An Analysis of Greenhouse Gas Emissions Associated with Shared Automated Electric Vehicles

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Updates on four studies exploring electrification and automation

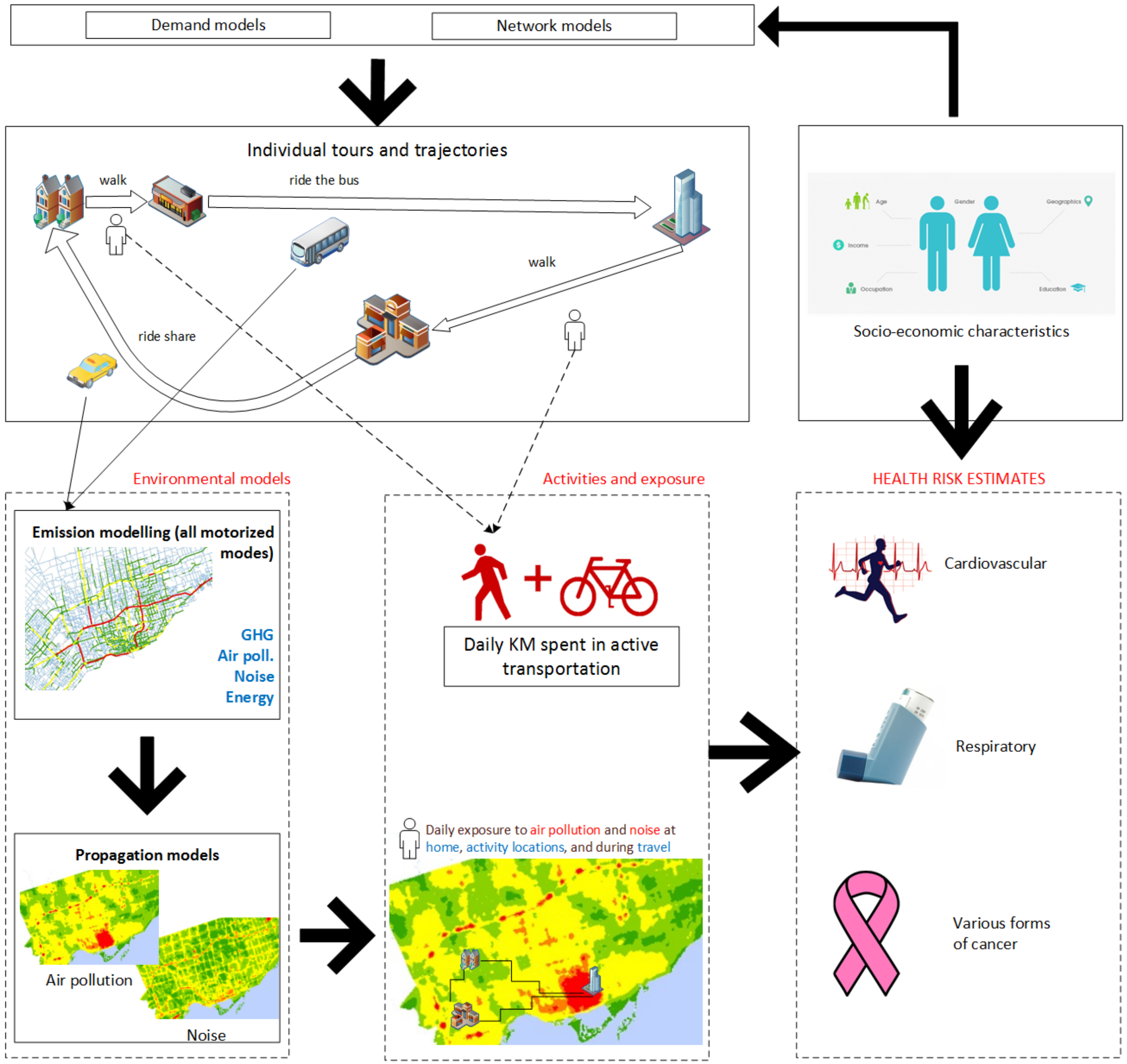
- Electrification and air quality/health

- Impact of EV charging behaviour on GHG emissions from electricity production

- Energy and GHG implications of high mileage electric vehicles

University of Toronto
Transportation and Air Quality Research Group (TRAQ)

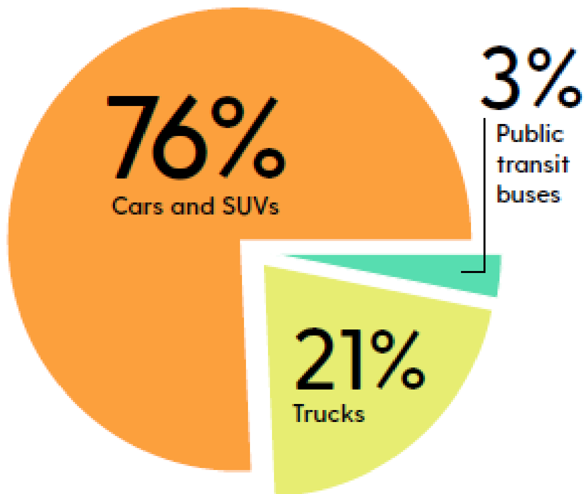
Electrification and air quality/health


Demand models
Network models
Individual tours and trajectories
walk
ride the bus
walk
ride share
Socio-economic characteristics
Environmental models
Emission modelling (all motorized modes)
GHG
Air poll.
Noise
Energy
Propagation models
Air pollution
Noise
Activities and exposure
Daily KM spent in active transportation
Daily exposure to air pollution and noise at home, activity locations, and during travel
HEALTH RISK ESTIMATES
Cardiovascular
Respiratory
Various forms of cancer

2016 traffic-related emission inventory in the GTHA

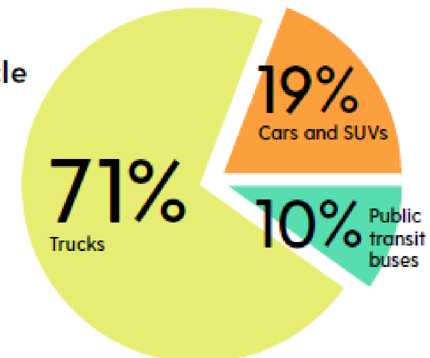
Traffic-related greenhouse gas (GHG) emissions by vehicle type in the GTHA

34,340 tonnes CO_2 eq./day



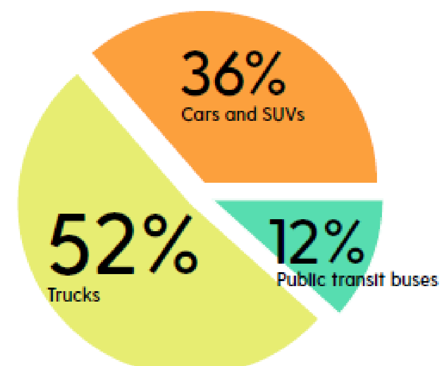
Traffic-related black carbon (BC) emissions by vehicle type in the GTHA

0.54 tonnes BC/day



Traffic-related nitrogen oxides (NO_x) emissions by vehicle type in the GTHA

30 tonnes NO_x/day



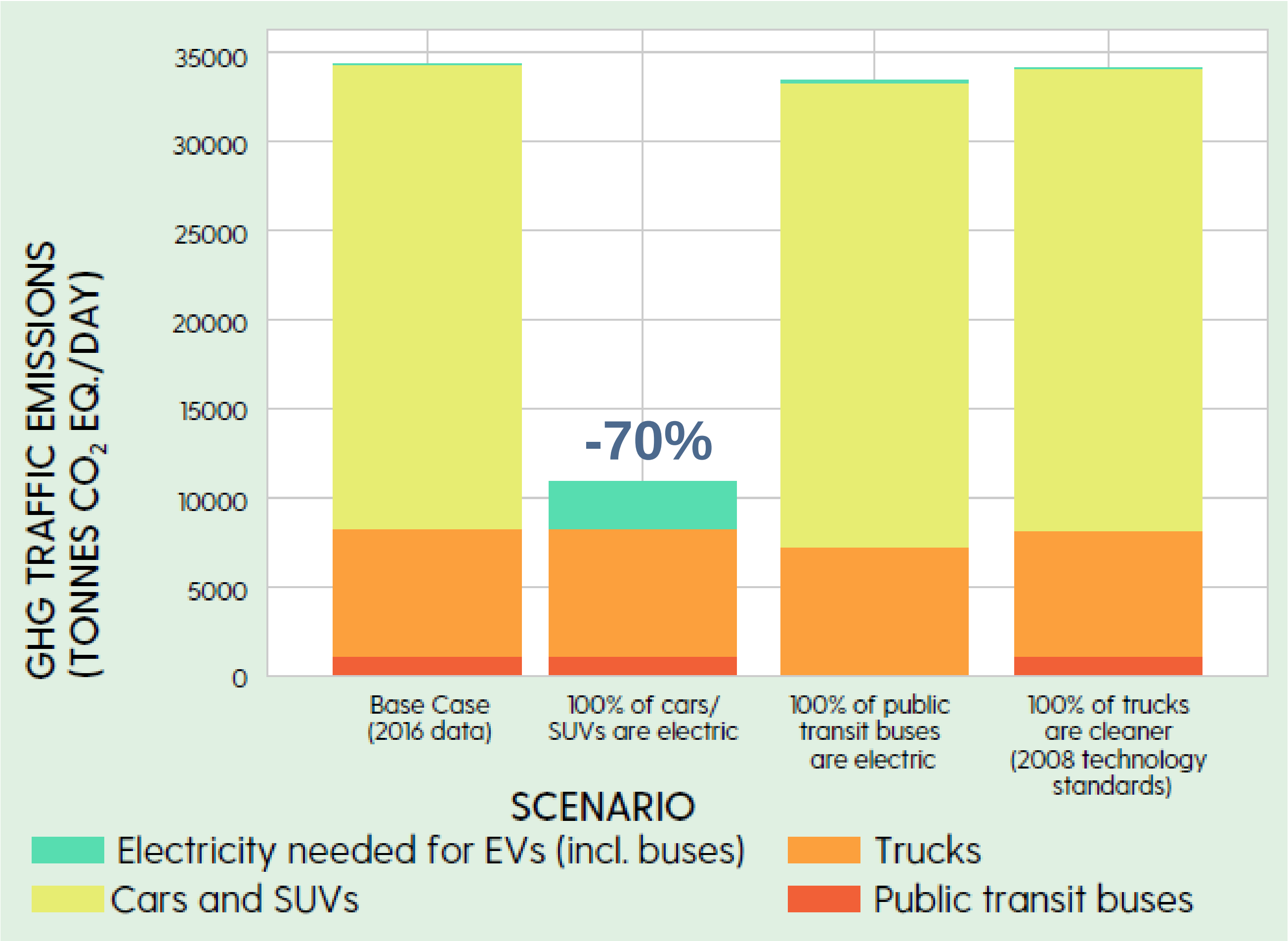
Base Case

Scenario 1 : cars and SUVs are 100% electric

Scenario 2 : transit buses are 100% electric

Scenario 3 : cleaner trucks (2008 technology standards)

Electrifying all private passenger vehicles would reduce GHG emissions by 70%



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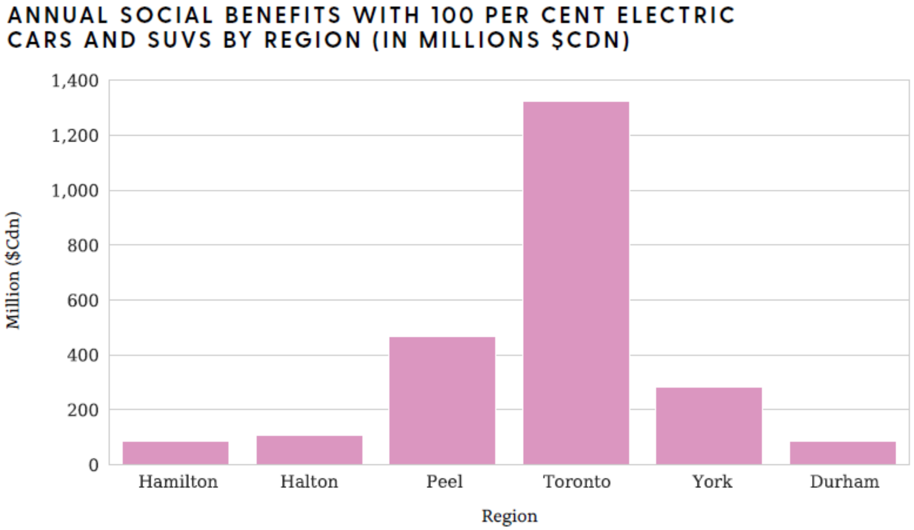
Scenario 1: cars and SUVs are 100% electric

313 premature deaths prevented

$2.4 billion per year in social benefits

7.6 mega tonnes (68.5%) annual GHG reductions

$9,850 social benefits per electric car deployed



Scenario 2: transit buses are 100% electric

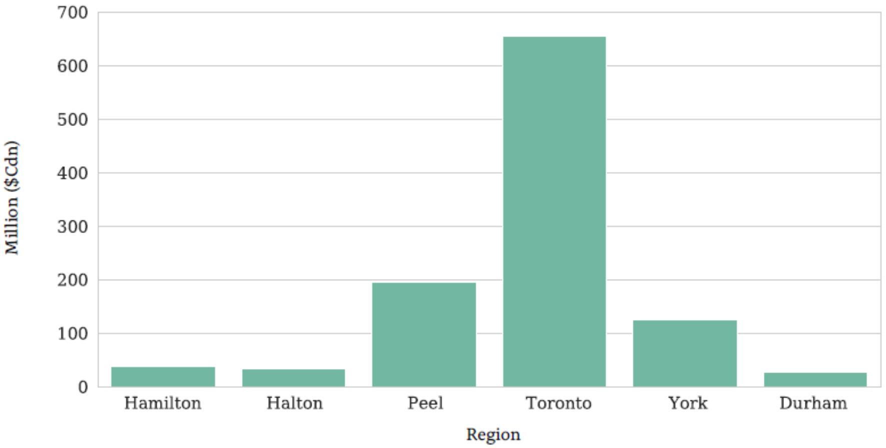
143 premature deaths prevented

$1.1 billion per year in social benefits

0.3 mega tonnes annual GHG reductions

Greatest benefits to residents in **City of Toronto**

ANNUAL SOCIAL BENEFITS WITH 100 PER CENT ELECTRIC PUBLIC TRANSIT BUSES BY REGION (IN MILLIONS $CDN)



Scenario 3: cleaner trucks (2008 technology standards)

275 premature deaths prevented

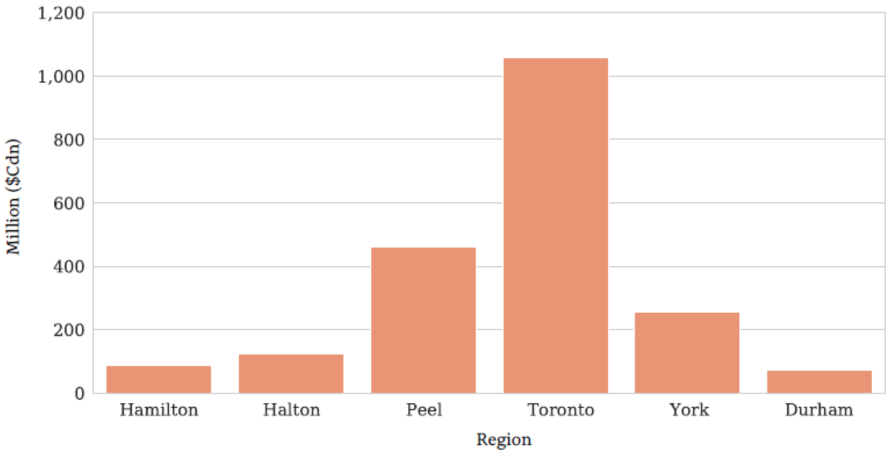
$2.1 billion per year in social benefits

0.06 mega tonnes annual GHG reductions

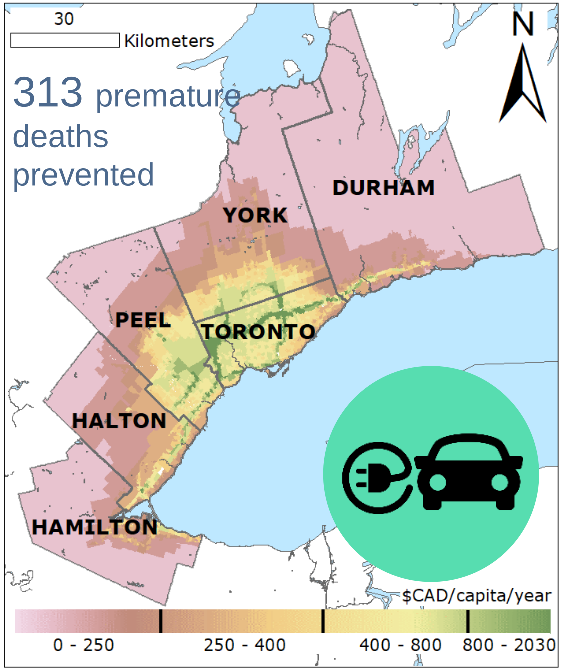
Greatest benefits **where truck traffic is concentrated**

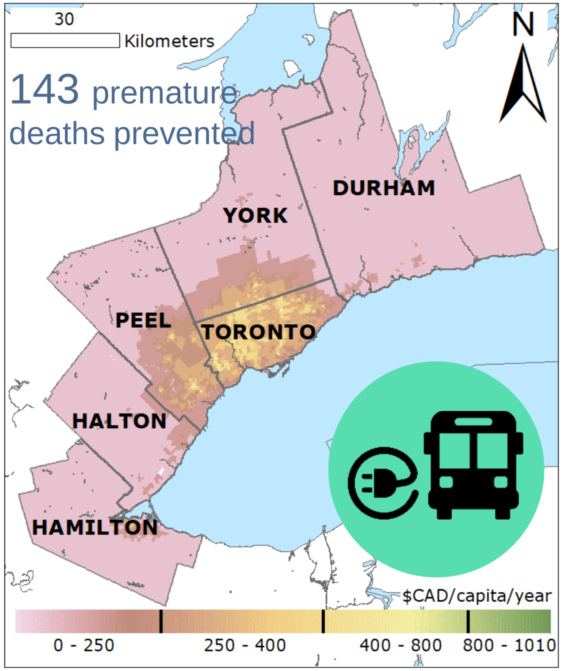
$308,000 social benefits per cleaner truck deployed

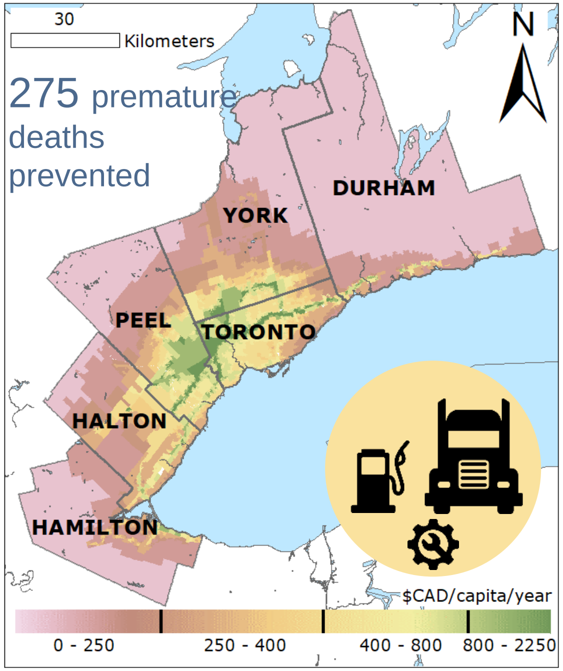
ANNUAL SOCIAL BENEFITS WITH 100 PER CENT CLEANER TRUCKS BY REGION (IN MILLIONS $CDN)



Distribution of social benefits across the region







What Are the Social Benefits of Deploying Cleaner Vehicles?

CA$**9,850** / electric car or SUV

CA$**308,000** / cleaner truck

Compare with social costs of new policies

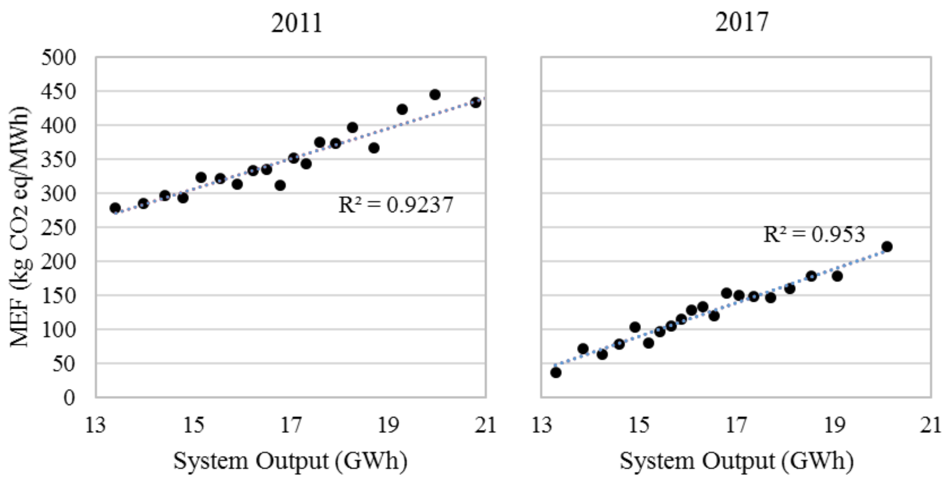
(e.g., subsidies of EV in Canada vs. Ontario)

CA$5,000

CA$10,000

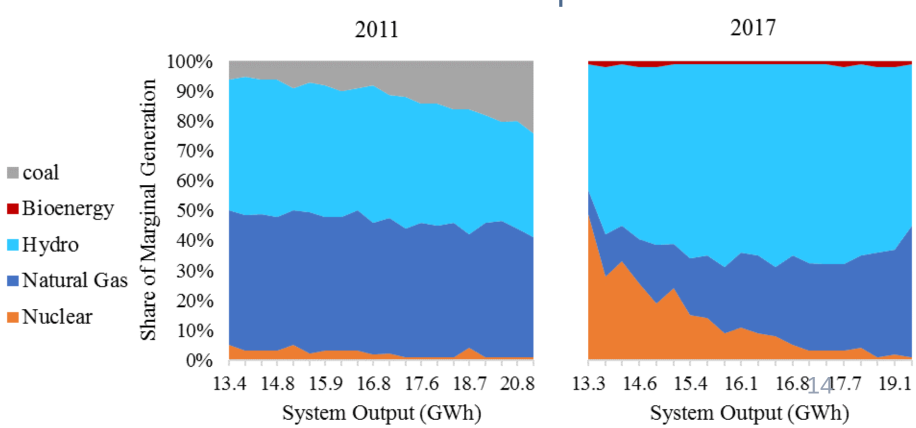
Impact of EV charging behaviour on GHG emissions from electricity production

Marginal GHG Emission Factors



MEF can be 2~4 times higher than AEF.

Share of marginal generation as a function of system output



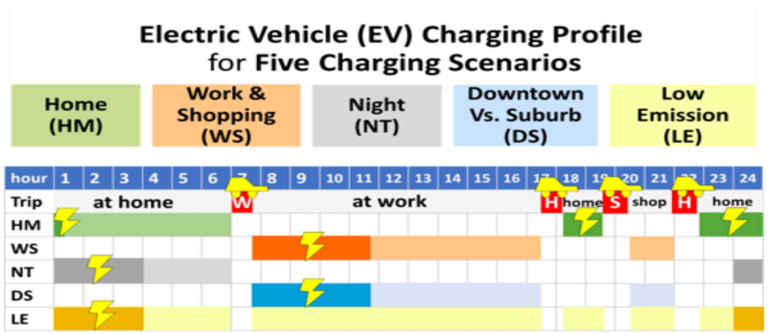
Marginal GHG Emission Factors

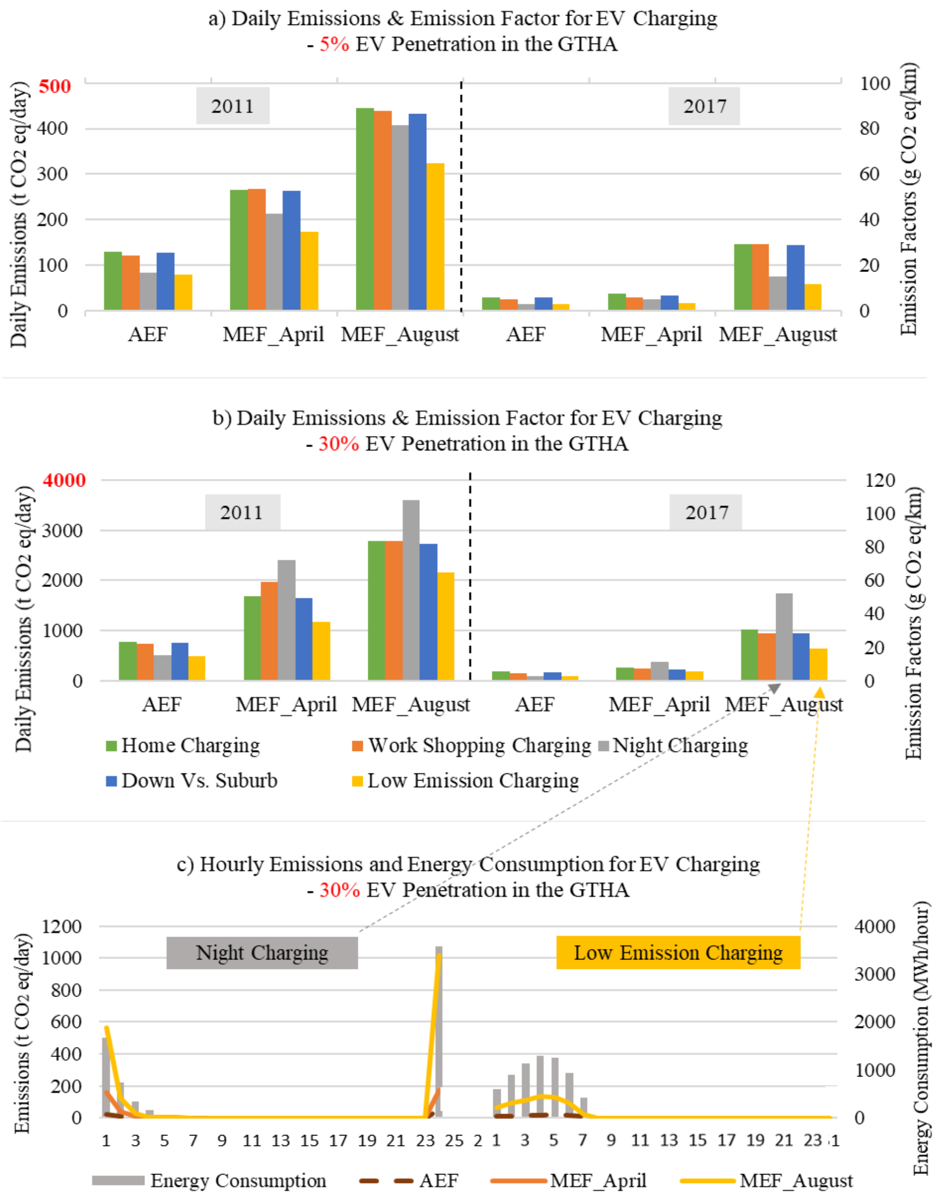
MEF by season and hour in 2017

(b) Based on historical data in 2017

Hour	AEF	Marginal Emission Factors (based on historical data in 2017) (kg CO2 eq/MWh)											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	13	104	62	78	28	14	0	8	65	90	0	75	101
2	13	88	22	44	26	0	0	0	25	51	0	46	64
3	13	86	16	29	24	0	0	0	21	32	0	35	53
4	14	84	14	96	22	0	0	0	68	64	0	22	44
5	15	82	93	95	4	11	0	41	76	72	10	91	79
6	17	83	88	97	12	18	0	39	92	126	13	92	89
7	18	90	73	107	18	26	20	46	104	149	26	95	113
8	20	100	80	129	19	30	36	70	121	148	49	123	150
9	21	110	102	137	19	31	43	96	124	159	58	145	182
10	23	115	114	73	35	32	52	121	122	166	59	154	195
11	24	106	34	84	36	35	58	137	136	178	46	97	200
12	25	103	31	77	36	34	60	155	130	182	46	152	161
13	26	102	44	79	35	34	64	163	136	180	62	151	154
14	27	99	42	69	34	10	66	177	130	184	63	150	196
15	28	111	28	130	34	33	68	177	131	199	63	150	197
16	29	112	105	129	20	36	74	179	146	212	56	154	199
17	31	116	101	130	23	39	80	183	151	216	67	155	209
18	31	125	98	135	23	15	79	204	134	101	73	168	236
19	31	113	111	137	25	39	79	131	115	198	77	136	217
20	30	122	62	150	28	41	78	138	113	116	84	146	215
21	27	124	69	121	44	41	75	122	135	177	77	154	212
22	23	131	111	152	43	47	91	163	167	221	60	158	210
23	18	137	108	151	40	47	80	137	147	216	38	147	199
24	15	120	83	108	33	27	26	64	111	161	16	114	157
								Min =	0	Mean =	85	Max =	236

Impacts of charging scenarios





EV Charging Optimization Based on Marginal Emission Factor

Objective : $\min Z = \frac{\sum_i \sum_j MEF_i \times x_{i,j}}{\delta \times (1-\gamma)}$

MEF_i is calculated by Eq. (S1), and $G_i = D_i + \sum_{j=1}^{V} x_{i,j}$;

Subject to:

(I) . $ER_{i,j} \times x_{i,j} = 0, \forall i, j$;

(II) . $\sum_{i=1}^{t} (ER_{i,j} - x_{i,j}) \leq BC, \forall j, t \in [1, 2, \cdots, T]$;

(III) . $\left| \sum_{i=1}^{T} (ER_{i,j} - x_{i,j}) \right| \leq \tau, \forall j$;

(IV) . $\sum_{j=1}^{V} x_{i,j} \leq S_i, \forall i$;

Where:

$x_{i,j} = \{0, 1.6, 7, 50\}$ kW is the level of charging for vehicle j during time i. Three levels of charging rate plus zero (which means no charging activity) are available for each$x_{i,j}$, as discussed in the next paragraph;

D_i is current electricity demand that exists in current network based on IESO dataset;

G_i is network electricity load at time i, which is the sum of current demand D_i and additional charging demand;

ΔG_i is the load changing rate at time i;

$ER_{i,j}$ is energy consumption of vehicle j during time$i$;

S_i is current spare capacity in the electricity network based on IESO dataset;

BC is the EV maximum available electrical energy;

τ is minimal charging volume, which equals to the product of minimal charging rate and length of time interval i;

δ is the charging efficiency rate (89.4% in this paper);

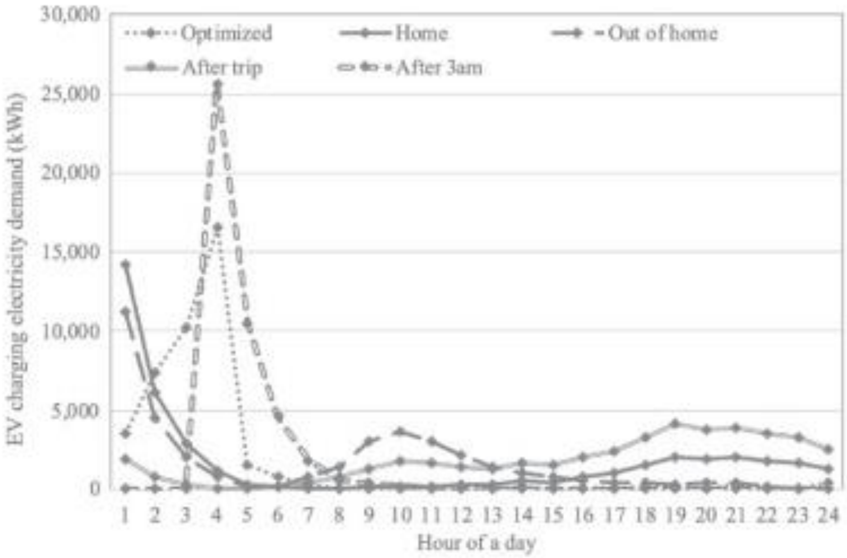
γ is the transmission and distribution line loss rate (9% in this paper);

T is total number of time intervals in one day;

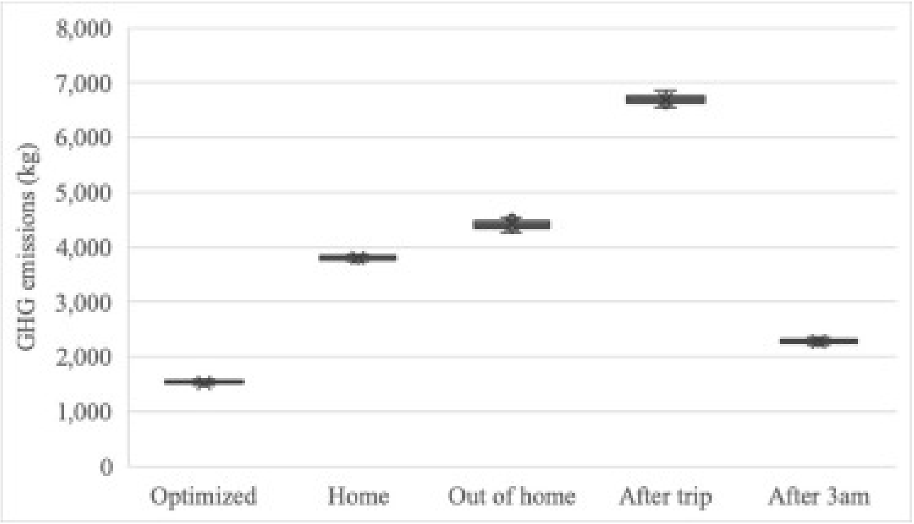
And V is total number of vehicles involved.

EV Charging Optimization Based on Marginal Emission Factor

Charging demand in different scenarios

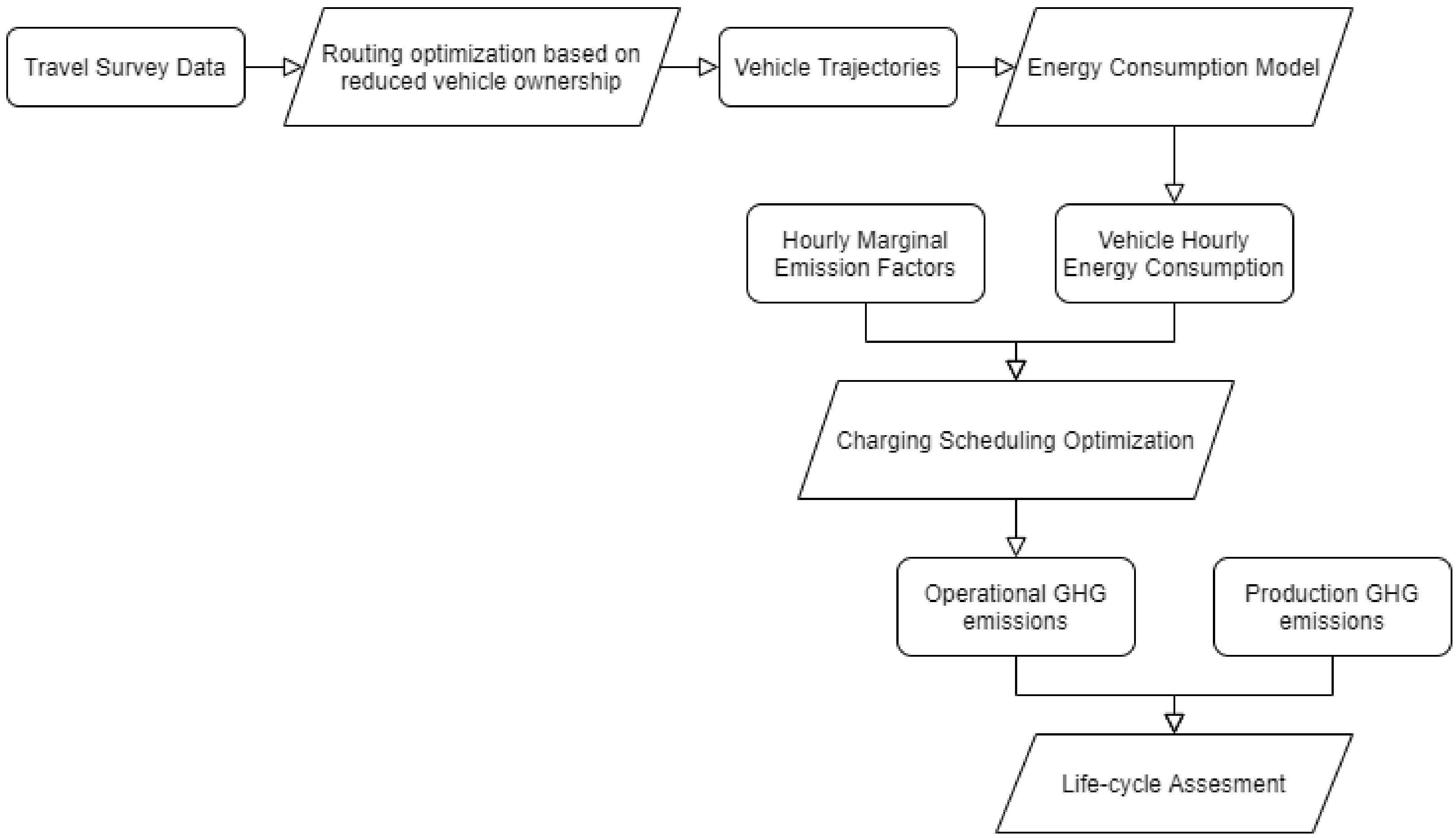


GHG Emissions of different charging scenarios



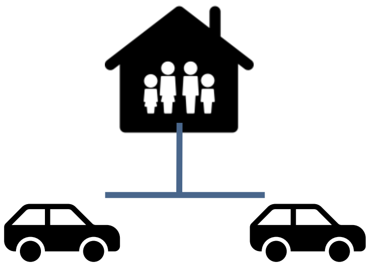
Energy and GHG implications of high-mileage EVs

Study Methods



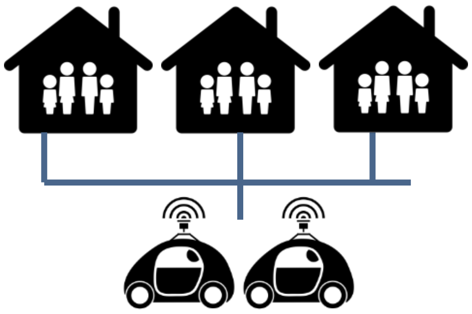
Three Scenarios

1. Base case: **Existing non-automated household vehicles**

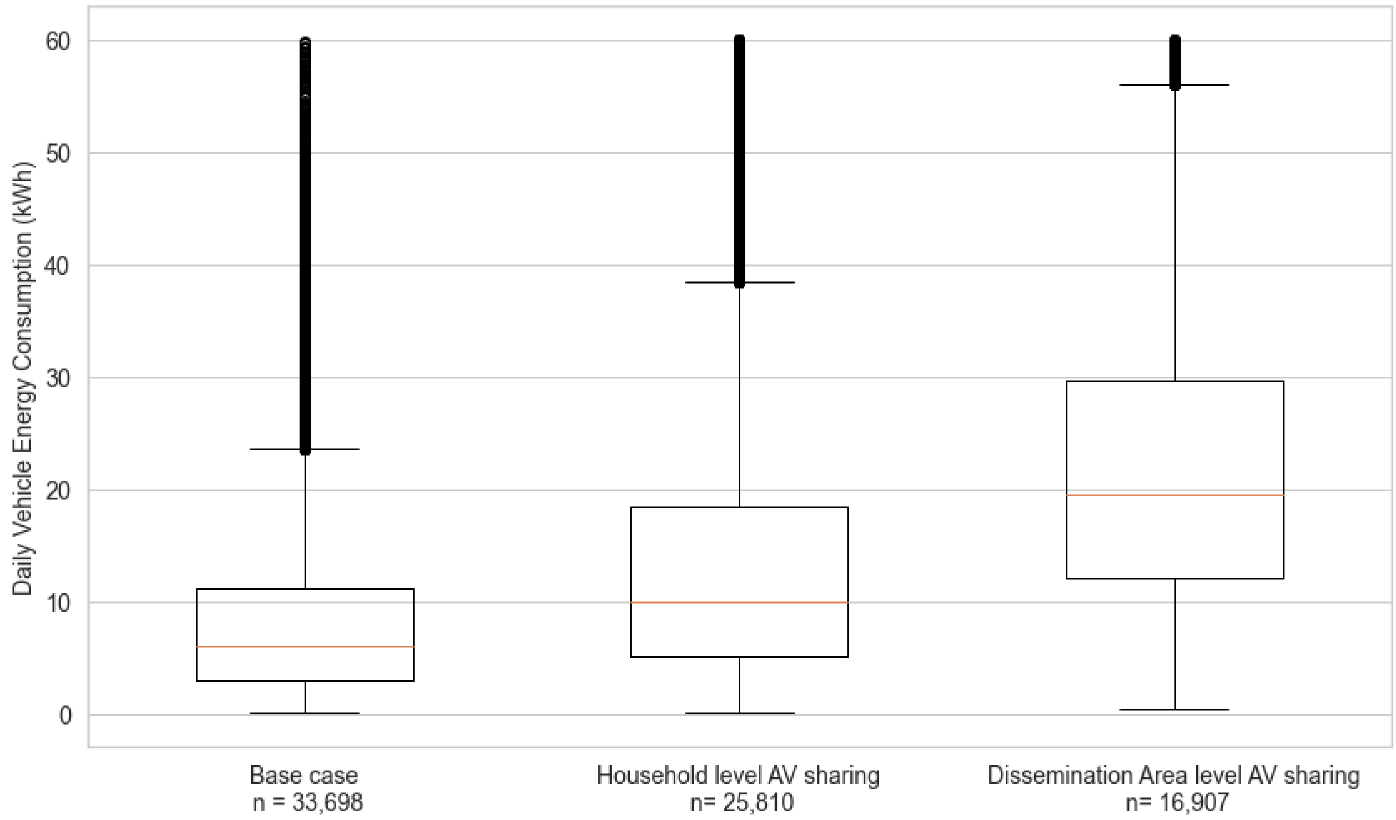


2. Household level AV sharing: AVs shared between members of **same household**

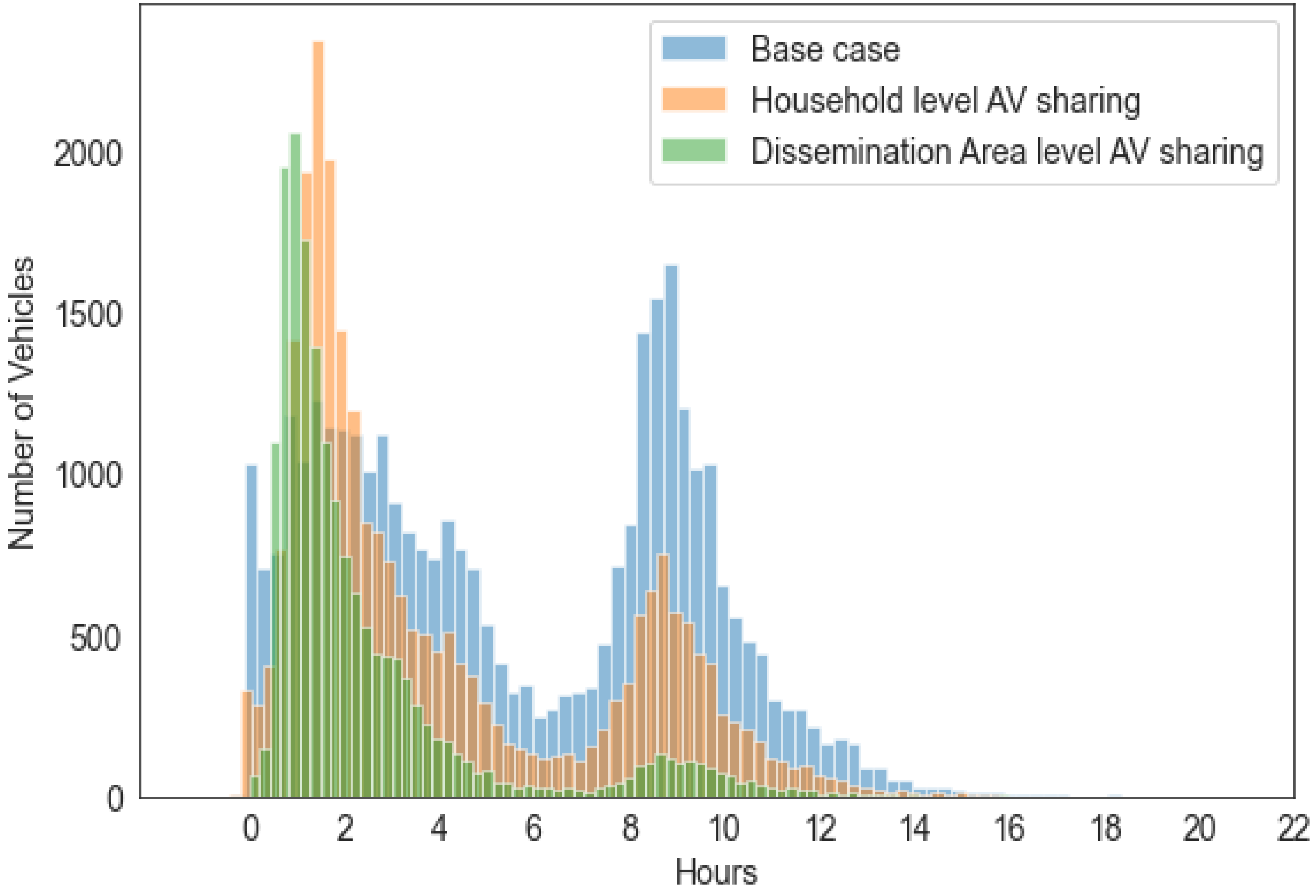
3. Dissemination area level AV sharing: AVs shared between members of **same dissemination area**



Daily vehicle energy consumption



Wait time between trips



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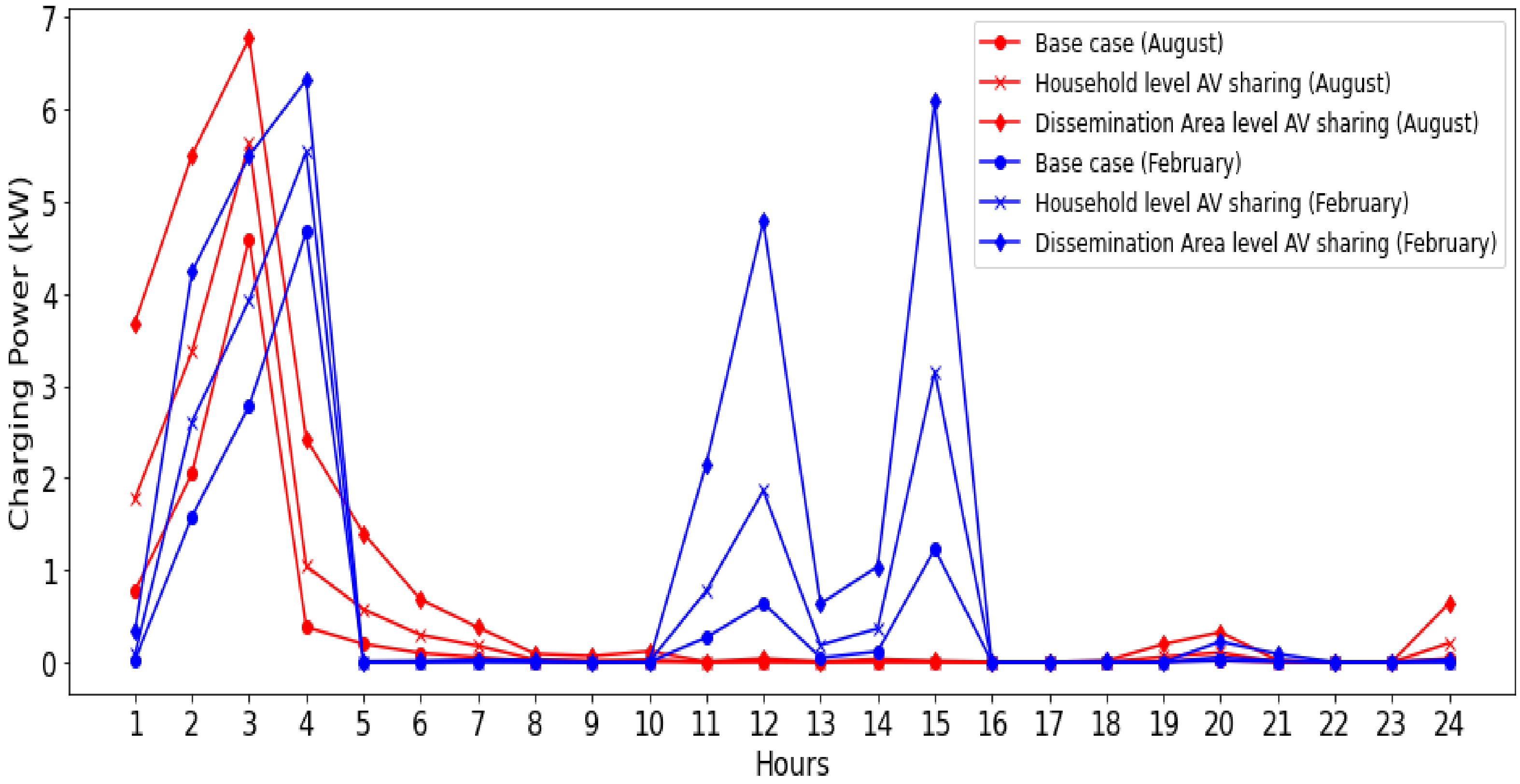
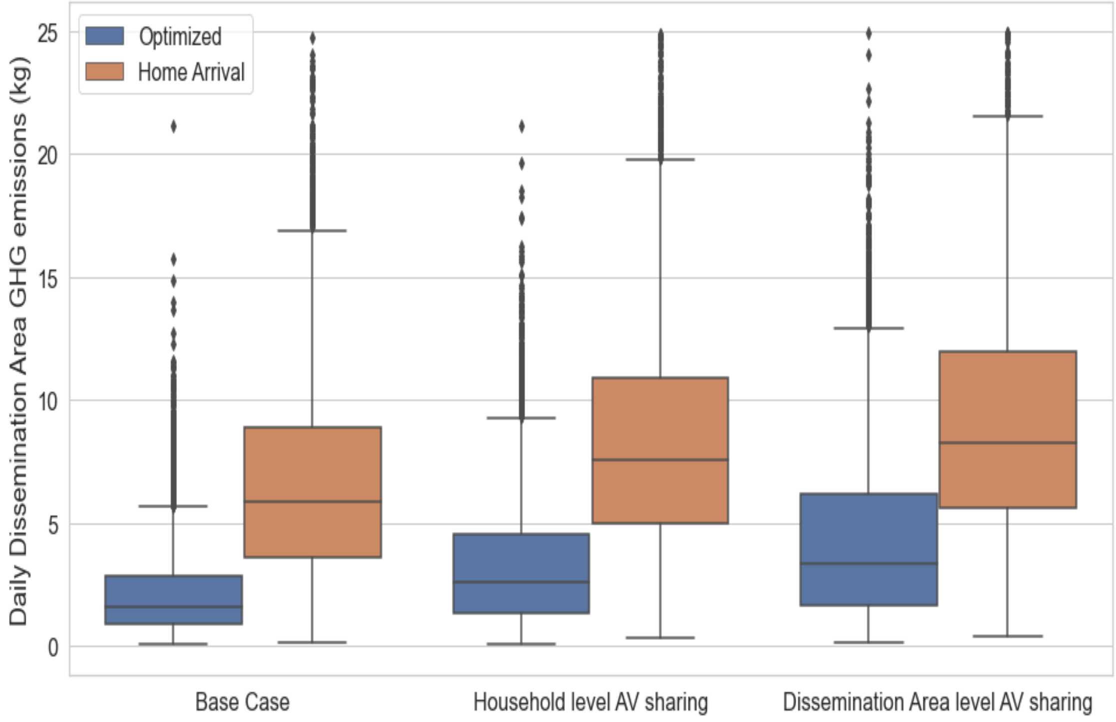
Hourly Optimized Charging schedule



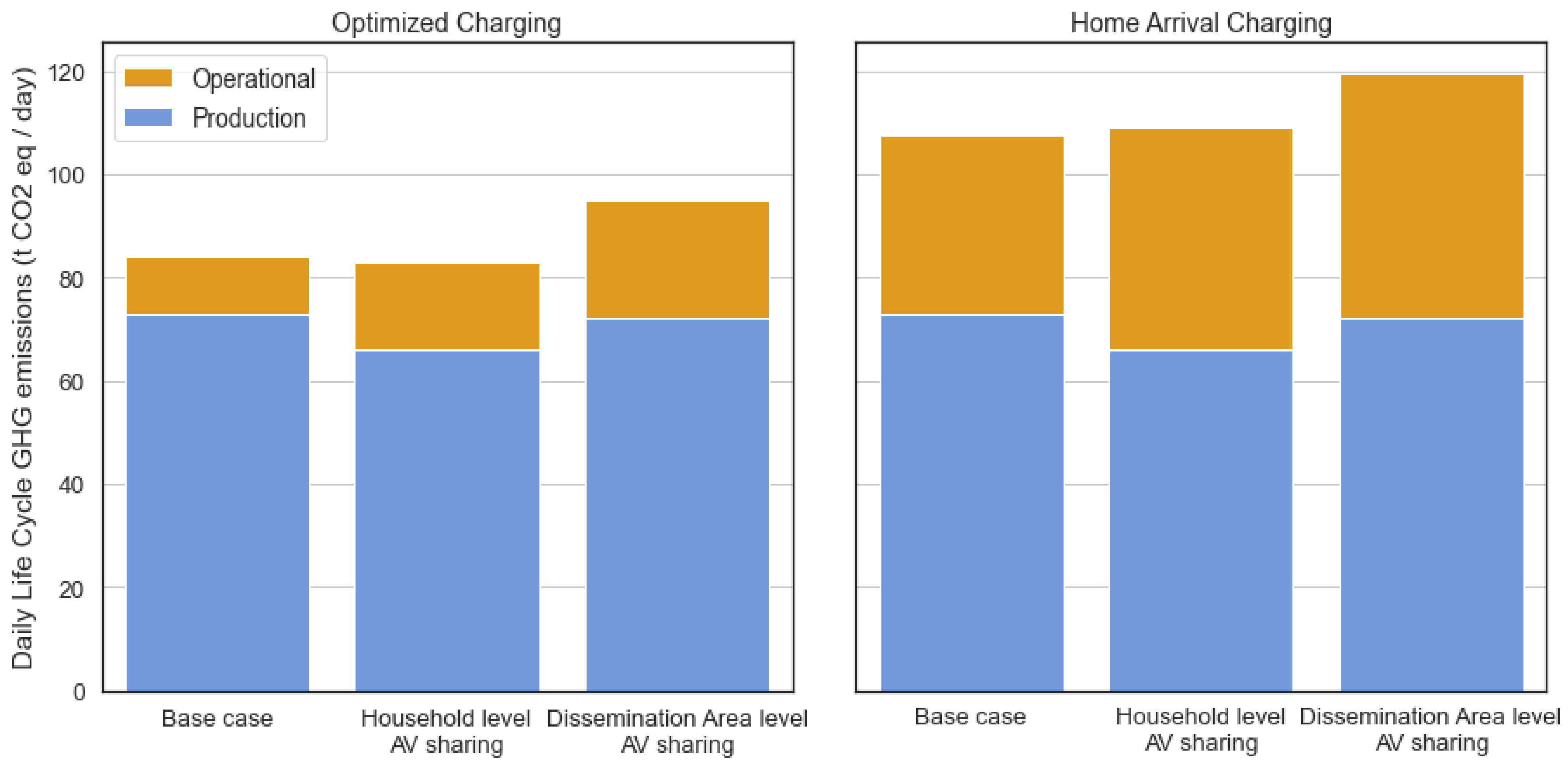
Operational GHG emissions

Average Emission Reduction:

- Base case: 64.1%
- Household level AV sharing: 59.6%
- Dissemination area level AV sharing: 52.3%



Lifecycle GHG emissions



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Questions