Alternative Fuel and Advanced Light-duty Vehicles in NETPLAN

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Outline of Topics

1. Incorporate your research into NETPLAN
2. LDVs in NETPLAN
Incorporate your research into NETPLAN

Formulate the technology (e.g., PEV) within NETPLAN
Formulation of technologies from your teammates
Principle of a specific technology (e.g., PEV)
Existing NETPLAN formulation
Data
Incorporate your research into NETPLAN

Formulate the technology (e.g., PEV) within NETPLAN

Formulation of technologies from your teammates

Existing NETPLAN formulation

Principle of a specific technology (e.g., PEV)

Data
min \{CostOpE + CostInvE + CostOpT + CostFleetInvT + CostInfInvT\} \quad (1a)

subject to:

Meet energy demand at every node
\[ \sum_i \eta_{(i,j)}(t) e_{(i,j)}(t) - \sum_i e_{(i,j)}(t) = d_j^E(t) + d_j^{ET}(t) \] \quad (1b)

Energy flow lower and upper bounds
\[ lbe_{(i,j)}(t) \leq e_{(i,j)}(t) \leq ube_{(i,j)}(t) \Delta t + \sum_{z=0}^{\frac{t}{\Delta t}} e_{(i,j)}(z) \Delta z \] \quad (1c)

DC power flow equations
\[ e_{(i,j)}(t) = b_{(i,j)}(\theta_i(t) - \theta_j(t)) , \quad \forall (i, j) \in A^E_{DC} \] \quad (1d)

Transportation demand for non-energy commodities
\[ \sum_m f_{(i,j,k,m)}(t) = d_{(i,j,k)}^T(t), \quad k \in K \setminus K_c \] \quad (1e)

Transportation demand for energy commodities
\[ \sum_m f_{(i,j,k,m)}(t) = heatContent_k^{-1}(t) e_{(n_{(i,j),h}, a_h, m)}/(t), \quad k \in K_c \] \quad (1f)

Fleet upper bound for transportation flows
\[ \sum_k f_{(i,j,k,m)}(t) \leq ubFleet_{(i,j,m)}(t) \Delta t + \sum_{z=0}^{\frac{t}{\Delta t}} fleetInv_{(i,j,m)}(z) \Delta z \] \quad (1g)

Infrastructure upper bound for transportation flows
\[ \sum_k \sum_{m \in M_t} f_{(i,j,k,m)}(t) \leq ubInf_{(i,j,t)}(t) \Delta t + \sum_{z=0}^{\frac{t}{\Delta t}} infInv_{(i,j,t)}(z) \Delta z \] \quad (1h)

where:

\[ CostOpE = \sum_t \sum_{(i,j)} (1 + r)^{-t} costOp_{(i,j)}(t) e_{(i,j)}(t) \] \quad (1i)

\[ CostInvE = \sum_t \sum_{(i,j)} (1 + r)^{-t} costInv_{(i,j)}(t) e_{Inf_{(i,j)}}(t) \] \quad (1j)

\[ CostOpT = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} costOp_{(i,j,k,m)}(t) f_{(i,j,k,m)}(t) \] \quad (1k)

\[ CostFleetInvT = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} costFleetInv_{(i,j,k,m)}(t) fleetInv_{(i,j,k,m)}(t) \] \quad (1l)

\[ CostInfInvT = \sum_t \sum_{(i,j,t)} (1 + r)^{-t} costInf_{(i,j,t)}(t) infInv_{(i,j,t)}(t) \] \quad (1m)

Energy demand from the transportation system
\[ d_j^{ET(t)} = \sum_{(a,b) \in A^T_a} \sum_{m \in M_t} fuelCons_{(a,b,m)}(t) \sum_k f_{(a,b,k,m)}(t) \] \quad (1n)

Decision variables:

Energy flows: \[ e_{(i,j)}(t) \geq 0 \] \quad (1o)

Energy capacity inv.: \[ lbe_{Inf_{(i,j)}}(t) \leq e_{Inf_{(i,j)}}(t) \leq ube_{Inf_{(i,j)}}(t) \] \quad (1p)

Transportation flows: \[ f_{(i,j,k,m)}(t) \geq 0 \] \quad (1q)

Fleet inv.: \[ lbe_{Fleet_{(i,j,m)}}(t) \leq fleet_{(i,j,m)}(t) \leq ube_{Fleet_{(i,j,m)}}(t) \] \quad (1r)

Infrastructure inv.: \[ lbe_{Inf_{(i,j,t)}}(t) \leq inf_{(i,j,t)}(t) \leq ube_{Inf_{(i,j,t)}}(t) \] \quad (1s)

Phase angles: \[ -\pi \leq \theta_e(t) \leq \pi \] \quad (1t)
The NODE concept in NETPLAN

State C
- Node 11
  - Elec. Demand

State B
- Node 10
  - Elec. Demand
- Gas Turbine
- Wind Turbine
- Wind Demand
- Node 6
- Node 7
- Node 8
- Node 9
- Node 5
- Elec. Demand
- Coal fired plant

State A
- Gas Turbine
- Gas Demand
- Node 1
- Natural gas
- Node 2
- Node 3
- Node 4
- Coal fired plant
- Coal
- Node 1
- Node 4
- Node 5
- Elec. Demand
Objectives

Transportation demand:

- freight
- passenger
  - personal light-duty vehicles
  - airplanes
  - trains
  - others
Modeling methods: $\alpha, \beta$

$\alpha$ whether account for the interdependency between the charge-depleting range (CDR) and the travel pattern

$\beta$ whether model the number of new sale light-duty vehicles ($N_{LV}^{sale}(t)$) as decision variables, where $LV \in \{SV^{fuel}, HEV^{fuel}, d_1^x, \cdots, d_n^x, FC^{fuel}\}$, $x \in \{fuel, EV\}$, $fuel \in \{gasoline, hydrogen, natural gas, \cdots \}$
Modeling methods: $\alpha \beta$

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- gasoline V
- hydrogen V
- natural gas V
- biodiesel V
- methanol V
- \ldots

- gasoline HEV
- hydrogen HEV
- natural gas HEV
- biodiesel HEV
- methanol HEV
- \ldots

- gasoline PHEV
- hydrogen PHEV
- natural gas PHEV
- biodiesel PHEV
- methanol PHEV
- \ldots

- gasoline FC
- hydrogen FC
- natural gas FC
- biodiesel FC
- methanol FC
- \ldots

and EV
Modeling methods: $\alpha . \beta$

$\alpha$ whether account for the interdependency between the charge-depleting range (CDR) and the travel pattern

$\beta$ whether model the number of new sale light-duty vehicles ($N_{LV}^{sale}(t)$) as decision variables, where $LV \in \{SV_{fuel}, HEV_{fuel}, d_1^x, \cdots, d_n^x, FC_{fuel}\}$, $x \in \{fuel, EV\}$, $fuel \in \{gasoline, hydrogen, natural gas, \cdots\}$
Model 0.0

\[ \min \{ \text{CostOp}^E + \text{CostInv}^E + \text{CostOp}^T + \text{CostFleetInv}^T + \text{CostInfInv}^T \} \]  
subject to:

Meet energy demand at every node

\[ \sum_i \eta(i,j)(t)e(i,j)(t) - \sum_i e(i,j)(t) = d_j^E(t) + d_j^{ET}(t) \]  

Energy flow lower and upper bounds

\[ lbe(i,j)(t) \leq e(i,j)(t) \leq ube(i,j)(t) \Delta t + \sum_{z=0} \varepsilon_{i,j}(z) \Delta z \]  

DC power flow equations

\[ e(i,j)(t) = b(i,j) \left( \theta_i(t) - \theta_j(t) \right), \quad \forall (i, j) \in A^E_{DC} \]  

Transportation demand for non-energy commodities

\[ \sum_m f_{i,j,k,m}(t) = d_{i,j,k}(t), \quad k \in K \backslash K_c \]  

Transportation demand for energy commodities

\[ \sum_m f_{i,j,k,m}(t) = heatContent_{k}^{-1}(t) e_{n_{i,j,k},n_{i,j,k}}(t), \quad k \in K_c \]  

Fleet upper bound for transportation flows

\[ \sum_k f_{i,j,k,m}(t) \leq ubFleet_{i,j,m}(t) \Delta t + \sum_{z=0} fleet_{i,j,m}(z) \Delta z \]  

Infrastructure upper bound for transportation flows

\[ \sum_k \sum_{m \in M_1} f_{i,j,k,m}(t) \leq ubInf_{i,j,l}(t) \Delta t + \sum_{z=0} inf_{i,j,l}(z) \Delta z \]  

where:

\[ \text{CostOp}^E = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costOp}^E_{i,j,t} e_{i,j}(t) \]  

\[ \text{CostInv}^E = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInv}^E_{i,j,t} e_{i,j}(t) \]  

\[ \text{CostOp}^T = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} \text{costOp}^T_{(i,j,k,m)} f_{(i,j,k,m)}(t) \]  

\[ \text{CostFleetInv}^T = \sum_t \sum_{(i,j,m)} (1 + r)^{-t} \text{costFleetInv}^T_{i,j,m}(t) \text{ fleet}_{i,j,m}(t) \]  

\[ \text{CostInfInv}^T = \sum_t \sum_{(i,j,l)} (1 + r)^{-t} \text{costInfInv}^T_{i,j,l}(t) \text{ inf}_{i,j,l}(t) \]  

Energy demand from the transportation system

\[ d_j^{ET}(t) = \sum_{(a,b) \in A^T_{f}} \sum_{m \in M_2} fuelCon_{s_{b,k,m}}(t) \sum_{k} f_{(a,b,k,m)}(t) + d_j^{ETPL}(t) \]  

Decision variables:

Energy flows: \( e_{i,j}(t) \geq 0 \)  
Energy capacity inv.: \( lbe_{i,j}(t) \leq e_{i,j}(t) \leq ube_{i,j}(t) \)  
Transportation flows: \( f_{i,j,k,m}(t) \geq 0 \)  
Fleet inv.: \( lbFleet_{i,j,m}(t) \leq fleet_{i,j,m}(t) \leq ubFleet_{i,j,m}(t) \)  
Infrastructure inv.: \( lbInf_{i,j,l}(t) \leq inf_{i,j,l}(t) \leq ubInf_{i,j,l}(t) \)  
Phase angles: \(-\pi \leq \theta_i(t) \leq \pi \)
Model 0.0

\[
\begin{align*}
\min & \quad \{ \text{CostOp}_E + \text{CostInv}_E + \text{CostOp}_T + \text{CostFleetInv}_T + \text{CostInfInv}_T \} \\
\text{subject to:} & \\
\text{Meet energy demand at every node:} & \\
\sum_i \eta(i,j)(t)e(i,j)(t) - \sum_i e(i,j)(t) = d_j^E(t) + d_j^{ET}(t) \\
\text{Energy flow lower and upper bounds:} & \\
lb_e(i,j)(t) \leq e(i,j)(t) \leq ub_e(i,j)(t) \Delta t + \sum_{z=0}^{t} \text{inv}(i,j)(z) \Delta z & (1a) \\
\text{DC power flow equations:} & \\
e(i,j)(t) = b(i,j) \left( \theta_i(t) - \theta_j(t) \right), \quad \forall(i,j) \in A^{E}_E & (1b) \\
\text{Transportation demand for non-energy commodities:} & \\
\sum_m f(i,j,k,m)(t) = d_{(i,j,k)}^T(t), \quad k \in K \backslash K_c & (1c) \\
\text{Transportation demand for energy commodities:} & \\
\sum_m f(i,j,k,m)(t) = \text{heatContent}^{-1}_k(t) e(i,j)(t), \quad k \in K_c & (1d) \\
\text{Fleet upper bound for transportation flows:} & \\
\sum_k f(i,j,k,m)(t) \leq u_bFleet(i,j,m)(t) \Delta t + \sum_{z=0}^{t} \text{inv}(i,j,m)(z) \Delta z & (1e) \\
\text{Infrastructure upper bound for transportation flows:} & \\
\sum_k \sum_{m \in M_t} f(i,j,k,m)(t) \leq u_bInf(i,j,t)(t) \Delta t + \sum_{z=0}^{t} \text{inv}(i,j,t)(z) \Delta z & (1f) \\
\end{align*}
\]

where:

\[
\begin{align*}
\text{CostOp}_E & = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costOp}_E(i,j)(t) e(i,j)(t) & (1i) \\
\text{CostInv}_E & = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInv}_E(i,j)(t) \text{inv}(i,j)(t) & (1j) \\
\text{CostOp}_T & = \sum_t \sum_{(i,j,k)} (1 + r)^{-t} \text{costOp}_T(i,j,k)(t) f(i,j,k,m)(t) & (1k) \\
\text{CostFleetInv}_T & = \sum_t \sum_{(i,j,m)} (1 + r)^{-t} \text{costFleetInv}_T(i,j,m)(t) \text{fleetInv}(i,j,m)(t) & (1l) \\
\text{CostInf}_T & = \sum_t \sum_{(i,j,t)} (1 + r)^{-t} \text{costInf}_T(i,j,t)(t) \text{infInv}(i,j,t)(t) & (1m) \\
\text{Energy demand from the transportation system:} & \\
d_j^{ET}(t) & = \sum_{(a,b)} \sum_{m \in M_t} \text{fuelCon}(a,b,m)(t) \sum_k f(a,b,k,m)(t) + d_j^{ETPL}(t) & (1n) \\
\end{align*}
\]

Decision variables:

\[
\begin{align*}
\text{Energy flows:} & \quad e(i,j)(t) \geq 0 & (1o) \\
\text{Energy capacity inv.:} & \quad lb\text{inv}(i,j)(t) \leq \text{inv}(i,j)(t) \leq ub\text{inv}(i,j)(t) & (1p) \\
\text{Transportation flows:} & \quad f(i,j,k,m)(t) \geq 0 & (1q) \\
\text{Fleet inv.:} & \quad lb\text{Fleet}(i,j,m)(t) \leq \text{fleet}(i,j,m)(t) \leq ub\text{Fleet}(i,j,m)(t) & (1r) \\
\text{Infrastructure inv.:} & \quad lb\text{inf}(i,j,t)(t) \leq \text{inf}(i,j,t)(t) \leq ub\text{inf}(i,j,t)(t) & (1s) \\
\text{Phase angles:} & \quad -\pi \leq \theta_i(t) \leq \pi & (1t) \\
\end{align*}
\]
Model 0.1

\[
\begin{align*}
\min & \quad \{ \text{CostOp}^E + \text{CostInv}^E + \text{CostOp}^T + \text{CostFleetInv}^T + \text{CostInfInv}^T \} \\
\text{subject to:} & \\
\text{Meet energy demand at every node} & \\
\sum_i \eta(i,j)(t)e(i,j)(t) - \sum_i \bar{e}(i,j)(t) = d_j^E(t) + \bar{d}_j^E(t) \quad (1a)
\end{align*}
\]

\[
\begin{align*}
\text{Energy flow lower and upper bounds} & \\
\bar{b}e(i,j)(t) & \leq e(i,j)(t) \leq \bar{u}b\bar{e}(i,j)(t) + \sum_{z=0}^t e\text{Inf}(i,j)(z) \Delta z \quad (1b)
\end{align*}
\]

\[
\begin{align*}
\text{DC power flow equations} & \\
e(i,j)(t) = b(i,j) \left( \theta_i(t) - \theta_j(t) \right), \quad \forall(i,j) \in A_{DC}^E \\
\text{Transportation demand for non-energy commodities} & \\
\sum_m f_{(i,j,k,m)}(t) &= d^T_{(i,j,k)}(t), \quad k \in K \backslash K_c \quad (1c)
\end{align*}
\]

\[
\begin{align*}
\text{Transportation demand for energy commodities} & \\
\sum_m f_{(i,j,k,m)}(t) &= \text{heatContent}_{i,k}^{-1}(t) e(n_{(i,j,k,m)}(t), a_{(i,j,k,m)}(t)), \quad k \in K_c \\
\text{Fleet upper bound for transportation flows} & \\
\sum_k f_{(i,j,k,m)}(t) & \leq ub\text{Fleet}(i,j,m)(t) + \sum_{z=0}^t \text{FleetInf}(i,j,m)(z) \Delta z \quad (1d)
\end{align*}
\]

\[
\begin{align*}
\text{Infrastructure upper bound for transportation flows} & \\
\sum_k f_{(i,j,k,m)}(t) & \leq ub\text{Inf}(i,j,m)(t) + \sum_{z=0}^t \text{InfInf}(i,j,m)(z) \Delta z \quad (1e)
\end{align*}
\]

\[
\begin{align*}
\text{LDV sales} & \\
\sum_{LV} N_{LV}^{\text{sale}}(t) &= N_{\text{sale}}(t)
\end{align*}
\]

where \( LV \in \{ \text{SV}^{\text{fuel}}, \text{HEV}^{\text{fuel}}, d_1^\times, \ldots, d_n^\times, \text{FC}^{\text{fuel}} \} \), \( x \in \{ \text{fuel}, \text{EV} \} \)

\[
\begin{align*}
\text{where:} & \\
\text{CostOp}^E & = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costOp}_{(i,j)}^E(t) e_{(i,j)}(t) \quad (1f) \\
\text{CostInv}^E & = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInv}_{(i,j)}^E(t) e_{(i,j)}(t) \quad (1g) \\
\text{CostOp}^T & = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} \text{costOp}_{(i,j,k,m)}^T(t) f_{(i,j,k,m)}(t) \quad (1h) \\
\text{CostFleetInv}^T & = \sum_t \sum_{(i,j,m)} (1 + r)^{-t} \text{costFleetInv}_{(i,j,m)}(t) \text{fleInf}_{(i,j,m)}(t) + \sum_t \text{vehCost}(t, LV) N_{LV}^{\text{sale}}(t) \\
\text{CostInfInv}^T & = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInf}_{(i,j)}(t) \text{infInf}_{(i,j)}(t) \quad (1i)
\end{align*}
\]

\[
\begin{align*}
\text{Energy demand from the transportation system} & \\
N_{LV}^{\text{sum}}(j, t) &= N_{LV}^{\text{sum}}(j, t - 1) - s_j N_{LV}^{\text{sale}}(t - T_{LV}) + s_j N_{LV}^{\text{sale}}(t) \\
d_j^E(t) &= \sum_{(a,b) \in A_T} \sum_{m \in M_j} \text{fuelCons}_{(a,b,m)}(t) f_{(a,b,k,m)}(t) + \sum_{LV} E_{LV}(t) N_{LV}^{\text{sum}}(j, t) \quad (1j)
\end{align*}
\]

\[
\begin{align*}
\text{Decision variables:} & \\
\text{Energy flows:} & \\
e_{(i,j)}(t) & \geq 0 \quad (1k) \\
\text{Energy capacity inv.:} & \\
\bar{b}e\text{Inf}_{(i,j)}(t) & \leq e\text{Inf}_{(i,j)}(t) \leq \bar{u}b\text{Inf}_{(i,j)}(t) \quad (1l) \\
\text{Transportation flows:} & \\
f_{(i,j,k,m)}(t) & \geq 0 \quad (1m) \\
\text{Fleet inv.:} & \\
\bar{b}f\text{Fleet}_{(i,j,m)}(t) & \leq \text{fleInf}_{(i,j,m)}(t) \leq \bar{u}b\text{Fleet}_{(i,j,m)}(t) \quad (1n) \\
\text{Infrastructure inv.:} & \\
\bar{b}f\text{Inf}_{(i,j)}(t) & \leq \text{infInf}_{(i,j)}(t) \leq \bar{u}b\text{Inf}_{(i,j)}(t) \quad (1o) \\
\text{Phase angles:} & \\
-\pi & \leq \theta_i(t) \leq \pi \quad (1p) \\
\text{LDV sale:} & \\
N_{LV}^{\text{sale}}(t) & \geq 0 \quad (1q)
\end{align*}
\]
Model 1.0 (same as 0.0 except $P_{d}^{fuels} (\cdot)$ function)

\[
\min \{ \text{CostOp}^E + \text{CostInv}^E + \text{CostOp}^T + \text{CostFleetInv}^T + \text{CostInfInv}^T \} \quad (1a)
\]

subject to:

Meet energy demand at every node
\[
\sum_i \eta(i,j) e(i,j)(t) - \sum_i c(i,j) = d^E_j(t) + d^{ET}_j(t) \quad (1b)
\]

Energy flow lower and upper bounds
\[
\text{lb}(i,j)(t) \leq e(i,j)(t) \Delta t + \sum z e^z(i,j)(z) \Delta z \quad (1c)
\]

DC power flow equations
\[
e(i,j)(t) = b(i,j) (\theta_i(t) - \theta_j(t)), \quad \forall (i, j) \in A^E_{DC} \quad (1d)
\]

Transportation demand for non-energy commodities
\[
\sum_{m} f(i,j,k,m)(t) = d^T_{(i,j,k)}(t), \quad k \in K \setminus K_c \quad (1e)
\]

Transportation demand for energy commodities
\[
\sum_{m} f(i,j,k,m)(t) = \text{heatContent}^{-1}_k(t) e^z(i,j,k,m)(t), \quad k \in K_c \quad (1f)
\]

Fleet upper bound for transportation flows
\[
\sum_k f(i,j,k,m)(t) \leq ubFleet(i,j,m)(t) \Delta t + \sum z ubFleet^z(i,j,m)(z) \Delta z \quad (1g)
\]

Infrastructure upper bound for transportation flows
\[
\sum_k \sum_{m} f(i,j,k,m)(t) \leq ubInf(i,j,t)(t) \Delta t + \sum z ubInf^z(i,j,t)(z) \Delta z \quad (1h)
\]

where:

\[
\text{CostOp}^E = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costOp}^E_{(i,j)}(t) e(i,j)(t) \quad (1i)
\]

\[
\text{CostInv}^E = \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInv}^E_{(i,j)}(t) e(i,j)(t) \quad (1j)
\]

\[
\text{CostOp}^T = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} \text{costOp}^T_{(i,j,k,m)}(t) f(i,j,k,m)(t) \quad (1k)
\]

\[
\text{CostFleetInv}^T = \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} \text{CostFleetInv}^T_{(i,j,k,m)}(t) \text{fleett}_{(i,j,k,m)}(t) \quad (1m)
\]

Energy demand from the transportation system
\[
d^{ET}_j(t) = \sum_{(a,b,k,m)} fuelCons_{(a,b,k,m)}(t) \sum_k f_{(a,b,k,m)}(t) + d^{ETPLV}_j(t) \quad (1n)
\]

Decision variables:

Energy flows: $e(i,j)(t) \geq 0 \quad (1o)$
Energy capacity inv.: $\text{lb}(i,j)(t) \leq e(i,j)(t) \leq ub(i,j)(t) \quad (1p)$
Transportation flows: $f(i,j,k,m)(t) \geq 0 \quad (1q)$
Fleet inv.: $\text{lbFleet}(i,j,m)(t) \leq \text{fleett}(i,j,m)(t) \leq ubFleet(i,j,m)(t) \quad (1r)$
Infrastructure inv.: $\text{lbInf}(i,j,t)(t) \leq \text{inf}(i,j,t)(t) \leq ubInf(i,j,t)(t) \quad (1s)$
Phase angles: $-\pi \leq \theta_i(t) \leq \pi \quad (1t)$
Model 1.0 (same as 0.0 except \( P_{d}^{fuel} (\cdot) \) function)

\[
\begin{align*}
\min \{& \text{CostOp}^E + \text{CostInv}^E + \text{CostOp}^T + \text{CostFleetInv}^T + \text{CostInfInv}^T \} \quad (1a) \\
\text{subject to:} \\
& \text{Meet energy demand at every node} \\
\sum_i & \eta_{i,j}(t) e_{i,j}(t) - \sum_i e_{i,j}(t) = d_j^E(t) + d_j^{ET}(t) \quad (1b) \\
\text{Energy flow lower and upper bounds} \\
\bar{b}e_{i,j}(t) & \leq e_{i,j}(t) \leq \bar{b}e_{i,j}(t) \Delta t + \sum_{z=0}^{t} e_{i,j}(z) \Delta z \quad (1c) \\
\text{DC power flow equations} \\
e_{i,j}(t) = b_{i,j} \left( \theta_i(t) - \theta_j(t) \right), \quad \forall (i, j) \in A_{DC}^E \quad (1d) \\
\text{Transportation demand for non-energy commodities} \\
\sum_m f_{i,j,k,m}(t) = d_{i,j-1,k}(t), \quad k \in K \setminus K_c \quad (1e) \\
\text{Transportation demand for energy commodities} \\
\sum_m f_{i,j,k,m}(t) = \text{heatContent}_k^{-1}(t) e_{a,b,k}(t), \quad k \in K_c \quad (1f) \\
\text{Fleet upper bound for transportation flows} \\
\sum_k f_{i,j,k,m}(t) \leq \bar{b}e_{Fleet, i,j,m}(t) \Delta t + \sum_{z=0}^{t} \text{fleetInv}_{i,j,m}(z) \Delta z \quad (1g) \\
\text{Infrastructure upper bound for transportation flows} \\
\sum_k \sum_{m \in M_l} f_{i,j,k,m}(t) \leq \bar{b}e_{Inf, i,j,l}(t) \Delta t + \sum_{z=0}^{t} \text{infInv}_{i,j,l}(z) \Delta z \quad (1h)
\end{align*}
\]

where:

\[
\begin{align*}
\text{CostOp}^E &= \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costOp}^E_{i,j}(t) e_{i,j}(t) \quad (1i) \\
\text{CostInv}^E &= \sum_t \sum_{(i,j)} (1 + r)^{-t} \text{costInv}^E_{i,j}(t) e_{i,j}(t) \quad (1j) \\
\text{CostOp}^T &= \sum_t \sum_{(i,j,k,m)} (1 + r)^{-t} \text{costOp}^T_{i,j,k,m}(t) f_{i,j,k,m}(t) \quad (1k) \\
\text{CostFleetInv}^T &= \sum_t \sum_{(i,j,m)} (1 + r)^{-t} \text{costFleetInv}^T_{i,j,m}(t) \text{fle}ntInv_{i,j,m}(t) \quad (1l) \\
\text{CostInfInv}^T &= \sum_t \sum_{(i,j,l)} (1 + r)^{-t} \text{costInfInv}^T_{i,j,l}(t) \text{infInv}_{i,j,l}(t) \quad (1m)
\end{align*}
\]

Energy demand from the transportation system

\[
d_j^{ET}(t) = \sum_{(a,b) \in A_{m}^e} \sum_k \text{fuelCons}_{a,b,k,m}(t) \sum_m f_{a,b,k,m}(t) + d_j^{ETPLV}(t) \quad (1n)
\]

Decision variables:

\[
\begin{align*}
\text{Energy flows:} \quad & e_{i,j}(t) \geq 0 \quad (1o) \\
\text{Energy capacity inv.:} \quad & \bar{b}e_{Inf, i,j}(t) \leq \text{Inf}_{i,j}(t) \leq \bar{b}e_{Inf, i,j}(t) \quad (1p) \\
\text{Transportation flows:} \quad & f_{i,j,k,m}(t) \geq 0 \quad (1q) \\
\text{Fleet inv.:} \quad & \bar{b}e_{Fleet, i,j,m}(t) \leq \text{fle}ntInv_{i,j,m}(t) \leq \bar{b}e_{Fleet, i,j,m}(t) \quad (1r) \\
\text{Infrastructure inv.:} \quad & \bar{b}e_{Inf, i,j,l}(t) \leq \text{infInv}_{i,j,l}(t) \leq \bar{b}e_{Inf, i,j,l}(t) \quad (1s) \\
\text{Phase angles:} \quad & -\pi \leq \theta_i(t) \leq \pi \quad (1t)
\end{align*}
\]

\begin{itemize}
\item \( N_{\text{sale}}^{\text{SV}_{fuel}}(t), N_{\text{sale}}^{\text{HEV}_{fuel}}(t), N_{\text{sale}}^{\text{PHEV}_{fuel}}(t), N_{\text{sale}}^{\text{EV}}(t), N_{\text{sale}}^{\text{FC}_{fuel}}(t) \). (e.g., \( N_{\text{sale}}^{\text{fuel}}(t) = N_{\text{sale}}^{\text{PHEV}_{fuel}}(t) P_{d}^{fuel} (d = d) \))
\item \( \text{CostFleetInv}^{TLP}_{LV} = \sum_t (1 + r)^{-t} \sum_{LV} \text{vehCost}(t, LV) N_{\text{cum}}^{\text{LV}}(t),\) where \( LV \in \{ \text{SV}_{fuel}, \text{HEV}_{fuel}, d_1^n, \ldots, d_n^n, \text{FC}_{fuel} \}, x \in \{ \text{fuel}, \text{EV} \} \)
\item \( d_j^{ETPLV}(t) = \sum_{LV} E_{LV}(t) N_{\text{cum}}^{\text{LV}}(j, t), (E \in \{ \text{gasoline, hydrogen, natural gas, electricity, \ldots} \}) \)
\end{itemize}
Model 1.0

It is assumed that for “most” vehicles in NHTS, the VMT happened on the assigned travel day “somehow” reflects their travel pattern on everyday basis.

\[ f_{m,d}(u, v) = f_{d|m}(v|u)f_m(u). \]

\[ f_d(x) = \int_0^\infty f_{m,d}(u, x) \, du = \int_0^\infty f_{d|m}(x|u)f_m(u) \, du. \]
Model 1. \frac{1}{2}

\min \ \{ CostOp^E + CostInv^E + CostOp^T + CostFleetInv^T + CostInfInv^T \} \tag{1a}

subject to:
Meet energy demand at every node
\[ \sum_i \eta(i,j) e(i,j)(t) - \sum_i e(j,i)(t) = d_j^E(t) + d_j^{ET}(t) \tag{1b} \]

Energy flow lower and upper bounds
\[ lb(e)(t) \leq e(i,j)(t) \leq ub(e)(t) \Delta t + \sum_{z=0}^t eInv(i,j)(z) \Delta z \tag{1c} \]

DC power flow equations
\[ e(i,j)(t) = b(i,j) \left( \theta_i(t) - \theta_j(t) \right), \quad \forall(i,j) \in \mathcal{A}_{BC}^B \tag{1d} \]

Transportation demand for non-energy commodities
\[ \sum_m f(i,j,k,m)(t) = d_{(i,j,k)}^T(t), \quad k \in \mathcal{K} \setminus \mathcal{K}_C \tag{1e} \]

Transportation demand for energy commodities
\[ \sum_m f(i,j,k,m)(t) = heatContent_E^{-1}(t) e_{(i,k,m)}(t), \quad k \in \mathcal{K}_C \tag{1f} \]

Fleet upper bound for transportation flows
\[ \sum_k f(i,j,k,m)(t) \leq ubFleet(i,j,m)(t) \Delta t + \sum_{z=0}^t fleetInv(i,j,m)(z) \Delta z \tag{1g} \]

Infrastructure upper bound for transportation flows
\[ \sum_k \sum_{m \in \mathcal{M}_i} f(i,j,k,m)(t) \leq ubInf(i,j,l)(t) \Delta t + \sum_{z=0}^t infInv(i,j,l)(z) \Delta z \tag{1h} \]

LDV sales
\[ \sum_{L_{LV}} N_{sale}(t) = N_{sale}(t) \]

where \( L_{LV} \in \{ SV^{fuel}, HEV^{fuel}, PHEV^{fuel}, EV, FC^{fuel} \} \)

where:
\[ CostOp^E = \sum_{i,j} (1 + r)^{-t} costOp_{(i,j)}(t) e(i,j)(t) \tag{1i} \]
\[ CostInv^E = \sum_{i,j} (1 + r)^{-t} costInv_{(i,j)}(t) eInv_{(i,j)}(t) \tag{1j} \]
\[ CostOp^T = \sum_{i,j,k,m} (1 + r)^{-t} costOp_{(i,j,k,m)}(t) f_{(i,j,k,m)}(t) \tag{1k} \]
\[ CostFleetInv^T = \sum_{i,j,m} (1 + r)^{-t} costFleetInv_{(i,j,m)}(t) fleetInv_{(i,j,m)}(t) \tag{1l} \]
\[ + \sum_{i,j,m} (1 + r)^{-t} \sum_{LV} vehCost(t,LV) N_{LV}^{sale}(t) \tag{1m} \]

Energy demand from the transportation system
\[ N_{LV}^{cum}(j,t) = N_{LV}^{cum}(j,t-1) - s_j N_{LV}^{sale}(t - T_{LV}) + s_j N_{LV}^{sale}(t) \tag{1n} \]
\[ d_j^{ET}(t) = \sum_{(a,b) \in \mathcal{A}} \sum_{m \in \mathcal{M}_j} fuelCons_{(a,b,m)}(t) \sum_k f_{(a,b,k,m)}(t) + \sum_{LV} E_{LV}(t) N_{LV}^{sale}(j,t) \tag{1n} \]

Decision variables:
Energy flows:
\[ e(i,j)(t) \geq 0 \tag{1o} \]
Energy capacity inv.: \[ lbInv_{(i,j)}(t) \leq eInv_{(i,j)}(t) \leq ubInv_{(i,j)}(t) \tag{1p} \]
Transportation flows:
\[ f_{(i,j,k,m)} \geq 0 \tag{1q} \]
Fleet inv.: \[ lbFleetInv_{(i,j,m)}(t) \leq fleetInv_{(i,j,m)}(t) \leq ubFleetInv_{(i,j,m)}(t) \tag{1r} \]
Infrastructure inv.: \[ lbInf_{(i,j,l)}(t) \leq infInv_{(i,j,l)}(t) \leq ubInf_{(i,j,l)}(t) \tag{1s} \]
Phase angles:
\[ -\pi \leq \theta(t) \leq \pi \tag{1t} \]
LDV sale:
\[ N_{LV}^{sale}(t) \geq 0 \tag{1u} \]