Supplementary Information

Transportation emissions scenarios for New York City under different carbon intensities of electricity and electric vehicle adoption rates

Mine Isik[1], Rebecca Dodder[2], P. Ozge Kaplan[2*]

[1] Oak Ridge Institute for Science and Engineering Fellow, U.S. Environmental Protection Agency, Office of Research and Development, 109 TW Alexander Dr., Durham, NC 27709
[2] U.S. Environmental Protection Agency, Office of Research and Development, 109 TW Alexander Dr., Durham, NC 27709

[*] corresponding author: Kaplan.Ozge@epa.gov; +1-919-541-5069

Supplementary Tables

Technology Name	**Fuel**	**Categories**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
TLEMCGSL	GSL	Mini car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLECGSL	GSL	Compact car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLEFDSL	DSL	Full size car-DSL	0.760	0.335	0.173	0.123	0.072	0.049	0.043	0.042	0.042
TLEFGSL	GSL	Full size car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLESSGSL	GSL	Small SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLELSGSL	GSL	Large SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLEMGSL	GSL	Minivan-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLEPGSL	GSL	Pickup-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLEPDSL	DSL	Pickup-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLECNGX	CNG	Full size car-CNG	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLELPGX	GSL	Full size car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLEELC	ELC	Compact car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLMCCONV10	GSL	Mini car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLCCONV10	GSL	Compact car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLCDSL10	DSL	Compact car-DSL	0.760	0.335	0.173	0.123	0.072	0.049	0.043	0.042	0.042
TLCDHEV15	DSL	Compact car-DSL	0.760	0.335	0.173	0.123	0.072	0.049	0.043	0.042	0.042
TLCETHX10	E85	Compact car-E85	0.648	0.331	0.142	0.110	0.082	0.064	0.058	0.057	0.057
TLCHEV10	GSL	Compact car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLFCONV10	GSL	Full size car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLFDHEV20	DSL	Full size car-DSL	0.760	0.335	0.173	0.123	0.072	0.049	0.043	0.042	0.042
TLFDSL10	DSL	Full size car-DSL	0.760	0.335	0.173	0.123	0.072	0.049	0.043	0.042	0.042
TLFHEV10	GSL	Full size car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLMCONV10	GSL	Minivan-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLMDHEV15	DSL	Minivan-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLMDSL10	DSL	Minivan-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLMHEV10	GSL	Minivan-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPCONV10	GSL	Pickup-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPDSL10	DSL	Pickup-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLPHEV15	GSL	Pickup-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLSSCONV10	GSL	Small SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLSSDHEV20	DSL	Small SUV-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLSSDSL10	DSL	Small SUV-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLSSHEV10	GSL	Small SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLLSCONV10	GSL	Large SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLLSDHEV20	DSL	Large SUV-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLLSDSL10	DSL	Large SUV-DSL	3.282	1.986	1.099	0.631	0.435	0.331	0.317	0.314	0.313
TLLSHEV10	GSL	Large SUV-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062

Supplementary Table 1. NO_x coefficients for light-duty vehicles in kt/billion Vehicle Mile Traveled (VMT). The first column represents the technology code which is used in the COMET model to identify vehicle types. The second column is used to list the fuel type consumed (ELC: Electricity, GSL: Gasoline, CNG: Compressed natural gas, DSL: Diesel) The third column provides the information of vehicle classification, and the last nine columns give different NO_x coefficients which are valid for each period.

Technology Name	Fuel	Categories	2010	2015	2020	2025	2030	2035	2040	2045	2050
TLCP10G10	GSL	Compact car-GSL	0.500	0.225	0.103	0.077	0.055	0.043	0.039	0.039	0.039
TLFP10G10	GSL	Full size car-GSL	0.500	0.225	0.103	0.077	0.055	0.043	0.039	0.039	0.039
TLPP10G15	GSL	Pickup-GSL	0.879	0.459	0.166	0.120	0.080	0.052	0.045	0.044	0.043
TLMP10G10	GSL	Minivan-GSL	0.879	0.459	0.166	0.120	0.080	0.052	0.045	0.044	0.043
TLLSP10G10	GSL	Large SUV-GSL	0.879	0.459	0.166	0.120	0.080	0.052	0.045	0.044	0.043
TLSSP10G10	GSL	Small SUV-GSL	0.879	0.459	0.166	0.120	0.080	0.052	0.045	0.044	0.043
TLCPHVG10	GSL	Compact car-GSL	0.357	0.161	0.074	0.055	0.040	0.031	0.028	0.028	0.028
TLFPHVG10	GSL	Full size car-GSL	0.357	0.161	0.074	0.055	0.040	0.031	0.028	0.028	0.028
TLMPHVG10	GSL	Minivan-GSL	0.628	0.328	0.119	0.086	0.057	0.037	0.032	0.031	0.031
TLPPHVG15	GSL	Pickup-GSL	0.628	0.328	0.119	0.086	0.057	0.037	0.032	0.031	0.031
TLSSPHVG10	GSL	Small SUV-GSL	0.628	0.328	0.119	0.086	0.057	0.037	0.032	0.031	0.031
TLLSPHVG10	GSL	Large SUV-GSL	0.628	0.328	0.119	0.086	0.057	0.037	0.032	0.031	0.031
TLCCNG10	CNG	Compact car-CNG	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLCCNGX10	CNG	Compact car-CNG	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLFCNG10	CNG	Full size car-CNG	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLFCNGX10	CNG	Full size car-CNG	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLMCNG10	CNG	Minivan-CNG	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLMCNGX10	CNG	Minivan-CNG	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPCNG10	CNG	Pickup-CNG	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPCNGX10	CNG	Pickup-CNG	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLCLPGX10	GSL	Compact car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLFLPGX10	GSL	Full size car-GSL	0.715	0.322	0.148	0.110	0.079	0.061	0.056	0.056	0.056
TLMLPG10	GSL	Minivan-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLMLPGX10	GSL	Minivan-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPLPG10	GSL	Pickup-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLPLPGX10	GSL	Pickup-GSL	1.256	0.655	0.237	0.171	0.115	0.074	0.064	0.063	0.062
TLCFCH10	ELC	Compact car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLFFCH15	ELC	Full size car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLMFCH15	ELC	Minivan-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLSSFCH10	ELC	Small SUV-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLLSFCH25	ELC	Large SUV-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLMCELC10	ELC	Mini car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLCELC10	ELC	Compact car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLFELC10	ELC	Full size car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLFELCB10	ELC	Full size car-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLMELC10	ELC	Minivan-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLMELCB10	ELC	Minivan-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLSSELC10	ELC	Small SUV-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TLSSELCB10	ELC	Small SUV-ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 1 (Cont'd). NO_x coefficients for light-duty vehicles in kt/billion VMT. The first column represents the technology code which is used in the COMET model to identify vehicle types. The second column is used to list the fuel type. The third column provides the information of vehicle classification, and the last nine columns give different NO_x coefficients which are valid for each period.

Technology Name	Fuel	Categories	2010	2015	2020	2025	2030	2035	2040	2045	2050
TLEMCGSL	GSL	Mini car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLECGSL	GSL	Compact car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLEFDSL	DSL	Full size car-DSL	0.039	0.036	0.035	0.035	0.034	0.033	0.033	0.033	0.033
TLEFGSL	GSL	Full size car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLESSGSL	GSL	Small SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLELSGSL	GSL	Large SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLEMGSL	GSL	Minivan-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLEPGSL	GSL	Pickup-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLEPDSL	DSL	Pickup-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLECNGX	CNG	Full size car-CNG	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLELPGX	GSL	Full size car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLEELC	ELC	Compact car-ELC	0.037	0.033	0.031	0.030	0.029	0.028	0.028	0.028	0.028
TLMCCONV10	GSL	Mini car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLCCONV10	GSL	Compact car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLCDSL10	DSL	Compact car-DSL	0.039	0.036	0.035	0.035	0.034	0.033	0.033	0.033	0.033
TLCDHEV15	DSL	Compact car-DSL	0.039	0.036	0.035	0.035	0.034	0.033	0.033	0.033	0.033
TLFCONV10	GSL	Full size car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLFDHEV20	DSL	Full size car-DSL	0.039	0.036	0.035	0.035	0.034	0.033	0.033	0.033	0.033
TLFDSL10	DSL	Full size car-DSL	0.039	0.036	0.035	0.035	0.034	0.033	0.033	0.033	0.033
TLFHEV10	GSL	Full size car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLMCONV10	GSL	Minivan-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLMDHEV15	DSL	Minivan-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLMDSL10	DSL	Minivan-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLMHEV10	GSL	Minivan-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPCONV10	GSL	Pickup-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPDSL10	DSL	Pickup-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLPHEV15	GSL	Pickup-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLSSCONV10	GSL	Small SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLSSDHEV20	DSL	Small SUV-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLSSDSL10	DSL	Small SUV-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLSSHEV10	GSL	Small SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLLSCONV10	GSL	Large SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLLSDHEV20	DSL	Large SUV-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLLSDSL10	DSL	Large SUV-DSL	0.235	0.137	0.076	0.057	0.054	0.053	0.053	0.053	0.053
TLLSHEV10	GSL	Large SUV-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLCP10G10	GSL	Compact car-GSL	0.031	0.027	0.026	0.025	0.024	0.023	0.023	0.023	0.023

Supplementary Table 2. PM$_{10}$ coefficients for light-duty vehicles in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the fuel type consumed. The third column provides the information of vehicle classification, and the last nine columns give different PM$_{10}$ coefficients which are valid for each period.

Technology Name	Fuel	Categories	2010	2015	2020	2025	2030	2035	2040	2045	2050
TLFP10G10	GSL	Full size car-GSL	0.031	0.027	0.026	0.025	0.024	0.023	0.023	0.023	0.023
TLPP10G15	GSL	Pickup-GSL	0.043	0.038	0.036	0.036	0.034	0.033	0.033	0.033	0.033
TLMP10G10	GSL	Minivan-GSL	0.043	0.038	0.036	0.036	0.034	0.033	0.033	0.033	0.033
TLLSP10G10	GSL	Large SUV-GSL	0.043	0.038	0.036	0.036	0.034	0.033	0.033	0.033	0.033
TLSSP10G10	GSL	Small SUV-GSL	0.043	0.038	0.036	0.036	0.034	0.033	0.033	0.033	0.033
TLCPHVG10	GSL	Compact car-GSL	0.022	0.019	0.018	0.018	0.017	0.017	0.016	0.016	0.016
TLFPHVG10	GSL	Full size car-GSL	0.022	0.019	0.018	0.018	0.017	0.017	0.016	0.016	0.016
TLMPHVG10	GSL	Minivan-GSL	0.031	0.027	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLPPHVG15	GSL	Pickup-GSL	0.031	0.027	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLSSPHVG10	GSL	Small SUV-GSL	0.031	0.027	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLLSPHVG10	GSL	Large SUV-GSL	0.031	0.027	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLCCNG10	CNG	Compact car-CNG	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLCCNGX10	CNG	Compact car-CNG	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLFCNG10	CNG	Full size car-CNG	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLFCNGX10	CNG	Full size car-CNG	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLMCNG10	CNG	Minivan-CNG	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLMCNGX10	CNG	Minivan-CNG	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPCNG10	CNG	Pickup-CNG	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPCNGX10	CNG	Pickup-CNG	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLCLPGX10	GSL	Compact car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLFLPGX10	GSL	Full size car-GSL	0.044	0.038	0.036	0.035	0.034	0.033	0.033	0.033	0.033
TLMLPG10	GSL	Minivan-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLMLPGX10	GSL	Minivan-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPLPG10	GSL	Pickup-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLPLPGX10	GSL	Pickup-GSL	0.062	0.054	0.052	0.051	0.049	0.048	0.048	0.048	0.048
TLCFCH10	ELC	Compact car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLFFCH15	ELC	Full size car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLMFCH15	ELC	Minivan-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLSSFCH10	ELC	Small SUV-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLLSFCH25	ELC	Large SUV-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLMCELC10	ELC	Mini car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLMCELCB10	ELC	Mini car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLCELC10	ELC	Compact car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLCELCB10	ELC	Compact car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLFELC10	ELC	Full size car-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLMELC10	ELC	Minivan-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLSSELC10	ELC	Small SUV-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024
TLSSELCB10	ELC	Small SUV-ELC	0.032	0.028	0.026	0.025	0.025	0.024	0.024	0.024	0.024

Supplementary Table 2 (Cont'd). PM_{10} coefficients for light-duty vehicles in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the fuel type consumed. The third column provides the information of vehicle classification, and the last nine columns give different PM_{10} coefficients which are valid for each period.

Technology Name	Category	Fuel	2010	2015	2020	2025	2030	2035	2040	2045	2050
TBDSLE	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBGSLE	Bus	GSL	3.385	2.020	0.600	0.470	0.469	0.468	0.468	0.468	0.468
TBCNGE	Bus	CNG	6.908	3.205	1.601	1.425	1.423	1.423	1.423	1.423	1.424
TBDSLC10	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBDSLC	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBDSLIM	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBDSLADV	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBDSLAH	Bus	DSL	8.969	3.670	1.625	0.926	0.906	0.902	0.902	0.902	0.902
TBCNGC	Bus	CNG	6.908	3.205	1.601	1.425	1.423	1.423	1.423	1.423	1.424
TBCNGIM	Bus	CNG	6.908	3.205	1.601	1.425	1.423	1.423	1.423	1.423	1.424
TBCNGADV	Bus	CNG	6.908	3.205	1.601	1.425	1.423	1.423	1.423	1.423	1.424
TBCNGAH	Bus	CNG	6.908	3.205	1.601	1.425	1.423	1.423	1.423	1.423	1.424
TBH2FC	Bus	H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TBH2HYB	Bus	H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TPDSLCR	Rail	DSL	0.221	0.373	0.525	0.676	0.828	0.980	1.132	1.284	1.435
TPELCCR	Rail	ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
THSGSLE	Heavy-duty	GSL	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSDSLE	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLE2	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSCNGE	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSLPGE	Heavy-duty	LPG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSGSL10	Heavy-duty	GSL	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSDSLC10	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLC	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSGSL102	Heavy-duty	DSL	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSDSLC102	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLC2	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLIM2	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLADV	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLAH2	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLIM	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLADV	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSDSLAH	Heavy-duty	DSL	8.516	3.972	1.892	0.995	0.953	0.937	0.940	0.945	0.949
THSCNGC10	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSCNGC	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317

Supplementary Table 3. NO_x coefficients for other modes of transportation in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the fuel type consumed. The third column provides the information of vehicle classification, and the last nine columns give different NO_x coefficients which are valid for each period.

Technology Name	Category	Fuel	2010	2015	2020	2025	2030	2035	2040	2045	2050
THSCNGIM	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSCNGADV	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
THSCNGAH	Heavy-duty	CNG	3.255	2.156	0.623	0.403	0.346	0.318	0.317	0.317	0.317
TMGSLE	Medium-duty	GSL	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMDSLE	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMCNGE	Medium-duty	CNG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMLPGE	Medium-duty	LPG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMGSLC10	Medium-duty	GSL	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMGSLC	Medium-duty	GSL	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMGSLIM	Medium-duty	GSL	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMGSLAH	Medium-duty	GSL	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMDSLC10	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMDSLC	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMDSLIM	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMDSLADV	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMDSLAH	Medium-duty	DSL	6.988	3.560	1.743	0.961	0.907	0.890	0.894	0.899	0.902
TMCNGC10	Medium-duty	CNG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMCNGC	Medium-duty	CNG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMCNGIM	Medium-duty	CNG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMCNGAH	Medium-duty	CNG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMLPGC10	Medium-duty	LPG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMLPGC	Medium-duty	LPG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMLPGIM	Medium-duty	LPG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TMLPGAH	Medium-duty	LPG	3.248	2.160	0.625	0.404	0.348	0.321	0.320	0.320	0.320
TRF25DSL	Rail	DSL	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
TRFAPU	Rail	DSL	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
TRF10DSL	Rail	DSL	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
TRF10DSL2	Rail	DSL	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
TRFDSL	Rail	DSL	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
TPELCSUB	Rail	ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 3 (Cont'd). NO_x coefficients for other modes of transportation in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the fuel type consumed. The third column provides the information of vehicle classification, and the last nine columns give different NO_x coefficients which are valid for each period.

Technology Name	Category	Fuel	2010	2015	2020	2025	2030	2035	2040	2045	2050
TBDSLE	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBGSLE	Bus	GSL	0.138	0.127	0.124	0.126	0.125	0.125	0.125	0.125	0.125
TBCNGE	Bus	CNG	0.146	0.093	0.084	0.084	0.084	0.084	0.084	0.084	0.084
TBDSLC10	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBDSLC	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBDSLIM	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBDSLADV	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBDSLAH	Bus	DSL	0.600	0.295	0.140	0.110	0.110	0.110	0.110	0.110	0.110
TBCNGC	Bus	CNG	0.146	0.093	0.084	0.084	0.084	0.084	0.084	0.084	0.084
TBCNGIM	Bus	CNG	0.146	0.093	0.084	0.084	0.084	0.084	0.084	0.084	0.084
TBCNGADV	Bus	CNG	0.146	0.093	0.084	0.084	0.084	0.084	0.084	0.084	0.084
TBCNGAH	Bus	CNG	0.146	0.093	0.084	0.084	0.084	0.084	0.084	0.084	0.084
TBH2FC	Bus	H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TBH2HYB	Bus	H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
THSGSLE	Heavy-duty	GSL	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSDSLE	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLE2	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSGSL10	Heavy-duty	GSL	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSDSLC10	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLC	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSGSL102	Heavy-duty	DSL	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSDSLC102	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLC2	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLIM2	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLADV	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLAH2	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLIM	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLADV	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSDSLAH	Heavy-duty	DSL	0.586	0.316	0.156	0.123	0.123	0.123	0.123	0.123	0.124
THSB20C10	Heavy-duty	B20	0.513	0.285	0.151	0.123	0.123	0.123	0.123	0.123	0.124
THSB20ADV	Heavy-duty	B20	0.513	0.285	0.151	0.123	0.123	0.123	0.123	0.123	0.124
THSB20AH	Heavy-duty	B20	0.513	0.285	0.151	0.123	0.123	0.123	0.123	0.123	0.124
THSCNGC10	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSCNGC	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSCNGIM	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSCNGADV	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSCNGAH	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079

Supplementary Table 4. PM_{10} coefficients for other modes of transportation in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the transportation mode. The third column provides the information of fuel type, and the last nine columns give different PM_{10} coefficients which are valid for each period.

Technology Name	Category	Fuel	2010	2015	2020	2025	2030	2035	2040	2045	2050
THSCNGE	Heavy-duty	CNG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSLPGE	Heavy-duty	LPG	0.100	0.084	0.079	0.079	0.079	0.079	0.079	0.079	0.079
THSB20C	Heavy-duty	B20	0.513	0.285	0.151	0.123	0.123	0.123	0.123	0.123	0.124
THSB20IM	Heavy-duty	B20	0.513	0.285	0.151	0.123	0.123	0.123	0.123	0.123	0.124
TMGSLE	Medium-duty	GSL	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMDSLE	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMCNGE	Medium-duty	CNG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMLPGE	Medium-duty	LPG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMGSLC	Medium-duty	GSL	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMGSLIM	Medium-duty	GSL	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMGSLAH	Medium-duty	GSL	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMDSLC10	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMDSLC	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMDSLIM	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMDSLADV	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMDSLAH	Medium-duty	DSL	0.501	0.260	0.117	0.086	0.086	0.086	0.086	0.086	0.086
TMB20IM	Medium-duty	B20	0.435	0.232	0.112	0.086	0.086	0.086	0.086	0.086	0.086
TMB20ADV	Medium-duty	B20	0.435	0.232	0.112	0.086	0.086	0.086	0.086	0.086	0.086
TMB20AH	Medium-duty	B20	0.435	0.232	0.112	0.086	0.086	0.086	0.086	0.086	0.086
TMCNGC10	Medium-duty	CNG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMCNGC	Medium-duty	CNG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMCNGIM	Medium-duty	CNG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMCNGAH	Medium-duty	CNG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMLPGC10	Medium-duty	LPG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMLPGC	Medium-duty	LPG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMLPGIM	Medium-duty	LPG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TMLPGAH	Medium-duty	LPG	0.101	0.085	0.080	0.079	0.079	0.079	0.079	0.079	0.080
TPDSLCR	Rail	DSL	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
TPELCCR	Rail	ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TRF25DSL	Rail	DSL	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TRF10DSL	Rail	DSL	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TRF10DSL2	Rail	DSL	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TRFDSL	Rail	DSL	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TRFDSL2	Rail	DSL	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TPELCSUB	Rail	ELC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Supplementary Table 4 (Cont'd). PM$_{10}$ coefficients for other modes of transportation in kt/billion VMT. The first column represents the technology code which is used in COMET model to identify vehicle types. The second column is used to list the transportation mode. The third column provides the information of fuel type, and the last nine columns give different PM$_{10}$ coefficients which are valid for each period.

Fuel Type	**Emission Coefficient (kton CO_2/ PJ)**
Compressed natural gas	55.98
Coal	100.60
Gasoline	74.79
Diesel	77.10
Residual fuel oil	83.14
Liquified petroleum gas	65.71

Supplementary Table 5. CO_2 emission coefficients for fuels. The first column represents the fuel type and the second column provides the related CO_2 emission coefficient.

	Discounted Total System Cost (2005 $US Million)		*Costs normalized to STEADY-STATE*	
Scenario	***NYS + NYC***	***NYC***	***NYS + NYC***	***NYC***
STEADY-STATE	680,914	471,518	1	1
DEPENDENCE	878,318	639,941	1.29	1.36
REVOLUTION	916,315	651,390	1.35	1.38
DEP_MODESWITCH	835,604	596,545	1.23	1.27
REV_MODESWITCH	851,382	586,625	1.25	1.24
DEP_BATTERY	885,270	646,237	1.30	1.37
REV_BATTERY	931,601	665,269	1.37	1.41
DEP_TNC	905,248	667,114	1.33	1.41
REV_TNC	964,342	699,974	1.42	1.48

Supplementary Table 6. The total discounted system cost with respect to scenarios. The first column represents the scenario types. The second column gives the summation of the objective function values for New York State (R_1, R_2, R_3, R_4, R_5, R_6). The third column gives the summation of the objective function values for New York City (R_2, R_3, R_4, R_5, R_6). The fourth column shows the ratio of total system cost for NYS and NYC compared to STEADY-STATE. The fifth column is used to list the ratio of the model objective function for emission mitigation scenarios for New York City with respect to the STEADY-STATE.

Fuel	Technology Type	Vehicle Classes						
		Mini-Compact	Compact	Full-size	Minivan	Pickup	Small SUV	Large SUV
Gasoline	Conventional	✓	✓	✓	✓	✓	✓	✓
	Advanced	✓	✓	✓	✓	✓	✓	✓
	Hybrid		✓	✓	✓	✓	✓	✓
	Plug-in Hybrid		✓	✓	✓	✓	✓	✓
Diesel	Conventional		✓	✓	✓	✓	✓	✓
	Hybrid		✓	✓	✓		✓	✓
Compressed Natural Gas	Conventional		✓	✓	✓	✓		
	Flex-fuel		✓	✓	✓	✓		
Hydrogen	Fuel Cell		✓	✓	✓	✓	✓	✓
Electricity	100-mile range	✓	✓	✓	✓	✓	✓	✓
	200-mile range	✓	✓	✓	✓	✓	✓	✓

Supplementary Table 7. Light-duty vehicle fuel and technology combinations to meet light-duty vehicle demand. U.S. EPA categorizes vehicles based on gross vehicle weight rating as light-duty (gross vehicle weight rating < 8,500 lb)[33]. This table illustrates the vehicle classes that are applied to the COMET model for light-duty vehicles. COMET also classifies light-duty vehicles with respect to total passenger and cargo volumes according to U.S. EPA car classes (mini-compact, compact, full-size, minivan, pickup, small SUV, and large SUV). The table also illustrates the available fuel and engine options for the above-mentioned categories. All these categories are made available across the model runs.

End-Use Category	Fuel Type	Efficiency Improvements			
Bus Demand	Diesel	Regular	Improved Efficiency	Advanced Technology	Advanced Hybrid
	Electricity	Regular	Improved Efficiency	Advanced Technology	
	Compressed Natural Gas	Regular	Improved Efficiency	Advanced Technology	Advanced Hybrid
	Hydrogen Fuel Cell		Hybrid		
Medium-duty Vehicles & Heavy-duty Vehicles – Short Haul Demand	Diesel	Regular	Improved Efficiency	Advanced Technology	Advanced Hybrid
	Compressed Natural Gas	Regular	Improved Efficiency	Advanced Technology	Advanced Hybrid
	Hydrogen Fuel Cell		Hybrid		
Transportation Rail Passenger Demand – Commuter	Diesel	Regular	Improved Efficiency		
	Electricity	Regular	Improved Efficiency		
Transportation Rail Passenger Demand – Passenger Rail Subways & Streetcars	Electricity	Regular	Improved Efficiency		

Supplementary Table 8. Heavy-duty vehicle and other transportation vehicle fuel and technology combinations to meet end-use demand. This table explains the end-use categories that belong to the transportation sector other than light-duty vehicles. This table illustrates the vehicle classes that are applied to the COMET model for heavy-duty vehicles. End-use transportation demand classification that is applied to the COMET model is taken from the New York City Greenhouse Gas Emission Inventory Report[34]. Fuel Type column represents the available fuel options in each end-use demand category. The efficiency improvements section represents the categories of evolution for each transportation type. The COMET-NYC can facilitate the analysis of additional fuel and technology combinations. However, the above combinations are the ones included in this study.

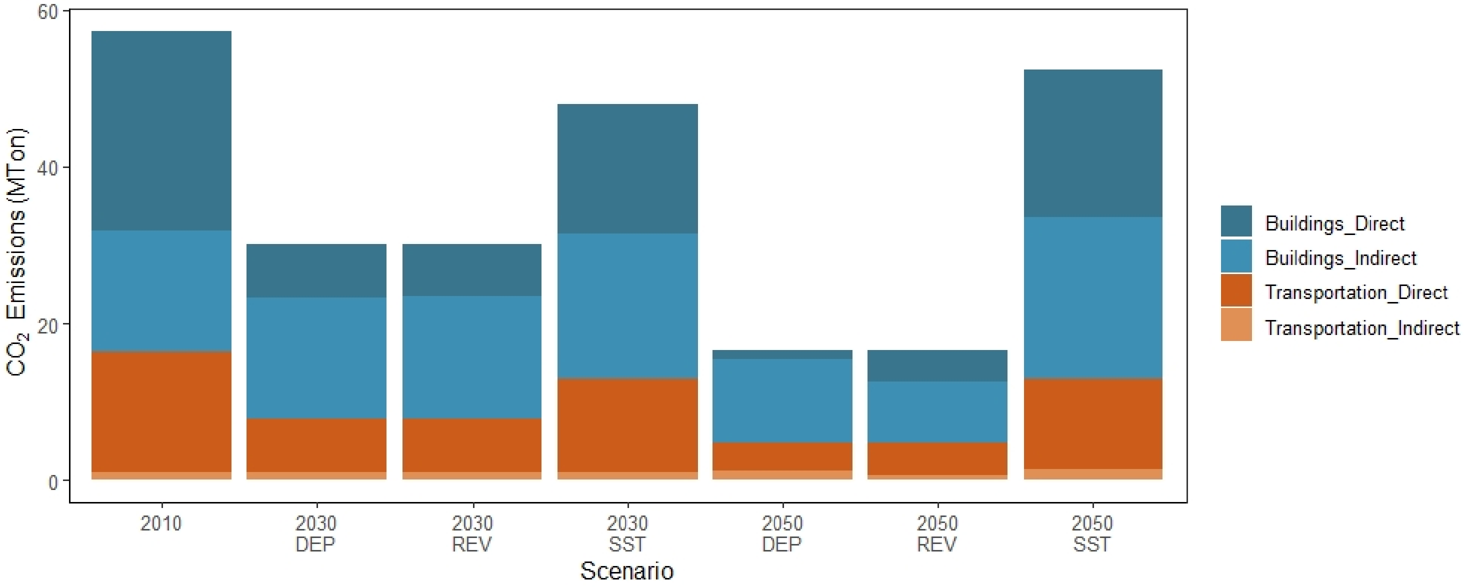
	Demand Type	Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
STEADY-STATE, REVOLUTION and DEPENDENCE	Light-duty vehicle (billion vehicle miles)	Brooklyn	10.43	10.67	10.85	11.11	11.49	11.84	12.02	12.27	12.53
		Bronx	5.77	5.85	5.93	6.1	6.34	6.55	6.68	6.83	6.98
		Manhattan	6.6	6.45	6.7	6.74	6.91	7.09	7.13	7.16	7.24
		Staten Island	1.95	1.95	1.97	2.03	2.05	2.07	2.08	2.09	2.11
		Queens	9.28	9.08	9.51	9.58	9.81	10.04	10.13	10.21	10.34
	Bus (billion vehicle miles)	Brooklyn	0.09	0.09	0.1	0.1	0.1	0.11	0.11	0.12	0.12
		Bronx	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07
		Manhattan	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
		Staten Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Queens	0.08	0.08	0.08	0.09	0.09	0.09	0.1	0.1	0.11
	Subway and railway (billion passenger miles)	Brooklyn	9.08	9.48	10	10.64	11.22	11.77	12.54	13.18	13.96
		Bronx	4.92	5.23	5.46	5.84	6.19	6.52	6.97	7.37	7.83
		Manhattan	5.64	5.91	6.19	6.53	6.83	7.09	7.47	7.86	8.27
		Staten Island	1.67	1.68	1.84	1.94	2.03	2.1	2.21	2.4	2.54
		Queens	8.0	8.41	8.8	9.26	9.67	10.07	10.65	11.32	11.95
	Heavy-duty short haul (billion vehicle miles)	Brooklyn	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24
		Bronx	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.13	0.13
		Manhattan	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.14
		Staten Island	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04
		Queens	0.14	0.15	0.15	0.16	0.16	0.17	0.18	0.19	0.20
	Medium duty vehicles (billion vehicle miles)	Brooklyn	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13
		Bronx	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
		Manhattan	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08
		Staten Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Queens	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11

Supplementary Table 9. End-use transportation demands for various modes of transport that are assumed for STEADY-STATE (SST), DEPENDENCE (DEP), and REVOLUTION (REV) scenarios. In this table, travel demand that belongs to New York City is shown in different units: rail passenger (billion passenger miles traveled) and the rest of the transportation system (in billion vehicle miles traveled). All the end-use demands are provided exogenously into the COMET from 2010 through 2050 in five-year increments.

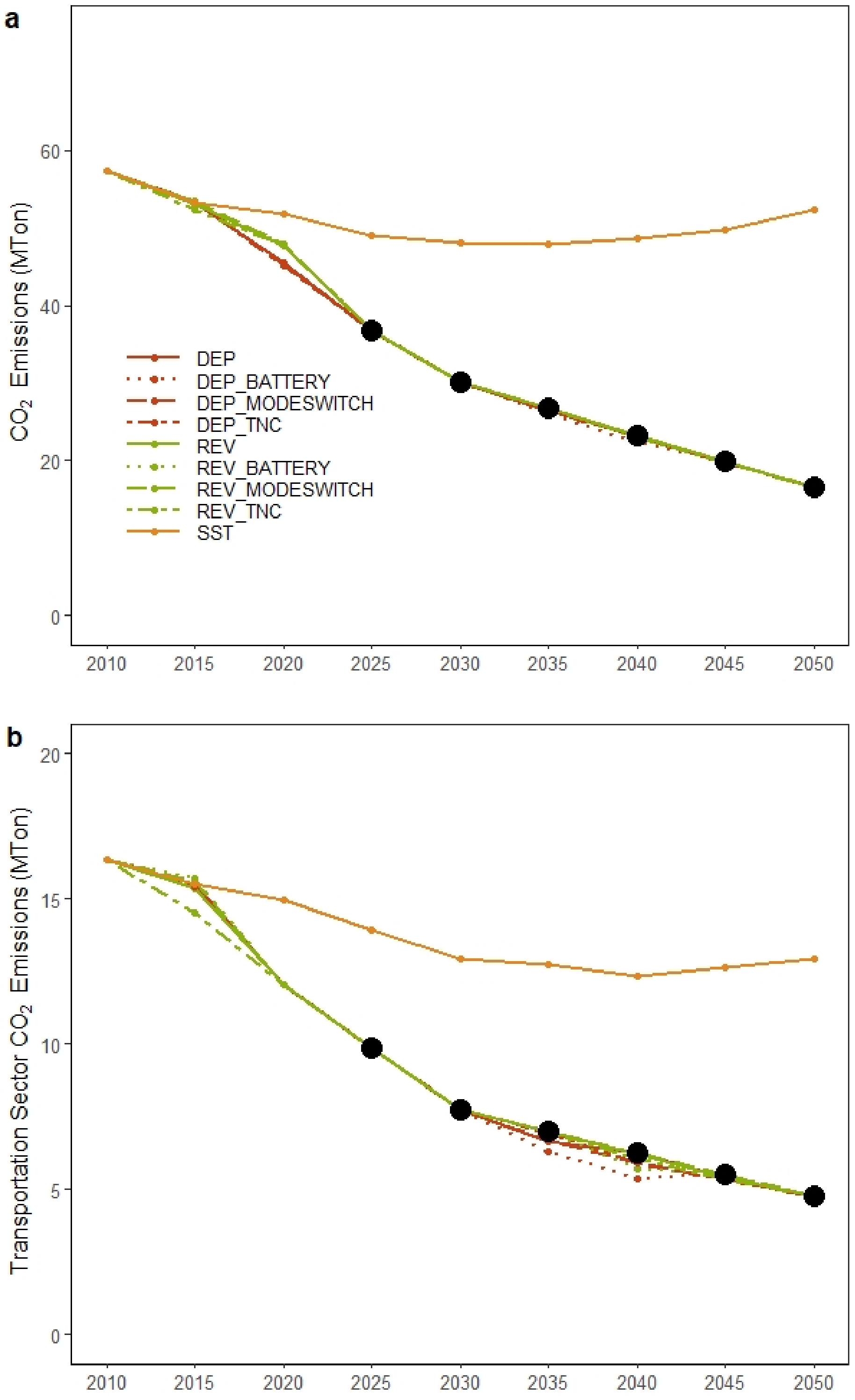
Assumed CO_2 intensity of electricity (kt/Pj)	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
DEPENDENCE	35.0	34.1	32.3	30.6	28.9	28.9	28.9	24.1	24.1
REVOLUTION	35.0	34.1	32.3	30.6	28.9	24.1	19.3	14.5	9.6

Supplementary Table 10. Assumed time-series data for CO_2 intensity of electricity in DEPENDENCE (DEP) and REVOLUTION (REV). Each column represents the unit electricity coefficient for the five-year periods between 2010 and 2050. These coefficients are included in the model constraint that meets the 80x50 target**.**

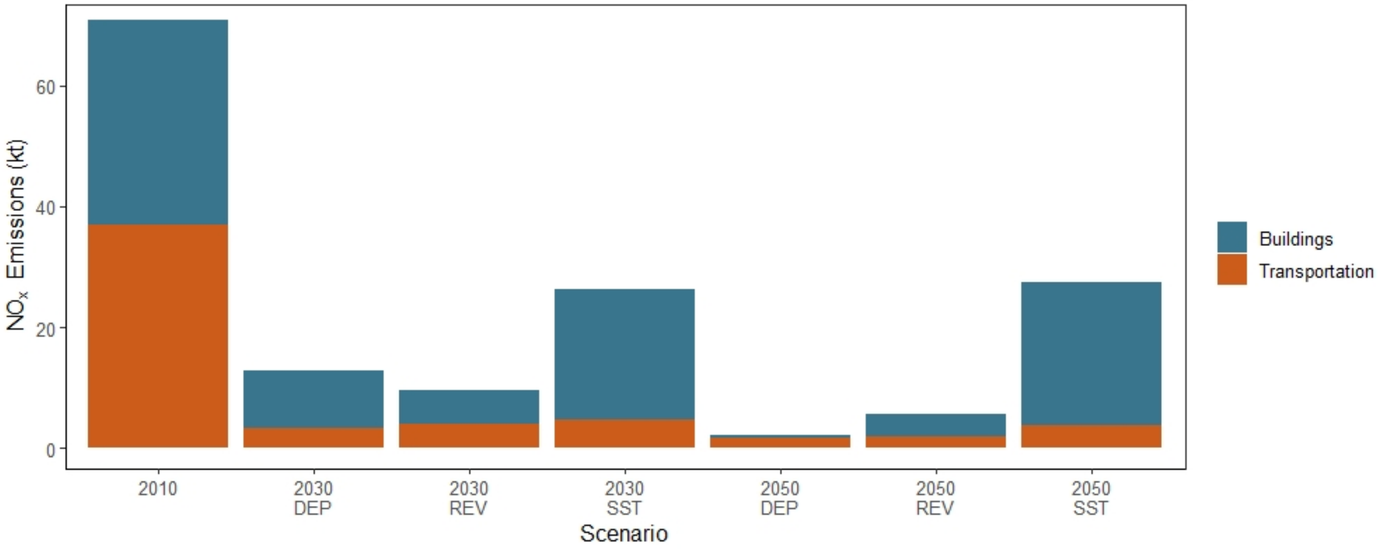
Supplementary Figures



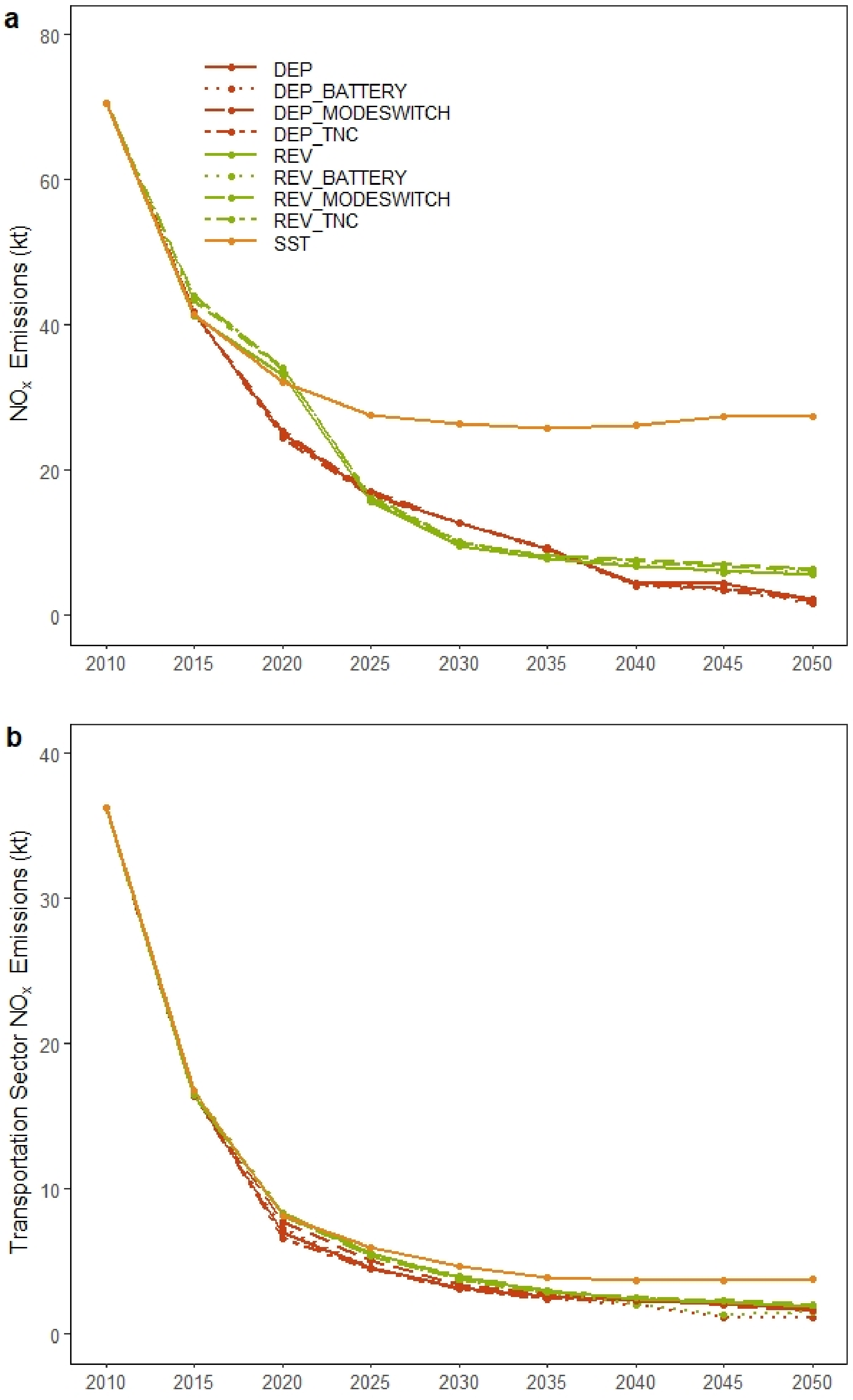
Supplementary Figure 1. Comparison of CO_2 emissions in MTon from buildings and transportation sectors across STEADY-STATE (SST), DEPENDENCE (DEP), and REVOLUTION (REV) scenarios. Each stacked bar represents the comparison of the CO_2 emission levels that are resulted from transportation and building sector in NYC under different scenario assumptions. The direct emission values cover fossil-fuel-based emissions whereas indirect emissions include upstream electricity emissions for both transportation and buildings. Buildings contribute significantly to the overall CO_2 emissions from the city, and there is a lot more potential to decrease CO_2 emissions from buildings through electrification as well as energy efficiency improvements. In the big picture, transportation emission reductions are much less pronounced than the buildings sector. This rather illustrates the significant challenge of transportation sector decarbonization.



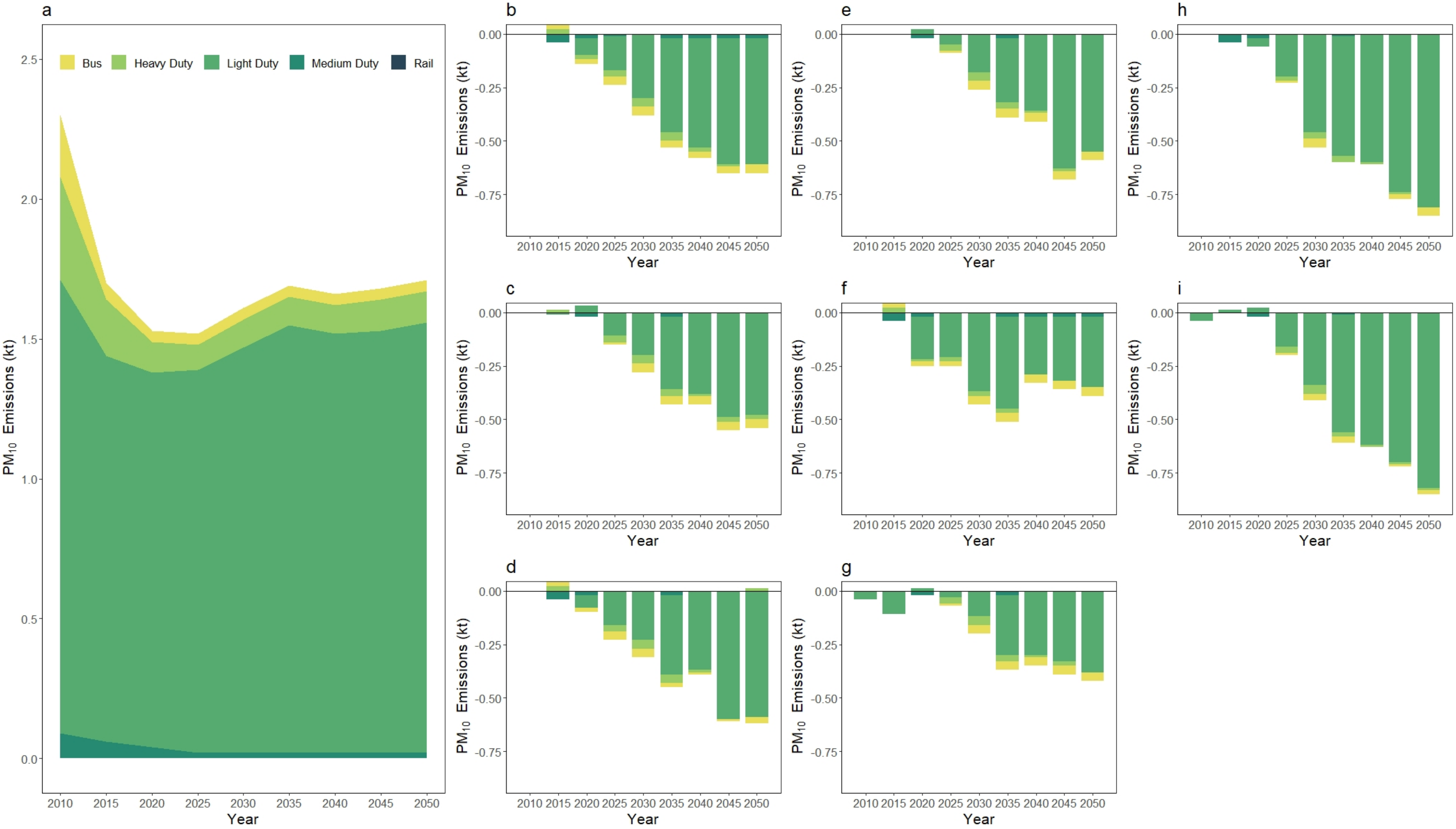
Supplementary Figure 2. CO$_2$ emissions in MTon. Panel **a** represents CO$_2$ emissions in the NYC both transportation and buildings sector, whereas Panel **b** compares CO$_2$ emissions from transportation sector across scenarios. Each color with solid line represents the main scenario type (STEADY-STATE, DEPENDENCE, and REVOLUTION) and the dashed lines present the sensitivity scenarios. x-axis represents the time frame whereas y-axis shows the aggregated emission level.



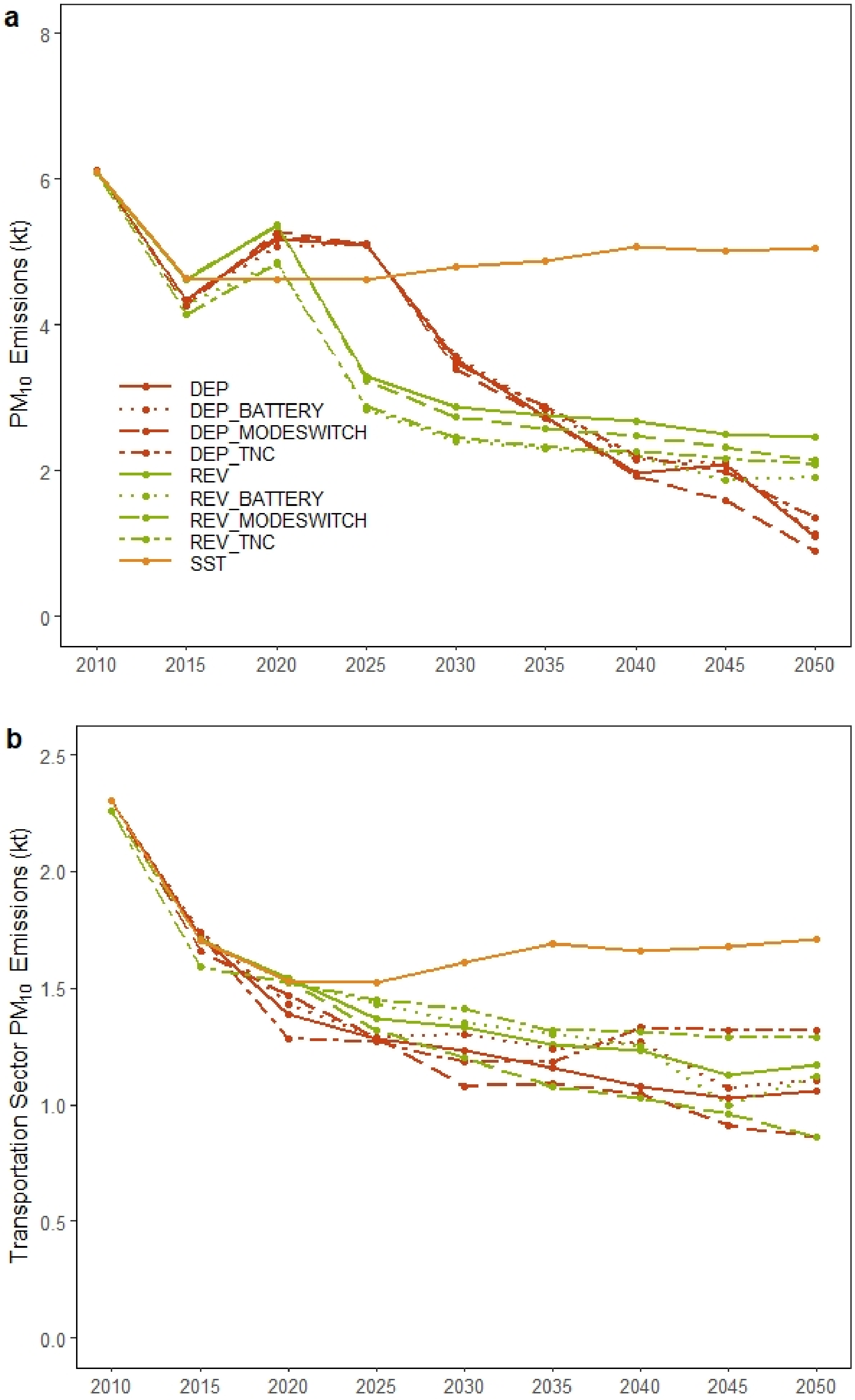
Supplementary Figure 3. Comparison of NO_x emissions in kt from buildings and transportation sectors STEADY-STATE (SST), DEPENDENCE (DEP), and REVOLUTION (REV) scenarios. Each stacked bar represents the comparison of the in-city NO_x emission levels that are attributed to transportation and building sector across scenarios. Building sector emissions also include NO_x resulted from combined heat and power technologies (distributed energy resources). Across all scenarios, city-level NO_x emissions decrease substantially beyond 2015. However, we observed some leakage effects for NO_x emissions. In 2030, DEPENDENCE results in higher buildings-related NO_x emissions than REVOLUTION. The increases in NO_x emissions are attributed to variations in technology and fuel choice to meet space heating demand in buildings which are more sensitive to changes in electricity price and emissions signals.



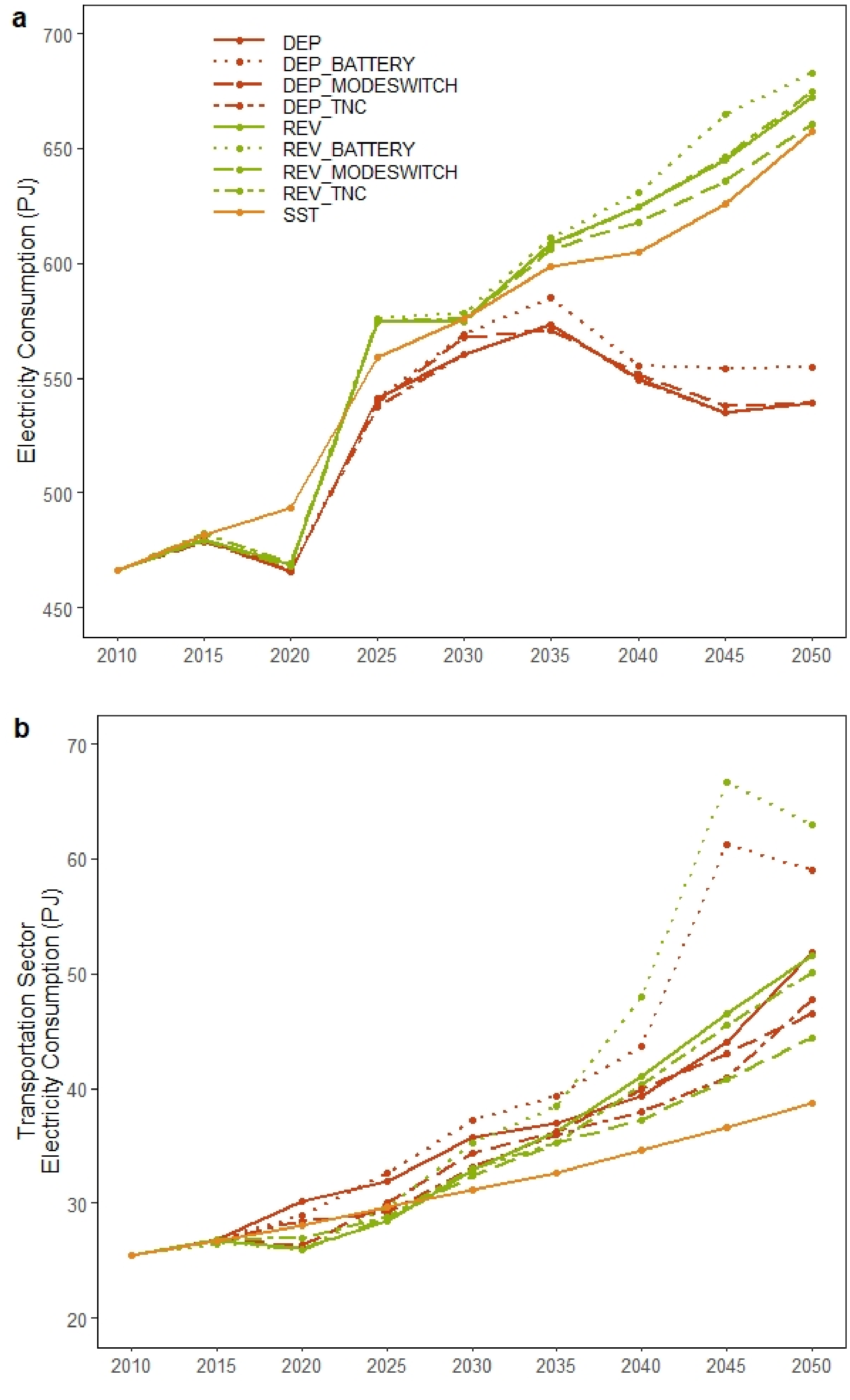
Supplementary Figure 4. NO_x emissions in kt. Panel **a** represents NO_x emissions in the NYC both transportation and buildings sector, whereas Panel **b** compares NO_x emissions from transportation sector across scenarios. Each color with solid line represents the main scenario type (STEADY-STATE, DEPENDENCE, and REVOLUTION) and the dashed lines present the sensitivity scenarios. x-axis represents the time frame whereas y-axis shows the aggregated emission level.



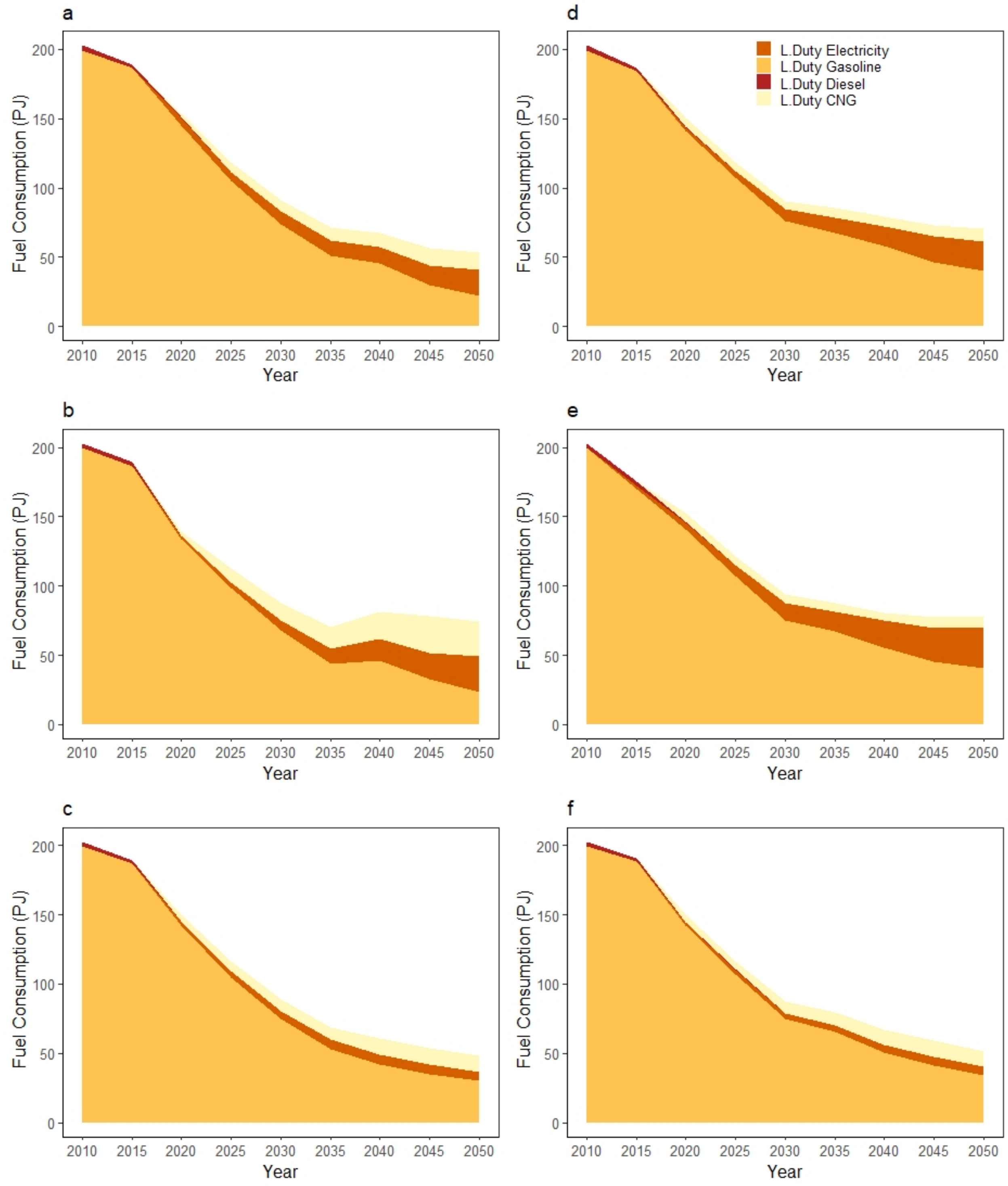
Supplementary Figure 5. Transportation sector PM_{10} emissions in kt. Panel **a** represents PM_{10} emissions in STEADY-STATE. Remaining panels present change in transportation sector PM_{10} emission levels in kt with respect to STEADY-STATE for each scenario: DEPENDENCE (**b**), REVOLUTION (**c**), DEP_BATTERY (**d**), REV_BATTERY (**e**), DEP_TNC (**f**), REV_TNC (**g**), DEP_MODESWITCH (**h**), REV_MODESWITCH (**i**). Each color represents the mode of transportation whereas the length shows the intensity of the relative reduction of PM_{10}. The downward growing stacked bar charts represent the emission reduction projections with respect to the base case scenario.



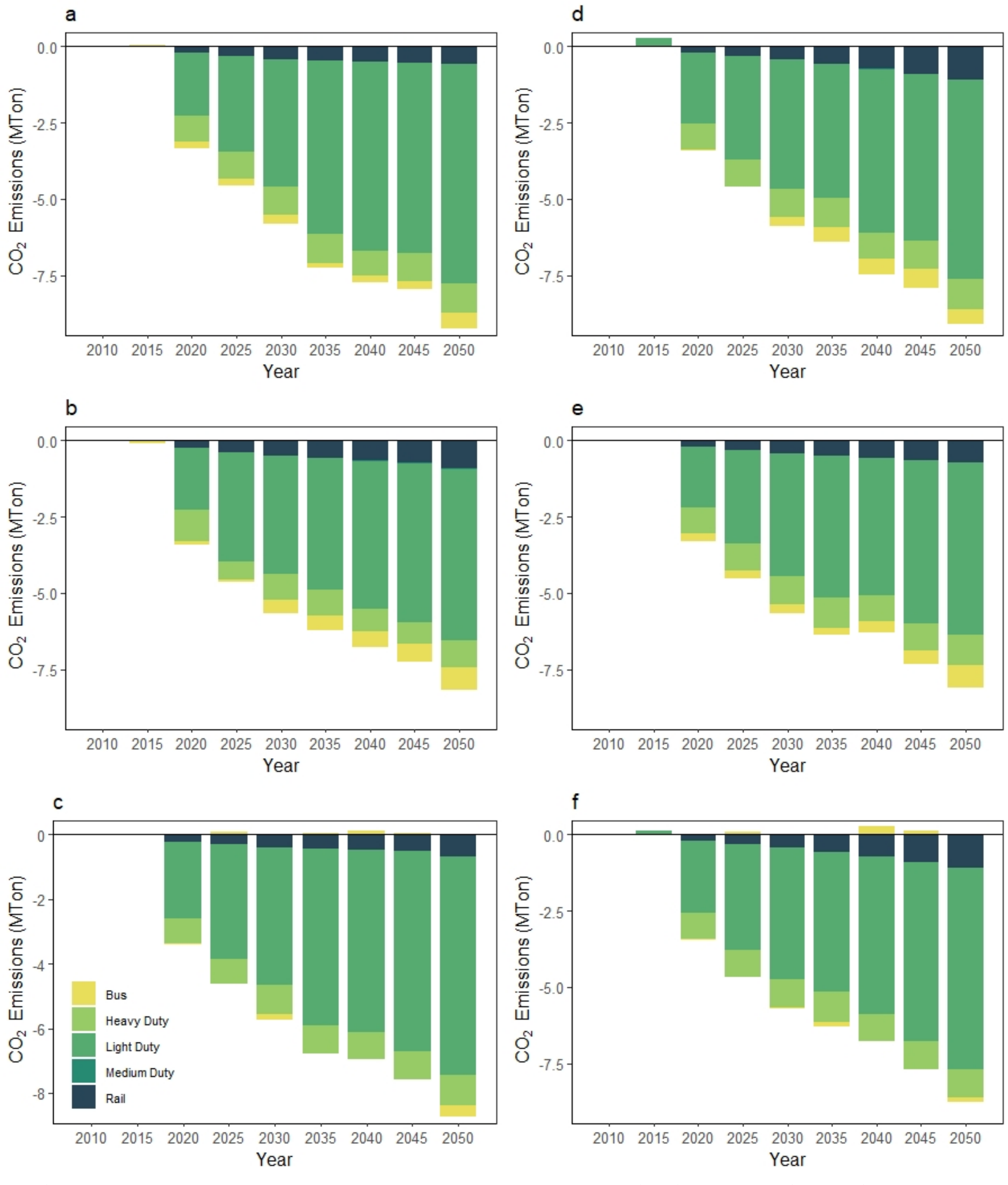
Supplementary Figure 6. PM_{10} emissions in kt. Panel **a** presents total PM_{10} emissions in the NYC both transportation and buildings sector, whereas Panel **b** compares PM_{10} emissions from transportation sector across scenarios. Each color with solid line represents the main scenario type (STEADY-STATE, DEPENDENCE, and REVOLUTION) and the dashed lines present the sensitivity scenarios. x-axis represents the time frame whereas y-axis shows the aggregated emission level.



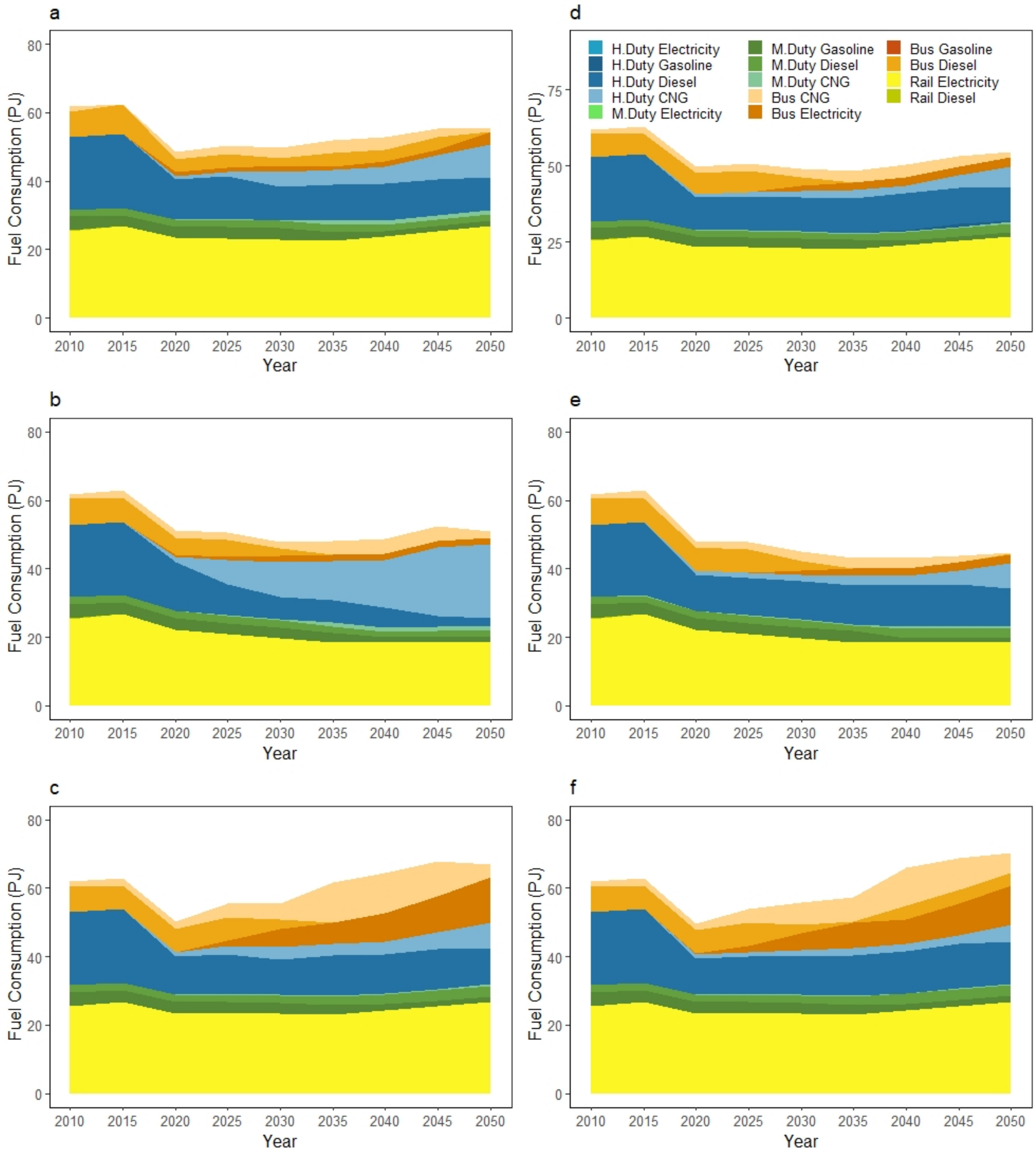
Supplementary Figure 7. Electricity consumption in PJ in New York City. Panel **a** presents system-wide electricity consumption (including source) in both transportation and buildings sector in New York City, whereas panel **b** presents electricity consumption in transportation sector. Color represents the main scenario; the type of the line differs for each sensitivity assumption.



Supplementary Figure 8. Fuel consumption in PJ per the mode of light-duty vehicle transportation. The panels present fuel consumption levels in NYC for each scenario: DEPENDENCE (**a**), DEP_TNC (**b**), DEP_MODESWITCH (**c**), REVOLUTION (**d**), REV_TNC (**e**), REV_MODESWITCH (**f**). Each color represents the fuel type whereas the area shows the amount of consumption.



Supplementary Figure 9. Transportation sector CO_2 emission reduction levels in MTon. The panels present change in transportation sector CO_2 emission levels in MTon with respect to STEADY-STATE for each scenario: DEP_BATTERY (**a**), REV_BATTERY (**d**), DEP_TNC (**b**), REV_TNC (**e**), DEP_MODESWITCH (**c**), REV_MODESWITCH (**f**). Each color represents the mode of transportation whereas the length shows the intensity of the relative reduction of CO_2. The downward growing stacked bar charts represent the emission reduction projections with respect to the base case scenario.



Supplementary Figure 10. Fuel consumption in PJ per the mode of transportation. The panels present fuel consumption levels in NYC for each scenario: DEPENDENCE (**a**), DEP_TNC (**b**), DEP_MODESWITCH (**c**), REVOLUTION (**d**), REV_TNC (**e**), REV_MODESWITCH (**f**). Each color represents the fuel type whereas the area shows the amount of consumption.

Supplementary Notes

Supplementary Note 1. Steady-State Scenario Results

New York City's energy flow is calibrated to match sector-by-sector energy consumption reported in the 2010 New York City Greenhouse Gas Inventory Report. The report provides fuel consumption values in GWh, PJ, etc., and the 2010 data was broken down into residential, commercial, industrial, and transportation sectors. For calibration purposes, energy service demands in 2010 are calculated based on the efficiency values of the existing technology batch. Fuel consumption is converted to end-use energy demands (water heating, space heating, space cooling, travel demand, etc.) on the sectorial basis by calibrating average technology efficiency with aggregate fuel consumption data for the base year. Hence, the demand projection for an end-use energy service does not also imply the amount of fuel consumed or the number of buildings but the provision of services (e.g., the lighting of homes, space heating of hotels, passenger transport demand). For the building sector, each individual demand is calculated separately. Rather than calculating the change in the building structure (number of multi-family buildings, number of 1 to 4-unit buildings, townhouses, etc., COMET captures the change in the parameters that have an influence on end-use energy service demands (such as Heating Degree Day, Cooling Degree Day, the change in the average number of household, the change in the area that requires lighting, the percentage of household air conditioning, etc.).

STEADY-STATE refers to business as usual condition reflecting the continuation of existing technologic, economic, population trends without any specific emission reduction targets. End-use energy service demands in STEADY-STATE change according to the economic and demographic projections. Existing fuel and technology shares for end-use demand services and electric generations are represented in the model. Estimated energy consumption in base year (2010) closely tracks reported data across building and transportation sectors as given in Figure 2 (Please see ref.[1] for calibration results).

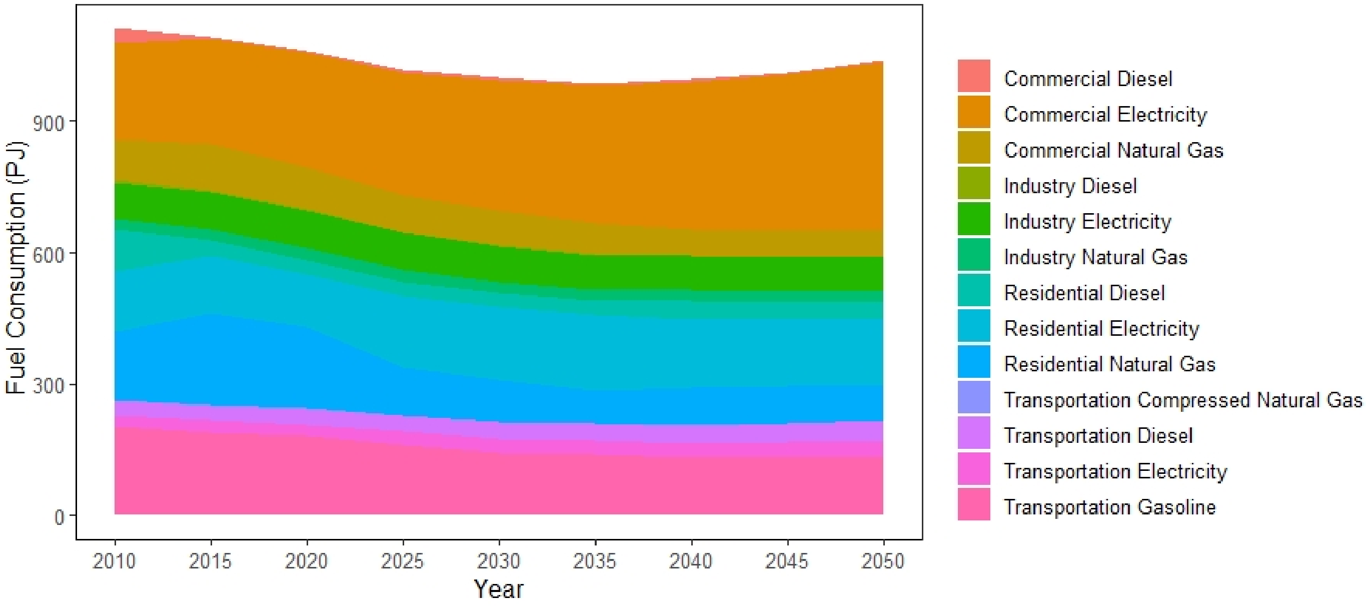
The future year end-use demands in STEADY-STATE are projected based on population growth and economic activity. Although main demand trajectories are taken from the AEO forecasts, they are adjusted for each borough according to population forecasts ref.[1]. Transportation sector demand data is checked against the official projections provided in the Regional Transportation Plan 2045 Maintaining the Vision for A Sustainable Region Chapter 2: Forecasting & Trends[2].

Supplementary Note 1.1. Fuel consumption in STEADY-STATE scenario

In STEADY-STATE, total demand for energy services is increasing, however resultant total energy consumption is projected to be stable due to efficiency gain resulted from new technology investments. The impact of the associated technological choices and the accompanying supply mix of the STEADY-STATE on total primary energy consumption values are depicted in Supplementary Figure 11.

The building sector including residential, commercial, and industrial buildings, shows a slow growth from 2035 to 2050. However, there is a slight decline (3% reduction in fuel consumption per period) from 2010 through 2035 despite the increase in the end-use energy service demands due to factors such as population growth, GDP growth, change in the average number of households, etc. In 2010, space heating has the highest share of energy consumption in both residential (47% of aggregate fuel consumption) and commercial buildings (28% of aggregate fuel consumption). Hence space heating has the highest room for improvement. For the base year, approximately 90% of total consumption for space heating can be attributed to diesel and natural gas, whereas this value is expected to decrease only to 83% if there is no emission constraint in the system. In terms of energy efficiency gain lighting is the most promising end-use energy service for both residential and commercial sectors. Although the lighting demand (bn-lum-yr) is expected to increase by 27% between 2010 to 2050, the electricity consumed is expected to decrease by 3%.

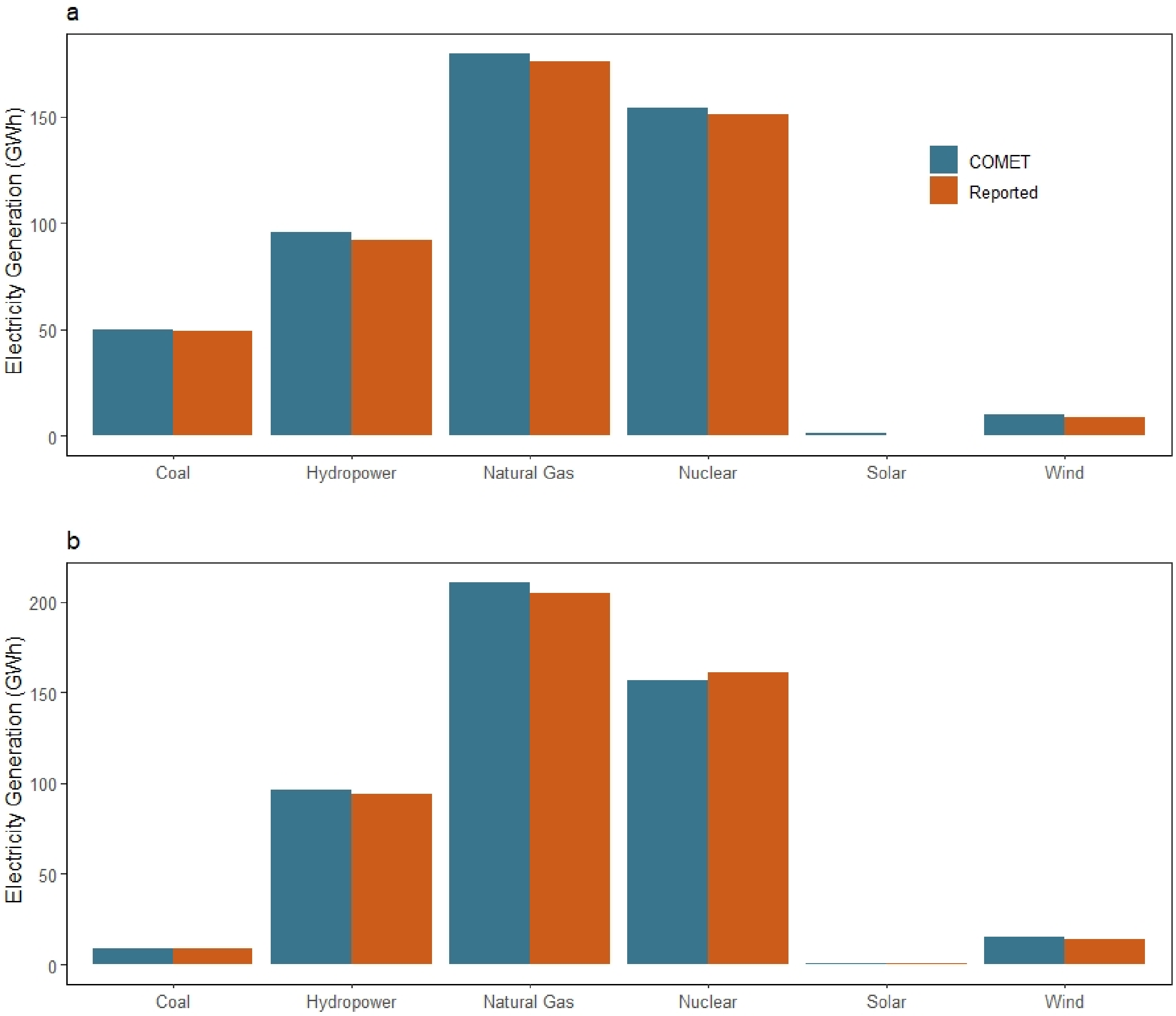
The transportation sector continues to be dominated by gasoline consumption with a decreasing rate during the modeling period. Although gasoline and diesel are expected to remain to be the highest demanded source of energy, the share of gasoline and diesel consumption will decrease from 76% in 2010 to 61% by 2050.



Supplementary Figure 11. City-wide fuel consumption (including source) in PJ in STEADY-STATE scenario. The stacked area chart shows the fuel consumption that belong to transportation, commercial, residential, and industry sectors in New York City from 2010 through 2050. Each color represents the type of fuel consumed by different sectors. The electricity values are presented in source energy consumption.

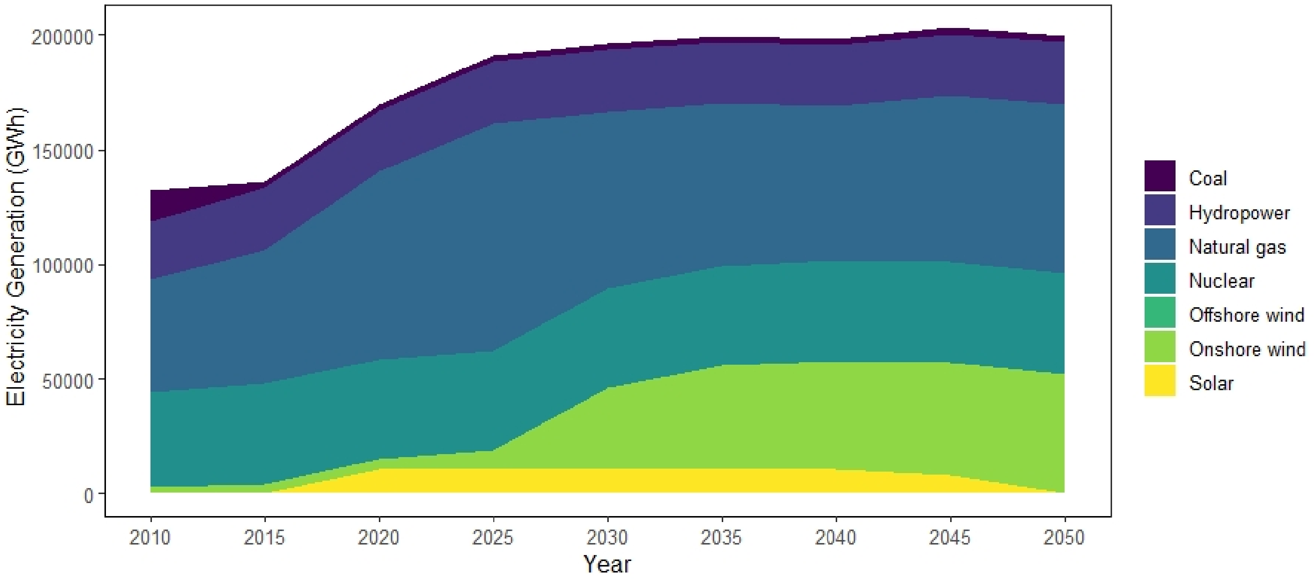
Supplementary Note 1.2 Power Sector in STEADY-STATE scenario

2010 and 2015 electricity generation output in STEADY-STATE is calibrated according to data provided in the EIA report for the State of New York. Supplementary Figure 12 provides a comparison of the electricity generation with respect to the primary energy sources. It should be noted that the electricity generation is an output of the model rather than a value defined exogenously. The state's electricity generation is not expected to fluctuate drastically during the 2010-2050 period, and it will increase gradually. Hence, there exists an upward trend in electricity generation under STEADY-STATE as given in Supplementary Figure 13.



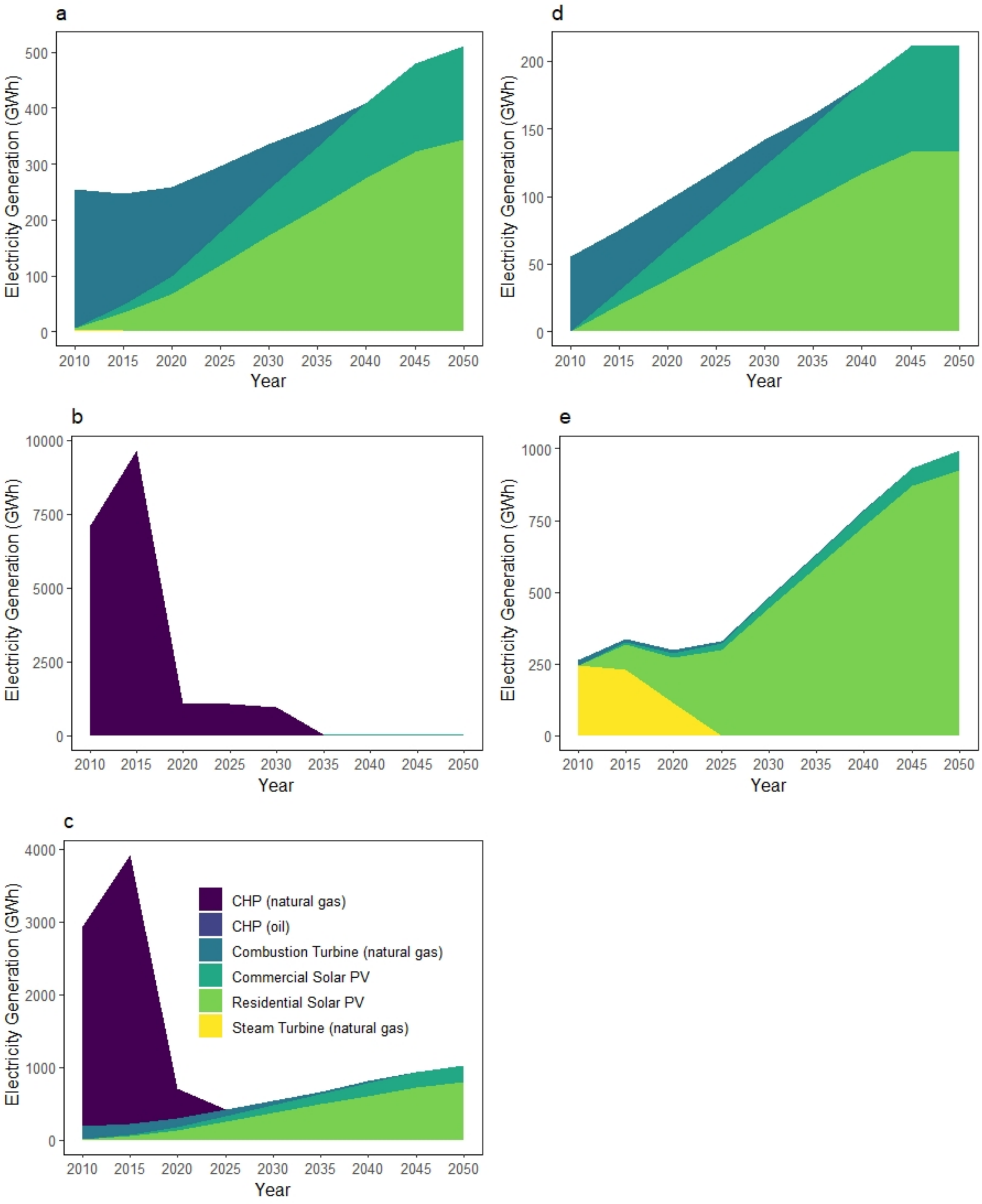
Supplementary Figure 12. Model Electricity Generation Estimates vs Reported Data in GWh in STEADY-STATE scenario. Each chart represents a specific time in modeling horizon. The double vertical bar graph compares the fuel consumption for the power sector reported by the state and COMET model results. Panel (**a**) represents this comparison for 2010 whereas Panel (**b**) shows the same comparison is for 2015.

In New York State, electricity generation will reach around 199,000 GWh by 2050 from 136,900 GWh in 2010, driving new investments in natural gas, wind, and solar capacity. The share of electricity generation from natural gas-fired power plants are expected to rise from 31% in 2010 to approximately 35% in 2050, whereas, electricity generation from coal power plants declines. About 61% of the total statewide electricity generation is expected to be from non-fossil sources.



Supplementary Figure 13. New York State's electricity generation by fuel in GWh in STEADY-STATE scenario. Each color represents generation value for different sources from 2010 through 2050. The figure doesn't include imports, it only represents in-state generation of the listed generation types.

Nuclear power is one of these sources although there are state polices to phase out nuclear plants in New York State, these policies are not implemented in the COMET-NYC since the plants are still in operations. We don't observe new capacity additions for nuclear power plants in any of the scenarios. Wind power becomes a strong player, especially after 2030. The contribution of solar remains low in the long run. Natural gas combined cycle plants generate the majority of electricity as expected in light of recent trends in cheaper natural gas resources and relatively cheap investment costs for NGCC. Supplementary Figure 14 presents the borough level electricity generation mix. In STEADY-STATE, existing CHP, combustion turbine, and steam turbine technologies drive near term electricity generation. Whereas, in the long term, no additional capacity investments in those technologies is observed. Regarding renewables, in Queens, the electricity generation rises slowly for the period from 2025 to 2050. Due to policy driven citywide capacity additions, electricity generation from solar power increases through 2050 to more than 2500 GWh. In terms of residential and commercial solar PV, Staten Island has a higher renewable penetration rate across the projection period.



Supplementary Figure 14. Borough based electricity generation values in GWh in STEADY-STATE scenario. The panels present the electricity generation for each borough: Brooklyn (**a**), Manhattan (**b**), Queens (**c**), Bronx (**d**), Staten Island (**e**). Each color represents the type of generation technology from 2010 through 2050.

Supplementary Note 1.3. Discussion on PM10 emissions

In STEADY-STATE scenario, PM_{10} emissions resulting from the transportation sector start to increase in 2025 (Supplementary Figure 6a). Couple of factors contribute to this. First, the increase in light-duty vehicle demand, second is the switch from CNG buses to diesel buses. The main reason for this upswing is the rise in NYC's travel demand. The deepest PM_{10} emissions reduction occurs in MODESWITCH scenarios which assume public transportation, walking, and biking will reduce the total passenger-km demand satisfied by light-duty vehicles. The highest PM_{10} saving is expected to be achieved in DEP_MODESWITCH which also prioritizes intense efficiency improvement specifically in the short-term and medium-term. Accordingly, we expect PM_{10} emissions reduce by half compared to STEADY-STATE level by 2050.

TNC scenarios result in the least PM_{10} emission savings. In our model, CNG fueled bus and heavy-duty short-haul trucks are relatively higher investment costs than diesel counterparts. Therefore, the least cost optimization results in a switch from CNG to diesel which in turn increases PM_{10} emissions. Across all scenarios, we observe PM_{10} emissions at various levels. In terms of the system wide PM_{10} emissions (including building and power sector), REVOLUTION scenario and all its variants (TNC, MODESWITCH, and BATTERY options) provide deeper PM_{10} emission reductions comparing to STEADY-STATE scenario as shown in Supplementary Figure 6a. Here, we found that electrification accompanied by clean electricity and increased energy efficiency can result in deep PM_{10} reductions. Within the transportation modes, regardless of the scenario assumptions, more than 90% of total PM_{10} emissions belong to light-duty vehicles followed by heavy-duty short-haul (Supplementary Figure 5). In order to achieve even deeper reduction in PM_{10} emissions, transportation demand management should be incorporated to the city's goals, especially for passenger cars. The model shows that PM_{10} emissions can be mitigated by 57% in 2050 in DEP_MODESWITCH, with respect to the STEADY-STATE level, through this joint effort.

Supplementary Figure 6a also shows a peak in the PM_{10} emissions in 2020 for DEPENDENCE and REVOLUTION scenarios. We observe that the model continues to utilize existing in-city electricity generation units such as natural gas fired utility scale and commercial CHP's. This in return results in continuous increase in PM_{10} emissions. By 2025, the capacity retires, and more solar PV capacity is added to the scenario.

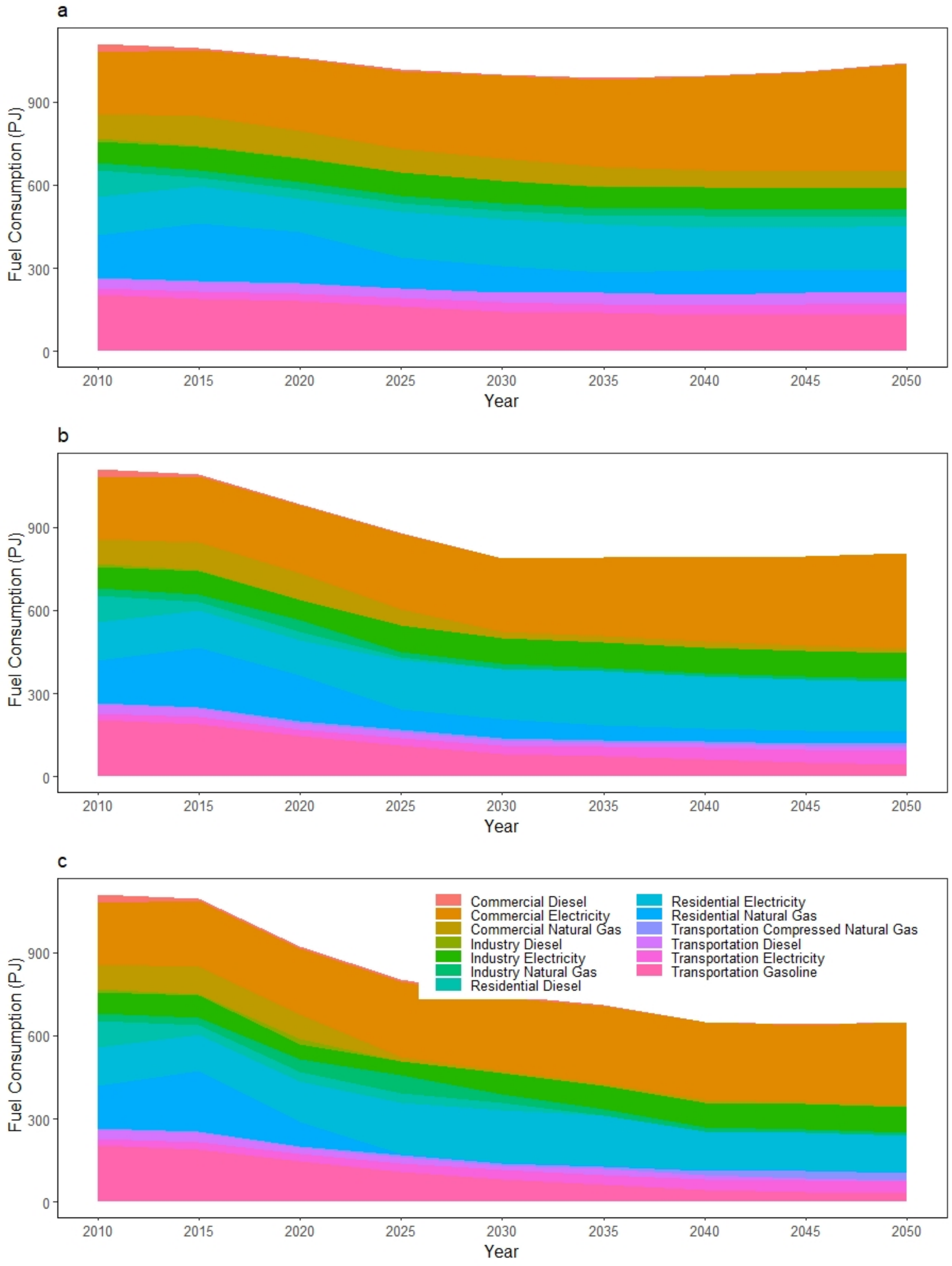
Regarding sectoral performances, on average, the approximate PM_{10} emission reduction is expected to be 95% in comparison with the 2010 level in the commercial sector by 2050. PM_{10} emissions in the residential sector are also expected to diminish over the years and hit "zero" by 2030 because of the reduction in natural gas consumption for space and water heating. Despite the efficiency gain and fuel switching, the transportation sector is projected to be the highest contributor to the PM_{10} emissions in 2050. The transportation sector is expected to be followed by the industry and electricity generation sector. Hence, to keep PM_{10} under control, the interaction between the price of electricity supplied by the grid and distributed electricity generation within the city should also be considered.

Supplementary Note 2. In-depth Results from Dependence and Revolution Scenarios

Both REVOLUTION and DEPENDENCE scenarios result in a downward trend in the aggregate fuel consumption despite energy service demands. Supplementary Figure 15 presents fuel consumption across scenarios. Here we observe that 75% of total energy consumption can be attributed to the building sector.

Total energy consumption in New York City decreases by approximately 41% in DEPENDENCE scenario from 2010 through 2050 whereas this rate equals to 27% in REVOLUTION scenario. In both emission reduction scenarios, we observe widespread investment in energy efficiency improvement driven by the 80x50 target. However, under the scenario where the grid provides clean electricity to the city, electrification of the end-use sectors is preferred.

In DEPENDENCE scenario, due to the assumption of slow grid decarbonization, unit electricity is comparatively dirty as a result the level of technology efficiency improvement takes the lead. Aggregate primary energy savings peak at 2030 and 2040 in DEPENDENCE scenario.

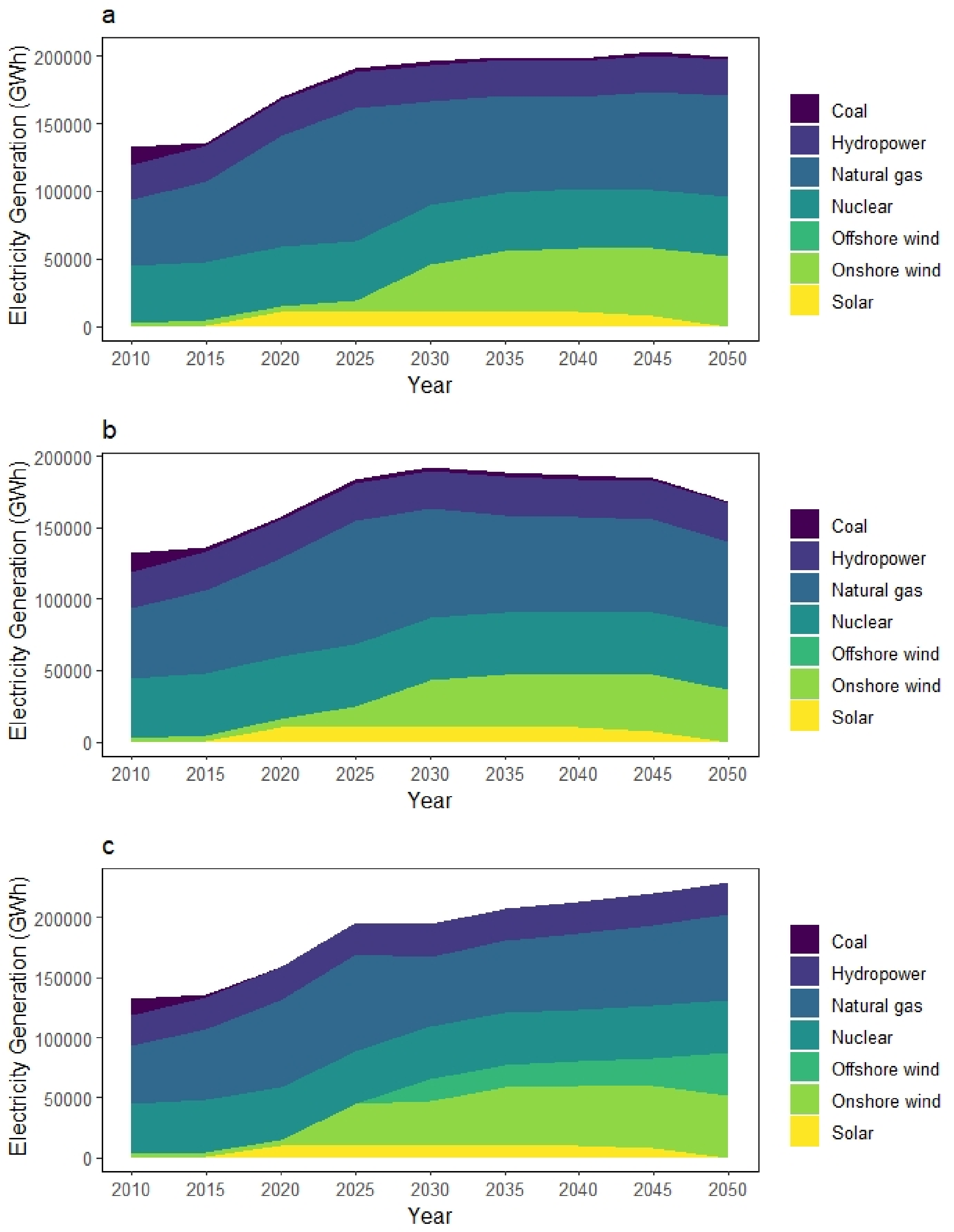


Supplementary Figure 15. City-wide fuel consumption (including source) in PJ. The panels present fuel consumption levels in NYC for each scenario: STEADY-STATE (**a**), REVOLUTION (**b**) and DEPENDENCE (**c**) scenarios. The stacked area charts show the fuel consumption that belongs to transportation, commercial, residential and industry sectors in New York City from 2010 through 2050. Each color represents the type of fuel consumed by different sectors. The electricity values are presented in source energy consumption.

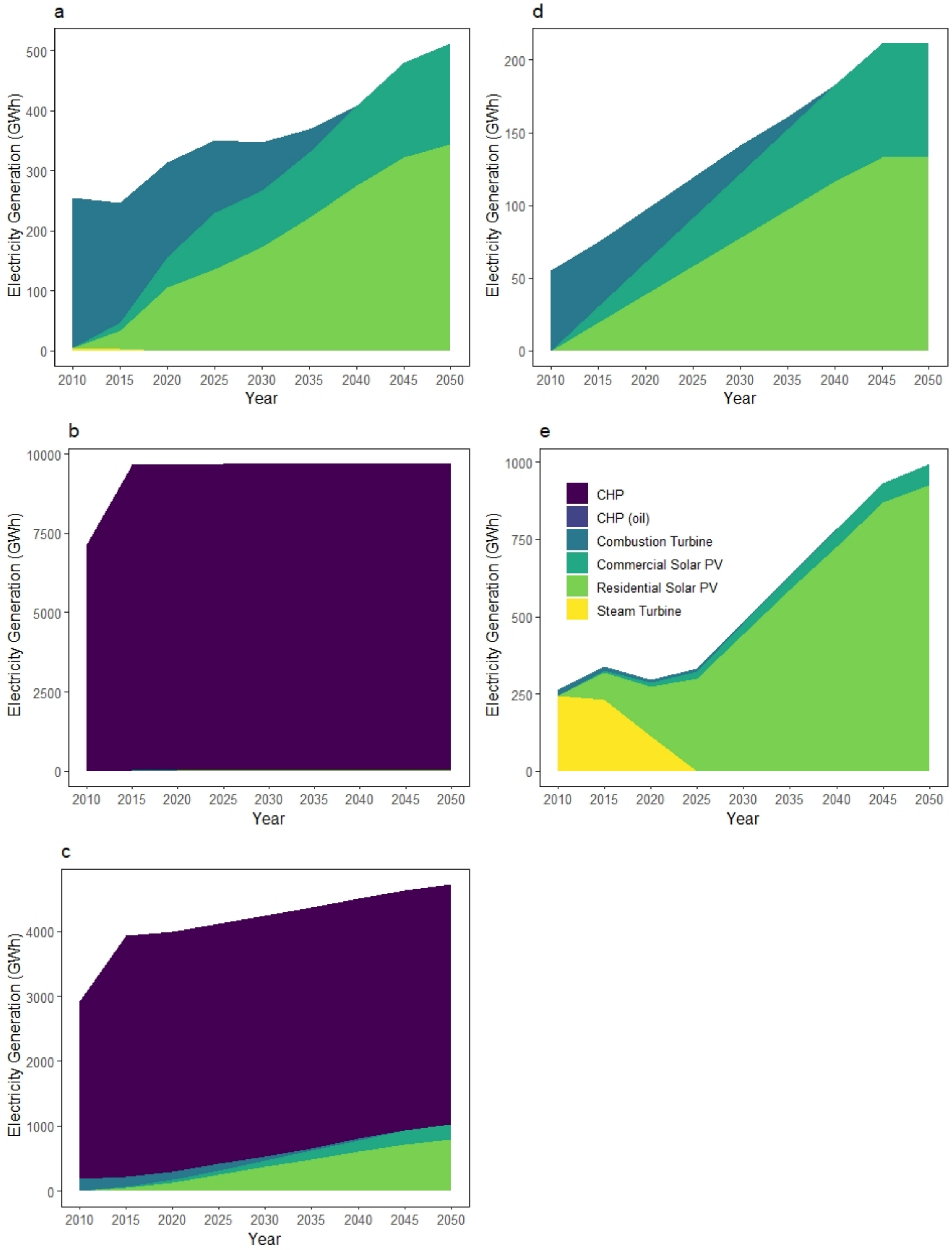
Supplementary Figure 16 presents the electricity generation fuel mix across scenarios. One distinct result includes the penetration of wind power. REVOLUTION scenario results in earlier penetration of onshore wind compared to STEADY-STATE. There is no electricity generation from offshore wind in DEPENDENCE and STEADY-STATE scenarios, however, we observe electricity generation from the offshore wind starting after 2025.

Supplementary Figure 16 includes electricity generation from “utility-scale” solar generations whereas, in city generation of residential and commercial sector solar is presented in Supplementary Figure 17 for DEPENDENCE and Supplementary Figure 18 for REVOLUTION. Model results reveal that in city solar generation is a preferable option. Although we see an increase in the electricity generated from solar power throughout the modeling horizon, when the electricity generated in the grid has a higher emission coefficient, we observe the highest utilization of the solar panels. In REVOLUTION scenario, in Brooklyn total electricity generated from solar power is 31% less comparing to DEPENDENCE scenario. Regarding the aggregate electricity generation level, we observe a decline in DEPENDENCE scenario. The electricity demanded is lower than other scenarios due to the faster transition to efficient technologies.

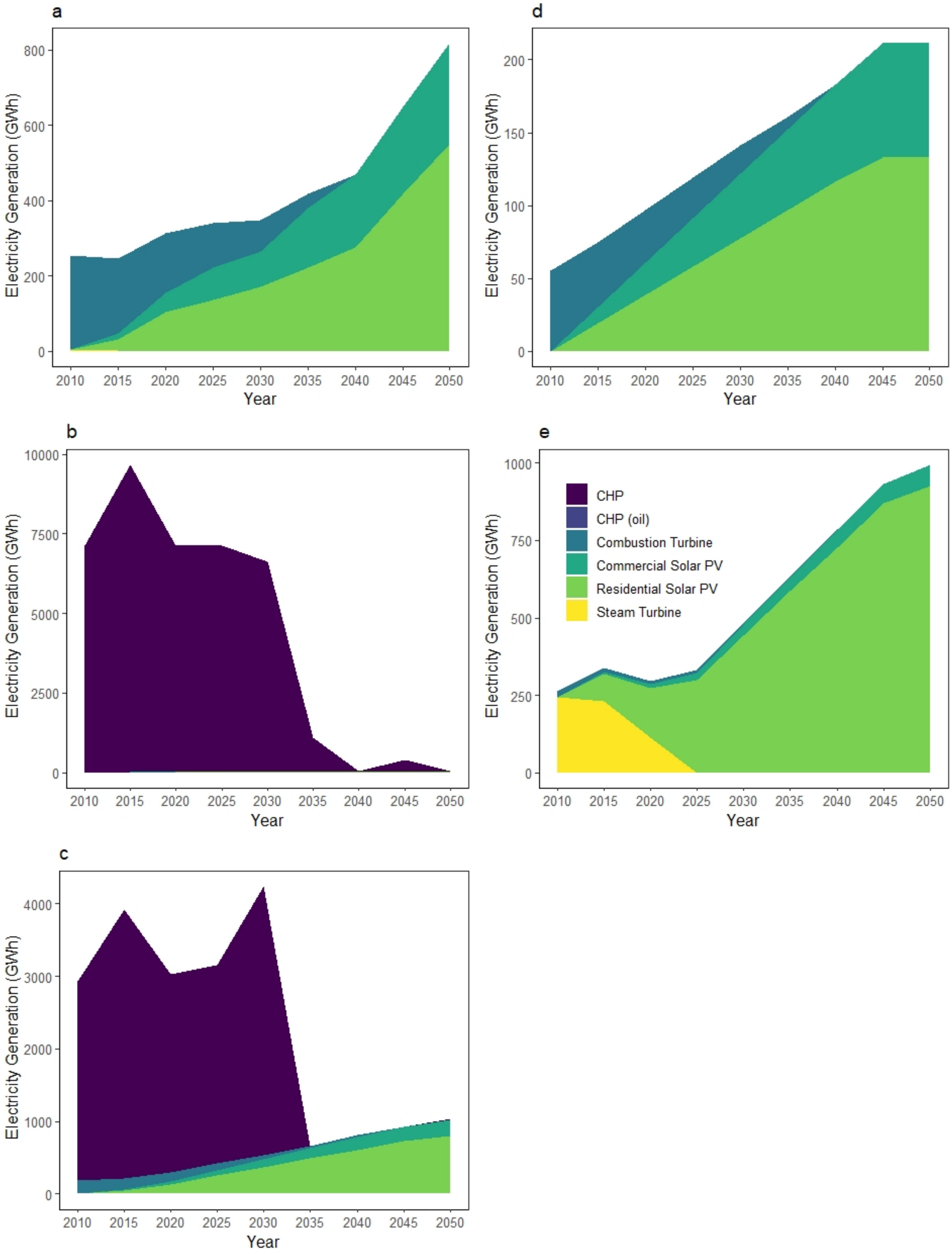
Combined Heat and Power (CHP) electricity generation varies between scenarios as presented in Manhattan and Queens, we observe that under REVOLUTION scenario the system tends to stop utilizing before the end of economic lifetime of the existing facilities, whereas under the assumption that the grid provides electricity with higher emission coefficient, the model keeps utilizing the existing CHP facilities.



Supplementary Figure 16. New York State's electricity generation by fuel in GWh. The panels present electricity generation levels by source for each scenario: STEADY-STATE (**a**), REVOLUTION (**b**) and DEPENDENCE (**c**) scenarios. Each color represents generation value for different sources from 2010 through 2050. The figure doesn't include imports, it only represents in-state generation of the listed generation types.



Supplementary Figure 17. Borough based electricity generation values in GWh in DEPENDENCE scenario. The panels present the electricity generation for each borough: Brooklyn (**a**), Manhattan (**b**), Queens (**c**), Bronx (**d**), Staten Island (**e**). Each color represents the type of generation technology from 2010 through 2050.



Supplementary Figure 18. Borough based electricity generation values in GWh in REVOLUTION scenario. The panels present the electricity generation for each borough: Brooklyn (**a**), Manhattan (**b**), Queens (**c**), Bronx (**d**), Staten Island (**e**). Each color represents the type of generation technology from 2010 through 2050.

Supplementary Note 3. Sensitivity variant on electrification of light-duty vehicle fleet

BATTERY scenario assumes that 30% and 100% of the light-duty vehicle purchases will be battery electric vehicles in 2030 and 2050. Although a lower bound is set to ensure those ratios in 2030 and 2050, no additional constraint is imposed on the choice of technology. This constraint excludes plug-in hybrids and hybrid vehicles.

In the STEADY-STATE scenario, light-duty vehicle fleet majorly relies on internal combustion engines, and only a small portion of the demand for light-duty vehicles satisfied by the plug-in hybrid electric vehicles. With the inclusion of battery constraint, REV_BATTERY uses a diverse mix of internal combustion engines, plug-in electric vehicles, and hybrid electric vehicles to meet the light-duty vehicle demand by 2030. Interestingly, DEP_BATTERY exceeds the market share of the battery electric vehicles than what is included in the constraint, and battery electric vehicles consists of 51% of the new car purchases in 2030. In addition, the technology choices in DEP_BATTERY have a lower CO_2 footprint per mile for the internal combustion engine and plug-in hybrid cars than the REV_BATTERY counterpart due to the fact that the technology turnover in DEP_BATTERY is higher than REV_BATTERY which in turn results in a more efficient vehicle fleet. By 2050, the majority of light-duty vehicle demand is satisfied by battery electric vehicles in both scenarios. DEP_BATTERY scenario tends to invest in more efficient vehicles to compensate for the negative impact of higher emission coefficient for unit electricity. The average emission efficiency of DEP_BATTERY is expected to be around 230 CO_2/bn-vmt with 97% electrified light-duty vehicle fleet. More aggressive efficiency improvements in DEP_BATTERY scenario has several benefits, the most notable of which is reduced NO_X emissions not only for light-duty vehicles but the transportation sector as a whole. From 2010 through 2050, an additional 28% NO_x reduction is achieved.

Demand Type		Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sensitivity Analysis: BATTERY	Light-duty Vehicle (billion vehicle miles)	Brooklyn	10.43	10.67	10.85	11.11	11.49	11.8	12.02	12.27	12.53
		Bronx	5.77	5.85	5.93	6.1	6.34	6.55	6.68	6.83	6.98
		Manhattan	6.6	6.45	6.7	6.74	6.91	7.09	7.13	7.16	7.24
		Staten Island	1.95	1.95	1.97	2.03	2.05	2.07	2.08	2.09	2.11
		Queens	9.28	9.08	9.51	9.58	9.81	10.04	10.13	10.21	10.34
	Bus (billion vehicle miles)	Brooklyn	0.09	0.09	0.1	0.1	0.1	0.11	0.11	0.12	0.12
		Bronx	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07
		Manhattan	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
		Staten Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Queens	0.08	0.08	0.08	0.09	0.09	0.09	0.1	0.1	0.11
	Subway and Railway (billion passenger miles)	Brooklyn	9.08	9.48	10	10.64	11.22	11.77	12.54	13.18	13.96
		Bronx	4.92	5.23	5.46	5.84	6.19	6.52	6.97	7.37	7.83
		Manhattan	5.64	5.91	6.19	6.53	6.83	7.09	7.47	7.86	8.27
		Staten Island	1.67	1.68	1.84	1.94	2.03	2.1	2.21	2.4	2.54
		Queens	8.0	8.41	8.8	9.26	9.67	10.07	10.65	11.32	11.95

Supplementary Table 11. Demand values for BATTERY sensitivity analysis. The end-use service demands for transportation is defined exogenously in COMET. We conducted three sets of sensitivity analysis to evaluate LDV electrification (BATTERY scenario variation), increased use of Transportation Network Companies (TNC scenario variation) and reduced LDV demand through behavior change (MODESWITCH scenario variation). BATTERY sensitivities have the same level of demand as STEADY-STATE, DEPENDENCE and REVOLUTION scenarios. TNC and MODESWITCH have distinct changes in transportation end-use service demand. The first column of the table represents the type of sensitivity. In the second column, the mode type and unit of the demand are presented. The third column stands for the region information. The rest of the table provides the demand defined in the model for the period between 2010 to 2050.

Supplementary Note 4. Sensitivity variant on increased use of ride-hailing services

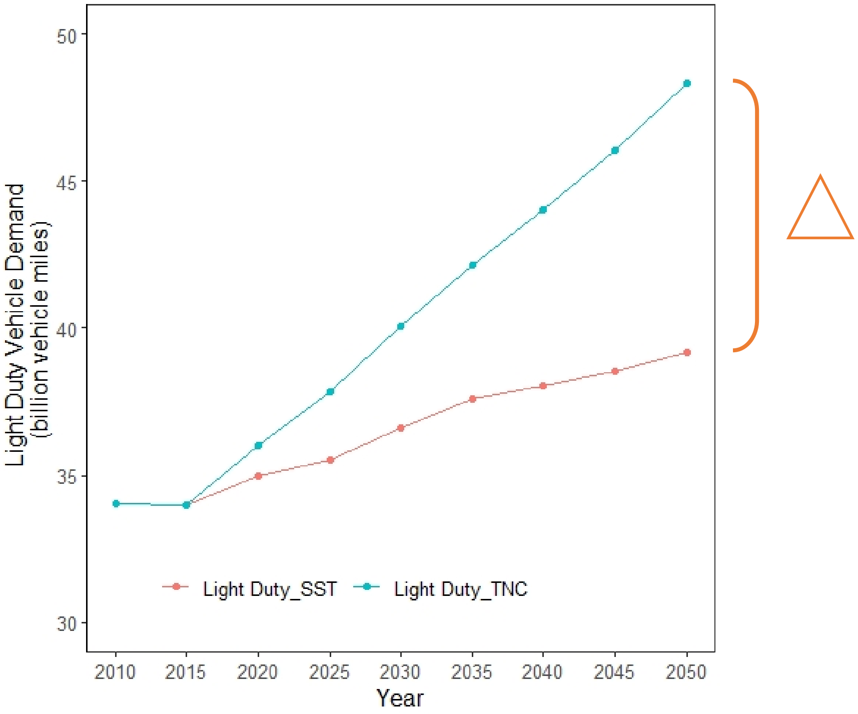
In this sensitivity analysis, we constructed a new light-duty vehicle demand series based on assumptions presented in Methods and as illustrated in Supplementary Figure 19. Total fuel consumption values that belong to heavy and medium-duty vehicles, bus and rail transportation are given in Supplementary Figure 10b and 10e. Under DEP_TNC and REV_TNC scenarios, the aggregate increase in fuel consumption is driven by two main reasons. Firstly, bus and subway transportation demands are reduced under the assumption that travelers prefer personal cars and for-hire vehicles over public transportation. Secondly, the growth of light-duty vehicle travel demand amplifies CO_2 emissions. To meet a system-wide CO_2 emission limit in REVOLUTION and DEPENDENCE, the investment patterns changed for heavy-duty and other transportation modes. To provide more flexibility with emission reductions, REV_TNC and DEP_TNC resulted in more fuel-efficient heavy-duty vehicles and busses in earlier periods than what is resulted in REVOLUTION and DEPENDENCE. For instance, by 2050, buses consume 3.41 PJ in 2050 in DEP_TNC, whereas this value is 4.11 PJ in DEPENDENCE scenario. Compressed natural gas is the fastest-growing source of energy in heavy-duty short-haul vehicles in TNC scenarios. In DEP_TNC, the market penetration of compressed natural gas is higher than REV_TNC (for both heavy- and medium-duty vehicles). In REV_TNC, electrification and gain in energy efficiency slows down the compress natural gas diffusion into the market. CNG engine efficiency is comparatively less than diesel engine efficiency ref.[3], p[14]. Thus, due to the higher penetration of compressed natural gas in DEP_TNC scenarios, we see slightly higher fuel consumption compared to REV_TNC scenarios between 2030 and 2050.

Total fuel consumption in REV_TNC is projected to be 1070 PJ for the period between 2010 and 2050. In contrast, this value is equal to 1057 PJ in REVOLUTION scenario. In REV_TNC scenario, average fuel per passenger mile efficiency for light-duty vehicles increases by 11% compared to REVOLUTION scenario. DEP_TNC scenario, result in the early adoption of electric vehicles with a higher penetration rate. Between

2020 and 2035, the amount of electricity demanded by light-duty vehicles is 16% higher than REV_TNC scenario.

$$\Delta = \mathit{Light\ Duty\ Vehicle\ Demand}_{TNC}(\mathit{bn\ vehicle\ miles}) - \mathit{Light\ Duty\ Vehicle\ Demand}_{SST}(\mathit{bn\ vehicle\ miles})$$

$$= \frac{[\mathit{Rail\&\ Subway\ Demand}_{SST}(\mathit{bn\ passenger\ miles}) - \mathit{Rail\&\ Subway\ Demand}_{TNC}(\mathit{bn\ passenger\ miles})]}{\mathit{Average\ number\ of\ passengers}_{\ car}} + [\mathit{Bus\ Demand}_{SST}(\mathit{bn\ vehicle\ miles}) - \mathit{Bus\ Demand}_{TNC}(\mathit{bn\ vehicle\ miles})] \times \frac{\mathit{Average\ number\ of\ passengers}_{\ bus}}{\mathit{Average\ number\ of\ passengers}_{\ car}} \qquad \text{Equation (3)}$$



Supplementary Figure 19. Light-duty demand comparison in billion vehicle miles TRANSPORTATION NETWORK COMPANIES (TNC) scenario with respect to STEADY-STATE scenario. The color of the line represents the scenario type. This graph presents the absolute change in light-duty vehicle demand due to the shifts in transportation mode. The area between two lines represents the increase in the light-duty vehicle demand. Equation 3 presents the formula for calculating the change in light-duty vehicle demand applied to TNC scenarios. Rail and subway demands are represented in the COMET model in billion passenger miles. The change in the rail and subway demand has been converted to billion vehicle miles by dividing it with the average number of passengers in a light-duty vehicle. Bus demand is represented in the COMET model in billion vehicle miles. The change in bus travel demand has been converted to billion vehicle miles by multiplying the ratio of the average number of passengers in a bus to the average number of passengers in a car.

Demand Type		Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sensitivity Analysis: TNC	Light-duty Vehicle (billion vehicle miles)	Brooklyn	10.43	10.67	11.18	11.83	12.57	13.26	13.91	14.66	15.45
		Bronx	5.77	5.85	6.10	6.49	6.93	7.34	7.73	8.16	8.60
		Manhattan	6.60	6.45	6.90	7.17	7.57	7.95	8.25	8.55	8.92
		Staten Island	1.95	1.95	2.03	2.16	2.24	2.32	2.41	2.49	2.60
		Queens	9.28	9.08	9.80	10.20	10.74	11.25	11.72	12.19	12.75
	Bus (billion vehicle miles)	Brooklyn	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
		Bronx	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Manhattan	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
		Staten Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Queens	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	Subway and Railway (billion passenger miles)	Brooklyn	9.08	9.48	9.48	9.48	9.48	9.48	9.48	9.48	9.48
		Bronx	4.92	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23
		Manhattan	5.64	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
		Staten Island	1.67	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68
		Queens	8.00	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41

Supplementary Table 12. Demand values for TRANSPORTATION NETWORK COMPANIES (TNC) sensitivity analysis. The end-use service demands for transportation is defined exogenously in COMET. We conducted three sets of sensitivity analysis to evaluate LDV electrification (BATTERY scenario variation), increased use of Transportation Network Companies (TNC scenario variation), and reduced LDV demand through behavior change (MODESWITCH scenario variation). BATTERY sensitivities have the same level of demand as STEADY-STATE, DEPENDENCE, and REVOLUTION scenarios. The TNC and MODESWITCH have different level of transportation end-use service demand values. The first column of the table represents the type of sensitivity. In the second column, the mode type and unit of the demand are presented. The third column stands for the region information. The rest of the table provides the demand values are input to the model for the period between 2010 to 2050. The demands for the ones not listed in the table are kept the same as in Supplementary Table 1.

Supplementary Note 5. Sensitivity on decreased LDV demand through walking and biking

In this sensitivity analysis, the total number of trips is calculated according to Equation (4) by implying the assumptions that are provided in the manuscript. The demands included in the model for MODESWITCH sensitivity analysis are given in Supplementary Table 13.

$$\sum Number\ of\ trips = \frac{Light\ Duty\ Vehicle\ Demand_{SST}(bn\ vehicle\ miles)}{Average\ trip\ length(miles)_{Light\ Duty\ Vehicle}} + \frac{Bus\ Demand_{SST}(bn\ vehicle\ miles)}{Average\ trip\ length(miles)_{Bus}} + \frac{Rail\&Subway_{SST}(bn\ passenger\ miles)}{Average\ trip\ length(miles)_{Rail\&Subway} \times Average\ number\ of\ passengers_{Rail\&Subway}} + Number\ of\ trips_{Walking\&Biking} \qquad Equation\ (4)$$

DEP_MODESWITCH and REV_MODESWITCH scenarios result in decreased aggregate fuel consumption value due to the fact that passenger mile travel in public transportation is higher. Energy efficiency improvements in DEP_MODESWITCH results in a 7% additional reduction in the unit fuel consumption per passenger mile of travel for subway and bus transportation than REV_MODESWITCH in 2050.

Regarding MODESWITCH runs, we observe an increase in the bus fleet efficiency. The transportation mode switch in favor of public transportation levels the total fuel consumption even though the travel demand is increasing over time. Thus, the model tends to invest cheapest light-duty vehicle options which result in a decline in average fuel per passenger mile value for light-duty vehicles. In REV_MODESWITCH the penetration of electric cars is still limited in the early period of the modeling horizon compared to DEP_MODESWITCH scenario.

Overall, we can see the response of the model under different demand projections and different emission levels of unit electricity in the transportation fleet mix. The high emission rate of electricity leads to higher penetration of energy-efficient fleet and switch to cleaner fuels such as compressed natural gas in near term whereas, clean electricity favors electrification over fuel efficiency in conventional gasoline and diesel vehicles.

Demand Type		**Region**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Sensitivity Analysis: MODESWITCH	Light-duty Vehicle (billion vehicle miles)	Brooklyn	10.43	10.67	10.85	10.16	9.44	8.70	7.96	7.24	6.49
		Bronx	5.77	5.85	5.93	5.58	5.21	4.82	4.42	4.03	3.61
		Manhattan	6.60	6.45	6.70	6.16	5.68	5.21	4.72	4.22	3.74
		Staten Island	1.95	1.95	1.97	1.85	1.68	1.52	1.38	1.23	1.09
		Queens	9.28	9.08	9.51	8.76	8.06	7.38	6.70	6.02	5.35
	Bus (billion vehicle miles)	Brooklyn	0.09	0.09	0.10	0.16	0.22	0.28	0.34	0.40	0.46
		Bronx	0.05	0.05	0.05	0.09	0.12	0.15	0.19	0.22	0.26
		Manhattan	0.06	0.06	0.06	0.10	0.13	0.17	0.20	0.24	0.27
		Staten Island	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08
		Queens	0.08	0.08	0.08	0.14	0.19	0.24	0.29	0.34	0.40
	Subway and Railway (billion passenger miles)	Brooklyn	9.08	9.48	10.00	10.67	11.35	12.03	12.72	13.28	13.93
		Bronx	4.92	5.23	5.46	5.86	6.26	6.66	7.07	7.43	7.82
		Manhattan	5.64	5.91	6.19	6.55	6.91	7.24	7.57	7.92	8.25
		Staten Island	1.67	1.68	1.84	1.95	2.05	2.15	2.24	2.42	2.54
		Queens	8.00	8.41	8.80	9.29	9.78	10.29	10.80	11.40	11.93

Supplementary Table 13. Demand values for MODESWITCH sensitivity analysis. The end-use service demands for transportation is defined exogenously in COMET. We conducted three sets of sensitivity analysis to evaluate LDV electrification (BATTERY scenario variation), increased use of Transportation Network Companies (TNC scenario variation), and reduced LDV demand through behavior change (MODESWITCH scenario variation). BATTERY sensitivities have the same level of demand as STEADY-STATE, DEPENDENCE and REVOLUTION scenarios. The TNC and MODESWITCH have different values in transportation end-use service demand. The first column of the table represents the type of sensitivity. In the second column, the mode type and unit of the demand are presented. The third column stands for the region information. The rest of the table provides the demand values are input to the model for the period between 2010 to 2050. The demands for the ones not listed in the table are kept the same as in Supplementary Table 1.

Supplementary Note 6. Cost implications of scenarios

In COMET, costs are calculated at the technology level with engineering economics principles while accounting for full life-cycle costs. While making technology investment decisions, the model doesn't solely consider capital costs, the endogenously generated fuel prices (including costs associated with extraction, production, processing, and transmission as well as imports), electricity prices (including costs associated with generation, distribution, and transmission as well as imports), salvaging costs for older technologies are also included. The model first calculates the annual life-cycle cost for each technology using a technology-specific interest rate (also referred to as "hurdle rates") per each modeling period as depicted in Equation 2 (Section 1.1). The objective function then incorporates annualized costs using a global discount rate to calculate the net present value of all life-cycle costs of investments (Equation 1). The costs which are incurred in all regions (i.e., resource supply region, New York City boroughs, and rest of New York State), are included in the objective function. Hence, the total system cost contains all energy sector related costs such as investment, operating and maintenance costs of the technologies within New York City's whole energy system (including electricity generation units in the city, transportation, and building sectors) and New York State's power sector. In addition, cost of fuel delivery, extraction, refinery, and import from outer regions are covered in the total system cost.

The model reports minimized the discounted total system cost per each region. From this data, we are able to compare total system cost performance of different scenarios for New York City and whole New York State as presented in Supplementary Table 6. Compared to STEADY-STATE, the total system cost of scenarios (NYS+NYC) resulted in 23% to 42% increase in total system cost. In comparison to REVOLUTION scenarios, DEPENDENCE scenarios provide more cost-effective strategies to achieve 80x50 targets considering both state and city expenses together. There are multiple drivers associated with this result. First, in REVOLUTION scenarios, we impose several constraints on New York State's power sector to mimic Clean Energy Standard (forcing the penetration of the renewables) and Reforming the Energy Vision Goals (ensuring 80% emission reduction in the grid). These constraints are also effective for electric generating units located in New York City. The decarbonization effort in the electric grid results in a significant structural change in the electric sector where unit electricity price increases. Although the unit electricity price is increasing, the model finds more cost-effective ways to electrify and reduce carbon emissions from the buildings sector than the transportation sector. Therefore, in REVOLUTION scenarios, we observe less burden on cost through end-use demand technology investments in the buildings sector compared to DEPENDENCE scenario counterparts (Supplementary Table 14). For instance, annualized investment costs in residential buildings for REVOLUTION is 39% less than the values for DEPENDENCE.

The second driver in the cost trends is the level of end-use energy service demand defined in the scenarios. For instance, we observe higher total discounted system costs as the light-duty vehicle transportation demand gets higher. REV_TNC results in $699,974 (2005 $US Million) for a total discounted system cost for New York City which is 48% higher than the STEADY-STATE. Whereas DEP_TNC results in 41% higher than STEADY-STATE. Similarly, REV_TNC ends up being the most expensive scenario both in total New York State + NYC as well as sole costs in New York City. Across the scenarios, we observe that approximately 70% of the end-use demand technology investments occur in the transportation sector. The transportation sector needs more structural change for achieving emission reductions than the buildings sector, therefore heavy investment in capital is essential. Lack of demand reduction measures can also exacerbate the costs. The resultant end-use demand technology investments for the transportation sector in REVOLUTION scenarios are relatively higher than DEPENDENCE counterparts with an exception on MODESWITCH scenarios. Here we found that the reduction in light-duty demand has more influence in cost than vehicle electrification goals. The MODESWITCH scenarios resulted in on average 10% less costly than TNC and BATTERY counterparts.

In addition to discounted total system costs, the model reports for each modeling period undiscounted total system costs (Supplementary Figure 20) as well as undiscounted total investment costs for demand technologies (Supplementary Figure 21). The values are reported for the whole modeling period, starting from 2010 which is a calibration year. In 2010, all the existing capacities and operating levels of all technologies are incorporated, and 2010 values reflect operations and maintenance as well as fuel costs. We observe a proportional increase in the total system cost until 2040. In order to achieve the emission mitigation targets in 2050, in both DEPENDENCE and REVOLUTION scenarios, the highest total system expenditure is observed in 2040 and 2045. STEADY-STATE scenario has the least-cost strategy to meet exogenously defined end-use service demands. This result is expected as there is no user-defined constraint on reducing CO_2 emissions in the system.

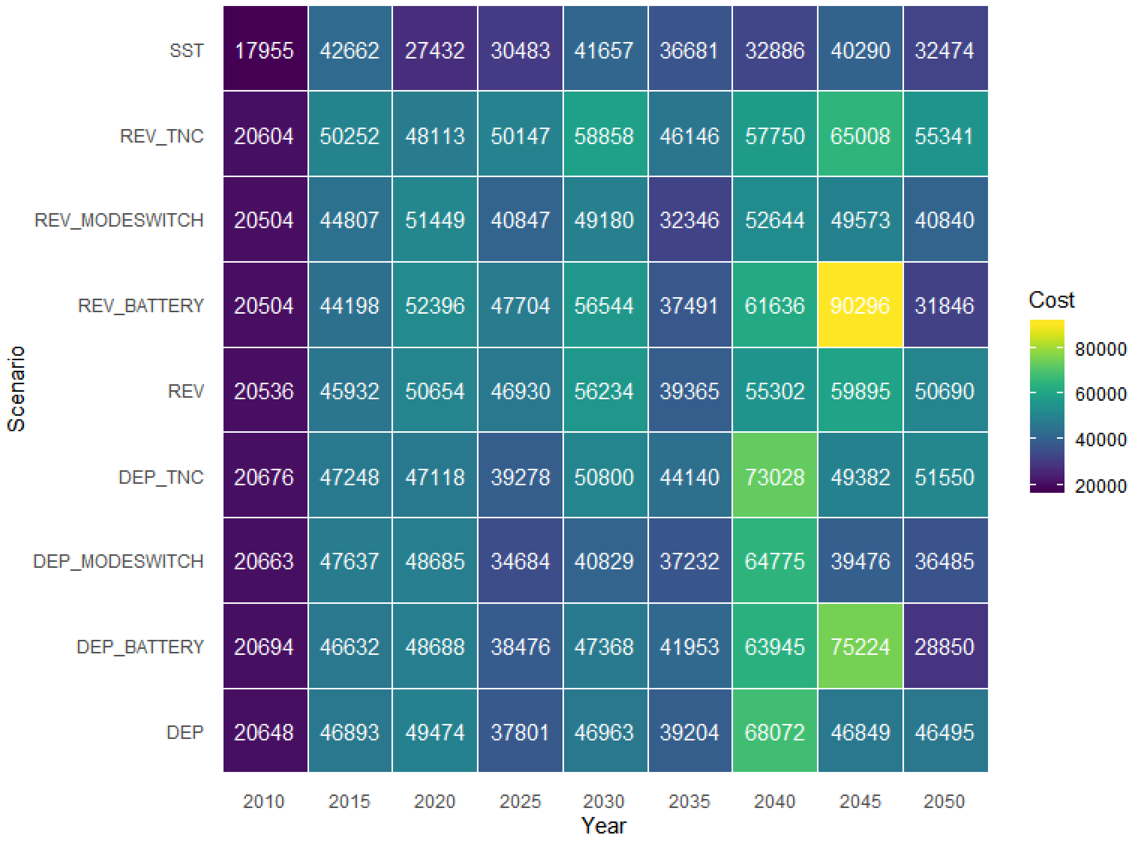
The undiscounted total system cost of STEADY-STATE equals to 17,955 (2005$ US Million) in 2010 and reaches its highest value in 2030. For the other scenarios, the peak value of the system cost varies with respect to different scenario assumptions. We see that the highest total system cost occurs in 2045 in the scenarios with 100% electrification of the light-duty fleet. In BATTERY scenarios, since the system tends to reach its target for transportation sector electrification in 2050, most of the car purchases and the grid electrification investments are expected to take place in 2045.

Regarding city-side investment costs for demand technology, we see similar patterns. REV_MODESWITCH and DEP_MODESWITCH scenarios simulate a reduction in the light-duty vehicle demand through changes in travel behavior (including switching from personal car travel to walking, biking, and use of public transportation). MODESWITCH scenarios result in the relatively lower cost values compared to REVOLUTION and DEPENDENCE scenarios. One caveat to this insight is that our modeling does not capture the change in opportunity costs related to this demand shift.

Surprisingly, heavy investment in decarbonizing the grid does not have much leverage over the need to the turnover capital stock in the transportation sector. Here we found that demand reduction, followed by fuel efficiency then electrification of the vehicle fleet is the most cost-effective measures to decarbonize the transportation sector.

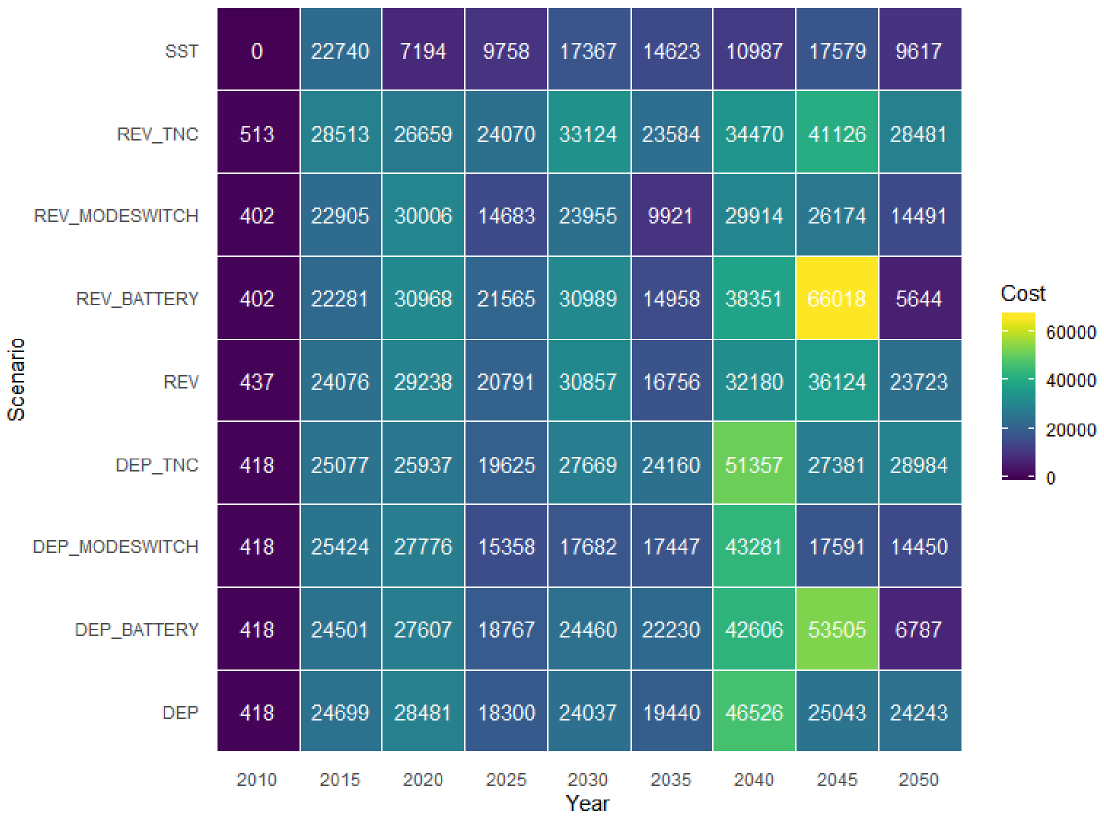
Scenario	*Transportation*	*Residential Buildings*	*Commercial Buildings*
STEADY-STATE	1.00	1.00	1.00
DEPENDENCE	1.56	1.71	1.27
REVOLUTION	1.65	1.32	1.25
DEP_MODESWITCH	1.28	1.72	1.27
REV_MODESWITCH	1.25	1.35	1.25
DEP_BATTERY	1.66	1.71	1.27
REV_BATTERY	1.84	1.32	1.25
DEP_TNC	1.72	1.89	1.27
REV_TNC	1.92	1.32	1.24

Supplementary Table 14. The ratio of the annualized investment cost values compared to STEADY-STATE. The first column presents the scenarios. Second, third and fourth columns give the ratio of investments in demand technologies for the transportation sector, residential buildings sector, and commercial buildings sector compared to STEADY-STATE.



Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
SST	17955	42662	27432	30483	41657	36681	32886	40290	32474
REV_TNC	20604	50252	48113	50147	58858	46146	57750	65008	55341
REV_MODESWITCH	20504	44807	51449	40847	49180	32346	52644	49573	40840
REV_BATTERY	20504	44198	52396	47704	56544	37491	61636	90296	31846
REV	20536	45932	50654	46930	56234	39365	55302	59895	50690
DEP_TNC	20676	47248	47118	39278	50800	44140	73028	49382	51550
DEP_MODESWITCH	20663	47637	48685	34684	40829	37232	64775	39476	36485
DEP_BATTERY	20694	46632	48688	38476	47368	41953	63945	75224	28850
DEP	20648	46893	49474	37801	46963	39204	68072	46849	46495

Supplementary Figure 20. Undiscounted total system cost value with respect to scenario types in 2005 $US Million. Each row belongs to different scenario options whereas x-axis represents periods. The color scale represents the intensity of the cost.



Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
SST	0	22740	7194	9758	17367	14623	10987	17579	9617
REV_TNC	513	28513	26659	24070	33124	23584	34470	41126	28481
REV_MODESWITCH	402	22905	30006	14683	23955	9921	29914	26174	14491
REV_BATTERY	402	22281	30968	21565	30989	14958	38351	66018	5644
REV	437	24076	29238	20791	30857	16756	32180	36124	23723
DEP_TNC	418	25077	25937	19625	27669	24160	51357	27381	28984
DEP_MODESWITCH	418	25424	27776	15358	17682	17447	43281	17591	14450
DEP_BATTERY	418	24501	27607	18767	24460	22230	42606	53505	6787
DEP	418	24699	28481	18300	24037	19440	46526	25043	24243

Supplementary Figure 21 Undiscounted total investment in demand technologies in NYC in 2005 $US Million. The color scale represents the intensity of the cost of the whole system. Each row belongs to different scenario options whereas x-axis represents the period. The color scale represents the amount of the investment costs of demand technologies.

Supplementary Note 7. Urban energy modeling frameworks with transportation

We examined existing energy-economy-environment modelling frameworks, specifically highlighting any analyses or models meeting these three criteria: high level of detail for the transport sector, spatial scale at the urban/community level, and characterization of air pollutant emissions and air quality impacts. Integrated Assessment Models incorporate energy systems and multiple economic sectors to analyze performance of different energy, environmental, and transport policies in the context of global climate goals. Studies related to transportation underscored the primary role of efficiency improvements and low carbon fuels in achieving mid-century CO_2 reductions, followed by travel demand and mode shifts to make reductions further into the end of the century[4-6]. Many bottom-up technology rich energy system modelling frameworks including MARKAL (MARKet ALlocation) and TIMES (The Integrated MARKAL-EFOM System) represent detailed techno-economic descriptions of individual end-use sectors[7]. Numerous studies have utilized the MARKAL/TIMES set of partial equilibrium optimization models to develop scenarios for more sustainable transportation pathways[8,9] and applied these models at a national[10-13], regional[14, 15] and state level[16-18]. For instance, a California TIMES model was used to evaluate a state-wide 80% greenhouse gas reduction goal where a shift toward electric drive and hydrogen fuel cell vehicles is seen in transportation sector[16-18].

There are fewer examples of energy system models at the community or city-scale. Some examples include the TIMES-Oslo model[19] and a bottom-up model to analyze energy transitions for cities within the European Union[20]. One of the challenges with developing an energy system modeling framework with greater spatial resolution for a highly urbanized area is that the transportation modes, technologies, and fuel mix may differ substantially from national or even regional/state representations. Place-specific data to build these types of models may not be readily available.

Another gap in urban-level studies is the integrated representation of emissions and air quality metrics. Air emission implications of transportation have considerable costs in U.S. metropolitan areas[21]. Several models reviewed above include air quality impacts in addition to greenhouse gas emissions[22, 23]. However, these global models are generally at a coarse-level of resolution, meaning they report emissions without subsequent air quality modelling, while some take the additional step of downscaling regionally aggregated emissions to a more local level obtain model concentrations[19]. There have also been efforts to better link energy system analyses with air quality impacts for the U.S.[24], regionally[24] and at the state-level[25-26]. Motivating this energy-air quality linkage is the potential for environmental co-benefits from mitigation strategies[27], including multi-pollutant air emissions reductions and water use benefits[28-29]. Capturing these dynamics at the local, urban level would facilitate additional air quality insights. This is highlighted by Lind & Espegren[19] as a shortcoming of their TIMES-Oslo model. In light of these gaps, we developed a technology-rich bottom-up planning tool for cities and local communities to aid them with identifying integrated strategies for energy planning.

Supplementary Note 8. City-based Optimization Model for Energy Technologies

City-based Optimization Model for Energy Technologies (COMET) is designed to capture the whole energy system from the introduction of the energy sources to conversion into useful energy to meet end-use energy service demands at the city-level from 2010 to 2050. The model provides long-term prospects for practical and applicable energy policy solutions, especially for cities that aim to achieve emission reduction targets by calculating the differences between business-as-usual and alternative emission mitigation scenarios. The model results reveal how the energy system balanced under a different set of scenario assumptions, and how system costs and resulting emissions change with respect to those scenarios.

COMET is used to model the energy system of New York City which includes transportation and building sectors while accounting for the generation of electricity and fuels coming from New York State. Fuel consumption is determined within the model to supply the necessary energy for transportation and building sector demand of New York City. The demanded electricity is produced either by electricity generation units located in New York State and New York City. Electricity generation level is determined by the model, whereas the travel, residential, commercial, or industry demand for New York City are introduced in the model exogenously. COMET-NYC includes borough-level detail for building stock and transportation mode shares.

COMET defines the energy system through technologies, commodities, and the flow of commodities. This simplified energy flow is called reference energy system (RES). Any device that transforms one commodity into another commodity is classified as technology (e.g., a natural gas combined cycle power plant converts natural gas into electricity), whereas commodities are representations of material, emission, energy carrier or service which is generated, or consumed by technology. COMET is built on the MARKet ALlocation (MARKAL) framework, providing a technology-rich basis for estimating energy system change over a modeling horizon. It is designed to determine the optimal energy system to meet the energy service demands over the entire time horizon at least cost.

MARKAL, which has been around since the 1970s, was developed by the International Energy Agency (IEA)'s Energy Technology Systems Analysis Program (ETSAP). ETSAP is one of the longest-running Technology Collaboration Programme of the IEA. ETSAP currently has 20 contracting parties including the European Commission and two private sector sponsors[30]. MARKAL is an optimization (linear programming) framework that aims to reach a partial equilibrium at every period for energy forms and services. Partial equilibrium is attained in such a way that the suppliers produce the same amount that customers are ready to purchase to meet their energy service demands. To reach the market equilibrium, MARKAL assumes that; there is a linear relationship between outputs and inputs of a technology; total cost is minimized over the entire horizon with perfect foresight; the market price of any commodity in the model is the same as its marginal value attained by the model; the whole market is competitive; and each agent in the system aims to maximize the profit.

Detailed input requirements (i.e., variable types and data) per sector is provided in Appendix A of ref.[1]. The model provides the optimal mix of technology investments (process, conversion, transmission, energy procurement, and demand technologies), trading activities (import and export of fuels and electricity), extraction of fuels, resulting costs and emissions (including carbon dioxide, nitrogen oxide, particulate matter < 10 µm, particulate matter < 2.5 µm, sulfur dioxide, volatile organic compounds, methane, carbon monoxide, organic carbon, and black carbon) for each region/borough and sector in the whole energy system for each period. Kaplan and Isik[1] gives detailed information regarding the emission accounting, residential sector, commercial sector, industrial sector, and transportation sector in sections 2.2.7, 4.1, 4.2, 4.3, and 5, respectively.

To capture “real world” dynamics including consumers’ risk aversion to new technologies, we utilize technology-specific discount factors also called “hurdle rates”. Risk aversion could be a result of the information gap, resistance to technology adoption, regulatory and economic barriers to fast adoption, etc. Hurdle rates add extra costs on technologies which are perceived to be risky by consumers, to limit their adoption within the optimization framework.

Once the model decides in an investment for a specific technology, that technology is ready to be used during its lifetime. The parameters such as operating and maintenance cost, efficiency, annual fixed cost, etc. are categorized by their vintage in each period by considering the time difference between time period t and vintage period v.

The objective function of the MARKAL model is to minimize discounted total system cost which includes the annualized expenses related to the extraction, production, processing, and delivery of primary energy sources (fuels and materials), conversion and demand technologies (fixed and variable operation and maintenance (O&M) and capital investment costs), air pollution control equipment investment, emission taxes – if defined, and health damages – if defined. Equation 1 presents a simplified objective function. The detailed mathematical formulation of the model through objective function and the constraints is presented in ref.[7] pages 62-64.

The model calculates the annual life-cycle cost for each technology investment using a technology-specific interest rate (also referred to as “hurdle rate”) per each modeling period as depicted in Equation 2. The objective function (Equation 1) then incorporates annualized costs using a global discount rate to calculate the net present value of all life-cycle costs of investments.

The global discount rate is 5%. This value can be interpreted as averaged inflation rate across the modeling horizon. The costs incurred in all regions (i.e., resource region, New York City boroughs, and the rest of New York State) are included in the objective function. Hence, the total system cost contains all energy sector related costs such as investment, operating, and maintenance costs of the technologies within New York City's whole energy system (including electricity generation units in the city, transportation, and building sectors) and New York State's power sector. Besides, the cost of fuel delivery, extraction, refinery and import from outer regions are also covered in the total system cost.

$$Discounted\ total\ system\ cost = \sum_{r=1}^{R}\sum_{t=1}^{t=y}(1+i)^{z\times(1-t)} \times Annualized\ Cost\ (r,t) \times [(1+(1+i)^{-1} + (1+i)^{-2} + \cdots + (1+i)^{1-z}\,] \qquad \text{Equation (1)}$$

where,

R = the number of regions where R_0: Resource supply, R_1: The rest of New York State, R_2: Brooklyn, R_3: Bronx, R_4: Manhattan, R_5: Staten Island, R_6: Queens.
y = the number of periods in the modeling horizon
z = the number of years in each period
i = the discount rate which is defined as a global parameter
Annualized cost (r,t) = the annualized total cost which belongs to region r for period t as presented in equation 2.

$$Annualized\ Investment\ Cost = \frac{Lumpsum\ Unit\ Investment\ Cost}{\sum_{j=1}^{k}(1+h)^{-j}} \qquad \text{Equation (2)}$$

Where,

k = the lifetime of a technology
h = the technology specific discount rate

A linear programming model is then set up to minimize total discounted system cost while satisfying the following set of constraints;

- **End-use demand satisfaction constraints**: Total available capacity (the sum of existing capacity and new capacity investments made by the model for each period) should be more than or equal to the amount that can satisfy user-defined (exogenous) energy service demand projections.

- **Capacity transfer constraints:** For each period, the model decides to invest in alternative technology options. Once the model invests in a technology, its capacity contributes to the total available capacity of that specific technology during its physical lifetime defined in the model. The available capacity in a time period can be calculated as the sum of all capacity investments that have been made in that particular technology that is still in their useful life.
- **Use of capacity:** The model is able to use less than or equal to the available capacity for a particular technology in each period. This value captures the activity levels and translates into a quantity of fuel/energy used in that technology. The model decides on how much capacity to utilize based on total discounted cost and user-defined constraints. In some instances, some capacity remains underutilized in the model runs.
- **Balance for commodities:** This constraint is used to balance the aggregate flow of a particular commodity into the system (via import/ production) with the aggregate outflow of the same commodity (via export/consumption) for each time period for each region.
- **Electricity & heat balance:** Electricity and heat balance constraint aim to the aggregate flow of electricity and heat into the system (via import/ production) with the aggregate outflow of them (via export/consumption/grid losses) for each time-slice (season, time of the day).
- **Peaking reserve constraints:** This constraint, which is only valid for electricity and heat, assures having adequate reserve margin to reduce the probability of heat/electricity shortage. It aims for any electricity generation technology to have a total available capacity, which is more than the average peak load by a certain percentage.
- **Environmental constraints:** These user-defined constraints are used to limit certain pollutants from a particular region, the whole system, and/or particular sector. Through these constraints

for instance, we model National Ambient Air Quality Standards implemented in the U.S. that limit criteria air pollutants from transportation and utility sectors.

Alongside the constraints mentioned above, the user can impose other “user-defined” constraints to shape the model in accordance with the real-life conditions for both demand and supply side of the model. In this model, the constraints are grouped for each end-use energy service demand. In this context, the constraints that are set for the building sector is composed of five sub-categories: lighting, space cooling, space heating, water heating, industrial facilities, and transportation sector constraints are also disaggregated into five sub-sectorial categories: bus, heavy-duty, light-duty, medium-duty and rail. On the other hand, the constraints that are imposed on the power sector have eight main categories according to the area of influence; the type of energy source, and the type of technology. More details on the user-defined constraints and underlying assumptions for New York City application of the COMET model are provided in the documentation of the model (Appendix B of ref.[1]). In addition, Supplementary Note 8 delves into a deeper investigation of user-defined constraints within the transportation sector, and its potential implications of the results.

Supplementary Note 9. Transportation Assumptions in COMET-NYC

COMET-NYC models New York City's light-duty sector via 72 different technology and fuel combinations, whereas New York State's transportation sector is not included in the model. Each technology option is defined by parameters such as cost values, emission coefficients, the type of fuel consumed, and the efficiency rate. Vehicle capacity investments are decision variables, which are selected in a model run under the objective of overall cost minimization.

In addition to technology-specific parameters, user-defined constraints are added in to cover market dynamics due to consumer behavior on the technology choice for the region and existing trends in technology and fuel. Constraints are structured based on fuel type and technology type. The constraints focusing on "fuel-based" limitations consider the existing fuel consumption data split for the city. "Technology-based" constraints try to preserve the market shares of technologies within the defined bounds. These bounds are determined via city-based declared targets, historical sales data, and/or AEO forecasts which are presented in Table 15. We also explain per each constraint whether it is binging per each scenario. A binding constraint means that the model solution is reaching the defined target/limit.

Transportation mode	Constraints	STEADY-STATE	REVOLUTION	DEPENDENCE	DEP_BATTERY	REV_BATTERY	DEP_TNC	REV_TNC	DEP_MODESWITCH	REV_MODESWITCH
Light-duty vehicles	**Constraint on light-duty vehicle car classes** In COMET, light-duty vehicle classes are introduced such as compact, full size, large utility, minivan, mini-compact, pickup, and small utility cars. The fraction of each vehicle class, i.e., compact, full size, large utility, minivan, mini-compact, pickup, and small utility cars are included as constraints into the model by setting lower bound on the classification splits. These lower bounds are gathered from the “Sales data by class” data from Annual Energy Outlook (2015) for the period: 2015 to 2040: New Vehicle Sales. (For more information related to light-duty vehicle car classifications and percent shares please see ref.[1]). The purpose of this constraint is to calibrate the model about the existing light-duty vehicle fleet structure by imposing lower bounds for vehicle classes. These constraints ensure that the share of each car class in the fleet is higher than the lowest possible value. Although we have a lower bound for light-duty vehicle car classes, no upper bound on investments is imposed in the model. Hence, the model has the flexibility to choose the optimal fleet under different scenario assumptions according to linear optimization rules.	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Upper bound on the adoption of 100-mile range electric cars in STEADY-STATE 100-mile range electric cars are comparatively cheaper within other light-duty electric car technology options. For 100-mile range electric cars not to take over the market, we put an upper bound on the investment level. In order to establish a baseline which considers the above-mentioned obstacles and the past trends in sales, STEADY-STATE scenario includes an upper bound for 100-mile range electric vehicle penetration. This bound is set as 10% of all new light-duty vehicle investments for each period. This value is based on the Annual Energy Outlook’s Light-Duty Vehicle Sales by Technology Type data for the Middle Atlantic Region[35]. 10% is the highest value for the share of 100-mile range EV forecast throughout 2050 and set as the upper bound for STEADY-STATE scenario.									

Supplementary Table 15. Transportation sector user-defined constraints. This table explains the transportation sector-related constraints that are defined in the COMET model and provides the reference for the assumptions used. The second column of the table provides data detail for the constraint whereas the first column represents the sector in which the constraint imposed. Columns 3 to 11 show the scenario options in which the constraint is binding. These constraints are added to all scenarios otherwise noted.

Transportation mode	Constraints	STEADY-STATE	REVOLUTION	DEPENDENCE	DEP_BATTERY	REV_BATTERY	DEP_TNC	REV_TNC	DEP_MODESWITCH	REV_MODESWITCH
Light-duty vehicles	**Upper bound on the adoption of 100-mile range electric cars in STEADY-STATE** According to model results, in STEADY-STATE scenario, this constraint is non-binding. The constraint has zero marginal value (in linear optimization modeling this situation can be explained as “the constraint is not binding, thus the change in the bound doesn’t impact the optimal solution of the model”). The model chooses to invest in 100-mile EV at a lower rate than the 10% of all light-duty vehicle car purchases constraint.									
	Upper bound on the adoption of 100-mile range electric cars in alternative scenarios New York City has a goal of light-duty vehicle electrification goal (Please see Table 1 in the main manuscript for details). This target is introduced into the model under emission reduction scenarios. We don’t want 10% maximum investment share constraint for 100-mile range electric cars to shape the market structure. Hence, after additional sensitivity analysis on the adoption of 100-mile range cars, we loosened the constraint from 2020 (15%) to 2050 (30%) to give more flexibility to the model. Under DEPENDENCE, DEP_BATTERY, DEP_TNC, and DEP_MODESWITCH scenarios the constraint is not binding.		✓			✓		✓		✓
	Upper bound on the adoption of 200-mile range electric cars In STEADY-STATE scenario 65% of all light-duty vehicle investments is set as an upper bound for 200-mile range electric cars. This value is taken according to the forecast for the share of electric light-duty vehicle sales provided by EPRI for the U.S. Department of Energy[36] and Center for Entrepreneurship & Technology Technical brief[37] considering market drivers such as consumer adoption, fuel costs, and network externalities. Under 100% electrification scenarios, the upper bound must be relaxed. In COMET, to give more flexibility to the model, new bound value for 200-mile is set as 75%. To ensure homogeneity between emission reduction scenarios 75% is set as the fixed upper bound for REVOLUTION, DEPENDENCE, REV_BATTERY, DEP_BATTERY, REV_TNC, DEP_TNC, REV_MODESWITCH, DEP_MODESWITCH. This constraint is not binding in any scenario.									

Supplementary Table 15 (Cont’d). Transportation sector user-defined constraints. This table explains the transportation sector-related constraints that are defined in the COMET model and provides the reference for the assumptions used. The second column of the table provides data detail for the constraint whereas the first column represents the sector in which the constraint imposed. Columns 3 to 11 show the scenario options in which the constraint is binding. These constraints are added to all scenarios otherwise noted.

Transportation mode	Constraints	STEADY-STATE	REVOLUTION	DEPENDENCE	DEP_BATTERY	REV_BATTERY	DEP_TNC	REV_TNC	DEP_MODESWITCH	REV_MODESWITCH
Light-duty vehicles	**Upper bound on the share of plug-in hybrid electric vehicle investments** In STEADY-STATE scenario 10 % in 2020, 25% in 2025, 50% in 2030 of all light-duty vehicle investments is set as an upper bound for each period. This constraint is not binging in STEADY-STATE scenario. For all other scenarios, it is effective for 2020 and 2025. Upper bound on Plug-in hybrid electric vehicle investment value is taken from the U.S.EPA Office of Transportation and Air Quality (OTAQ)'s memo to Docket ID No. EPA-HQ-OAR-2008-0318[38].	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Upper bound on the share of hybrid electric vehicle investments In all scenarios, this constraint is set as 55% of all light-duty vehicle investments in 2020. This value is calculated by U.S. EPA National Vehicle and Fuel Emissions Laboratory and used in the Volpe Model to estimate the cost of CO_2 emission controls for light-duty vehicles. Hence the upper bound on hybrid electric vehicle investment value is taken from the OTAQ's memo to Docket ID No. EPA-HQ-OAR-2008-0318[38]. This constraint is not binding in any scenario. It doesn't affect the model results.									
	Upper bound on the share of advanced combustion engine vehicle investments This constraint is set to ensure that light-duty vehicle share investments can be at most 85% of all investments in 2020. Upper bound on the market penetration share of advanced combustion engine technologies is taken from the OTAQ's memo to Docket ID No. EPA-HQ-OAR-2008-0318 on June 23, 2008[38]. This constraint is not binding in any scenario. It doesn't affect the model results.									
Medium-duty vehicles	**Upper bound on the share of medium-duty short-haul compressed natural gas** For medium-duty short-haul vehicles, the amount of investment in compressed natural gas in 2020 should be greater than 0.69% which is calculated by the official fuel consumption rate that belongs to New York City in 2015. This is a binding constraint in all scenarios.	✓	✓	✓	✓	✓	✓	✓	✓	✓

Supplementary Table 15 (Cont'd). Transportation sector user-defined constraints. This table explains the transportation sector-related constraints that are defined in the COMET model and provides the reference for the assumptions used. The second column of the table provides data detail for the constraint whereas the first column represents the sector in which the constraint imposed. Columns 3 to 11 show the scenario options in which the constraint is binding. These constraints are added to all scenarios otherwise noted.

Transportation mode	Constraints	STEADY-STATE	REVOLUTION	DEPENDENCE	DEP_BATTERY	REV_BATTERY	DEP_TNC	REV_TNC	DEP_MODESWITCH	REV_MODESWITCH
Medium-duty vehicles	**Upper bound on the share of medium-duty short-haul gasoline** For medium-duty short-haul vehicles, the amount of investment in gasoline in 2020 should be greater than 57% which is calculated by the official fuel consumption rate that belongs to New York City. This is a binding constraint in all scenarios.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Heavy-duty vehicles	**Upper bound on the share of heavy-duty short-haul compressed natural gas** For heavy-duty short-haul vehicles, the amount of investment in compressed natural gas in 2020 should be less than 0.49% in 2020 which is calculated by the official fuel consumption rate that belongs to New York City in 2015. This is a binding constraint in all scenarios.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bus	**Upper bound on the share of bus diesel** For busses, the amount of investment in diesel consumed vehicles in 2020 should be greater than 78% in 2015 which is calculated by the official fuel consumption rate that belongs to New York City. This is a binding constraint in all scenarios.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rail	**Constraint on Rail transportation split** The model has both commuter rail and subway to meet TRP demand. To keep the balance in order to mimic the actual sector conditions the percent of total demand that can be met by commuter rail is protected by lower bounds that belong to the actual NYC transportation data for 2010[37]. This is a binding constraint in all scenarios.	✓	✓	✓	✓	✓	✓	✓	✓	✓

Supplementary Table 15 (Cont'd). Transportation sector user-defined constraints. This table explains the transportation sector-related constraints that are defined in the COMET model and provides the reference for the assumptions used. The second column of the table provides data detail for the constraint whereas the first column represents the sector in which the constraint imposed. Columns 3 to 11 show the scenario options in which the constraint is binding. These constraints are added to all scenarios otherwise noted.

Supplementary Note 10. Discussion on the calibration of transportation NO_x emissions in 2010

Currently, in COMET-NYC, the emission factors are based on regional MOVES runs. Lack of city-specific NO_x emission factors for different modes of transportation is one of the caveats of our analysis. Most of the driving in the city is not highway speeds and mostly stop and go, fast acceleration driving. Current evidence suggests that stop and go driving and fast acceleration and deceleration (e.g., ramping the speed up at highway entrance or vice versa) will have more hot spots for emissions. One might argue that the city-specific NO_X emissions would not track similar to regional averages due to these differences in driving patterns, mix and age of light-duty and heavy-duty fleet. We conducted a thorough literature review and found no specific data on the city specific emission factors. We pulled out state emission inventories from National Emission Inventory and U.S. EPA's COBRA's tool[31]. COBRA utilizes county level emission inventory numbers per sector to report health damages and benefits of pollutant reduction policies. U.S. EPA's COBRA model relies on the National Emission Inventory[32] and MOVES modeling platform to generate baseline 2017 and future 2025 emission inventories.

Total NOx emissions in 2017 from Highway Vehicles (i.e., on-road vehicles) are 22,385 tons. This value includes totals from Bronx, New York, Kings, Queens, Richmond Counties. In 2017, 52% of those emissions came from Heavy-Duty Diesel Vehicles (HDDV) which includes both heavy-duty diesel short- and long-haul trucks. The rest came from light-duty vehicles (10,717 tons). When the data is checked for light-duty vehicles, our model results in approximately 9,700 tons of NOx in 2017. The aggregate NOx levels in COMET is similar to the COBRA NOx levels for NYC.

Supplementary References

1 Kaplan, P.O. & Isik, M. City-based optimization model for energy technologies: COMET - New York City documentation (EPA 600/R-19/124). https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=539956&Lab=CEMM (U.S. Environmental Protection Agency, 2020).

2 New York Metropolitan Transportation Council. The regional transportation plan 2045 maintaining the vision for a sustainable region chapter 2: forecasting & trends. https://www.nymtc.org/Required-Planning-Products/Regional-Transportation-Plan-RTP/Plan-2045-Maintaining-the-Vision-for-a-Sustainable-Region (2017).

3 City of New York. Building a strong and fair city - efficient mobility volume 8 of 9. http://1w3f31pzvdm485dou3dppkcq.wpengine.netdna-cdn.com/wp-content/uploads/2019/05/OneNYC-2050-Efficient-Mobility.pdf (2020).

4 Yeh, S. et al. Detailed assessment of global transport-energy models' structures and projections. *Transp. Res. D Transp. Environ.* **55**, 294-309 (2017).

5 Edelenbosch, O. Y. et al. Transport fuel demand responses to fuel price and income projections: comparison of integrated assessment models. *Transp. Res. D Transp. Environ.* **55**, 310-321 (2017).

6 Creutzig, F. et al. Transport: A roadblock to climate change mitigation? Urban mobility solutions foster climate mitigation. *Science.* **350**, 911-913 (2015).

7 Loulou, R. et al. Documentation for the TIMES model part-I. https://www.iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf (2016).

8 Yeh, S. et al. Optimizing U.S. mitigation strategies for the light-duty transportation sector: what we learn from a bottom-up model. *Environ. Sci* **42**, 8202-8210 (2008).

9 Zhang, H. et al. TIMES modelling of transport sector in China and USA: comparisons from a decarbonization perspective. *Appl. Energy* **162**, 1505-1514 (2016).

10 Anandarajah, G. et al. TIAM-UCL global model documentation. https://www.researchgate.net/profile/Gabrial_Anandarajah/publication/239917973_TIAM-UCL_Global_Model_Documentation/links/553a6def0cf29b5ee4b6354e.pdf (UK Energy Research Centre University College, 2011).

11 McDowall, W. et al. Implications of sustainability constraints on UK bioenergy development: assessing optimistic and precautionary approaches with UK MARKAL. *Energy Policy* **47**, 424-436 (2012).

12 Shi, J. et al. Modelling building's decarbonization with application of China TIMES model. *Applied Energy* **162**, 1303-1312 (2016).

13 Solano-Rodriguez & Pye, S. Documentation for the European Times Model at UCL. https://www.ucl.ac.uk/drupal/site_energy-models/sites/energy-models/files/tiam-ucl-manual.pdf (ETM-UCL UCL Energy Institute, 2014).

14 Brown, K. et al. Accounting for climate and air quality damages in future U.S. electricity generation scenarios. *Environ Sci Technol* **47**, 3065-3072 (2013).

15 Lenox, C. et al. EPA U.S. nine-region MARKAL database documentation. (EPA/600/B-13/2013) (U.S. Environmental Protection Agency, 2013).

16 Leighty, W. et al. Modelling transitions in the California light-duty vehicles sector to achieve deep reductions in transportation greenhouse gas emissions. *Energy Policy* **44**, 52-67. (2012).

17 McCollum, D. et al. Deep greenhouse gas reduction scenarios for California – Strategic implications from the CA-TIMES energy-economic systems model. *Energy Strategy Rev.* **1**, 19-32 (2012).

18 Yang, C. et al. Achieving California's 80% greenhouse gas reduction target in 2050: Technology, policy and scenario analysis using CA-TIMES energy economic systems model. *Energy Policy* **77**, 118-130 (2015).

19 Lind, A. & Espegren, K. The use of energy system models for analyzing the transition to low-carbon cities – The case of Oslo. *Energy Strategy Rev.* **15**, 44-56 (2017).

20 G. Simoes, S. et al. INSMART – Insights on integrated modelling of EU cities energy system transition. *Energy Strategy Rev.* **20**, 150-155 (2018).

21 Mashayekh, Y. et al. Costs of Automobile Air Emissions in U.S. metropolitan areas. *Journal of the Transportation Research Board* **2233**, 120-127 (2011).

22 McCollum, D. L. et al. Climate policies can help resolve energy security and air pollution challenges. *Clim. Change* **119**, 479-494. (2013).

23 Shi, W. et al. Projecting state-level air pollutant emissions using an integrated assessment model: GCAM-USA. *Appl. Energy* **208**, 511-521. (2017).

24 Trail, M. A. et al. Impacts of potential CO_2 reduction policies on air quality in the United States. *Environ. Sci. Technol.* **49**, 5133–5141 (2015).

25 Kinnon, M. et al. Considering future regional air quality impacts of the transportation sector*. Energy Policy* **124**, 63-80 (2019).

26 Zapata, C. B. et al. Low-carbon energy generates public health savings in California. *Atmospheric Chem. Phys.* **18**, 4817-4830 (2018).

27 Martinich, J., et al. Reducing risks through emissions mitigation. in impacts, risks, and adaptation in the united states: fourth national climate assessment, volume II NCA (1346-1386). Washington, DC, USA: U.S. Global Change Research Program (2018).

28 Segerstrom, R. Building a water-energy nexus modelling tool for new york city: development of a nyc water MARKAL model http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A467860&dswid=-4482 (Uppsala University, 2011).

29 Kaplan, P.O. & Kaldunski, B. An integrated approach to water & energy infrastructure decision making using the MARKAL framework: a case study of New York City. presented in ACEEE Summer Study on Energy Efficiency in Buildings (Pacific Grove, 2016).

30 IEA. IEA-ETSAP Community Tool Users https://iea-etsap.org/ (2020).

31 U.S. EPA user’s manual for the co-benefits risk assessment health impacts screening and mapping tool (COBRA) https://www.epa.gov/sites/production/files/2018-05/documents/cobra_user_manual_may2018_508.pdf (2018).

32 U.S. EPA. National emissions inventory https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei (2020).

33 U.S. Department of Energy Alternative Fuels Data Center. Vehicle weight classes and categories. https://afdc.energy.gov/data/10380 (2019).

34 The City of New York. The inventory of New York City greenhouse gas emissions in 2015. http://www.dec.ny.gov/docs/administration_pdf/nycghg.pdf (2017).

35 AEO Light Duty Vehicle Sales by Technology Type https://www.eia.gov/opendata/qb.php?category=3161941 (2019).

36 USDRIVE. grid integration tech team and integrated systems analysis tech team summary report on EVs at scale and the U.S. electric power system https://www.energy.gov/sites/prod/files/2019/12/f69/GITT%20ISATT%20EVs%20at%20Scale%20Grid%20Summary%20Report%20FINAL%20Nov2019.pdf (2019).

37 University of California. Electric vehicles in the United States a new model with forecasts to 2030. Center for Entrepreneurship & Technology (CET) Technical Brief (http://globaltrends.thedialogue.org/wp-content/uploads/2014/12/Electric-Vehicles-in-the-United-States-A-New-Model-with-Forecasts-to-2030.pdf (2009).

38 EPA National Vehicle and Fuel Emissions Laboratory. Documentation of updated light-duty vehicle GHG scenarios. Ann Arbor, Michigan. DC: EPA-HQ-OAR-2008-0318 (2008).