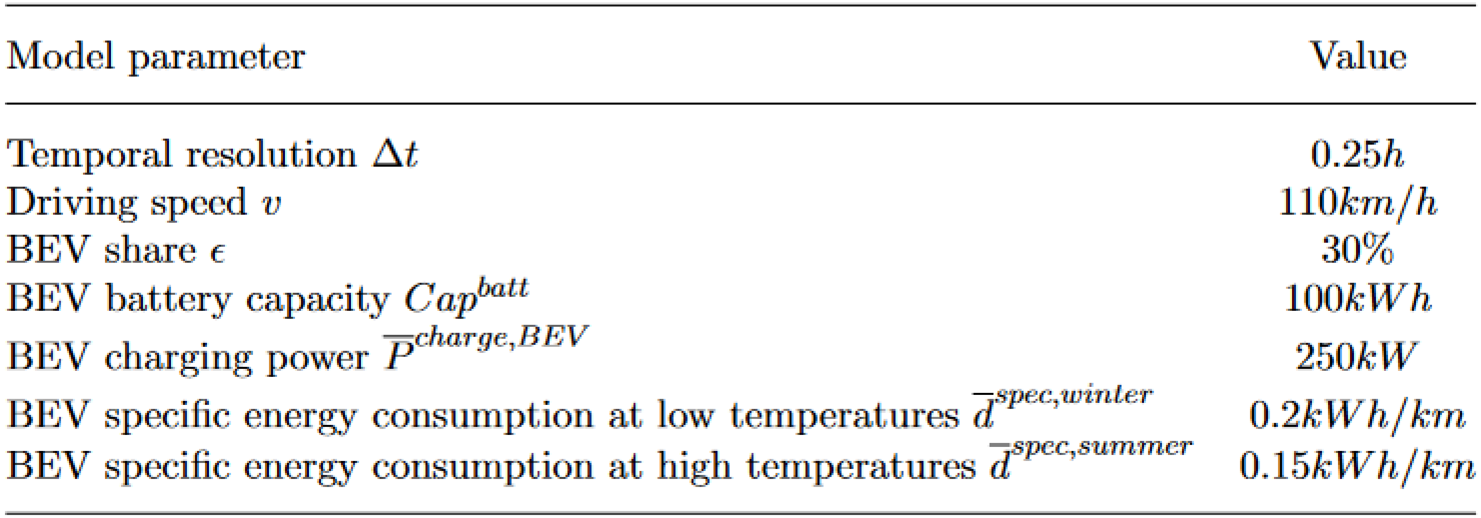
APPENDIX

RESULT SUMMARY



	Representative Days			
Metric	**Workday in winter**	**Workday in summer**	**Holiday in winter**	**Holiday in summer**
Total number of long-distance trips	**294,924**	294,924	208,222	208,222
Total energy consumed (GWh)	**8.7**	6.5	6.2	4.6
Total energy charged by all BEVs (GWh)	**3.3**	2.8	2.7	2.3
Avg. state of charge at arrival (%)	**33%**	35%	33%	35%
Avg. utility rate UR	**0.52**	0.48	0.47	0.43
Avg. difference between peak power and installed capacity $\Delta\hat{P}_c$ **in** kW **(nb. of not used poles)**	**874 (2 – 3)**	1579 (4 – 5)	1672(4 – 5)	2687 (7 – 8)
Objective value $\sum_{t,f,c} n_{f,c}^{queue,t}$	**0.0**	0.0	0.0	0.0

ASSUMPTIONS



Model parameter	Value
Temporal resolution Δt	$0.25h$
Driving speed v	$110km/h$
BEV share ϵ	30%
BEV battery capacity Cap^{batt}	$100kWh$
BEV charging power $\overline{P}^{charge,BEV}$	$250kW$
BEV specific energy consumption at low temperatures $\overline{d}^{spec,winter}$	$0.2kWh/km$
BEV specific energy consumption at high temperatures $\overline{d}^{spec,summer}$	$0.15kWh/km$

ASSUMPTIONS MADE IN THE PLANNING TOOL I

- Charging demand is defined at each rest stop and is **assumed to be the result of the energy consumption of long-distance BEV drivers** traveling along the highway network. Here, annual peaks in traffic load and increased energy consumption due to cold temperatures are taken into account. The algorithm determines where charging capacity should be allocated to meet this demand.

- This is done while **considering the limited range of BEVs** and the geographic distribution of traffic load along the highway network.

- The allocations of origin and destination points of BEVs traveling along the highway network are ignored.

WHAT NOW?

CONCLUSION & FUTURE WORK

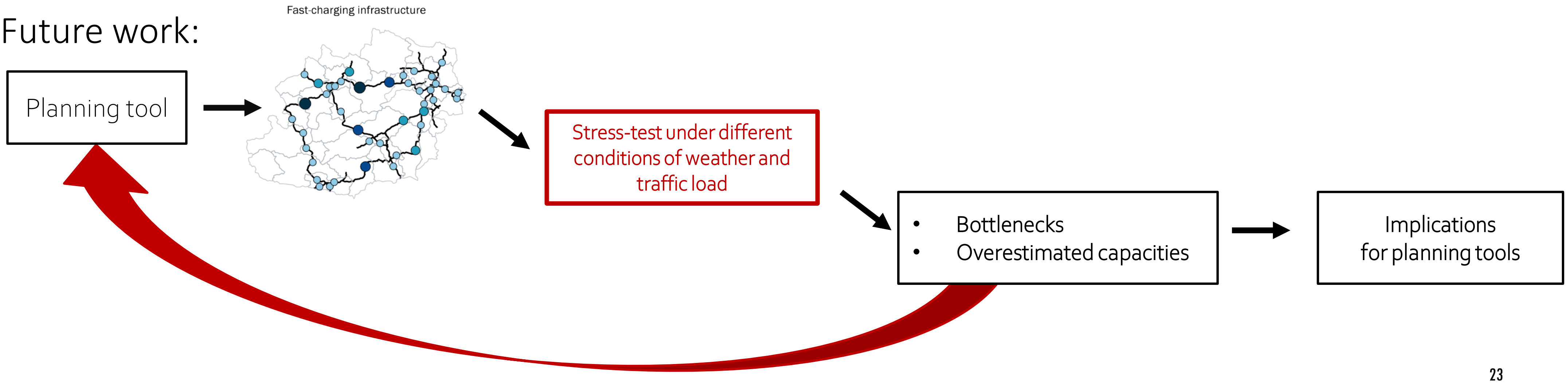
Conclusio:

- Minor seasonal differences in utilization of charging infrastructure detected
- Results hint at the importance of traffic flow rather than the local traffic counts

→ *Where do they come from? Where do they go?*

- Further studies on the **trade-offs** of this approach (linear program) in contrast to agent-based
- Introduction of constraints reflecting the **human decision-making** more realisticly

Future work:



Planning tool

Stress-test under different conditions of weather and traffic load

- Bottlenecks
- Overestimated capacities

Implications for planning tools