A Modelica Library and Scenarios for Sweden's Conversion from fossil powered to electric transportation

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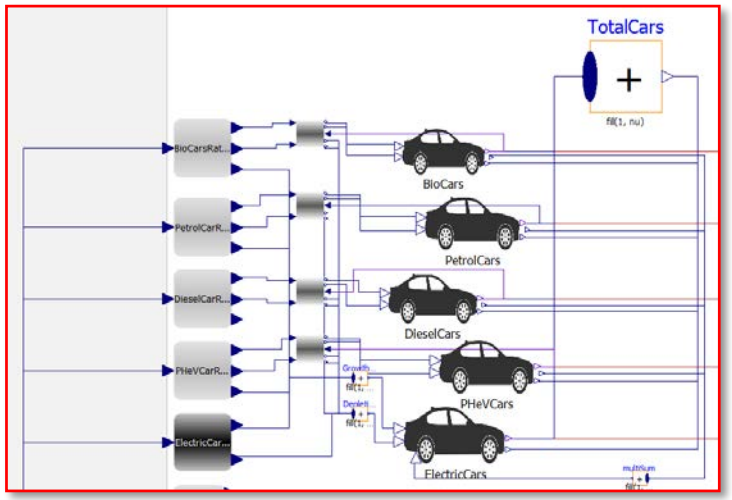
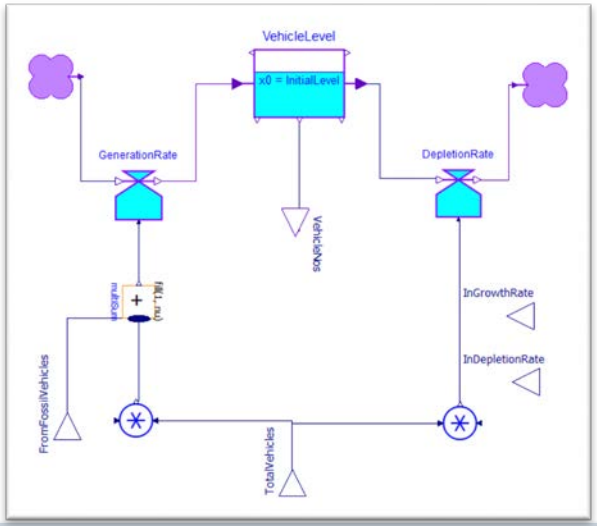


OpenModelica Workshop, Jan 31, 2022
(this version slightly updated 220422)

Acknowledgements to Lars Schütt for providing model parameters from the Swedish transport sector statistics and to the Swedish climate parliament (Klimatriksdagen) transport and mobility group for inspiring discussions.



Background – Eliminate Fossil Transport Emissions

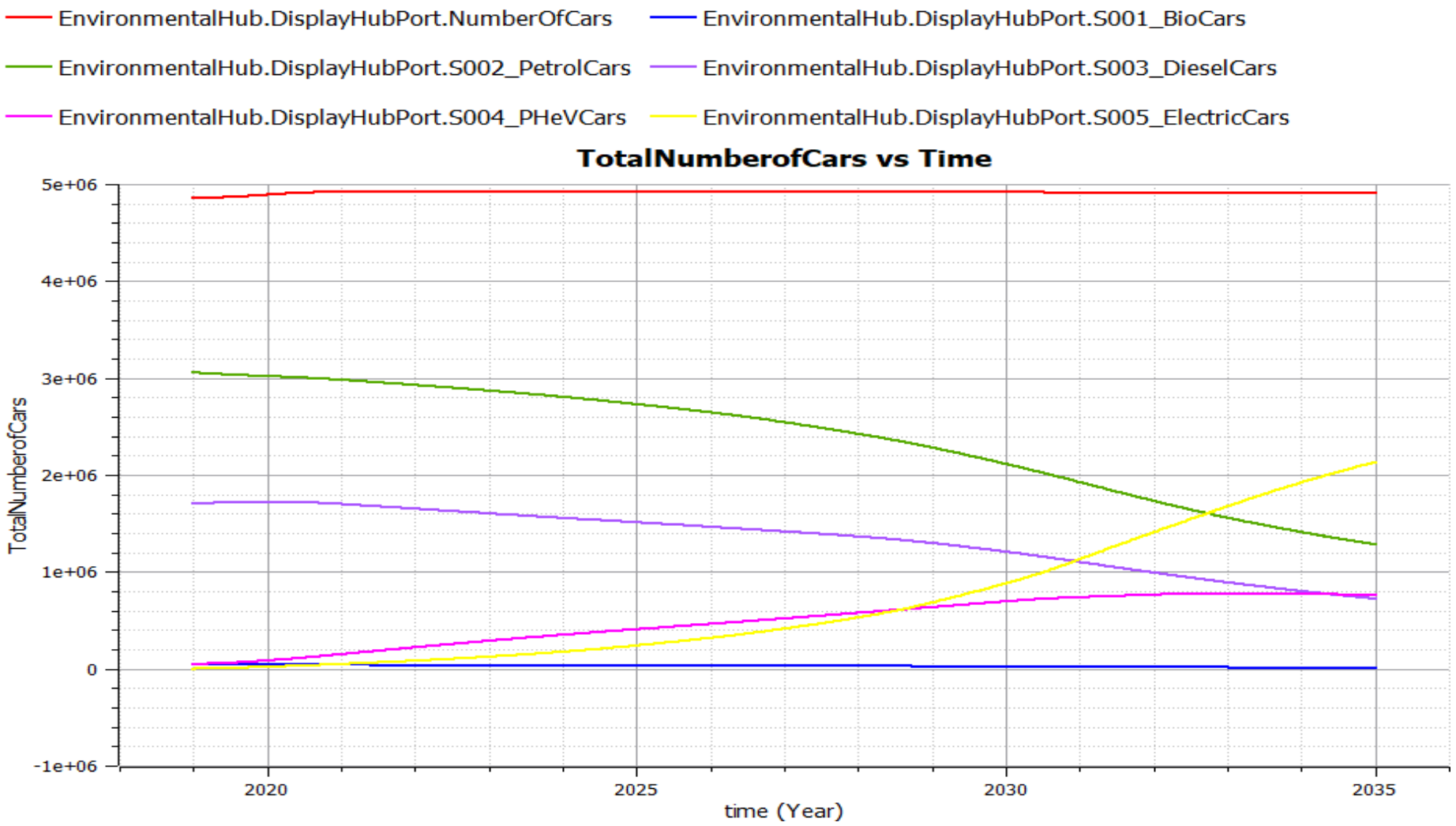
- A large part of the **Worlds CO2 emission** comes from **transportation**, from fossil fueled vehicles
- In Sweden, about 5 million **cars** emit about **10 Mton CO2e** annually
- In Sweden, **trucks** emit about **5 Mton CO2e** annually, **Construction** machines about **3Mton CO2e**

- Transition to **electric powered vehicles** to eliminate emissions
- Model library developed in Modelica using **System Dynamics** Library by Francois Cellier
- Investigation of 4 kinds of vehicles: **Cars**, **Light Trucks, Heavy Trucks, Buses**
- Subcategories: **Petrol Vehicles, Diesel Vehicles, PHeV Vehicles, Biogas Vehicles and Electric Vehicles**

- Four transition **Scenarios** simulated for the time span **2019 – 2035,** year 2035 is necessary to comply with the Paris agreement
  - **Scenario 1 – Gradual transition with increase of electric vehicles**
  - **Scenario 2 – Faster transition, with fossil ban year for sales of new fossil cars 2025**
  - **Scenario 3 – Also doubling public transport like buses, (train), reducing fossil car driving correspondingly**
  - **Scenario 4 – Hardware conversion of remaining fossil cars to electric**

Results Scenario 1 – Cars

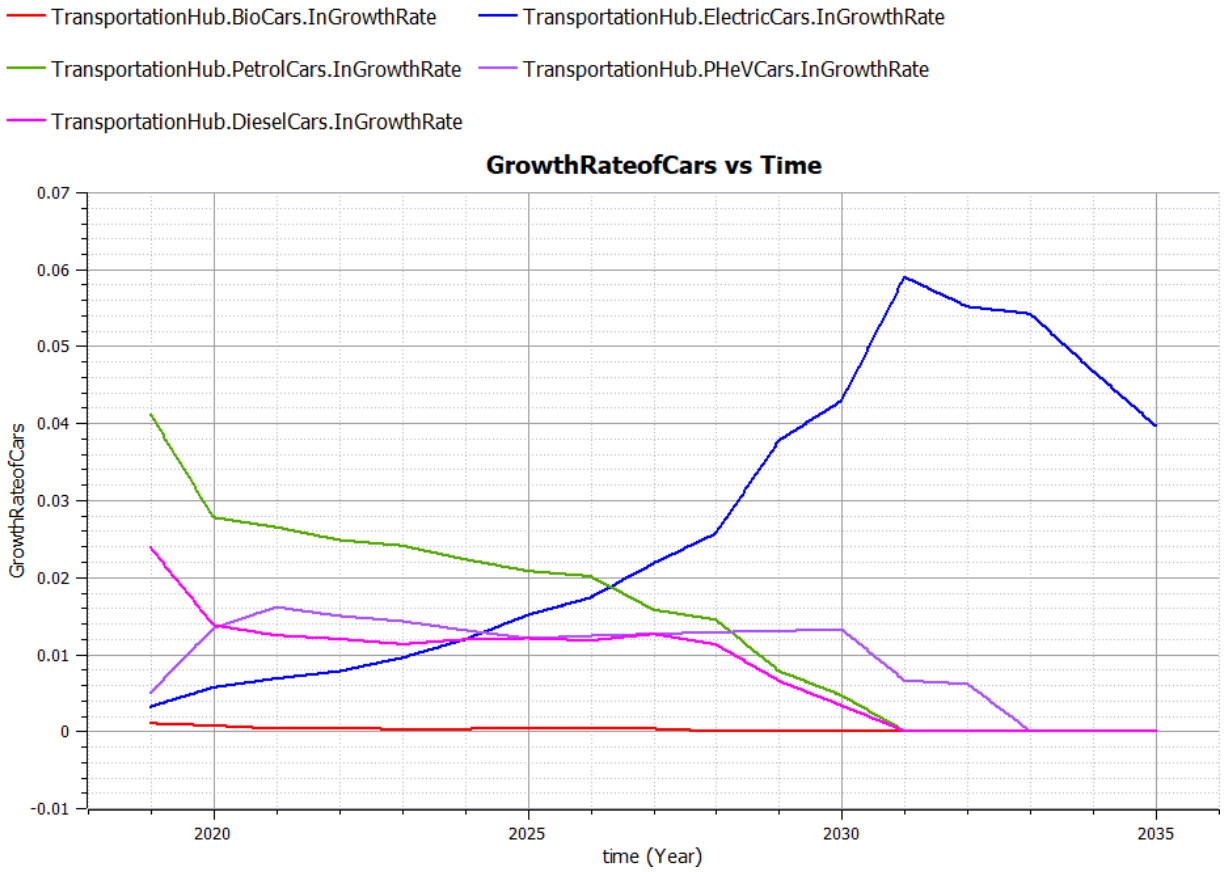
Conversion Percentage -None, Average driving range km Reduction – None, FossilBanSwitch - False

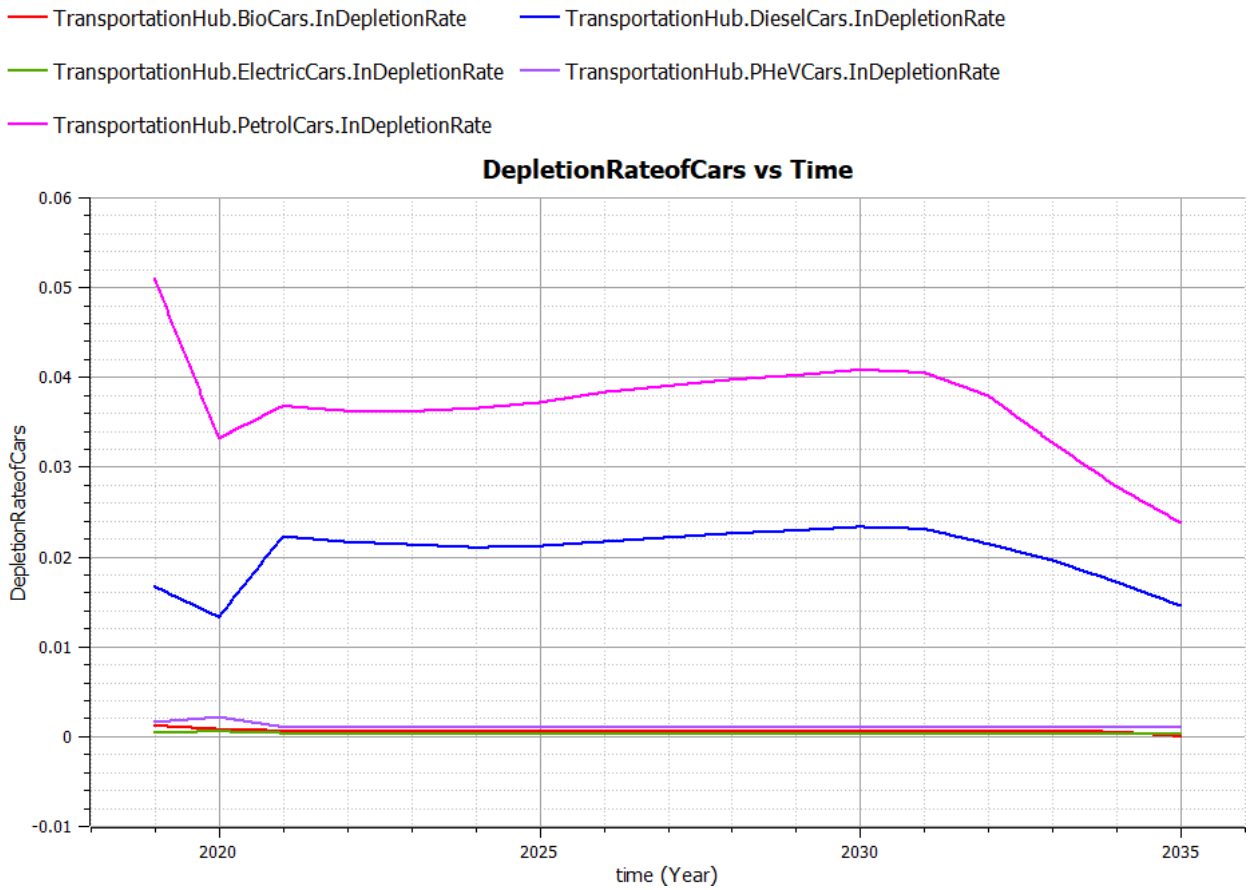


Car	Fossil Ban Year
Petrol	2100
Diesel	2100
Bio	2100
PHeV	2100

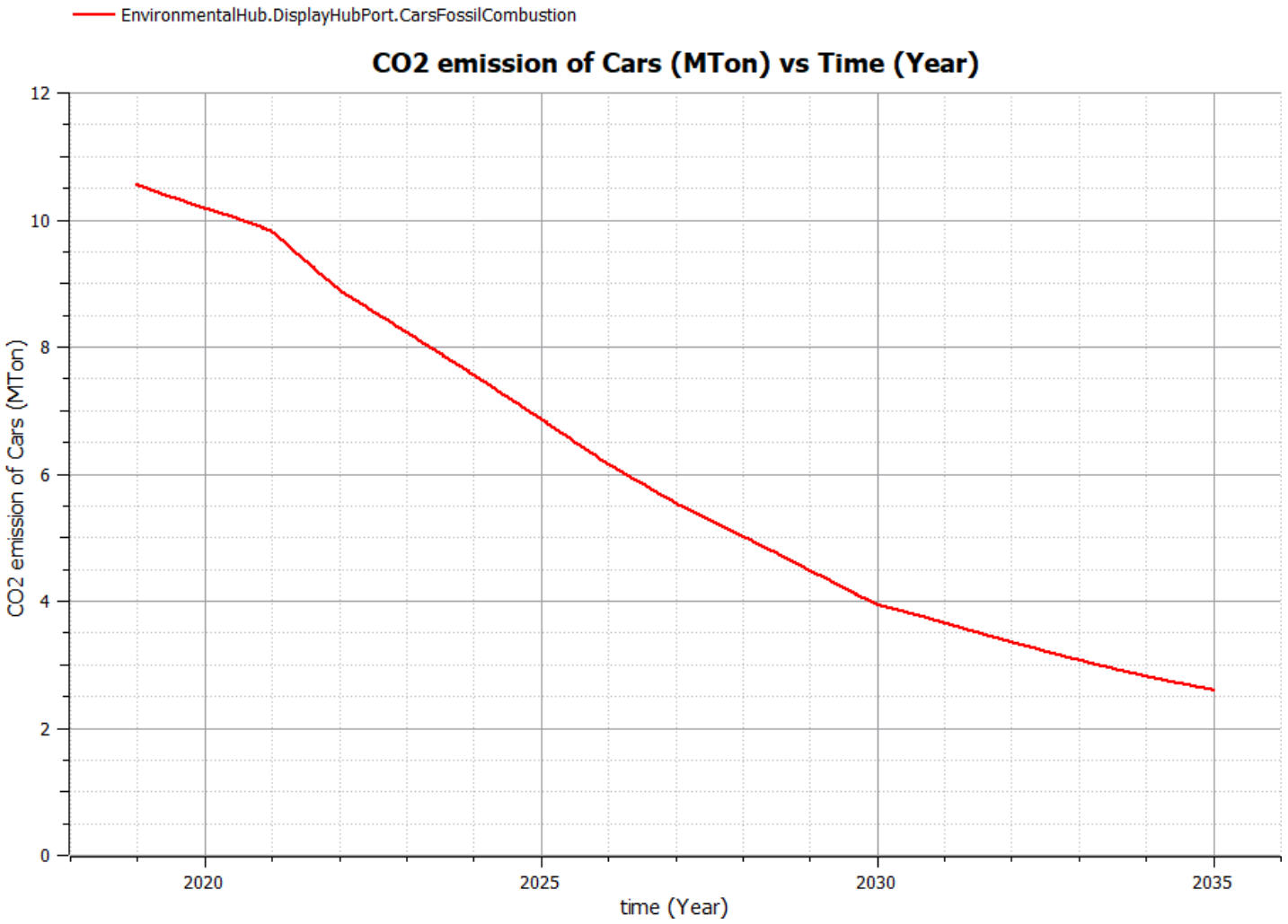
Vehicle	Legends
Total Number of Cars	
Bio Gas Cars	
Petrol Cars	
Diesel Cars	
PHeV Cars	
Electric Cars	

Results Scenario 1 – Cars Growth Rate and Depletion Rate

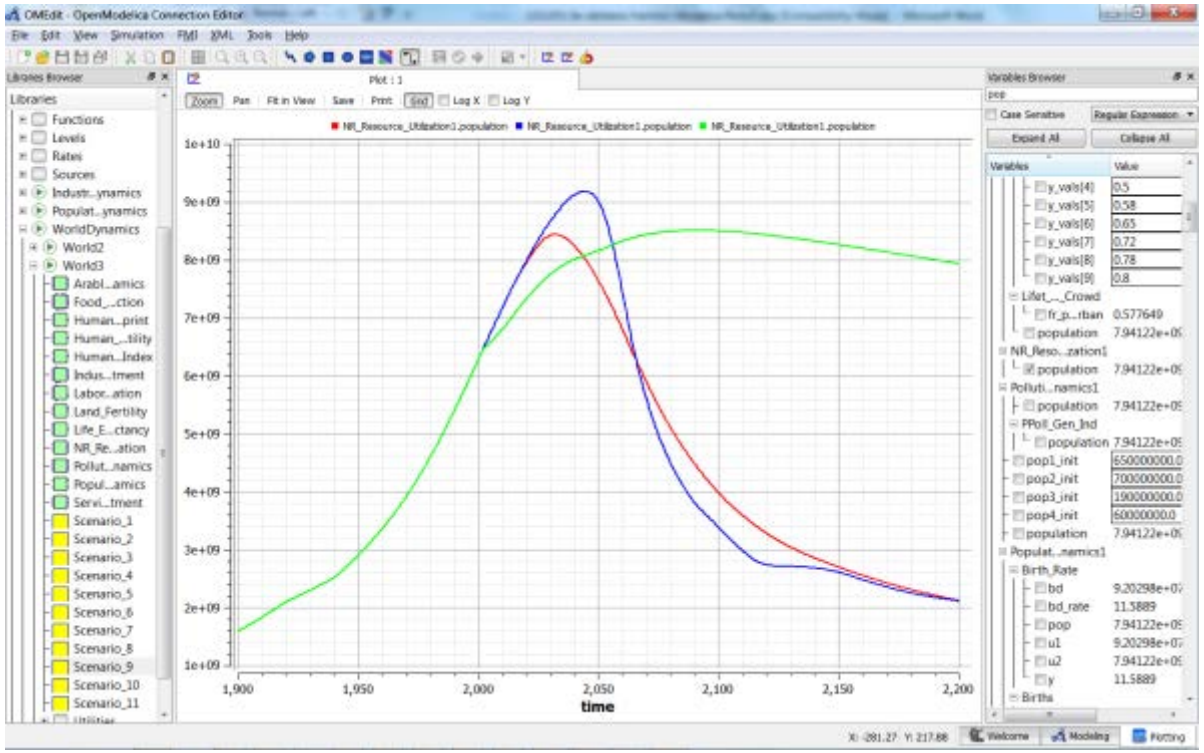


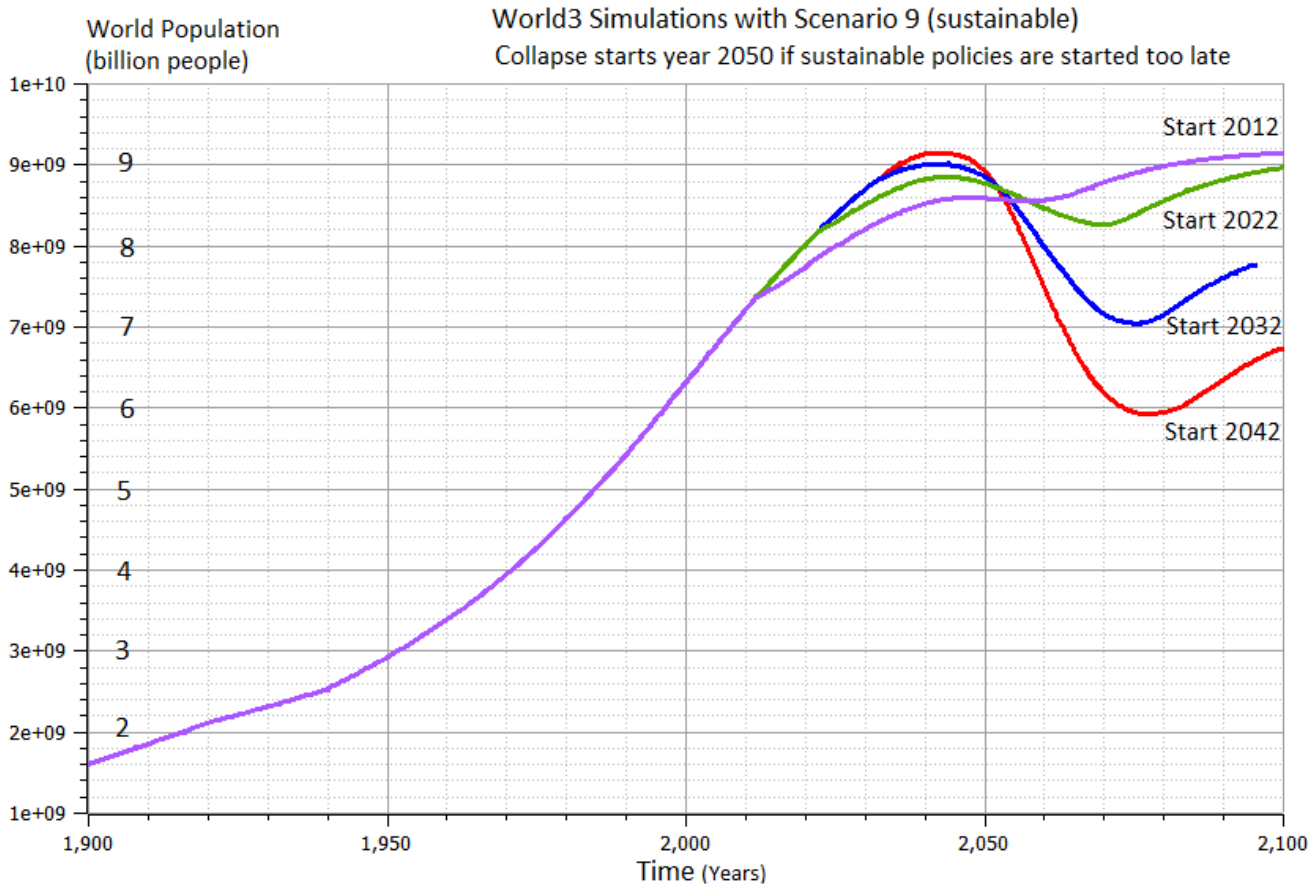


Results Scenario 1 – Total Cars CO2 Fossil Emissions



World3 Simulations with Different Start Years for Sustainable Policies – Collapse if starting too late





Left. System Dynamics World3 simulation with OpenModelica. World population. (ref Meadows et al)

- 2 collapse scenarios (close to current developments)
- 1 sustainable scenario (green).

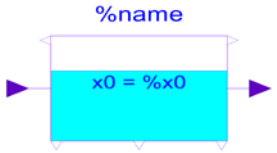
Transportation Library Background Information

- This package has been developed to Simulate Different Transportation Models Scenarios for electrification of the vehicle fleet for the reduction of Carbon Footprint.
- This package is model of physical Road Transportation which consists of Four kind of vehicles (**Cars, Light Trucks, Heavy Trucks and Buses**) and sub categorized as **Petrol Vehicles, Diesel Vehicles, PHeV Vehicles, Biogas Vehicles and Electric Vehicles**.
- It is a model which have four scenarios of Transportation Model i.e., Scenario 1, Scenario 2, Scenario 3 and Scenario4.
  - Under Scenarios, There are three modules i.e., Transportation Hub, Environmental Hub and transportation Integrator .Transportation Integrator is a main simulation model. It will run for the **time period of 2019 to 2035** which is hard coded in the model.
  - All the **data** is coming from the resource folder under the transportation model that consist of **Combitables**. If user get new data for this package, then the combitable must be updated with new data. The user will get three submodels in the output simulation screen:
  - EnvironmentalHub
  - TP
  - TransportationHub

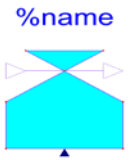
Modeling Components – Modelica System Dynamics and Blocks

The model uses component from the System Dynamics Library and some components from Modelica Blocks.* sublibraries

- Major components from System Dynamics Library are:
  - Level



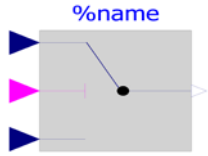
  - Rate_1



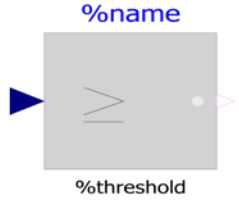
  - Source

  - Sink

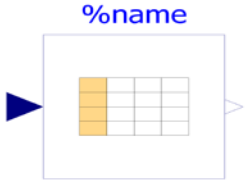
- From Modelica Blocks library:
  - Switch



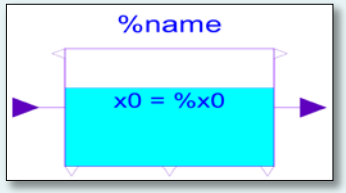
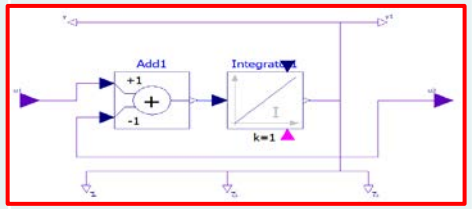
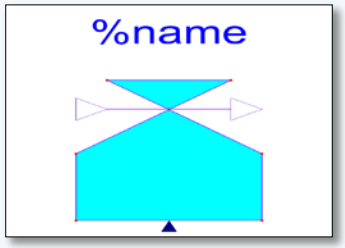
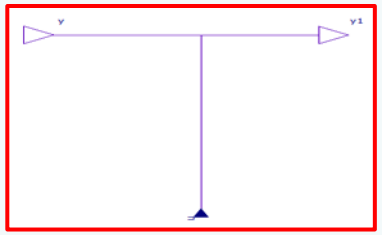
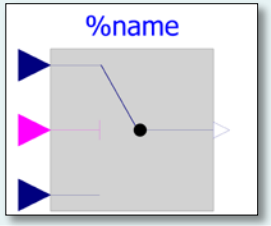
  - Greater Threshold



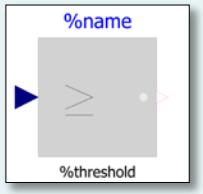
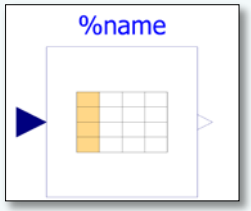
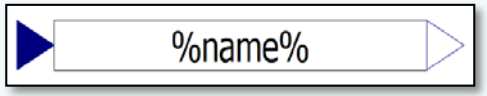
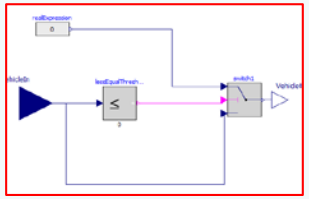
  - Combitable



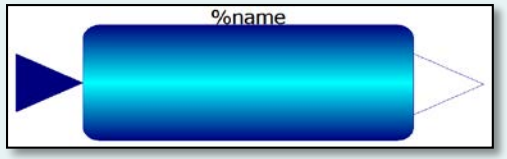
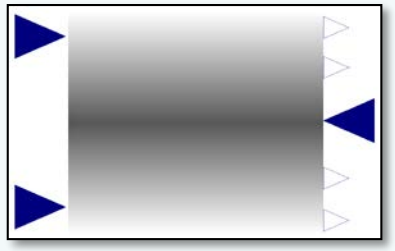
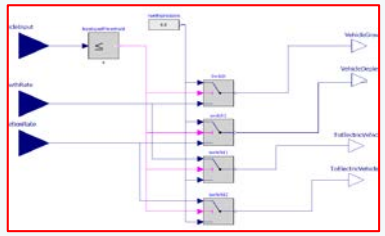
Modeling Components - *continued*

Block Name	Block Symbol	Block Diagram	Explanation
Level			• This block gives a continuous change in the **level of the tank**
Rate_1			• This is the general **System Dynamics unrestricted Rate element**, whereby the rate itself is determined by a single variable in its laundry list. • The indicated direction of mass flow simply denotes the **direction of positive mass flow**. However if the control signal of the rate assumes a negative value, mass will flow in the opposite direction.
Switch1			y = if u2 then u1 else u3; y is real output u2 is Boolean Input u1 and u3 is real input

Modeling Components - *continued*

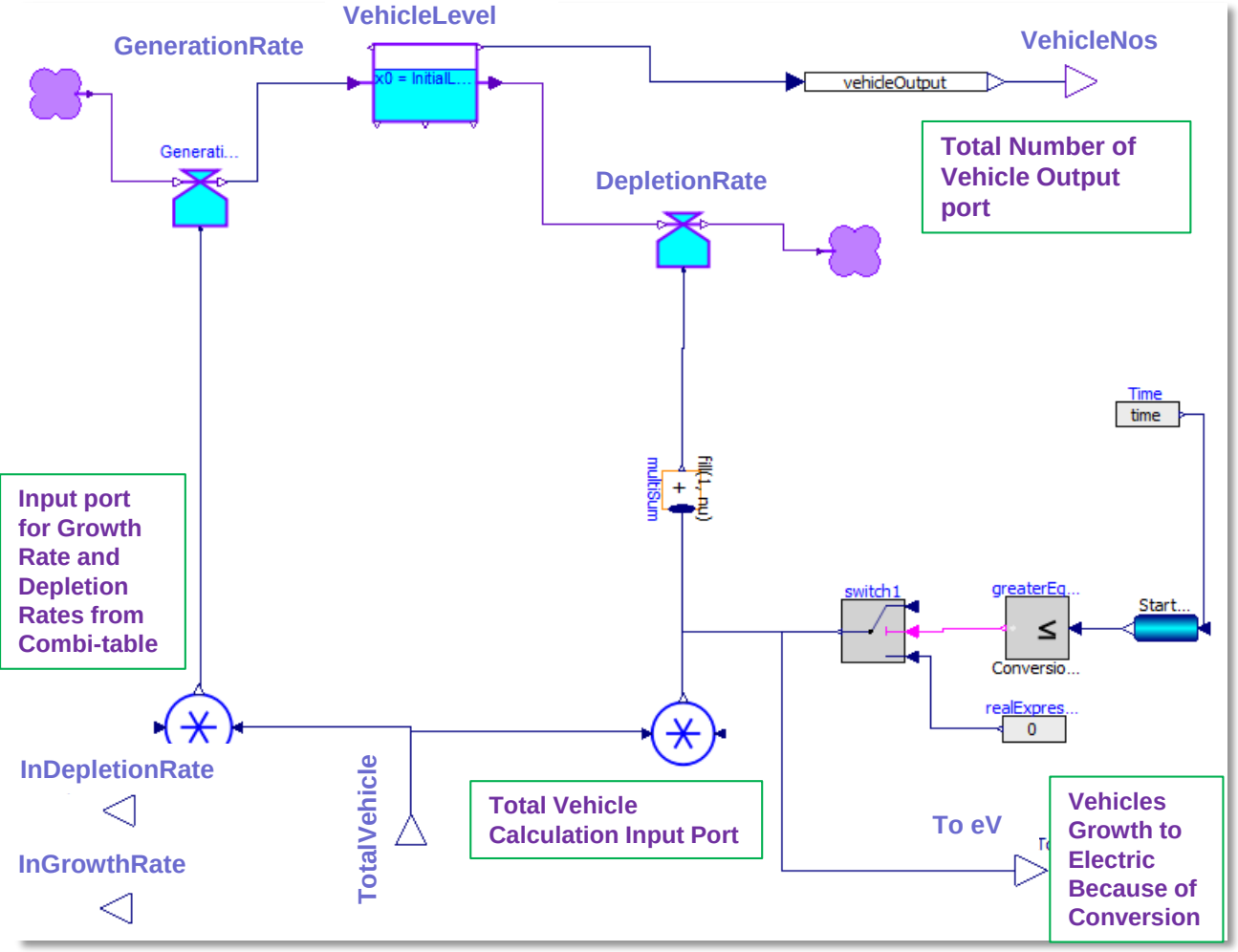
Block Name	Block Symbol	Block Diagram	Explanation
GreaterThreshold			y = u > threshold; Where y is Boolean Output u is Real Input
Combi-Table			• It helps to import te data from a external source file (like .txt) • Format of the table is 1st column is time the other contains numeric values • The time is an input of the combitable and It will give respective value as output
variableAverageKM			• It gives average km vehicle driving range that reduce w.r.t time with a given percentage
VehicleOutput			• If **VehicleIn** will be less than or equal to zero then VehiceOut value will be zero . Else it will be normal **VehicleLevel** values.

Modeling Components - *continued*

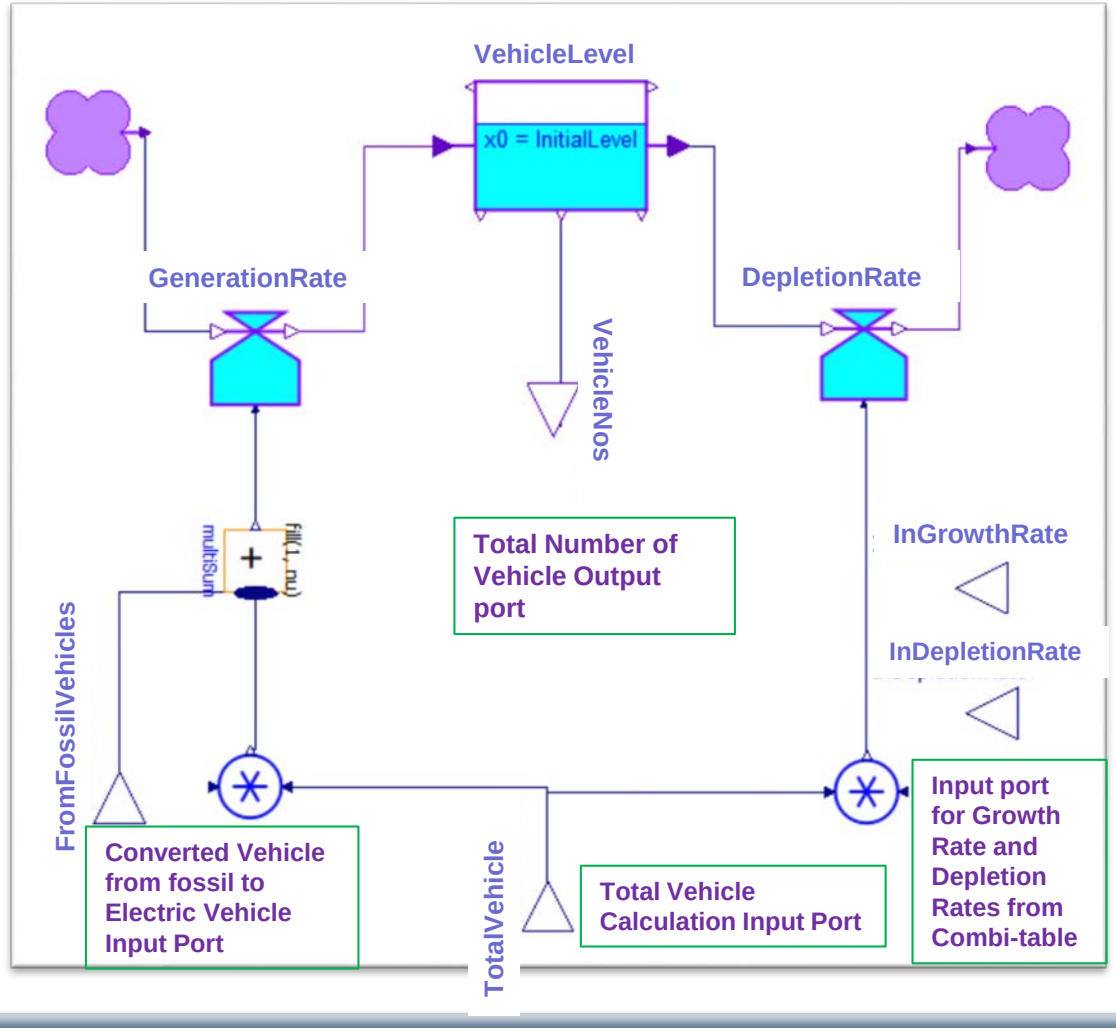
Block Name	Block Symbol	Block Diagram	Explanation
startConversionSwitch			• If this flag is true then this added part in vehicle pool will be active. • If the input time (in years)is greater or equal to the conversion year then input at u1 of switch1 will be output of switch 1 and added to the depletion number of vehicles, simultaneously this number will also add in the electric vehicles to balance the total number .
ConversionProgramme			• If Vehicles input are greater than zero then normal vehicles growth rate and vehicles depletion rate will pass and 0 will pass to electrical Vehicles growth and depletion . • if vehicles input are less than or equal to 0 then incoming growth and depletion rate will be added to electrical vehicles growth and electrical vehicles depletion rate respectively. • And same time 0 will pass to vehicles growth rate and depletion rate.

Model Components – Model for Total Number of Vehicle at end of the Simulation

Vehicles

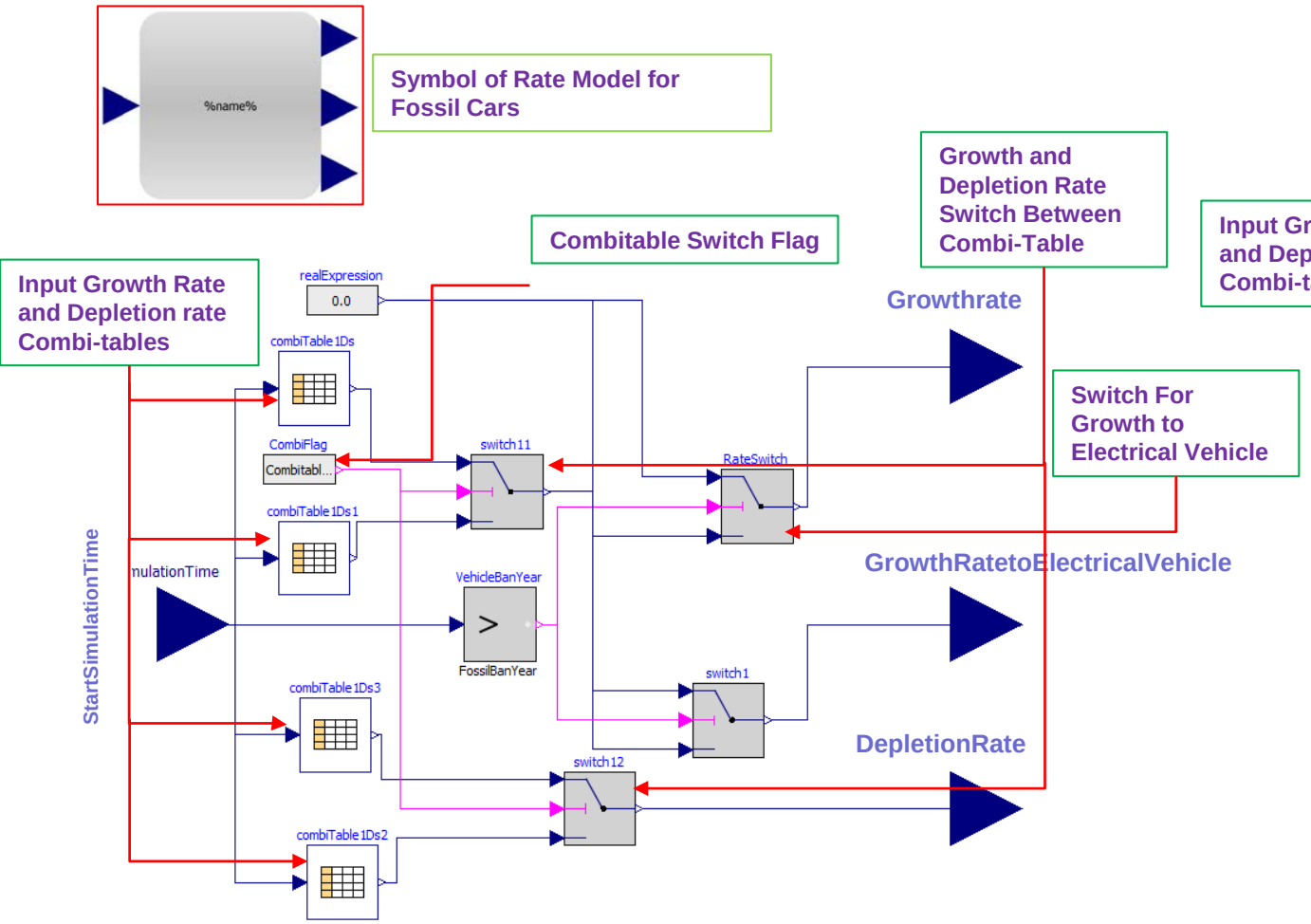


Electric Vehicles

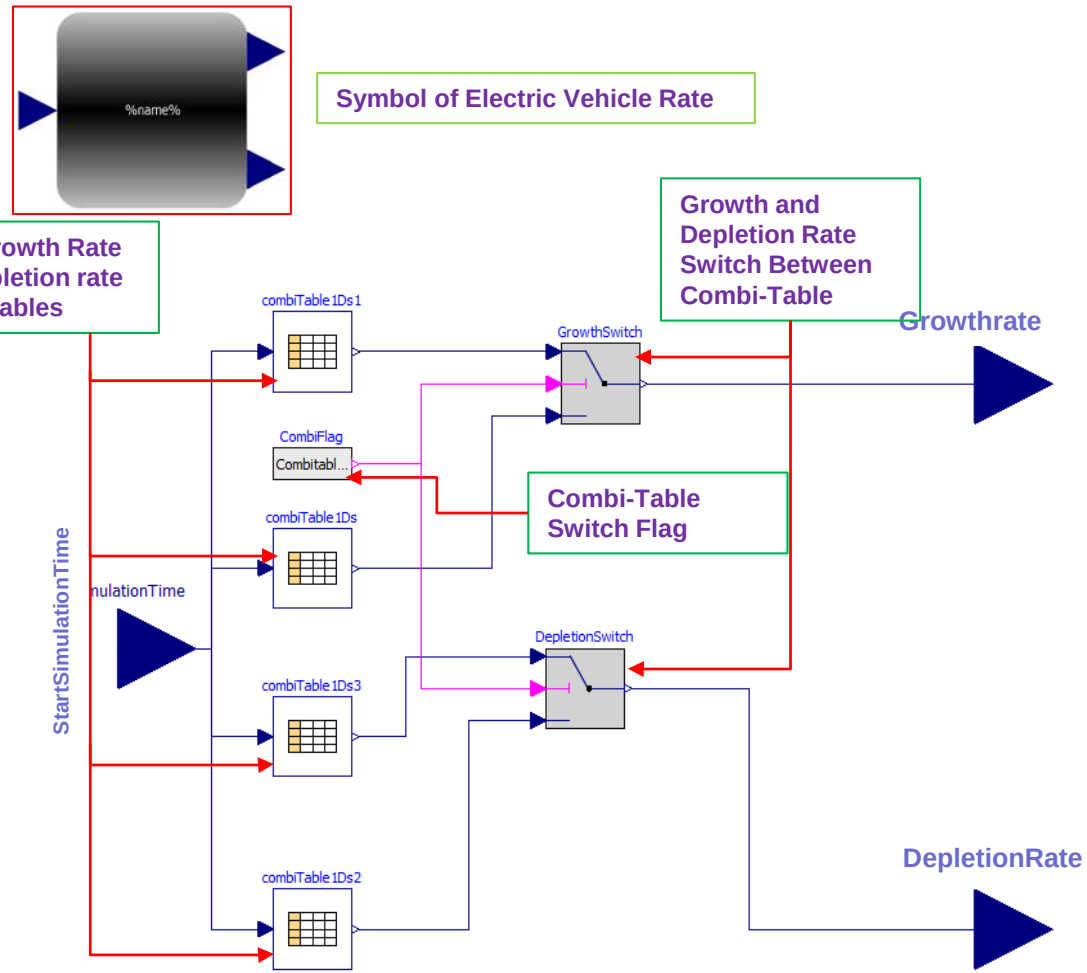


Model Components – Model for Growth Rate and Depletion Rate

- Rate model for Fossil Vehicle:

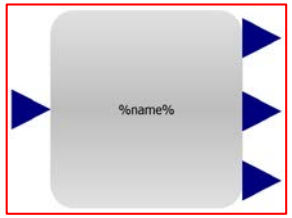


- Rate model for Electric Vehicles:

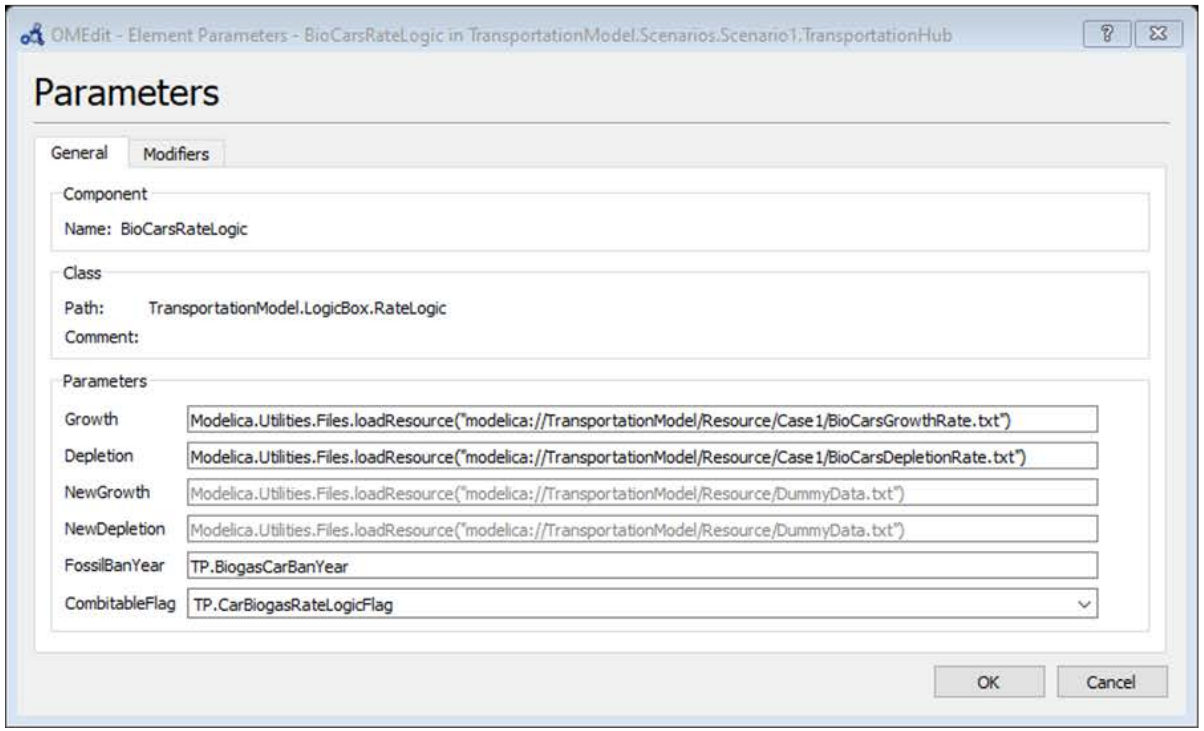


Model Components – Parameter Operation Dialog Box For Rate Logic

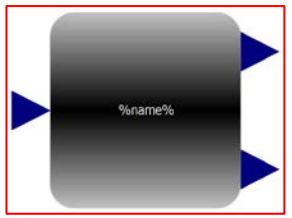
- Rate model For Fossil Vehicles:



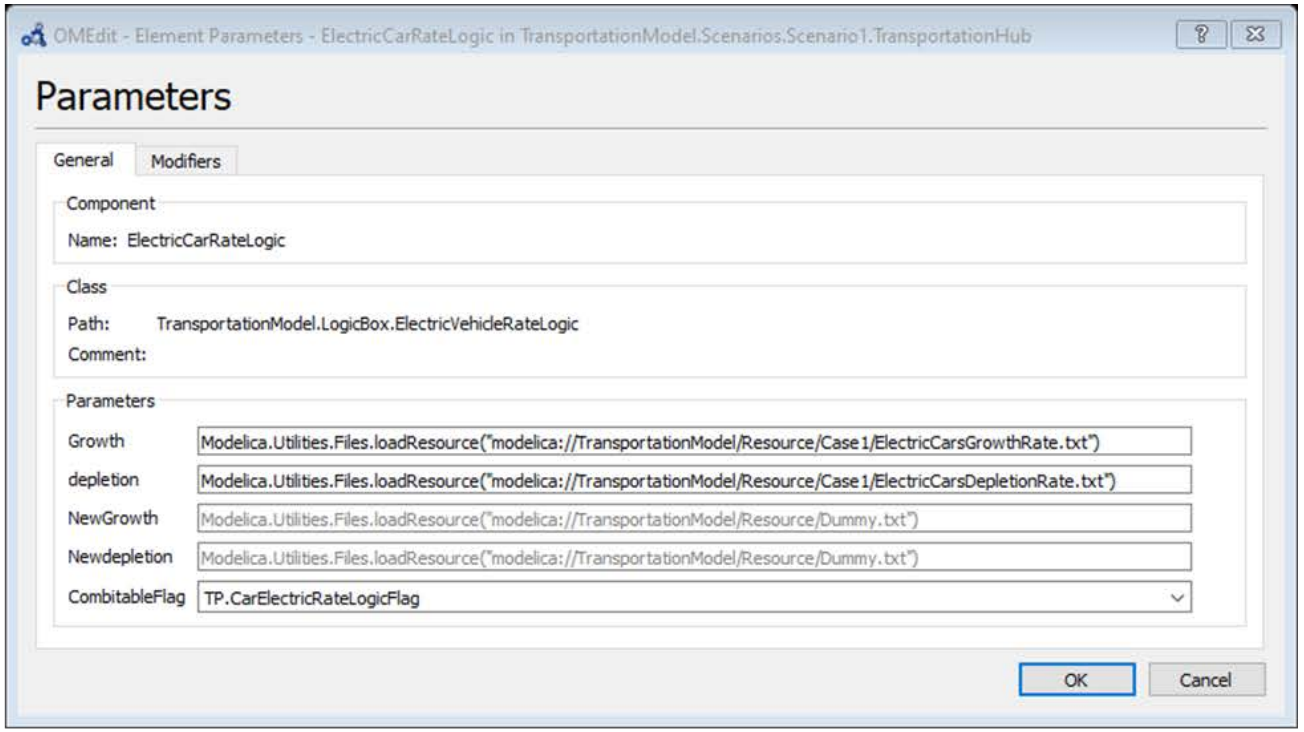
Symbol of Rate Logic for Fossil Cars



- Rate model for Electric Vehicles:

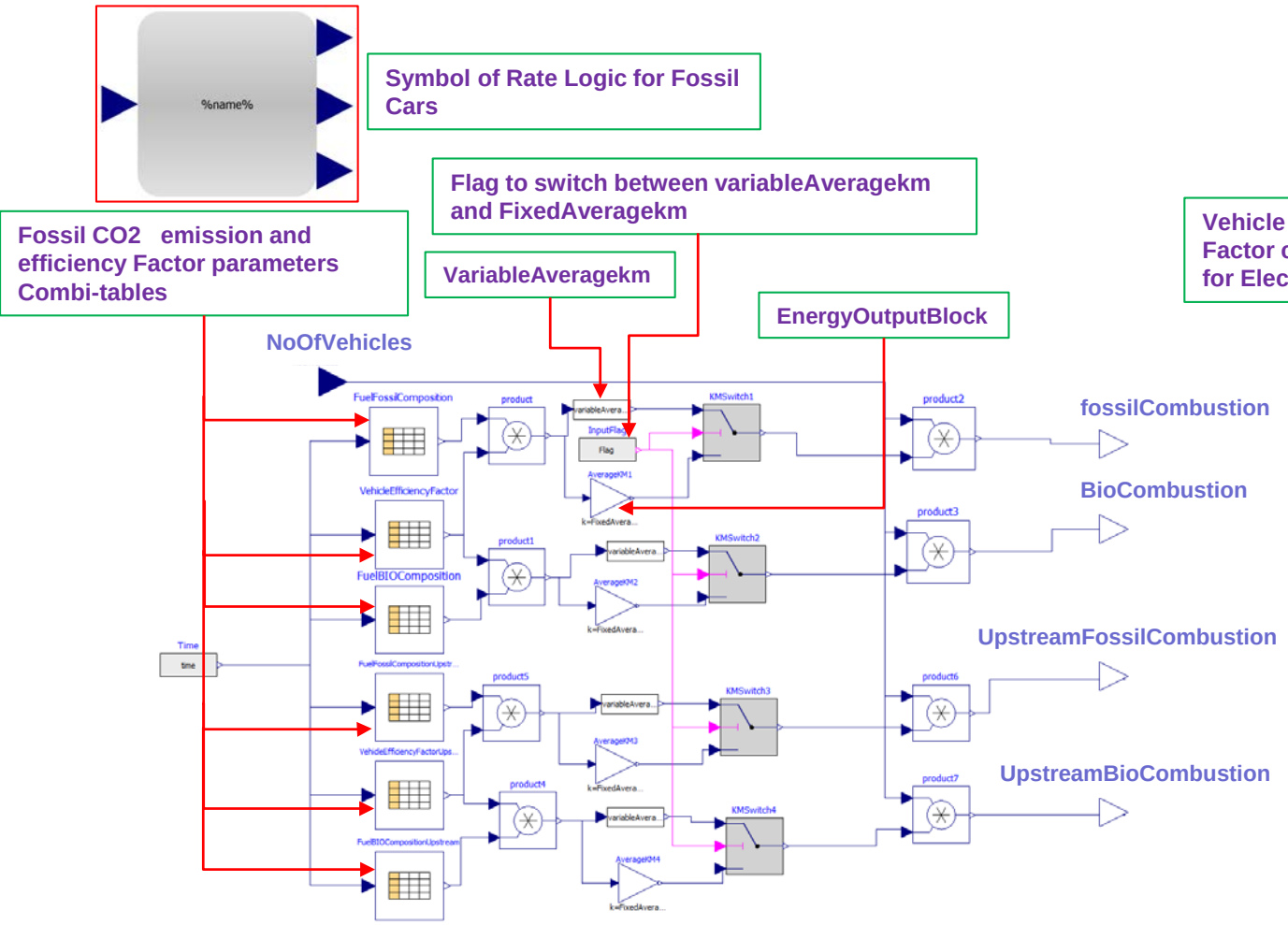


Symbol of Electric Vehicle Rate

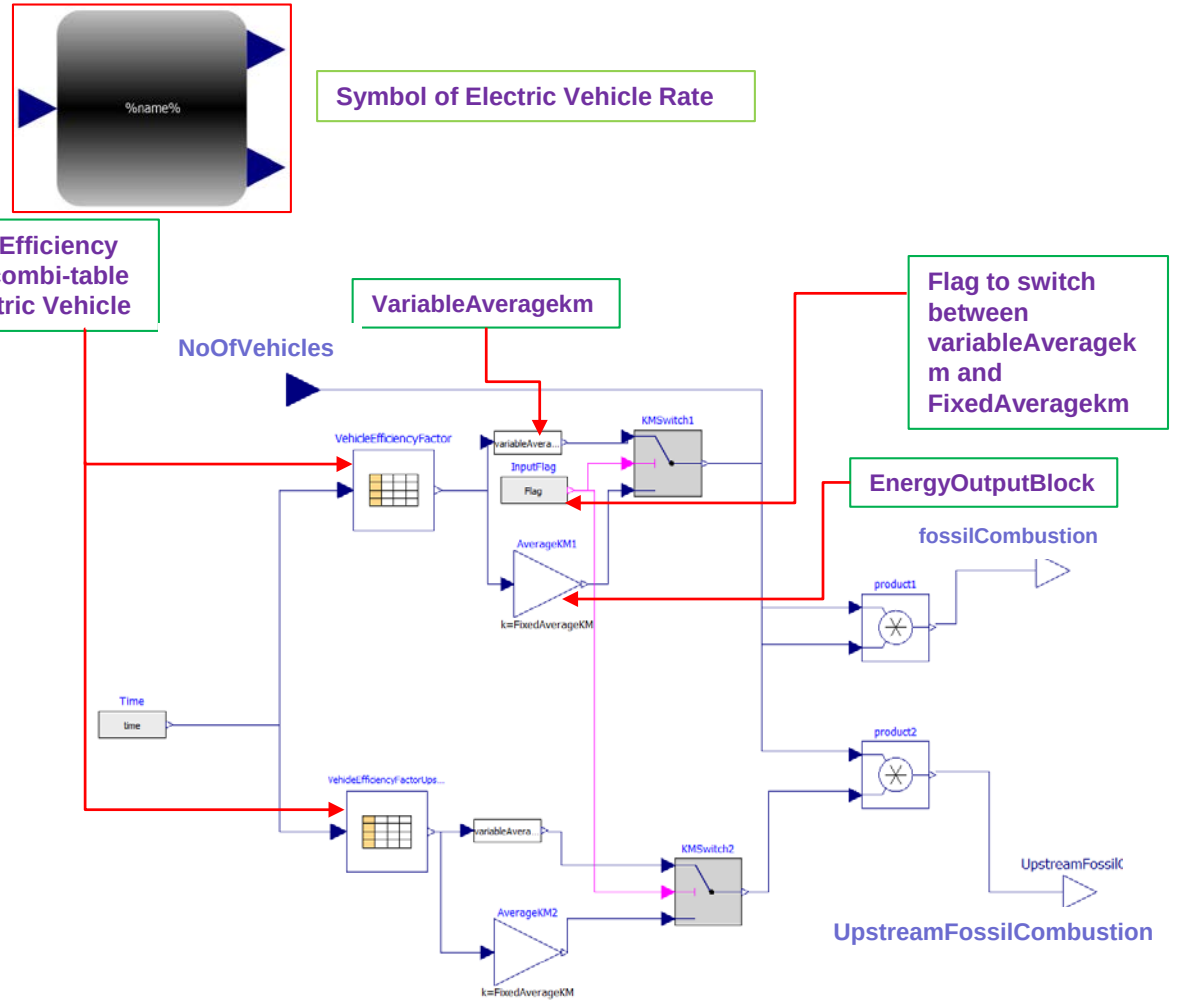


Model Components- Model for Total CO2 Emissions at end of the Simulation

- Energy Model Box For Fossil Vehicle:

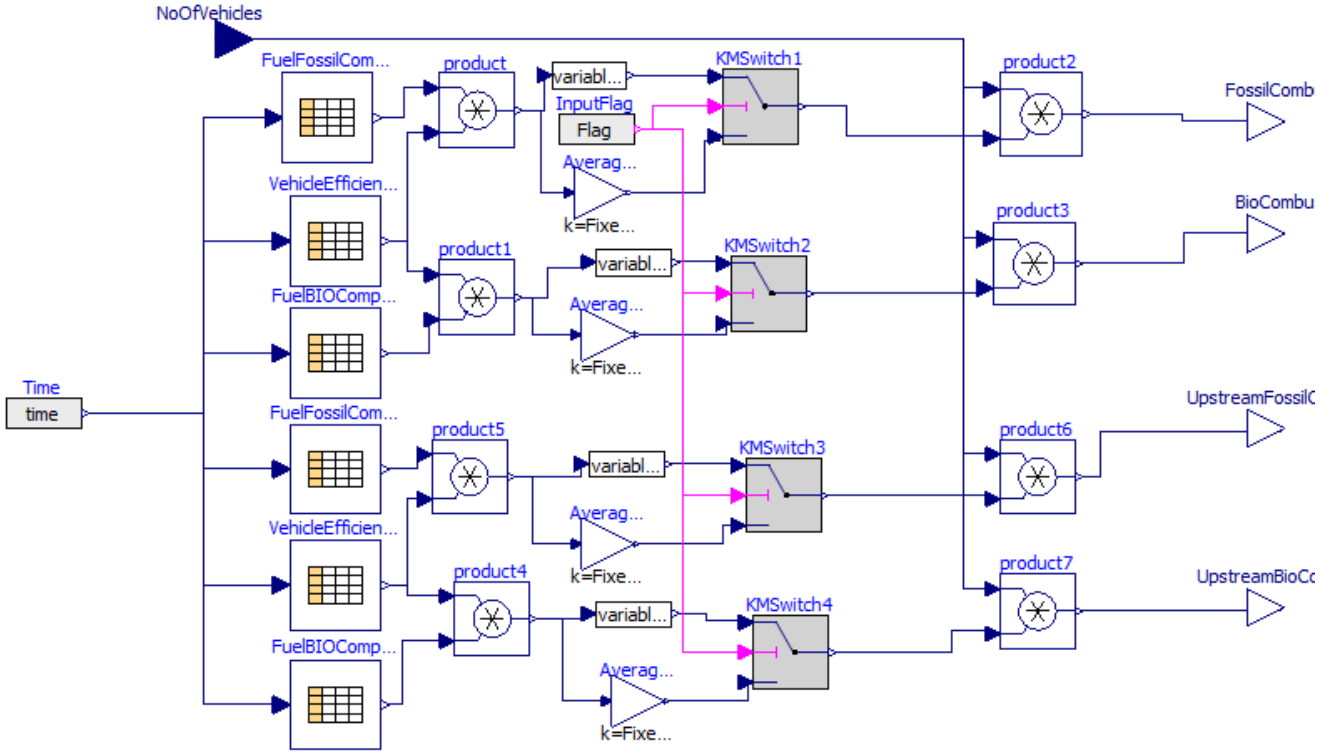


- Energy Model Box for Electric Vehicles:



Model Component – Equation used to calculate Energy and Emissions

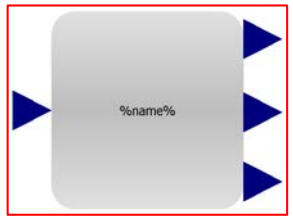
- Energyused GWh/yr = (kwh/km) * (efficient Factor) * Fuel Composition (as per energy) * average milage /car(km) * Number of cars(Starting of the year + new registration- scraped)
- Emissions = (Energy use GWh/yr) * (GHG Emissions(grammes/kWh))



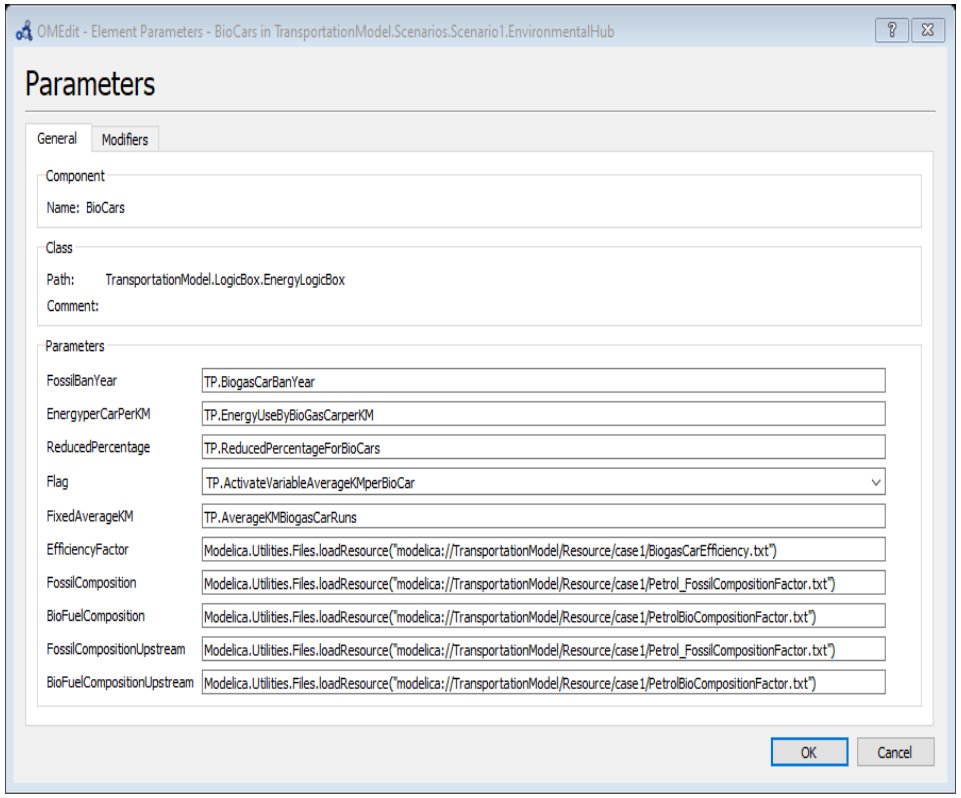
1.Efficient factor and fuel composition comes from combi table and multiplied
2. If fixed kilometer Logic is used, In gain block calculates the (Averagekm*Energyperkm) and if Variable averagekm is used, variableaveragekm block will give the result.
3. At product 2,3,6,7, previous number are multiplied by NoOfVehicles. Now you will get Energy use GWh.
4. In environmental hub these numbers are multiplied by a gain in which gramme/KWh stores and produces emissions.

Model Components- Parameter Operation Dialog Box For Energy Logic Box

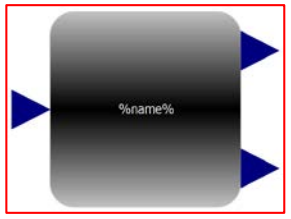
- Energy Logic Box For Fossil Vehicle:



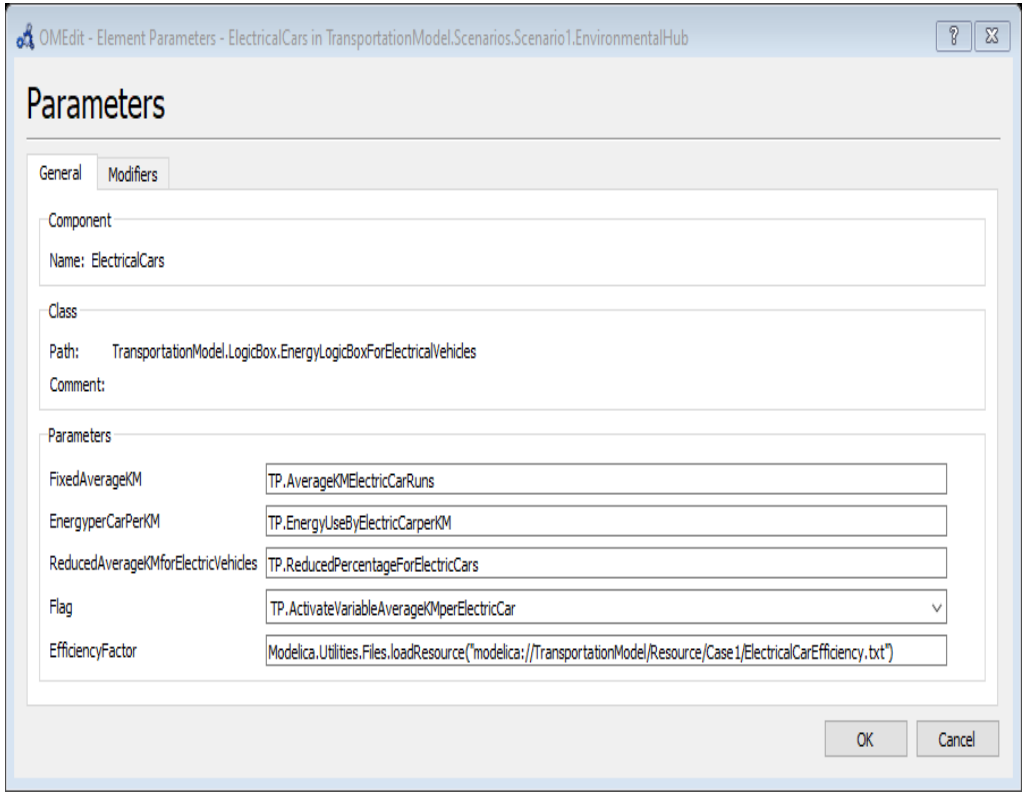
Symbol of Energy logic box for Fossil Cars



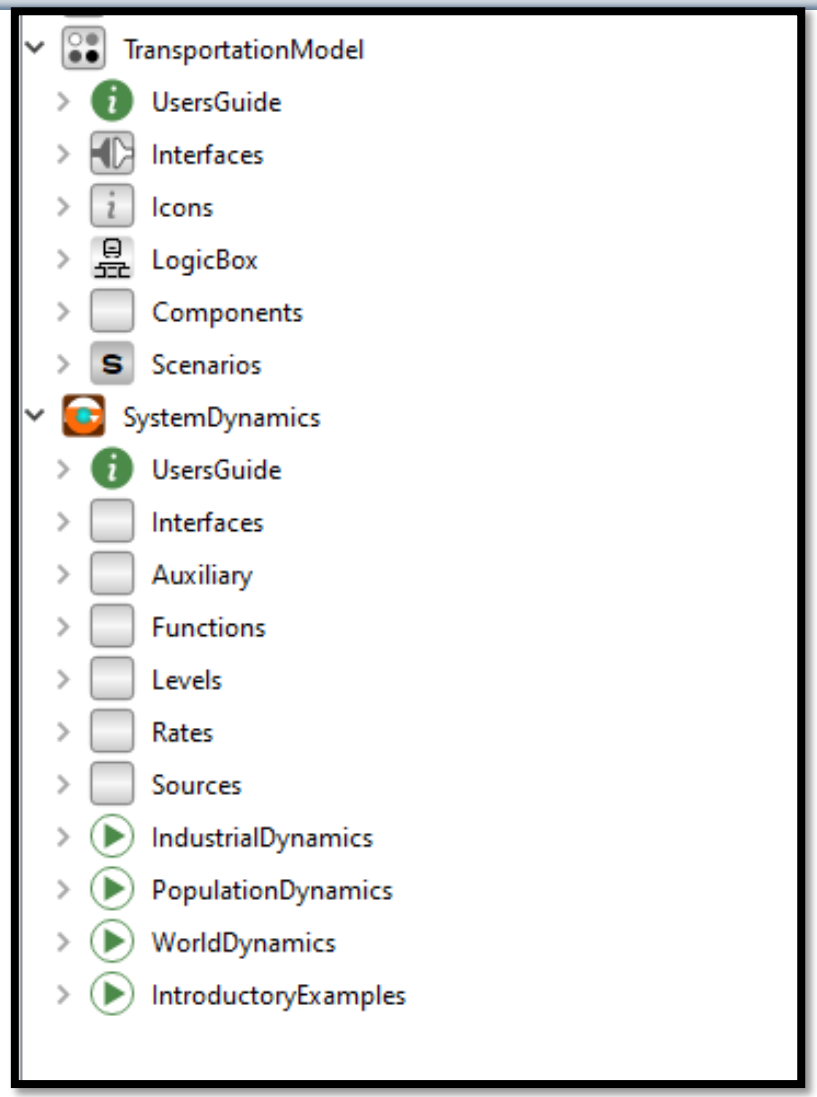
- Energy Logic Box for Electric Vehicles:

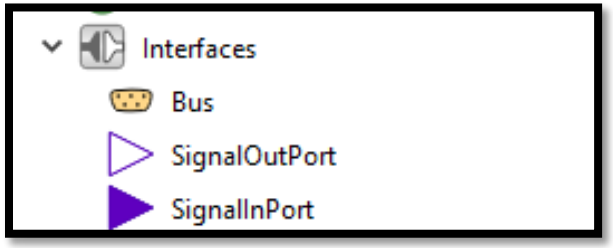


Symbol of Energy Logic Box Electric Vehicle Rate



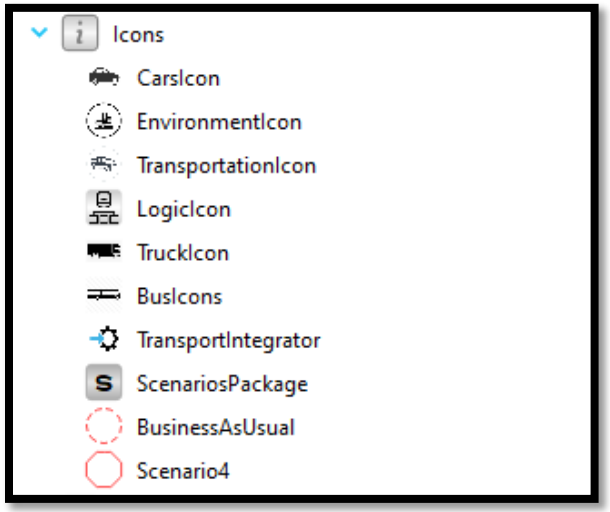
Transportation Library





Interfaces–

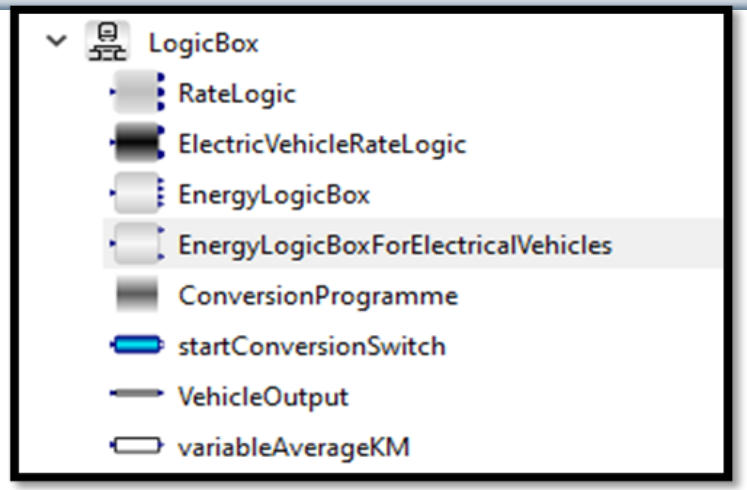
- **Bus - It is an extensible Bus to connect multiple components**
- **Single InPort – For input signals**
- **Signal OutPort – For Output signals**

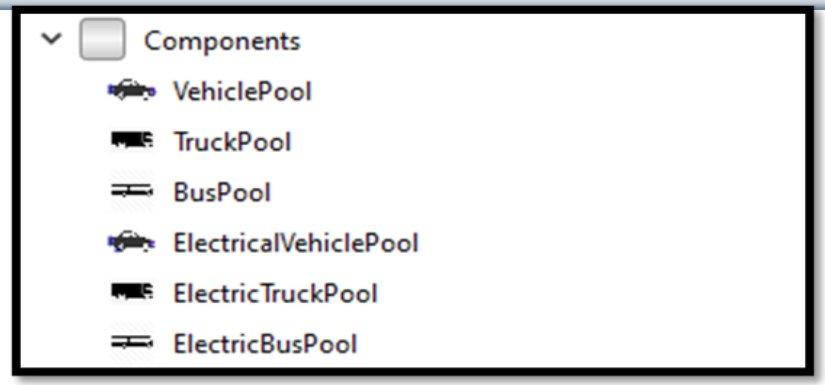


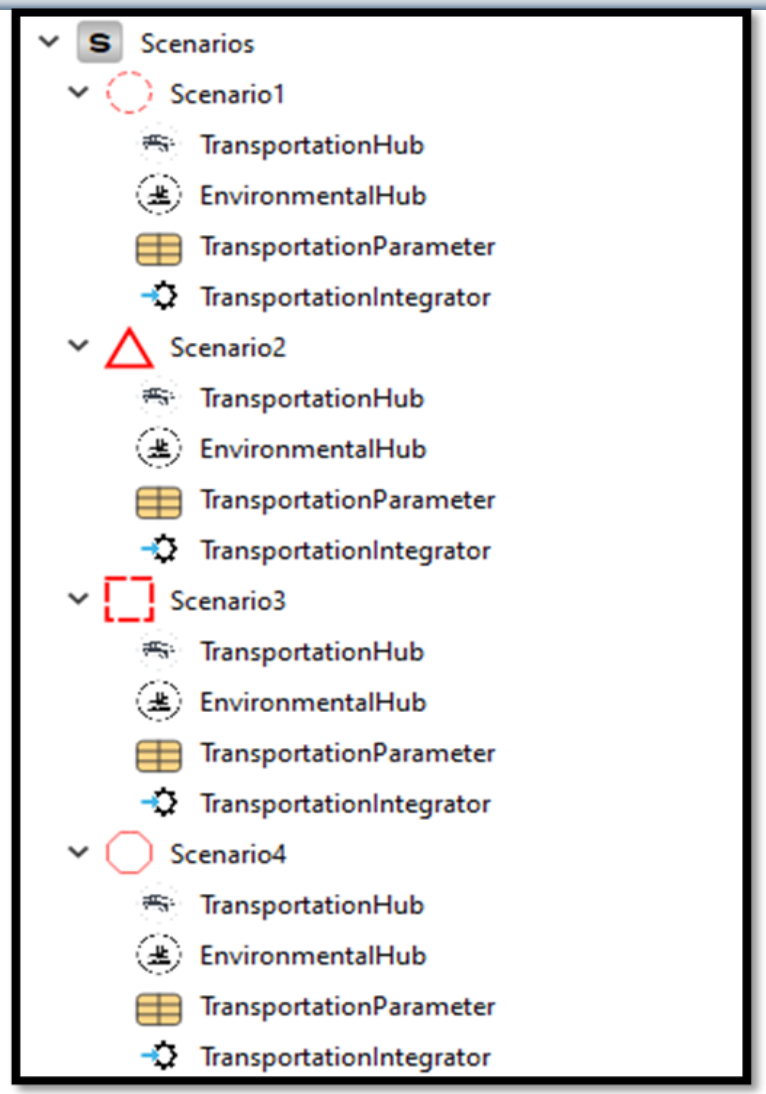
Icons-

- **Contains all the Icons used in the model for better representation**

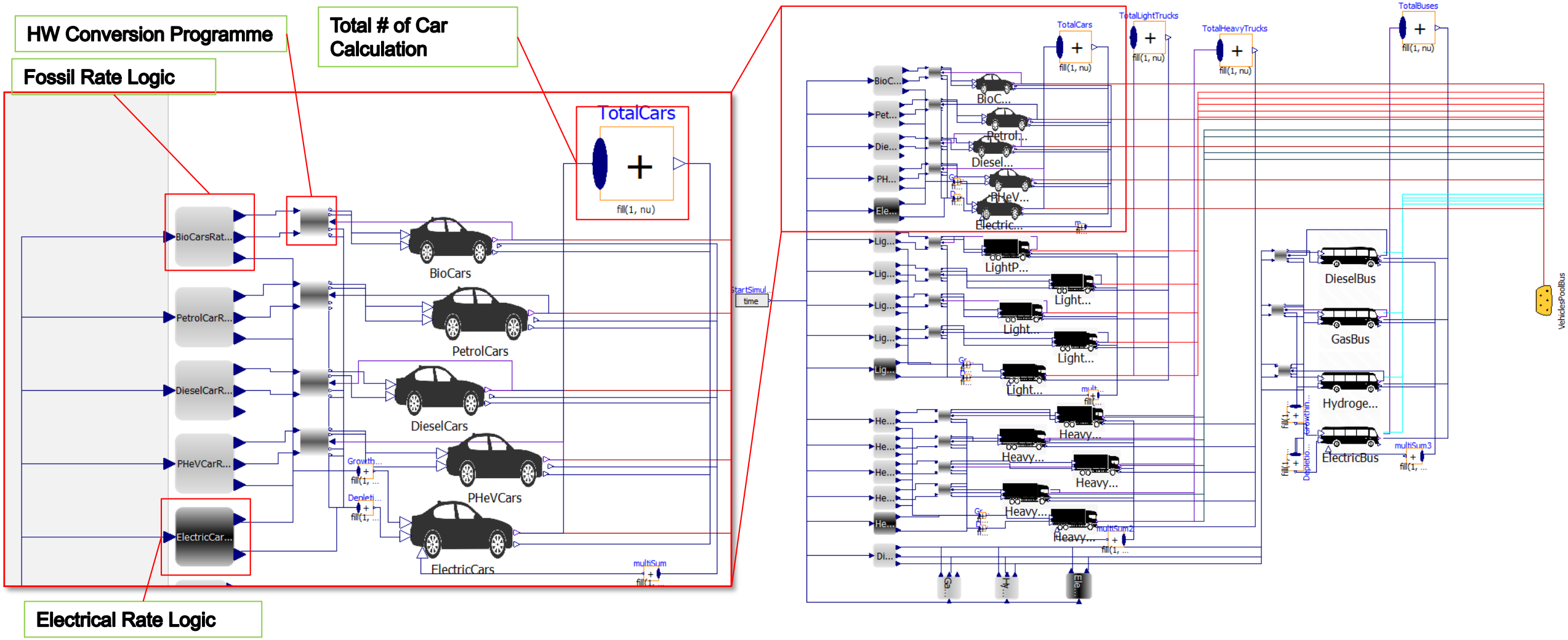
Transportation Library



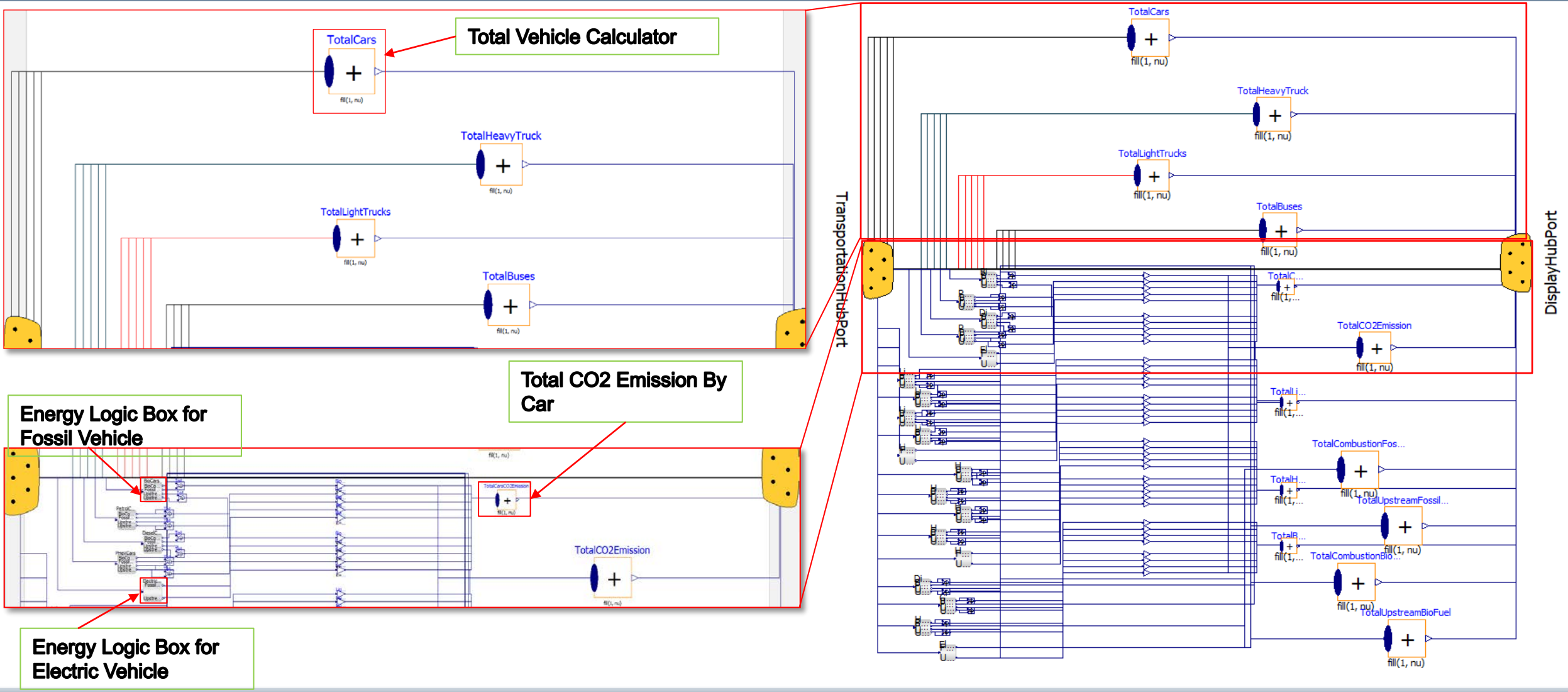




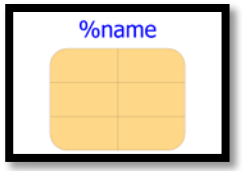
Scenario Models -TranspotationHub



Scenario Models- EnvironmentHub



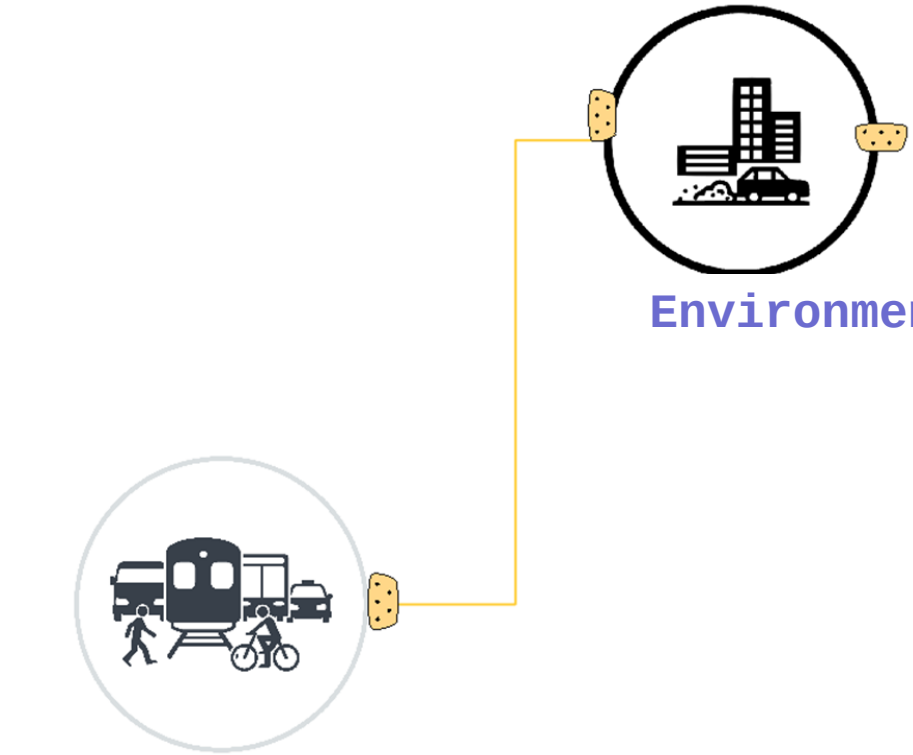
Scenario Model- TransportationParameter




```
within TransportationModel.Scenarios.Scenario1;

record TransportationParameter
extends Modelica.Icons.Record;
//flag for cars
  parameter Boolean BiogasCars_flag  = false;
  parameter Boolean PetrolCars_flag  = false;
  parameter Boolean DieselCars_flag  = false;
  parameter Boolean PHeVCars_flag    = false;

//Activate Variable Average KM Flag for Cars
  parameter Boolean ActivateVariableAverageKMperPetrolCar = false;
  parameter Boolean ActivateVariableAverageKMperDieselCar = false;
  parameter Boolean ActivateVariableAverageKMperPHeVCar = false;
  parameter Boolean ActivateVariableAverageKMperBioCar = false;
  parameter Boolean ActivateVariableAverageKMperElectricCar = false;

//Activate Variable Average KM Flag for Light Truck
  parameter Boolean ActivateVariableAverageKMperLightPetrolTruck = false;
  parameter Boolean ActivateVariableAverageKMperLightDieselTruck = false;
  parameter Boolean ActivateVariableAverageKMperLightPHeVTruck = false;
  parameter Boolean ActivateVariableAverageKMperLightBioTruck = false;
  parameter Boolean ActivateVariableAverageKMperLightElectricTruck = false;

//Activate Variable Average KM Flag for Light Truck
  parameter Boolean ActivateVariableAverageKMperHeavyPetrolTruck = false;
  parameter Boolean ActivateVariableAverageKMperHeavyDieselTruck = false;
  parameter Boolean ActivateVariableAverageKMperHeavyHydrogenTruck = false;
  parameter Boolean ActivateVariableAverageKMperHeavyBioTruck = false;
  parameter Boolean ActivateVariableAverageKMperHeavyElectricTruck = false;

//Activate Variable Average KM Flag for Bus
  parameter Boolean ActivateVariableAverageKMperDieselBus = false;
  parameter Boolean ActivateVariableAverageKMperHydrogenBus = false;
  parameter Boolean ActivateVariableAverageKMperGasBus = false;
  parameter Boolean ActivateVariableAverageKMperElectricBus= false;

//flag for LightTruck
  parameter Boolean LightBiogasTruck_flag = false;
  parameter Boolean LightPetrolTruck_flag = false;
```

- All the parameters are linked with the Transportation Hub and Environment Hub as required using inner and outer keywords
- All the parameters can be changed from a single Model i.e., transportationParameter and reflect everywhere in the Output screen.
- It makes the parameter manipulation easier and fast.

Scenario Model - TransportationIntegrator



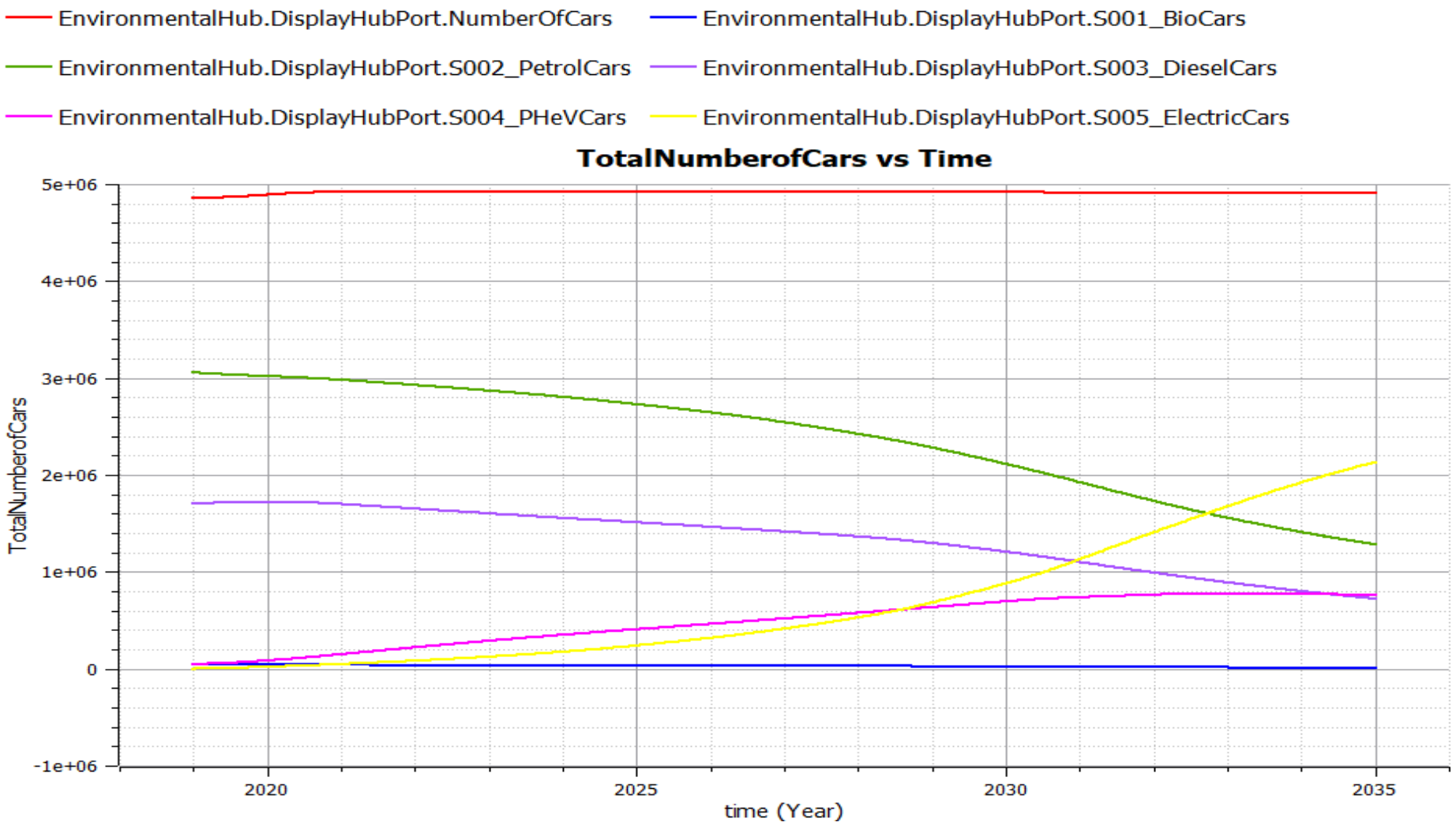
- This is the final Model of the package in each scenario.
- The Model is annotated with the start and stop time i.e., Start time = 2019 and the Stop Time = 2035.
- This Model should be Run for the simulation results

Four transition **Scenarios** for Sweden simulated for years **2019 – 2035**

- Scenario 1 – **Gradual** transition with increase of electric vehicles
- Scenario 2 – **Faster** transition, with **fossil ban year** for fossil cars 2025, similar for other vehicles
- Scenario 3 – Also doubling **public transport** like buses, **reducing fossil** cars annual **driving range**. correspondingly
- Scenario 4 – **Hardware conversion** of remaining fossil cars **to electric**, percentage per year

Results Scenario 1 – Cars

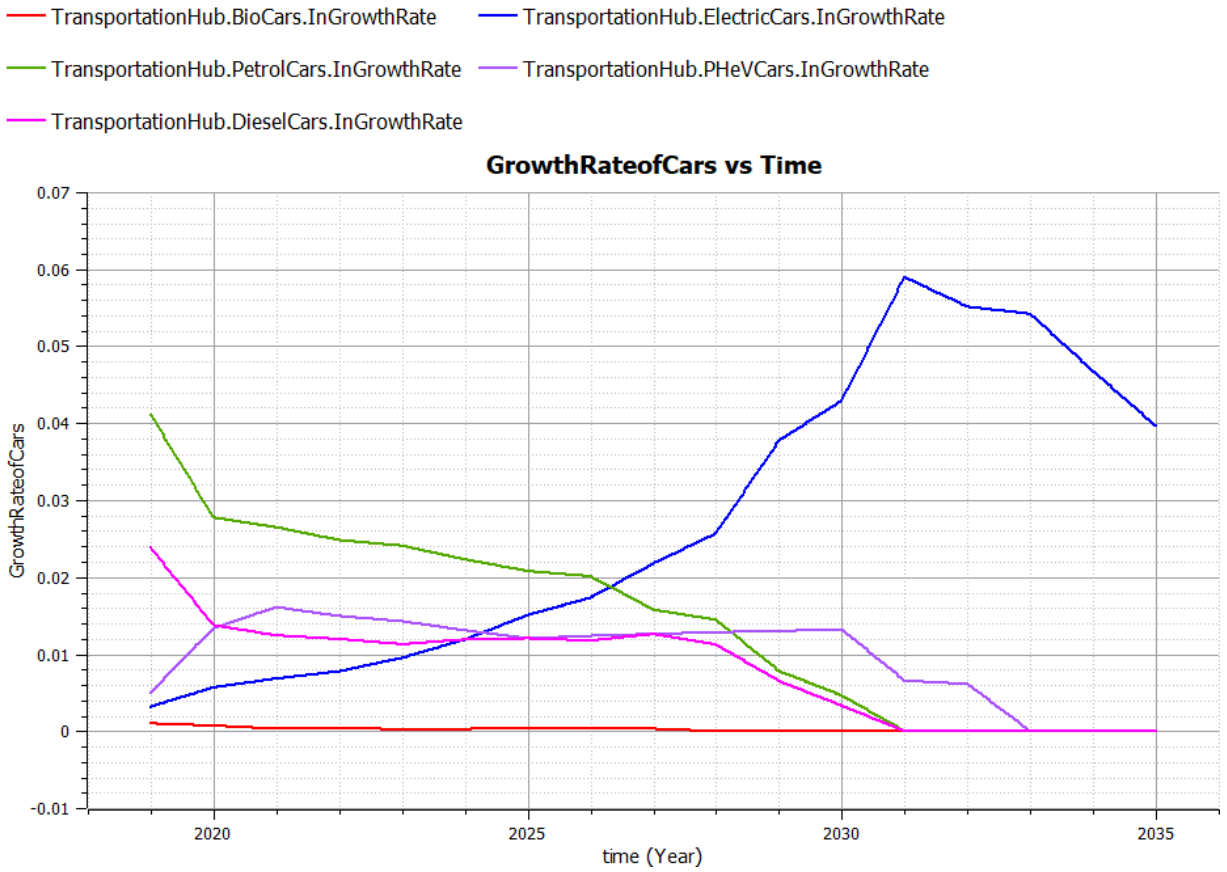
Conversion Percentage -None, Average driving range km Reduction – None, FossilBanSwitch - False

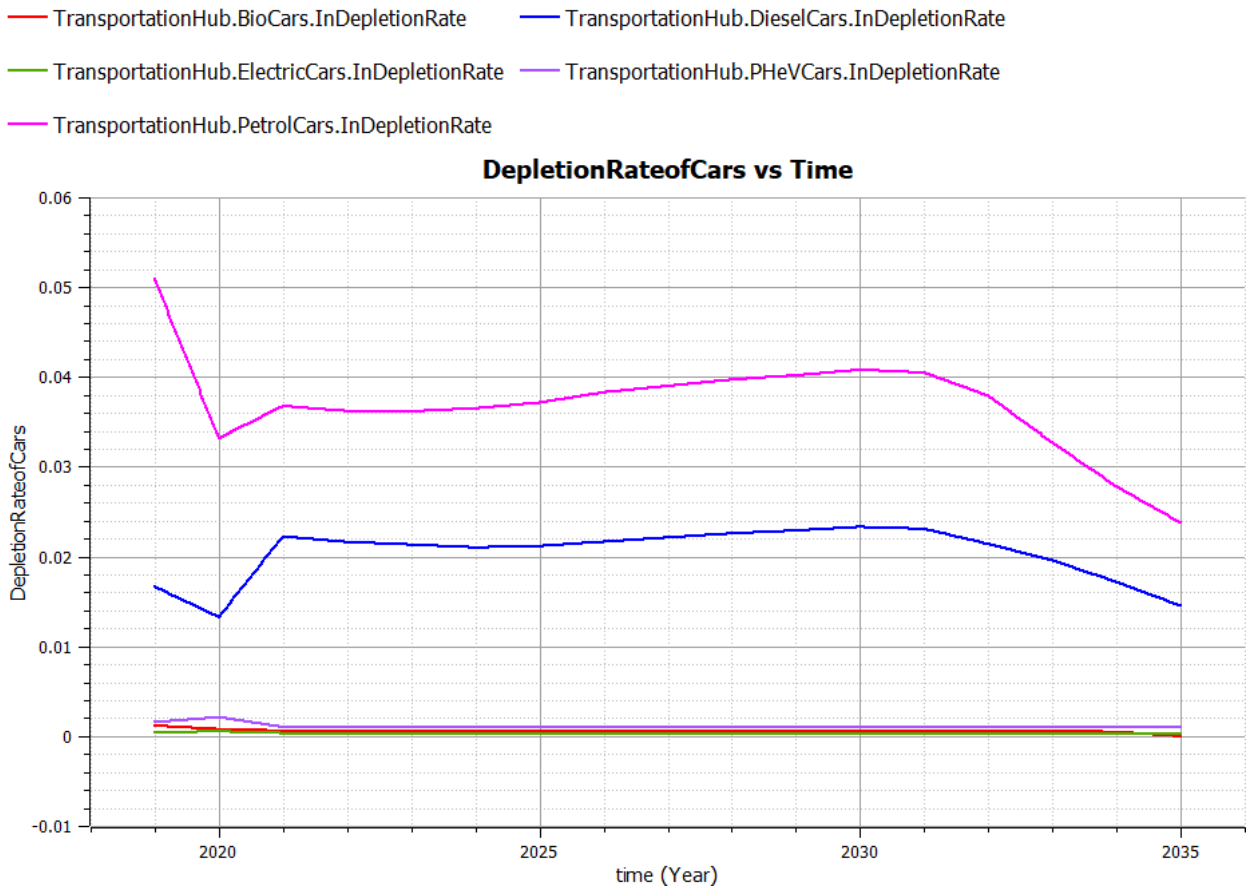


Car	Fossil Ban Year
Petrol	2100
Diesel	2100
Bio	2100
PHeV	2100

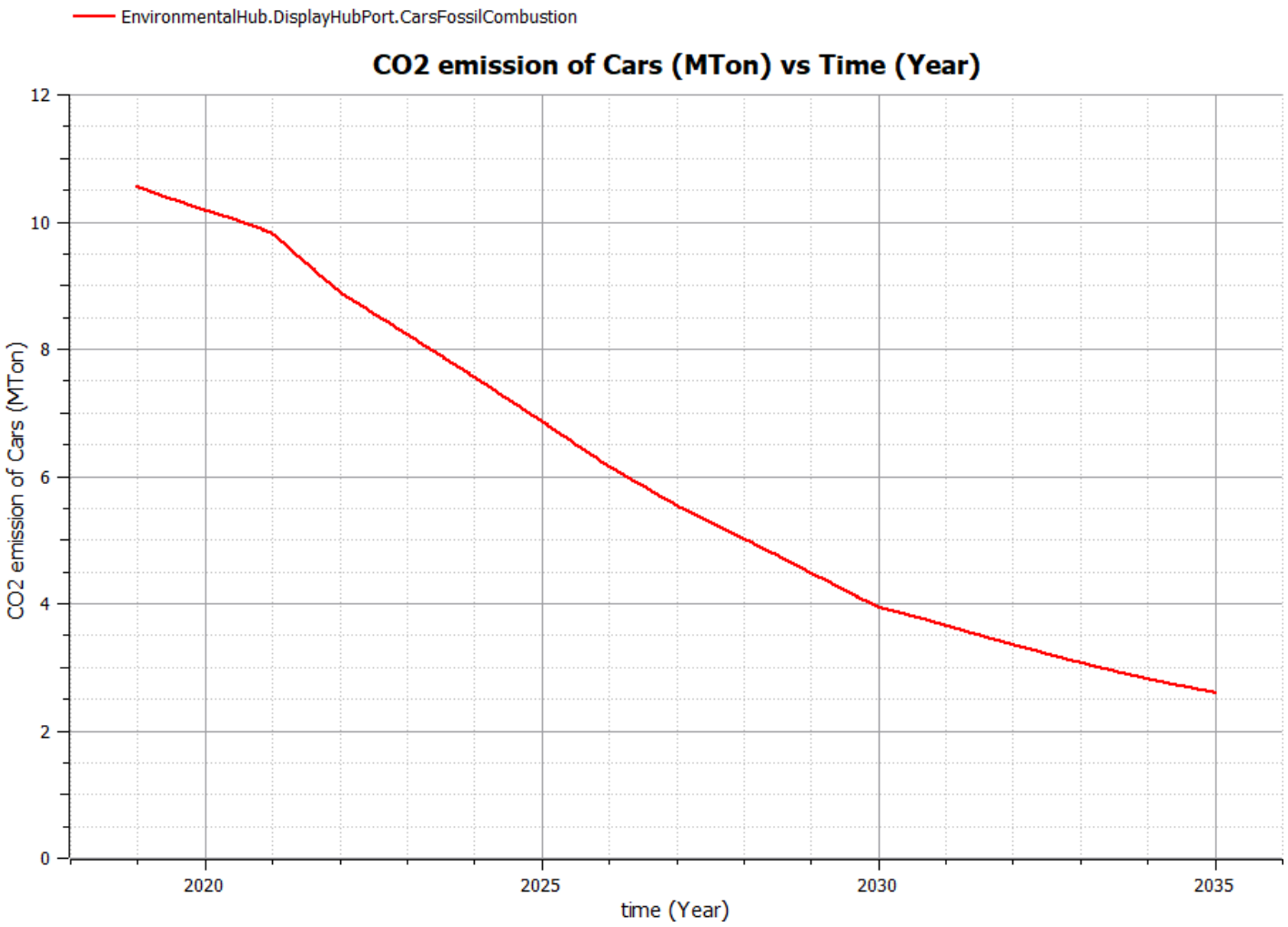
Vehicle	Legends
Total Number of Cars	
Bio Gas Cars	
Petrol Cars	
Diesel Cars	
PHeV Cars	
Electric Cars	

Results Scenario 1 – Cars Growth Rate and Depletion Rate

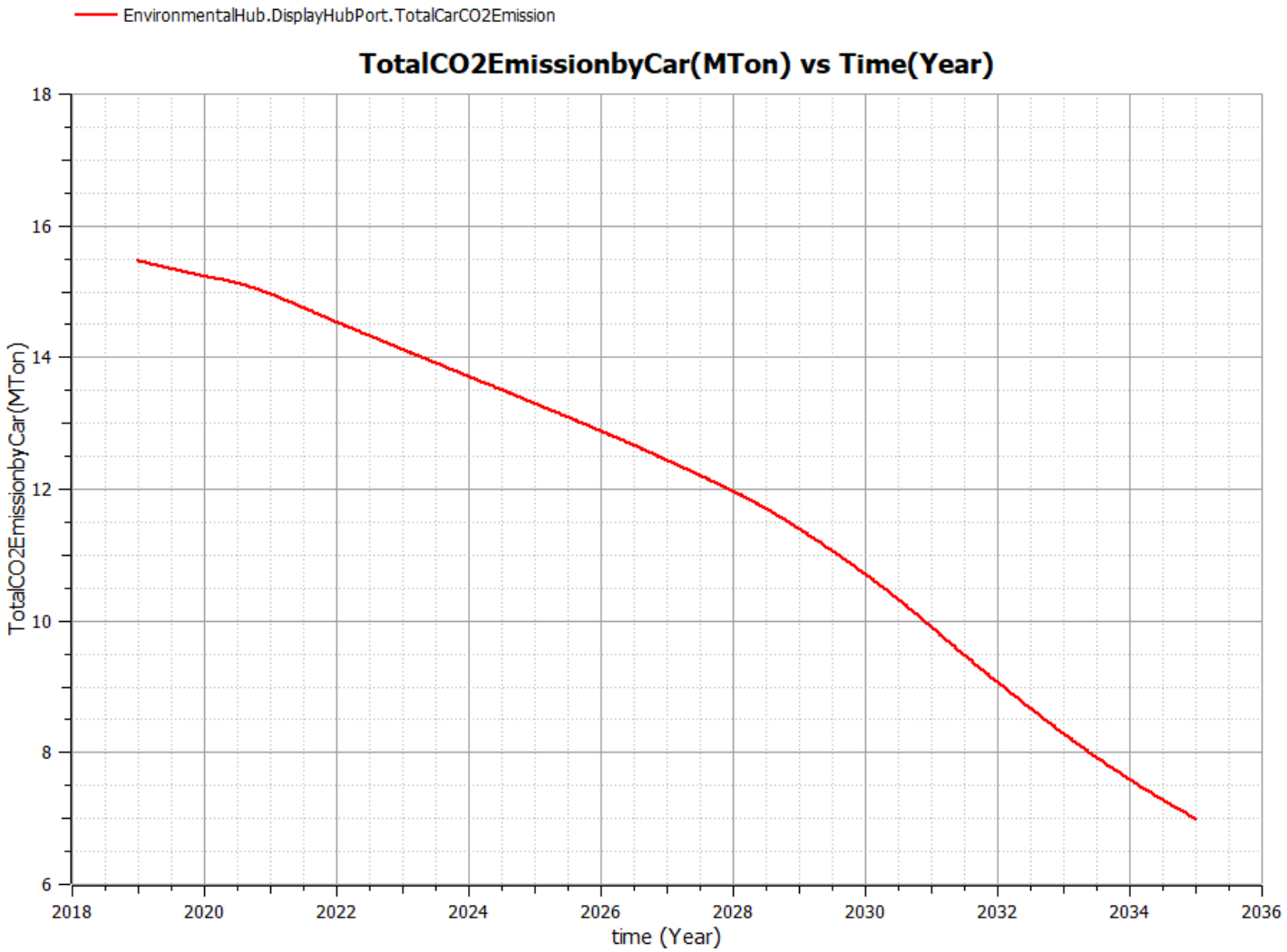




Results Scenario 1 – Total Cars Fossil CO2 Emissions

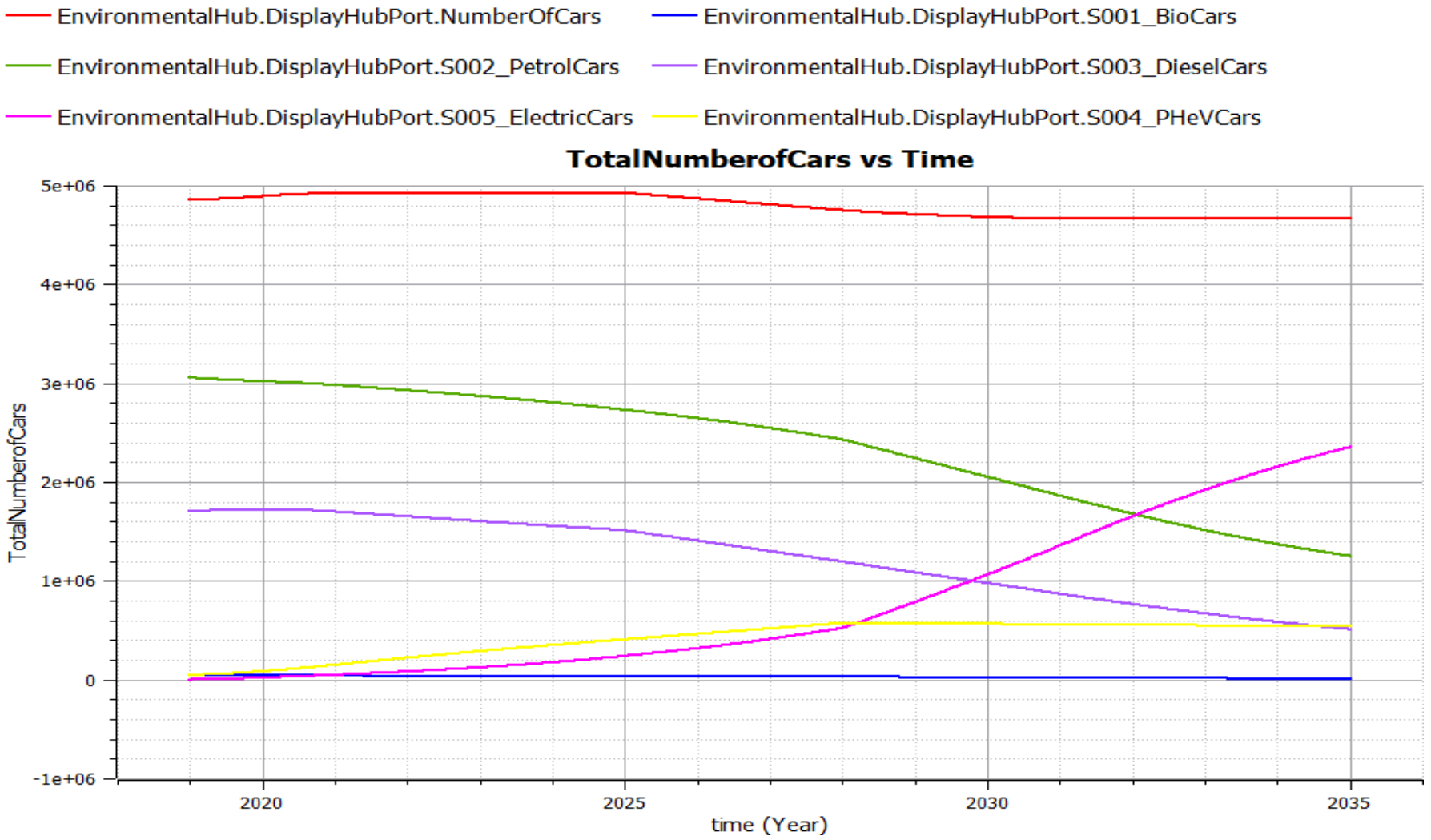


Results Scenario 1 – Total Cars CO2 Emissions incl Upstream and Biofuels



Results Scenario 2 – Cars

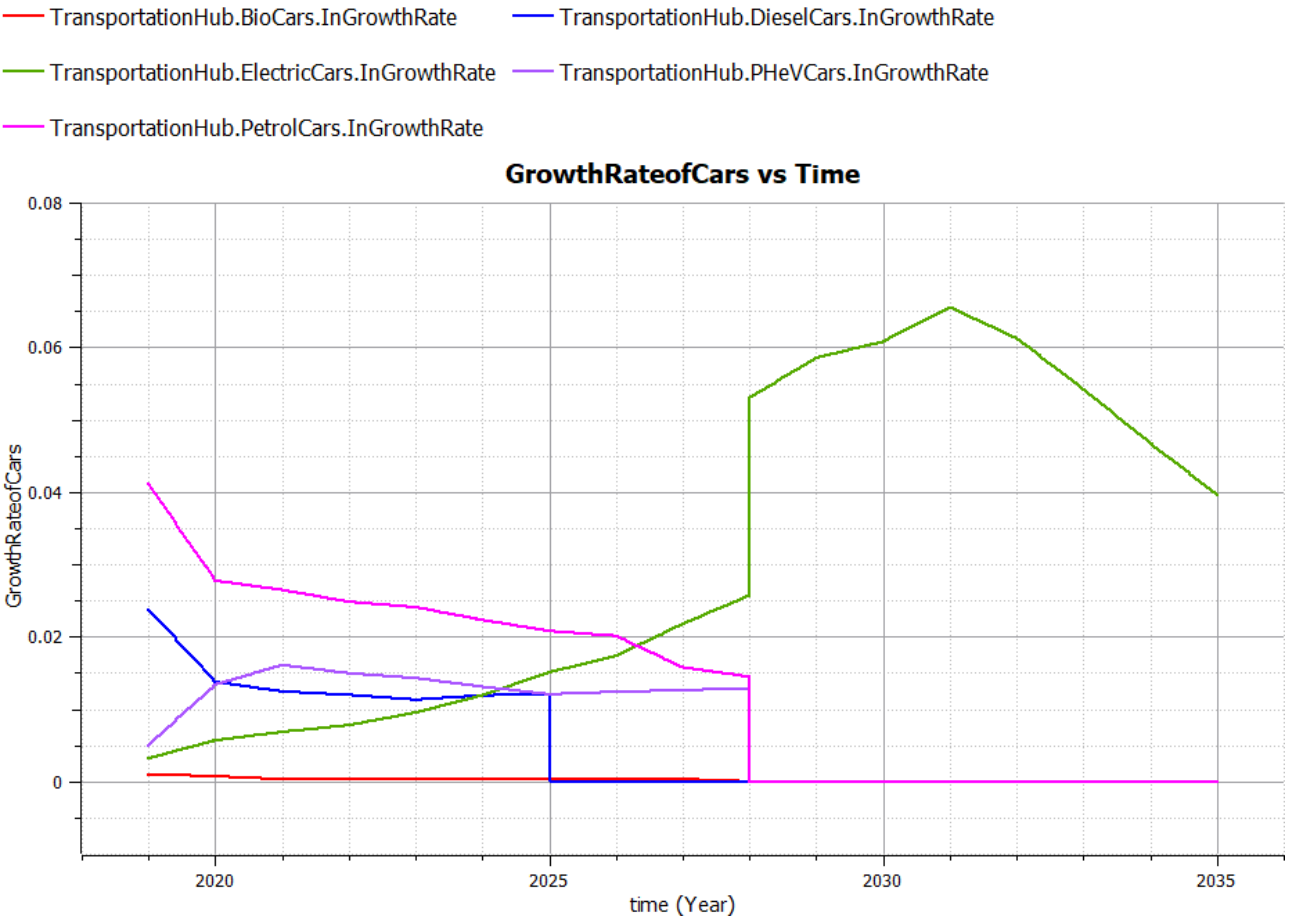
Conversion Percentage -None, Average driving range km Reduction – None, FossilBanSwitch - True

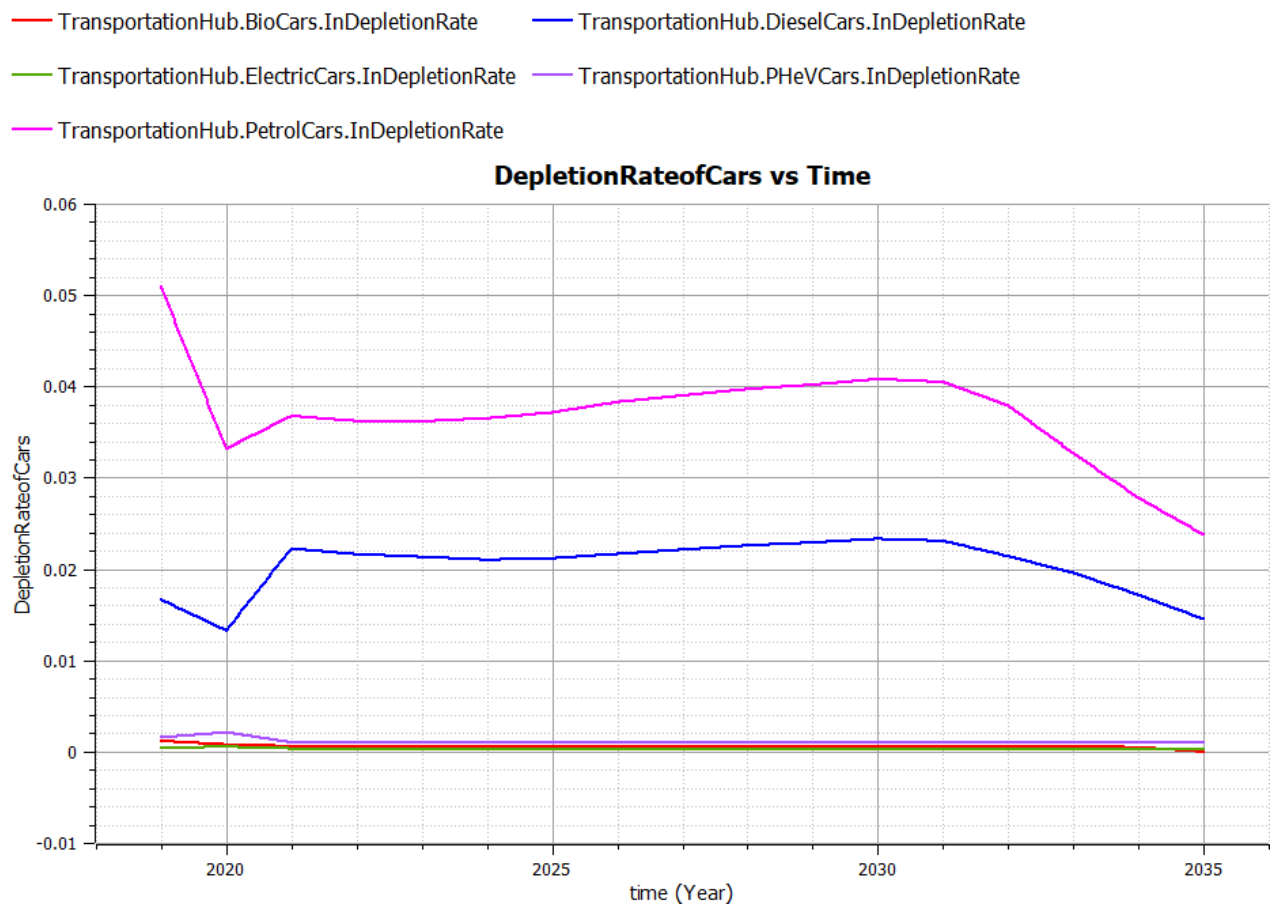


Car	Fossil Ban Year
Petrol	2028
Diesel	2025
Bio	2030
PHeV	2028

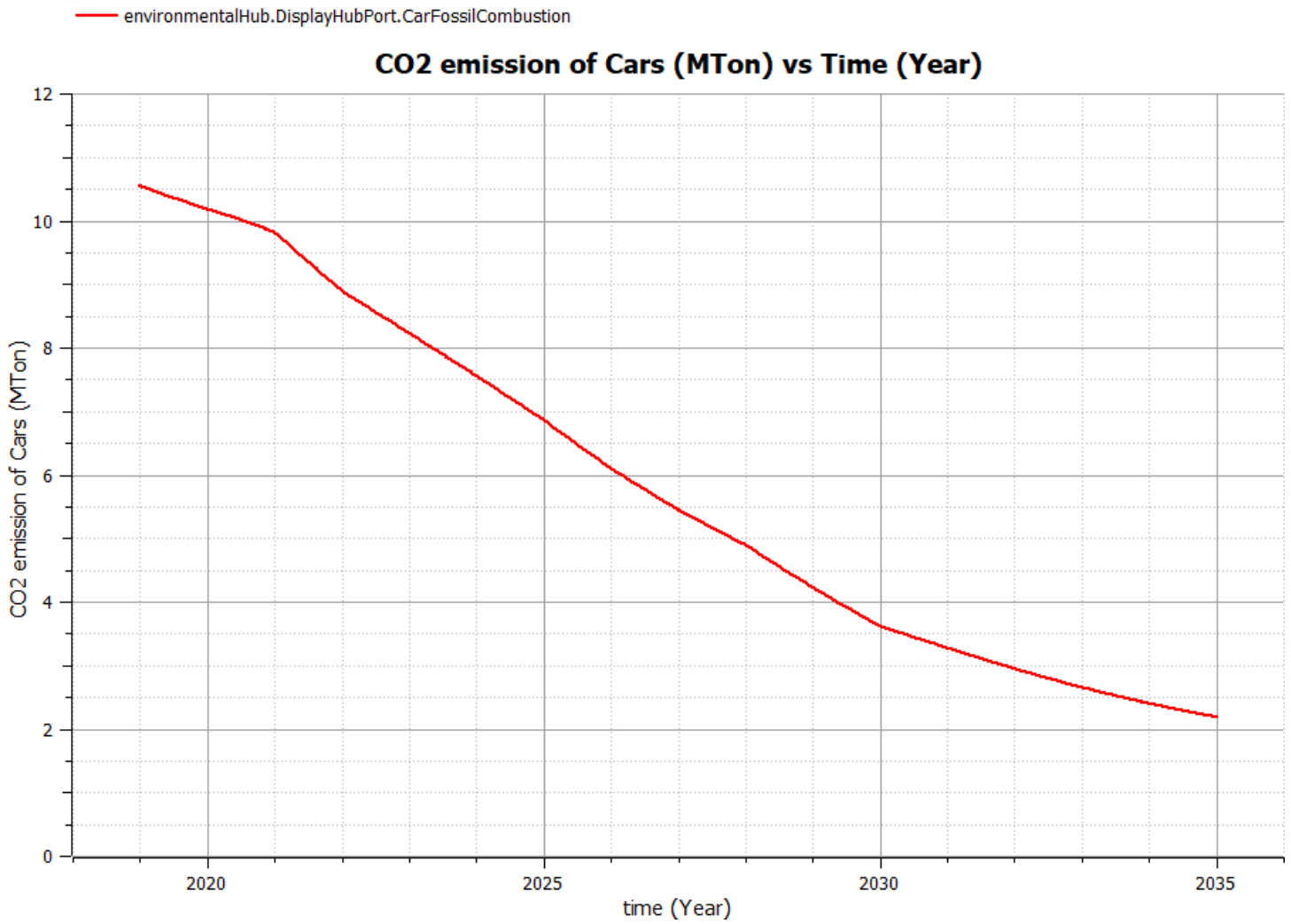
Vehicle	Legends
Total Number of Cars	
Bio Gas Cars	
Petrol Cars	
Diesel Cars	
Electric Cars	
PHeV Cars	

Results Scenario 2 – Cars Growth and Depletion Rate

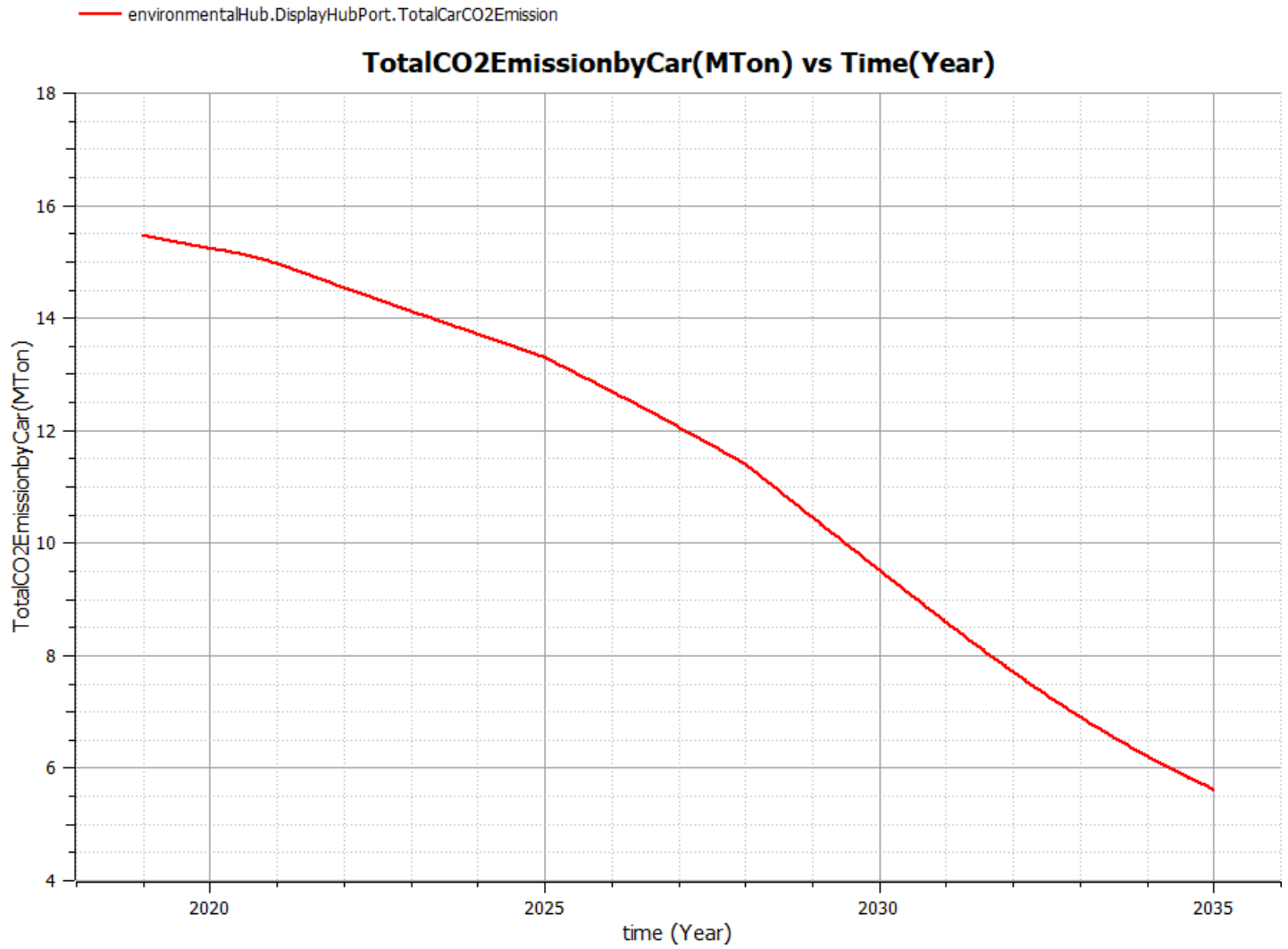




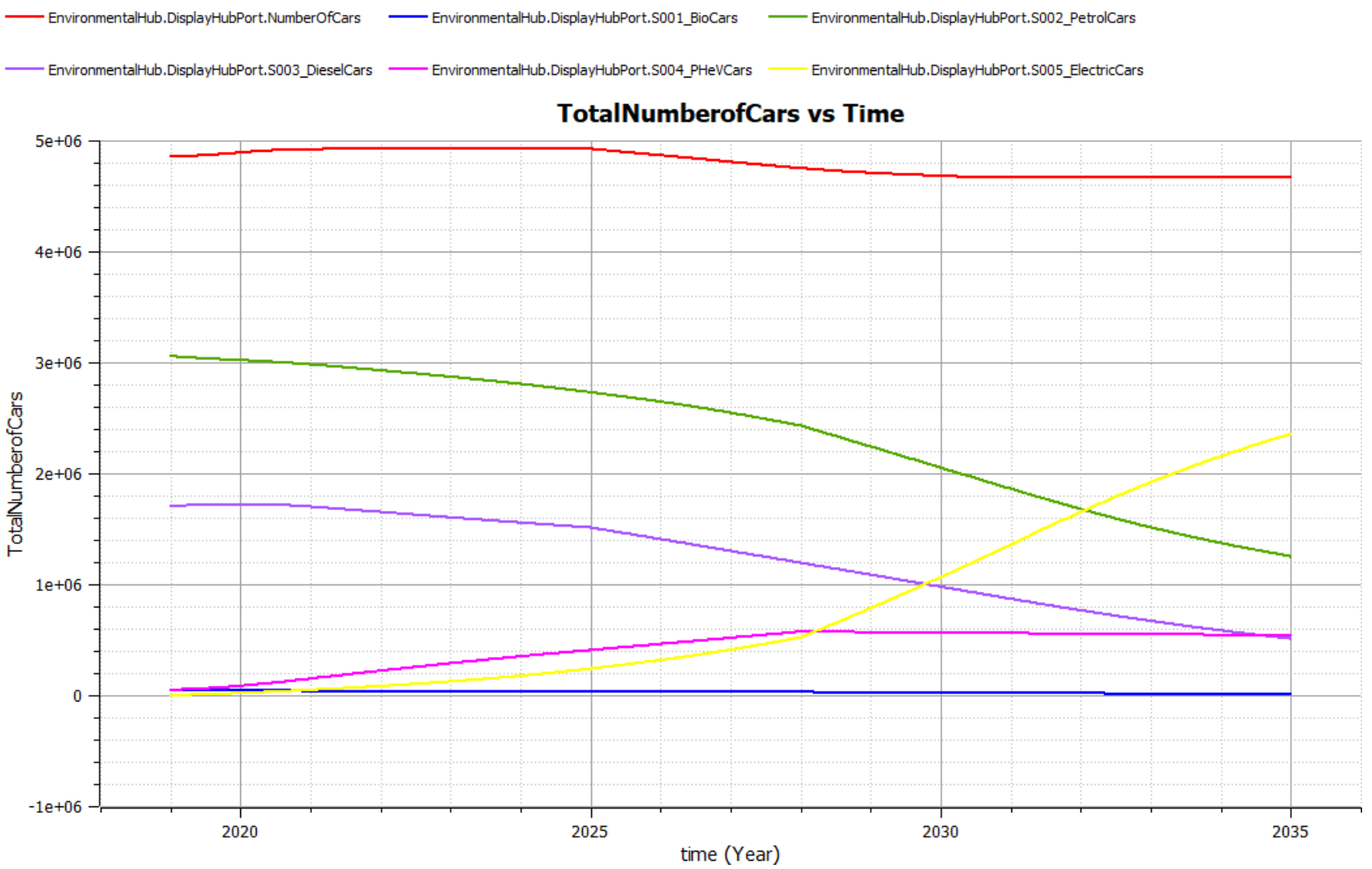
Results Scenario 2 – Total Cars Fossil CO2 Emissions



Results Scenario 2 – Total Cars CO2 Emissions incl upstream and biofuels



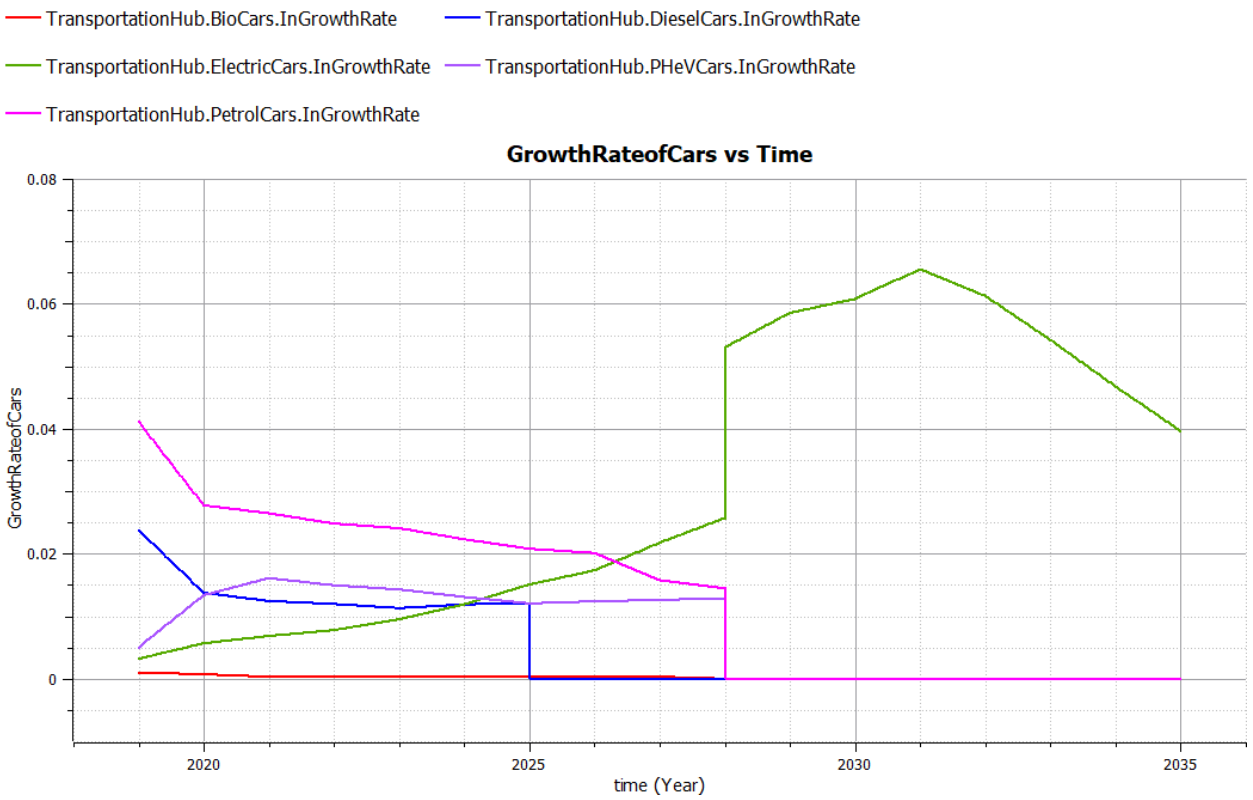
Results Scenario 3 – Cars- Average driving range km Reduction – 2%

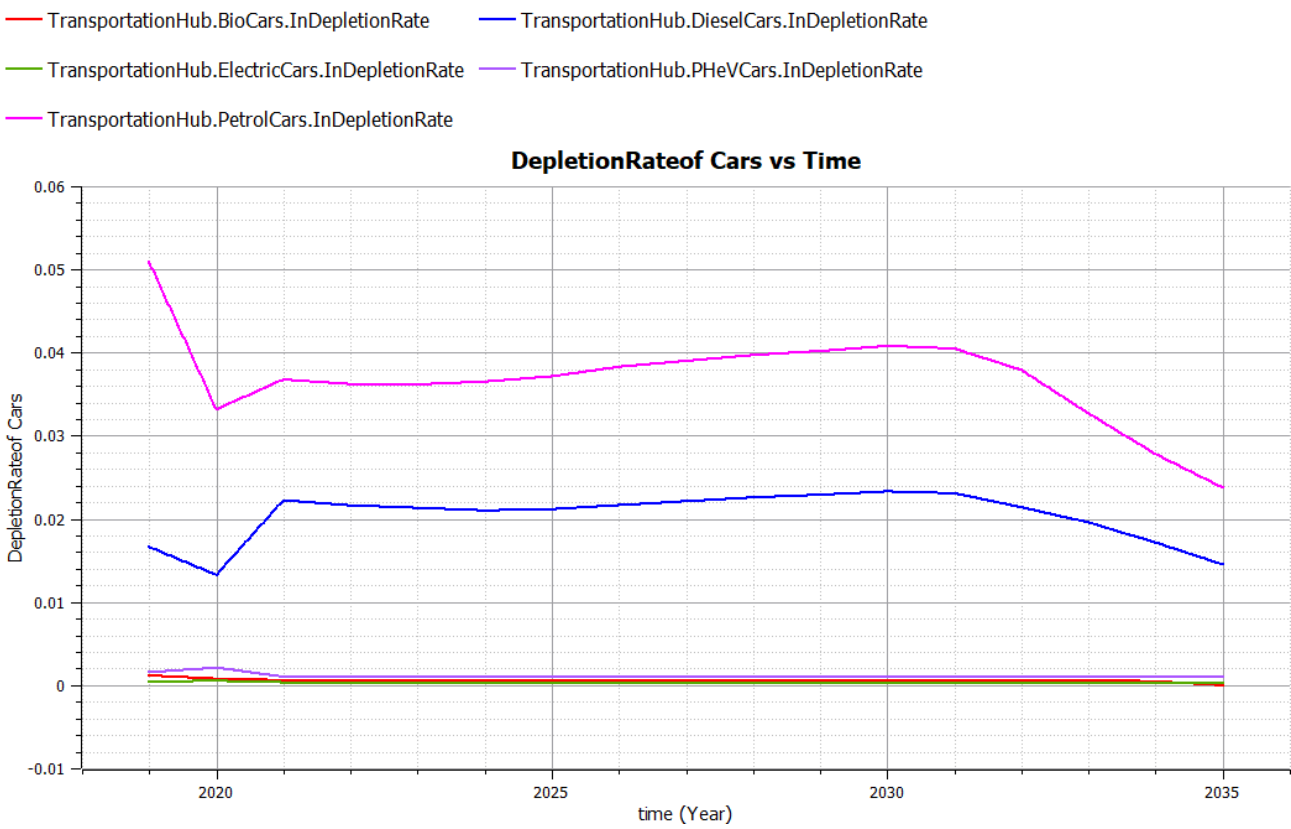


Vehicle	Fossil ban Year
BioGas	2030
Diesel	2025
Petrol	2028
PHeV	2028

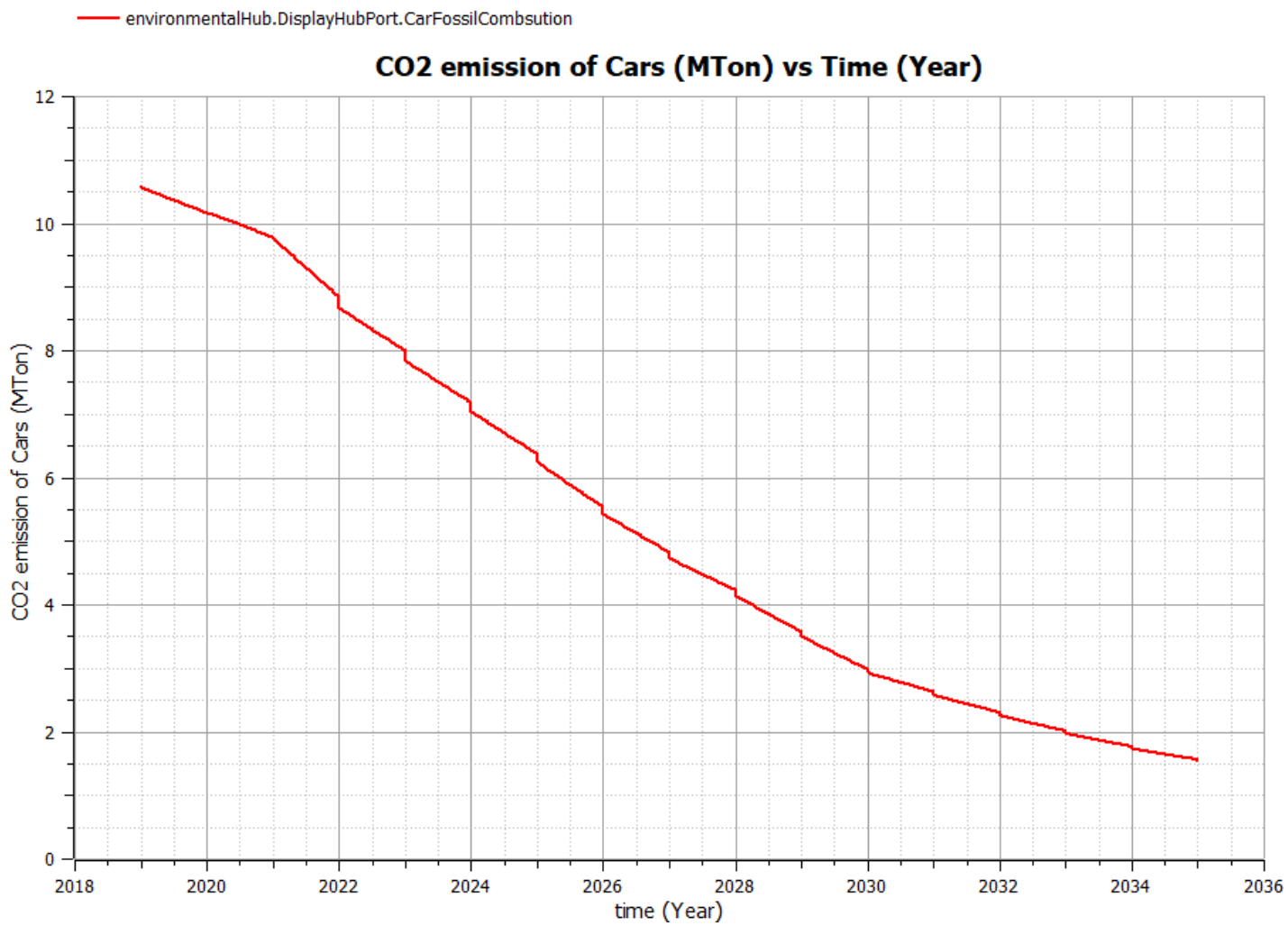
Vehicle	Legends
Total Number of Cars	
Bio Gas Cars	
Petrol Cars	
Diesel Cars	
PHeV Cars	
Electric Cars	

Results Scenario 3 – Number of Cars Growth and Depletion Rate

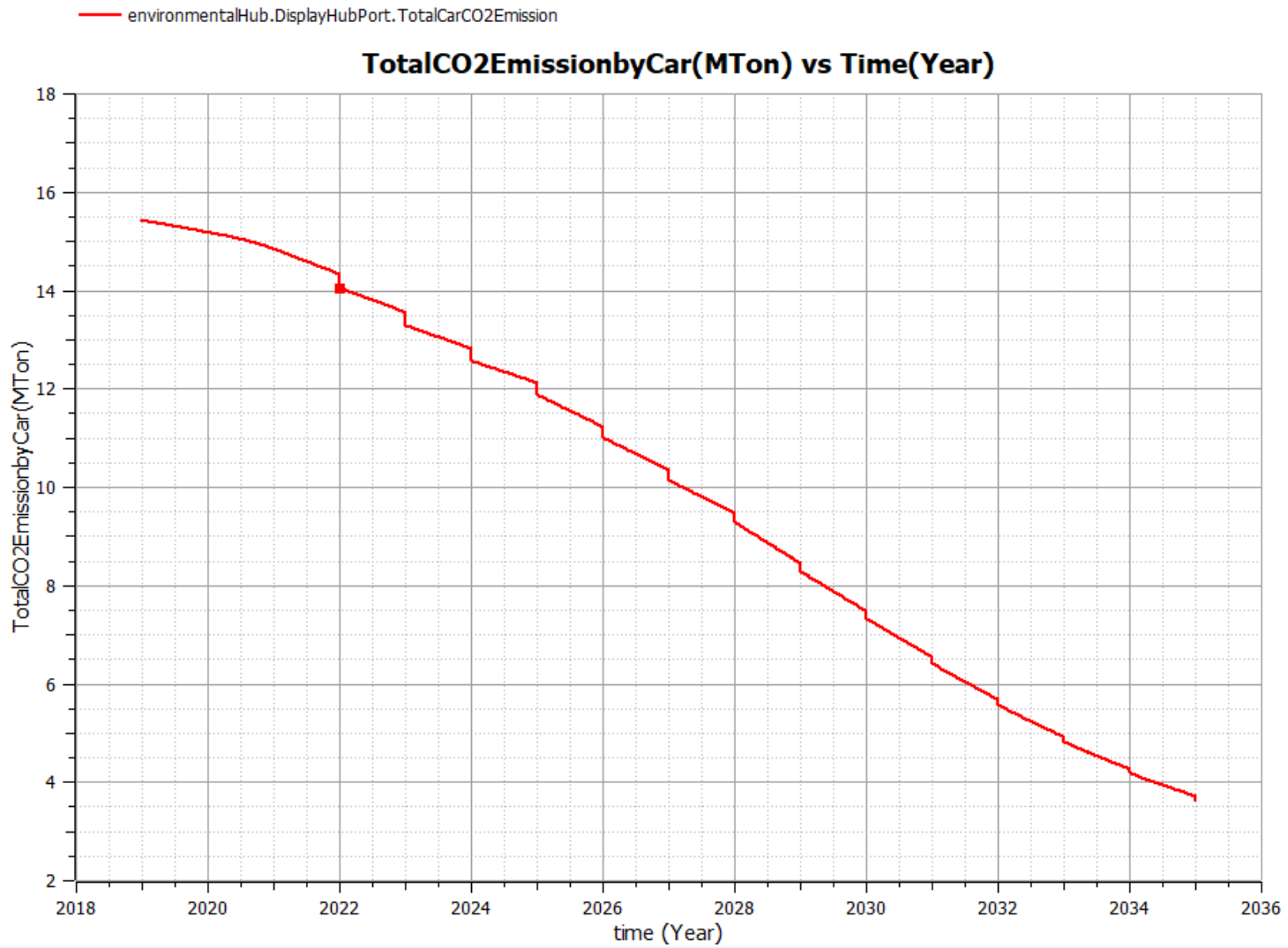




Results Scenario 3 – Total Cars CO2 Fossil Emission 2019 - 2035

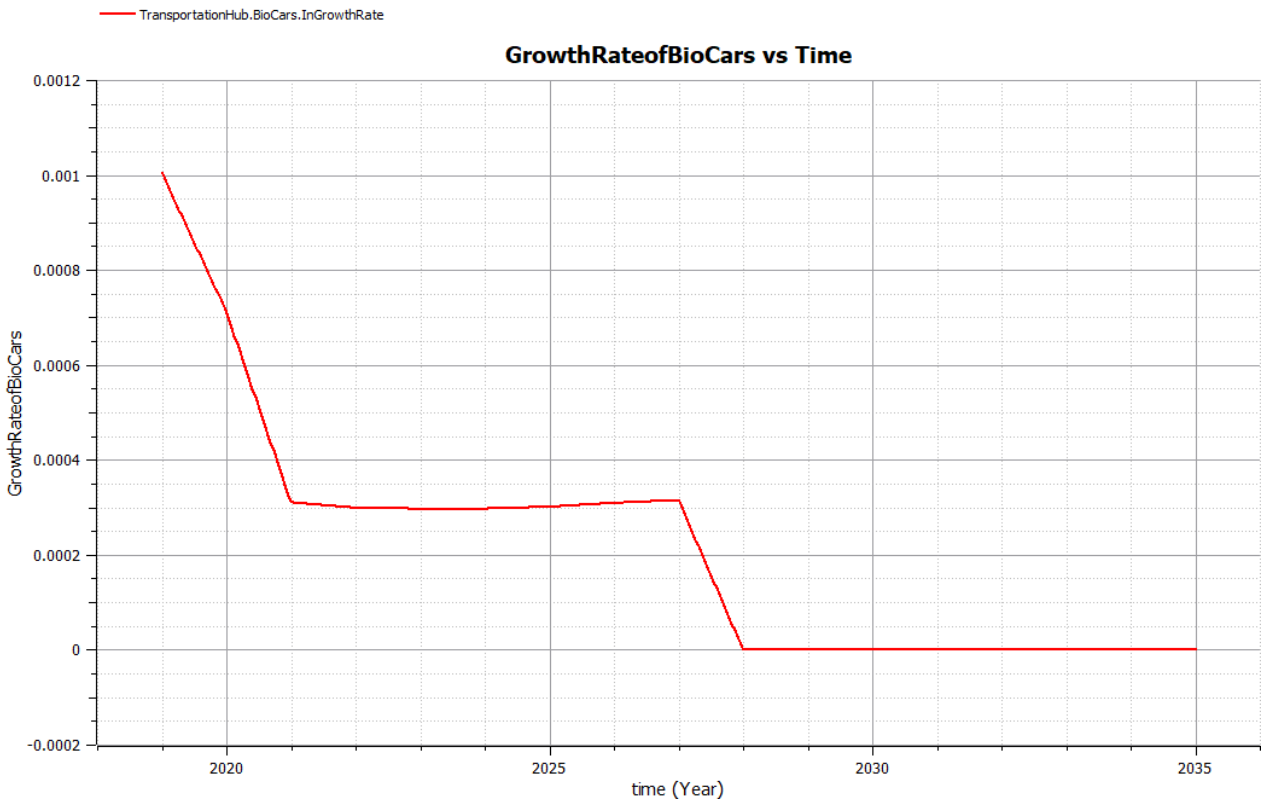


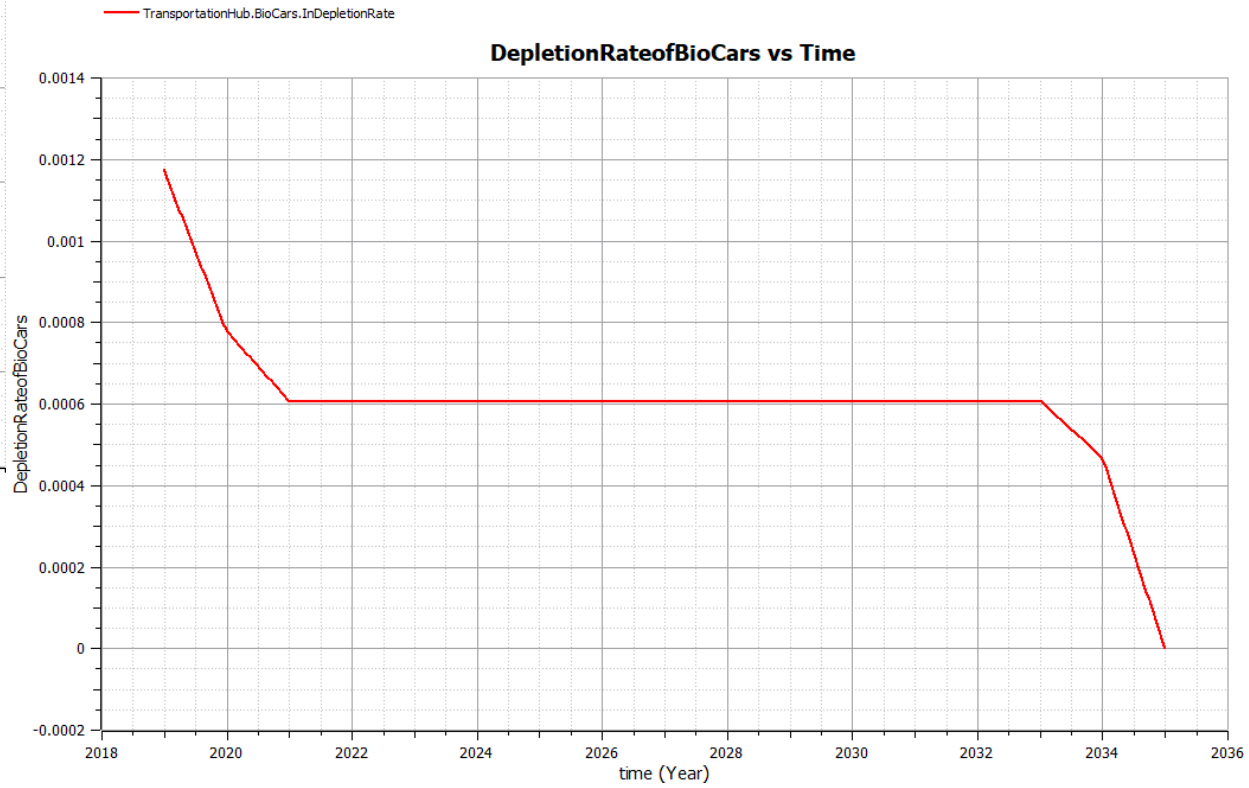
Scenario 3 – Total Cars CO2 Emission incl upstream and biofuels



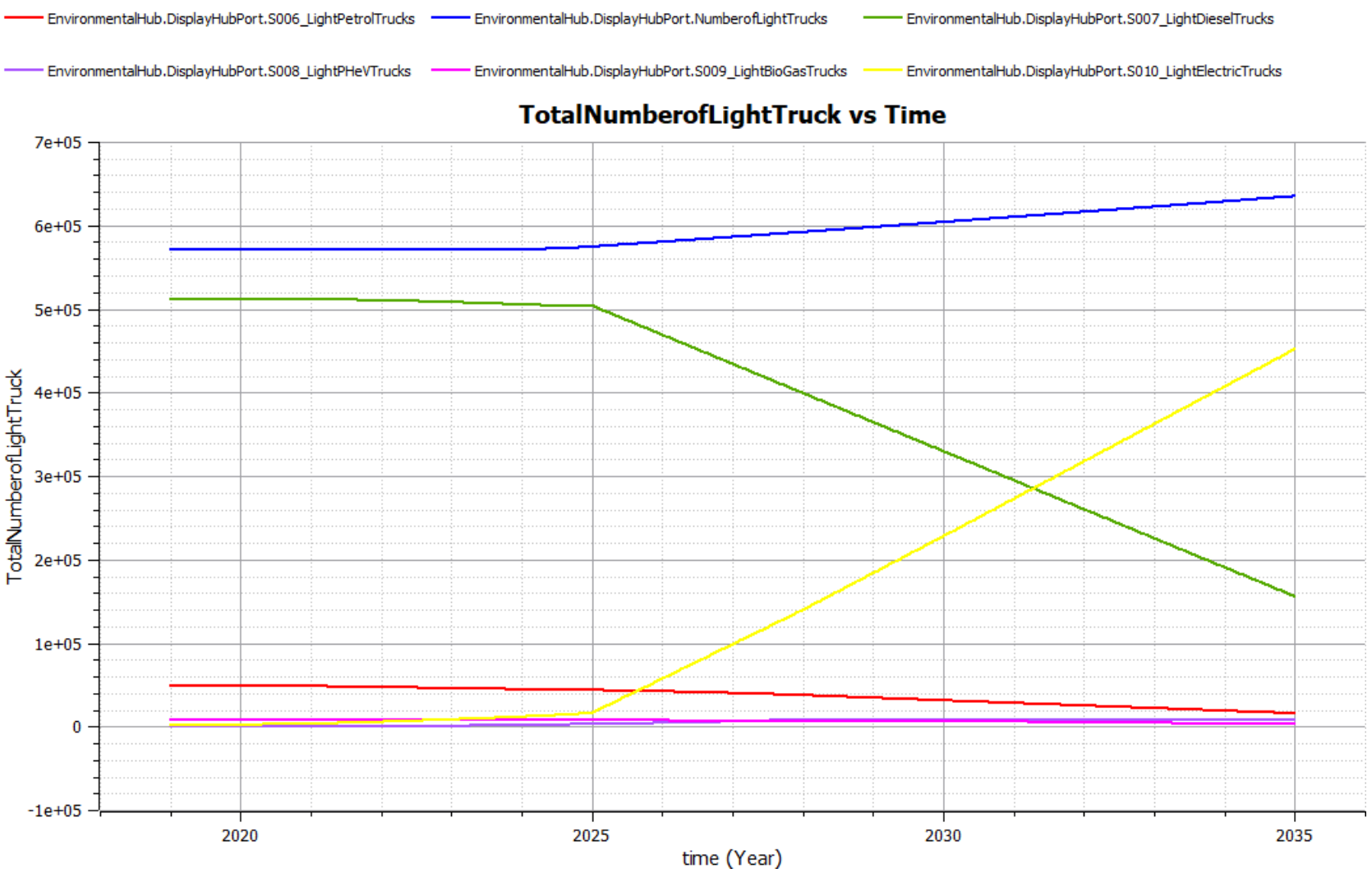
Results Scenario 3 – Car Growth and depletion rate

– Ex: BioGasCar – Fossil Ban Year -2028, Average driving range km Reduction – 2% per year



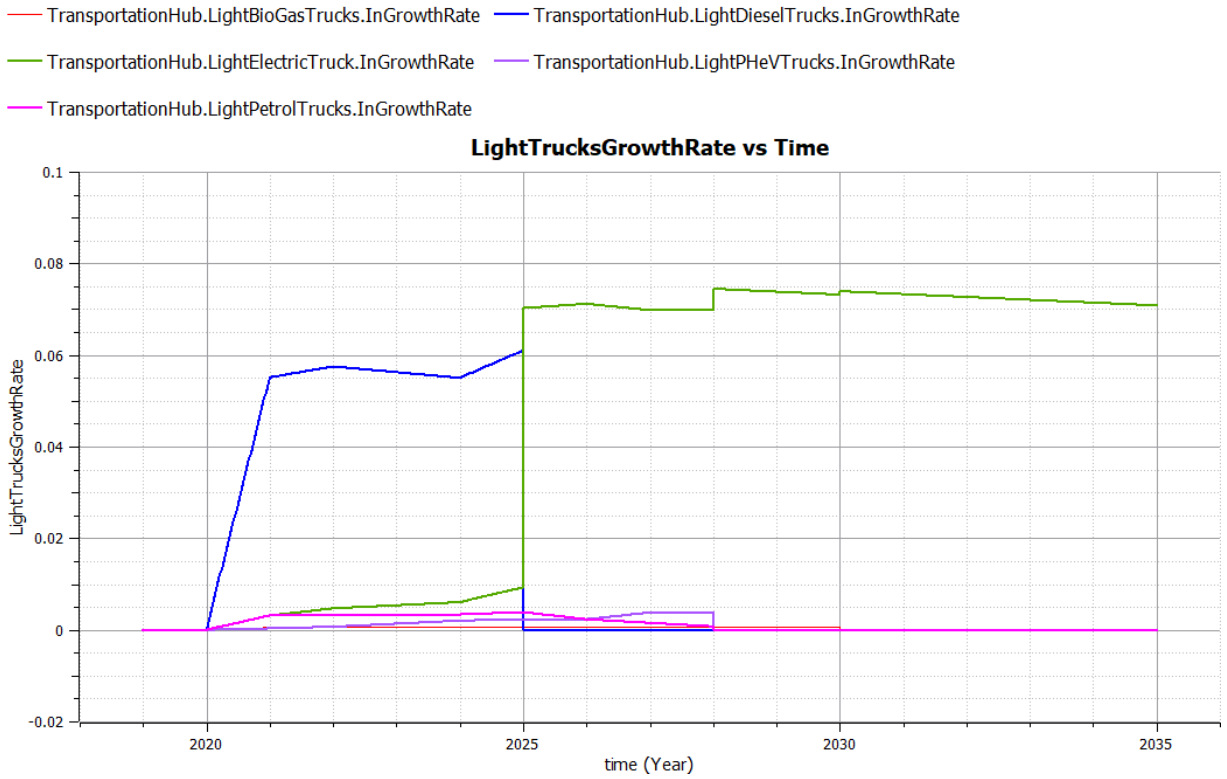


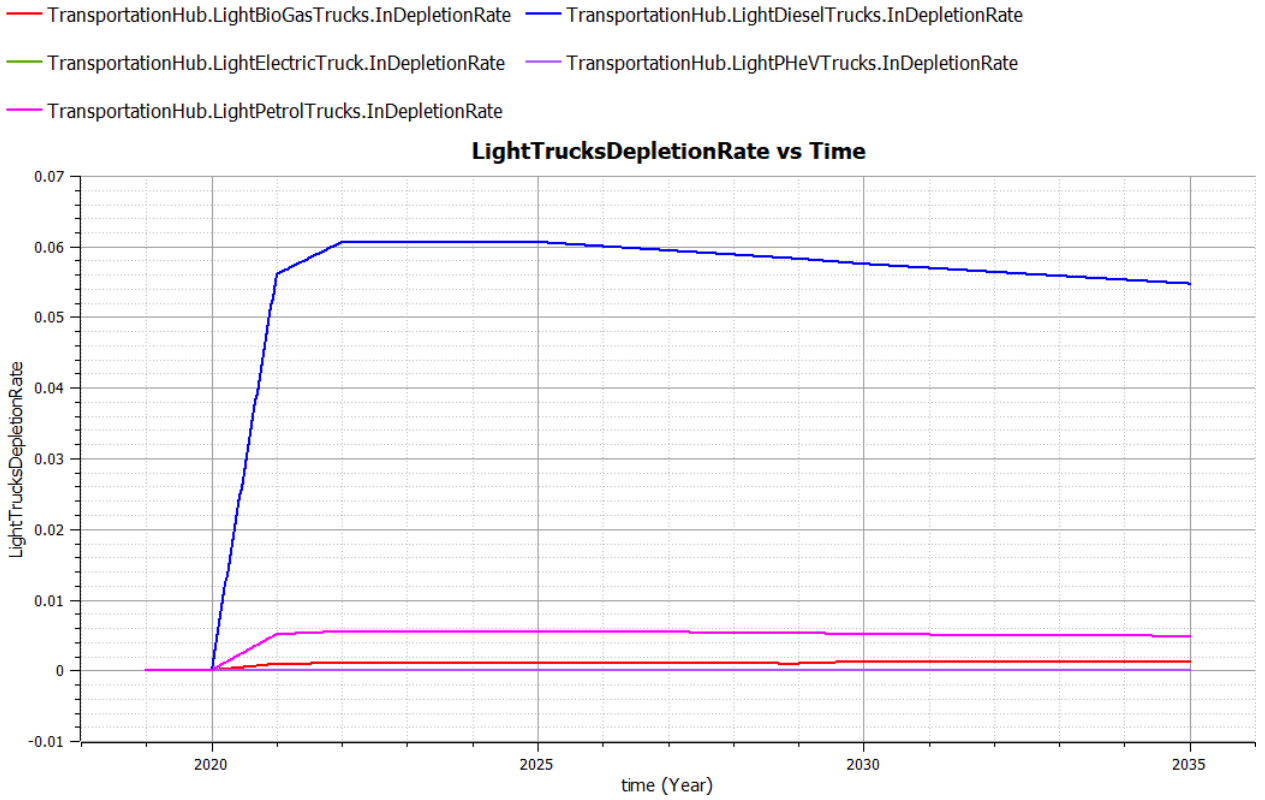
Results Scenario 3 – Light Trucks- Average driving range km Reduction – 2%



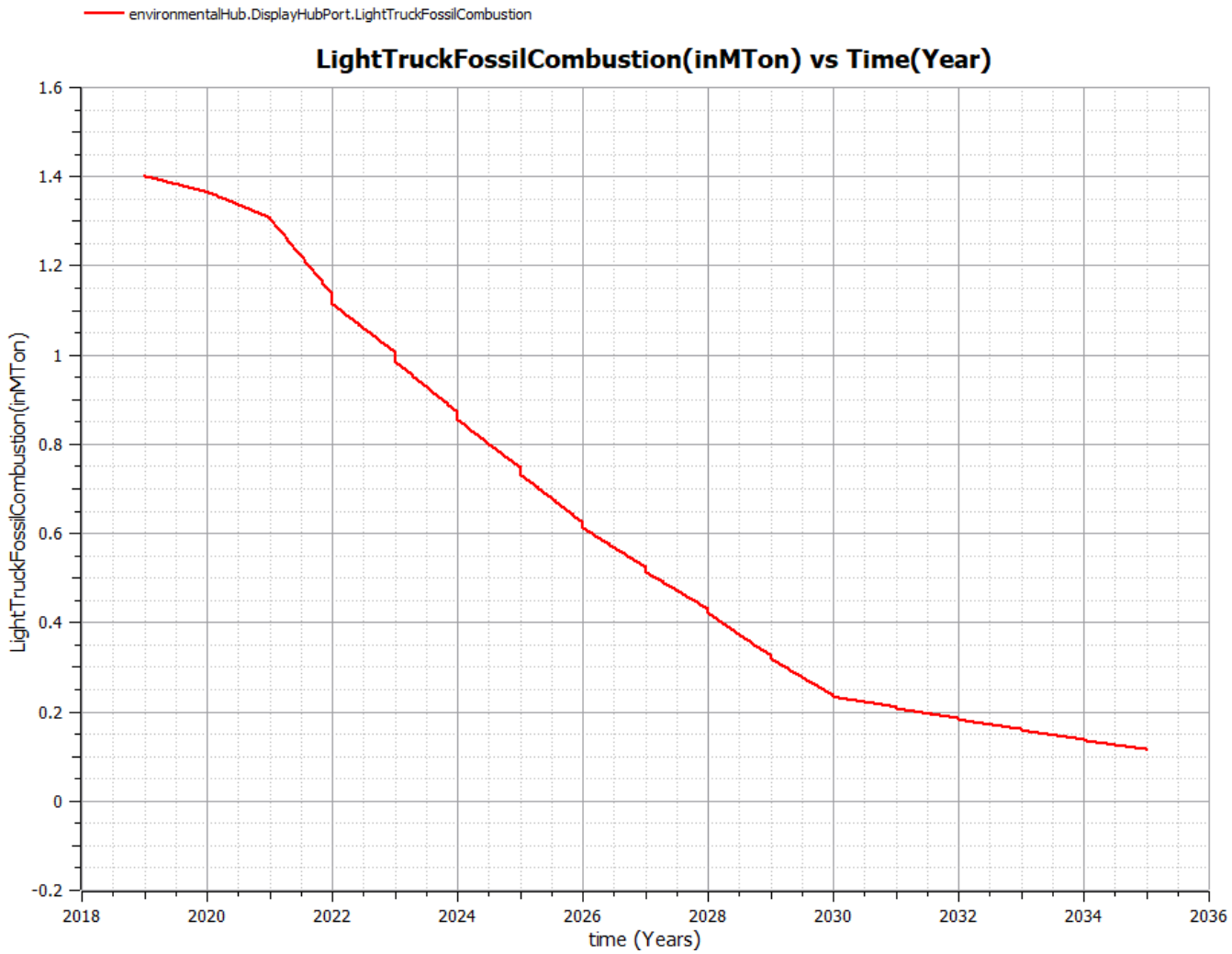
Trucks	Fossil Ban Year
Petrol	2028
Diesel	2025
BioGas	2030
PHeV	2028

Results Scenario 3 – Light Trucks-Growth Rate and Depletion Rate

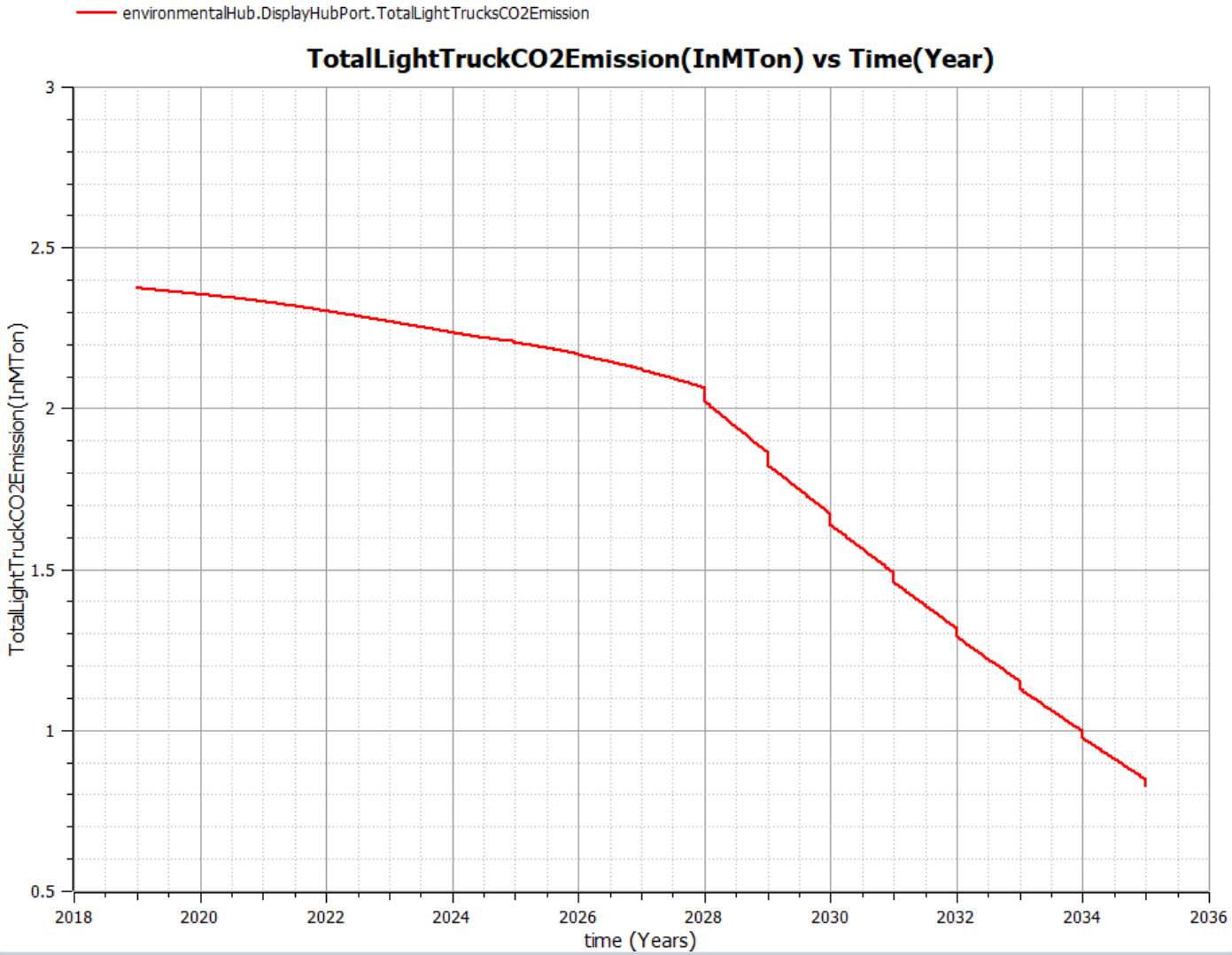




Results Scenario 3 – Light Trucks – Fossil CO2 Emissions

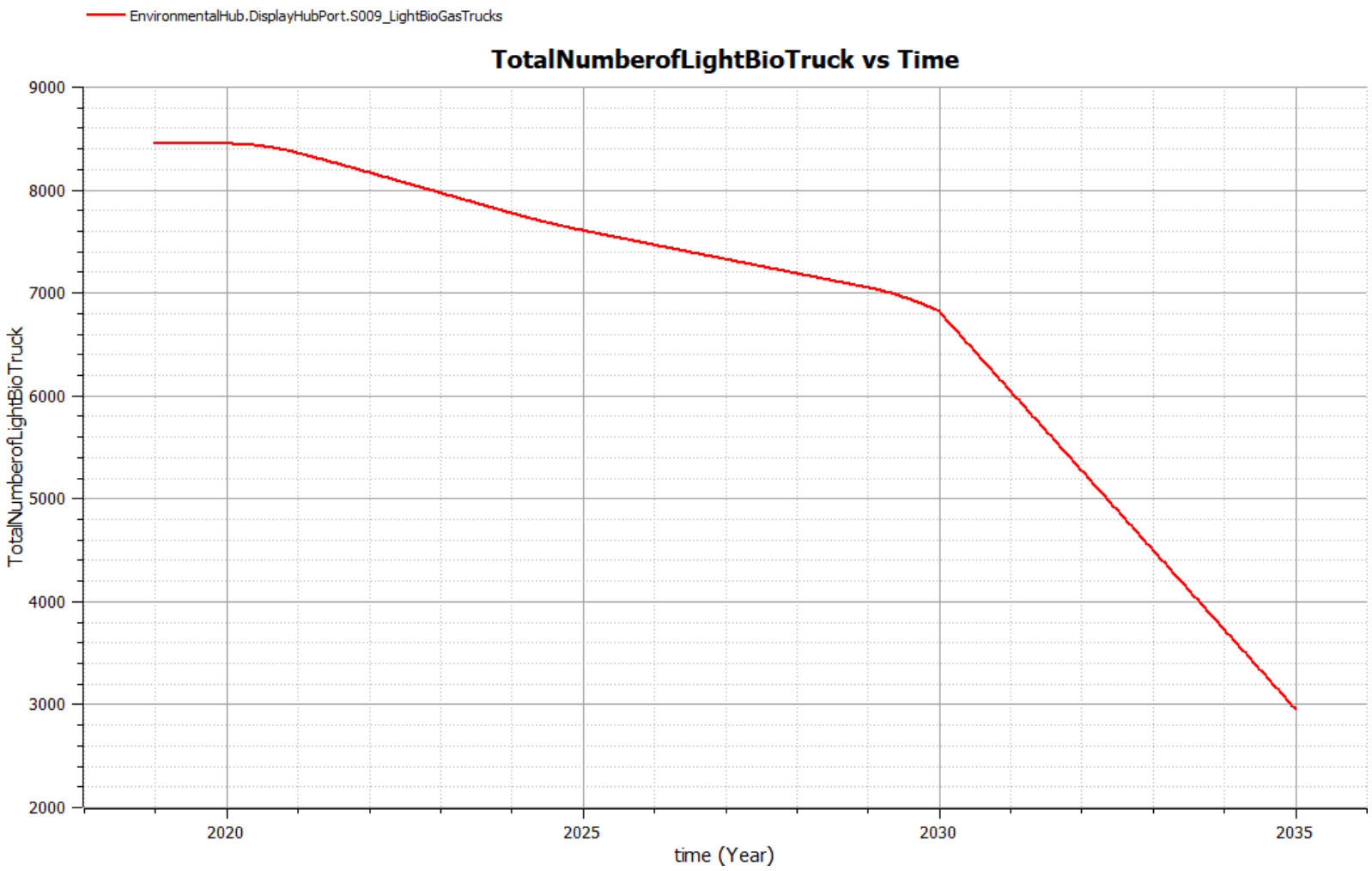


Results Scenario 3 – Light Trucks – CO2 Emissions including upstream and biofuels



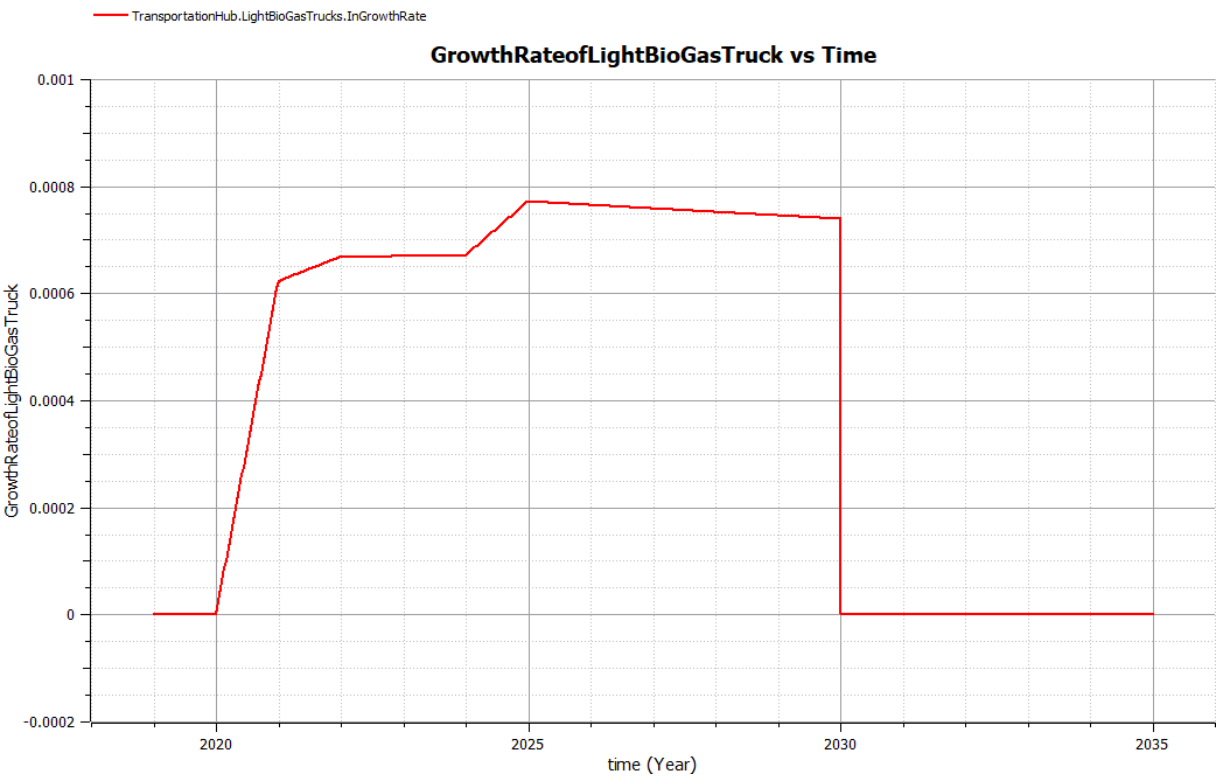
Results Scenario 3 –Total Number of Light Trucks

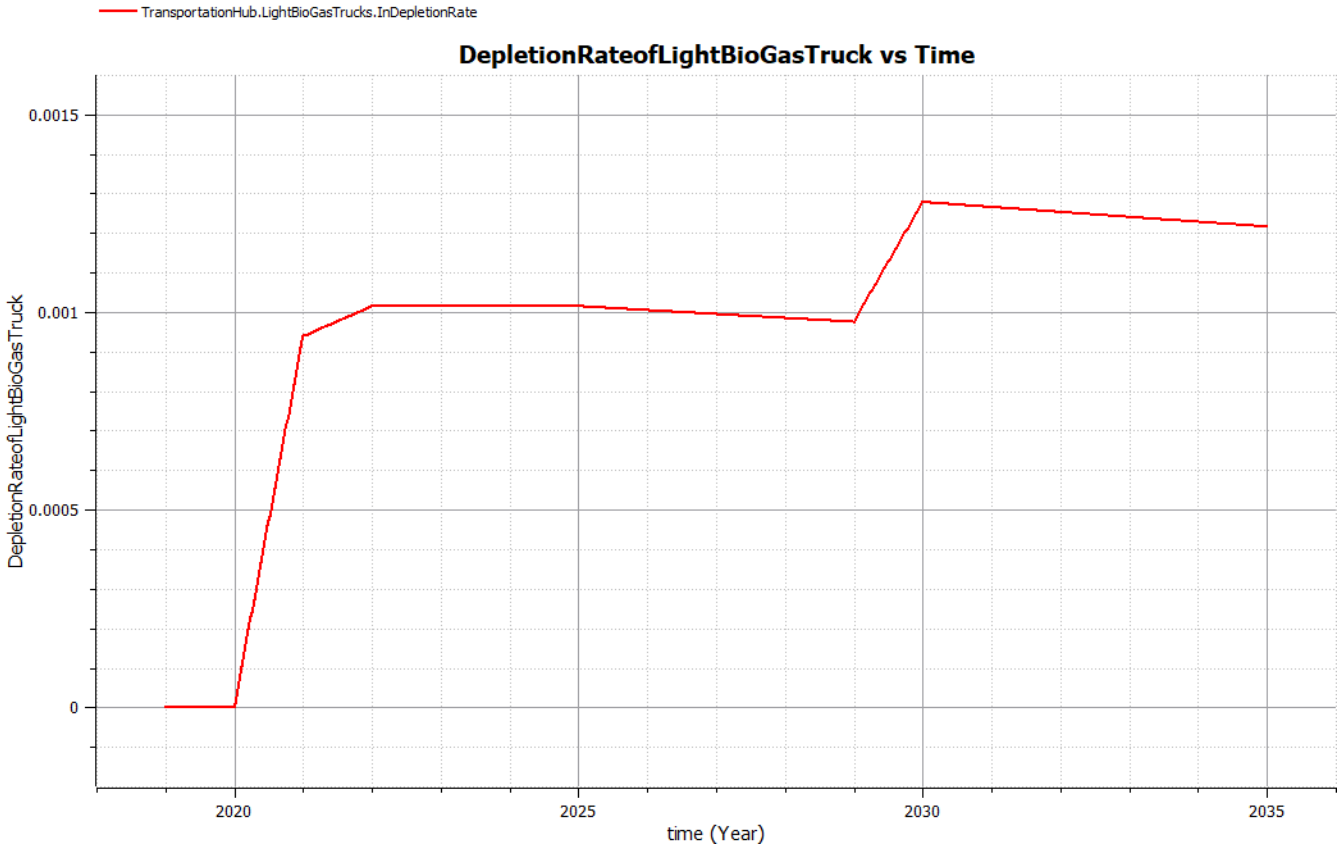
– Ex: LightBioTruck – Fossil Ban Year -2030, Average driving range km Reduction – 2% per year



Results Scenario 3 –Growth and Depletion Rates of Light Trucks

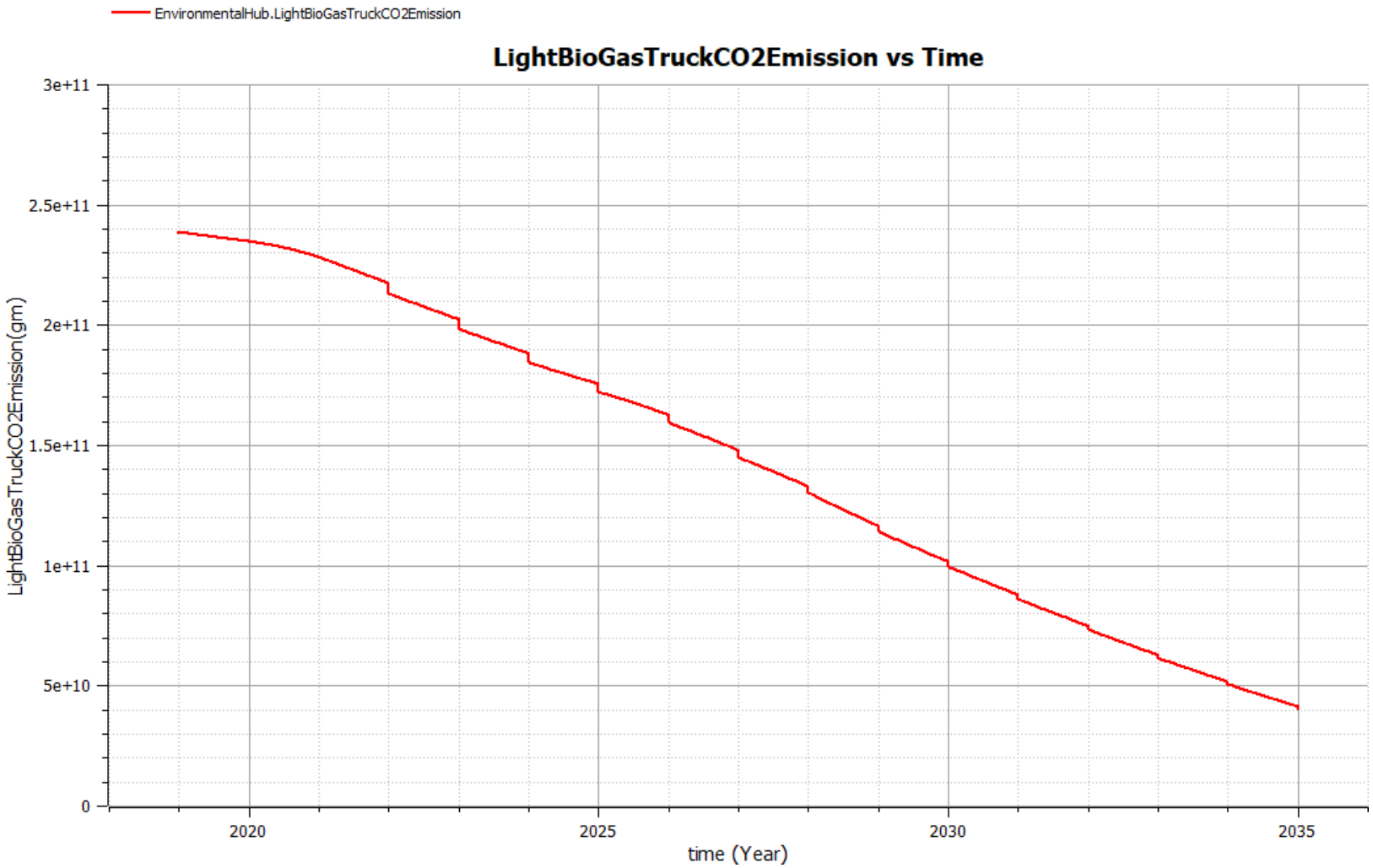
– Ex: LightBioTruck – Fossil Ban Year -2028, Average driving range km Reduction – 2% per year





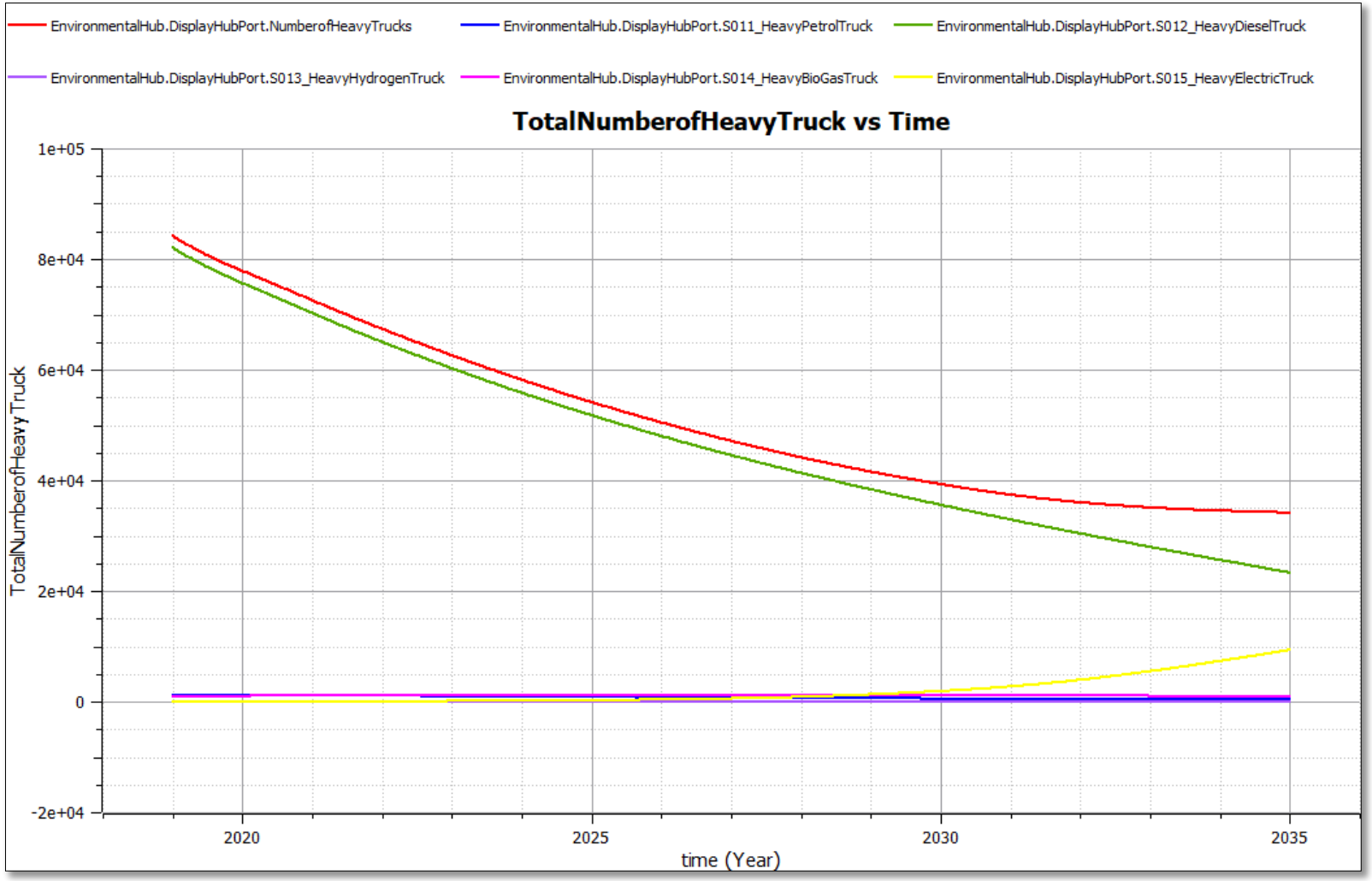
Results Scenario 3 – CO2 Emissions of Light Truck

– Ex: LightBioGasTruck – Fossil Ban Year -2030, Average driving range km Reduction – 2% per year



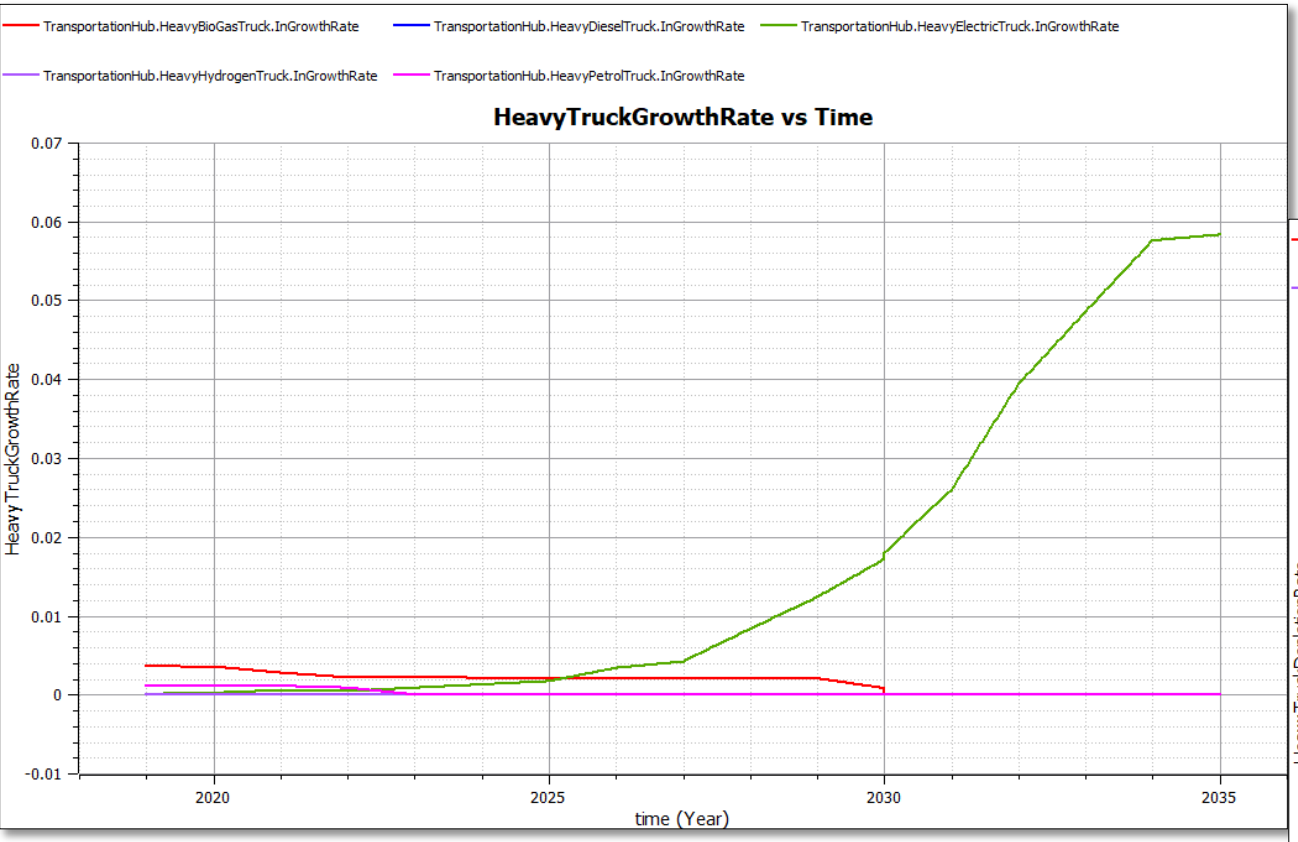
Results Scenario 3 – Heavy Truck

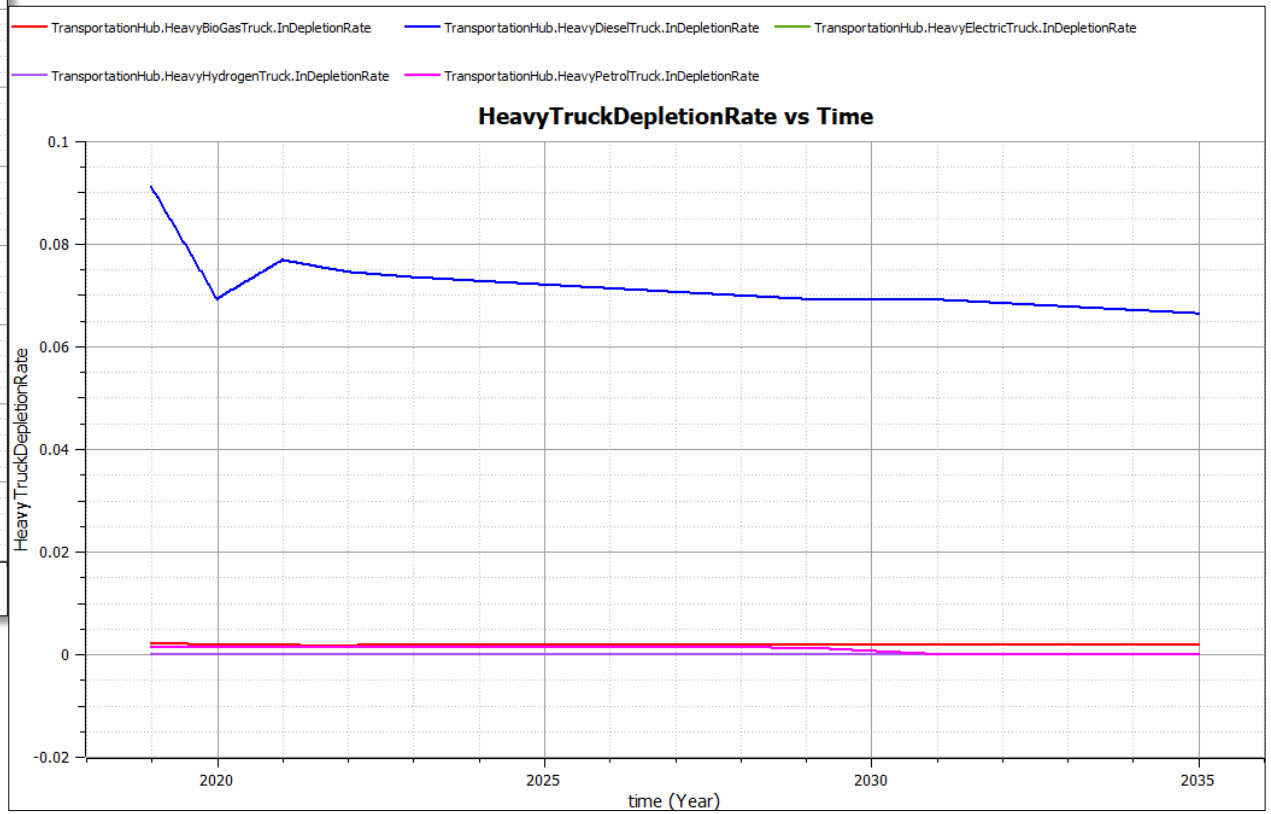
Average km driving distance Reduction 2% per year



Heavy Truck	Fossil Ban Year
Petrol	2028
Diesel	2025
Bio	2028
Hydro	2028

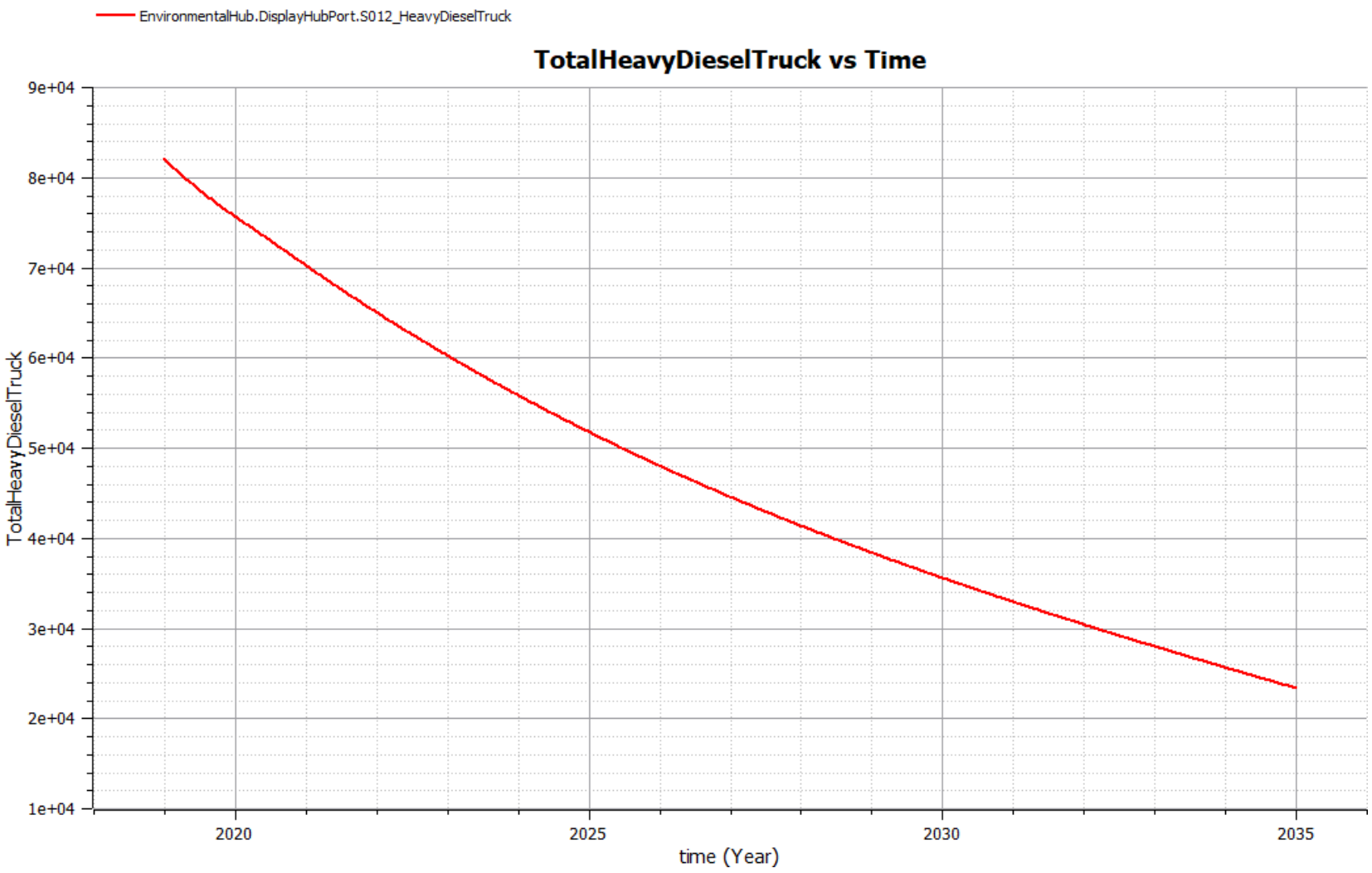
Results Scenario 3 – Heavy Truck - Growth and Depletion Rate





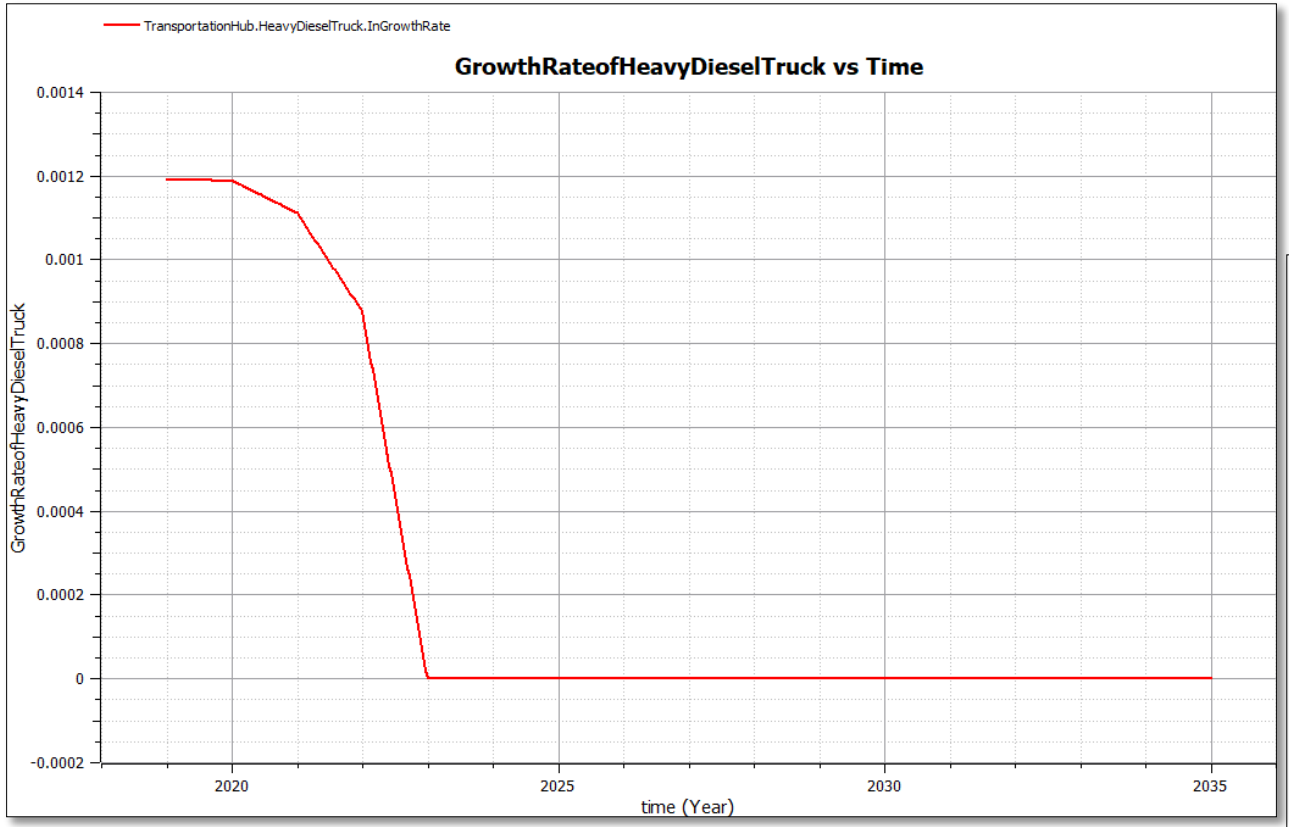
Results Scenario 3 – Total Number of Heavy Trucks

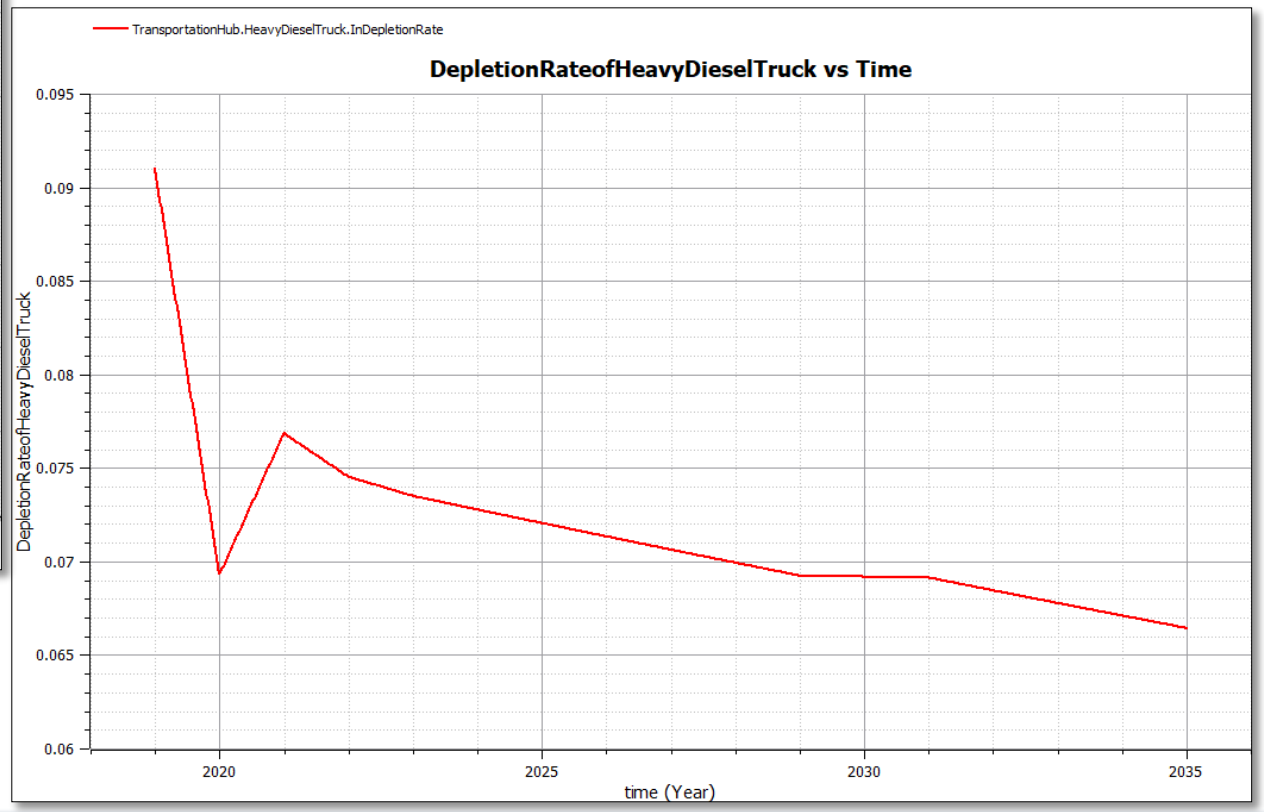
– Ex: HeavyDieselTruck – Fossil Ban Year -2025, Average driving range km reduction – 2%



Results Scenario 3 - Growth and Depletion Rates of Heavy Truck-

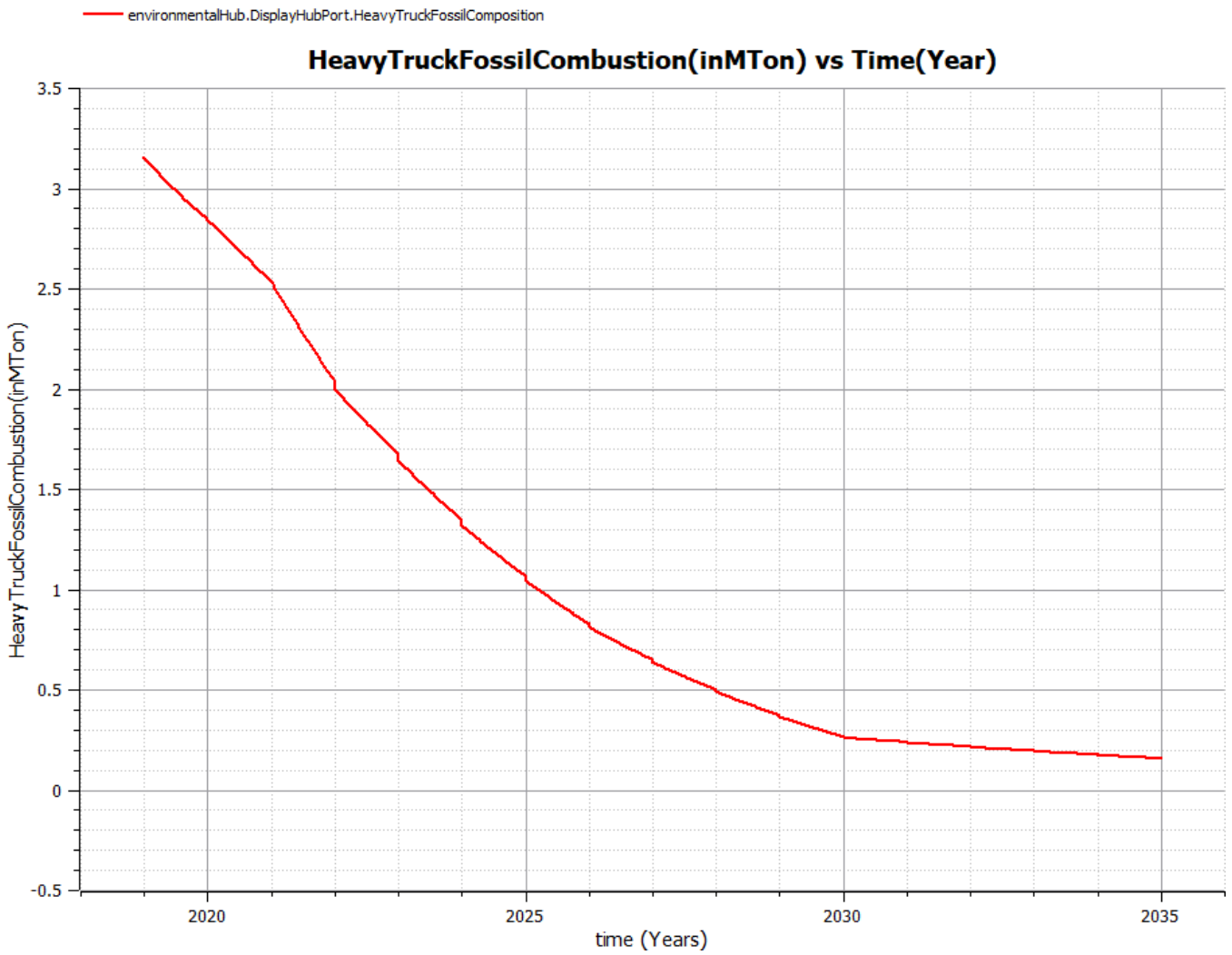
Ex: HeavyDieselTruck – Fossil Ban Year -2025, Average driving range km Reduction – 2%



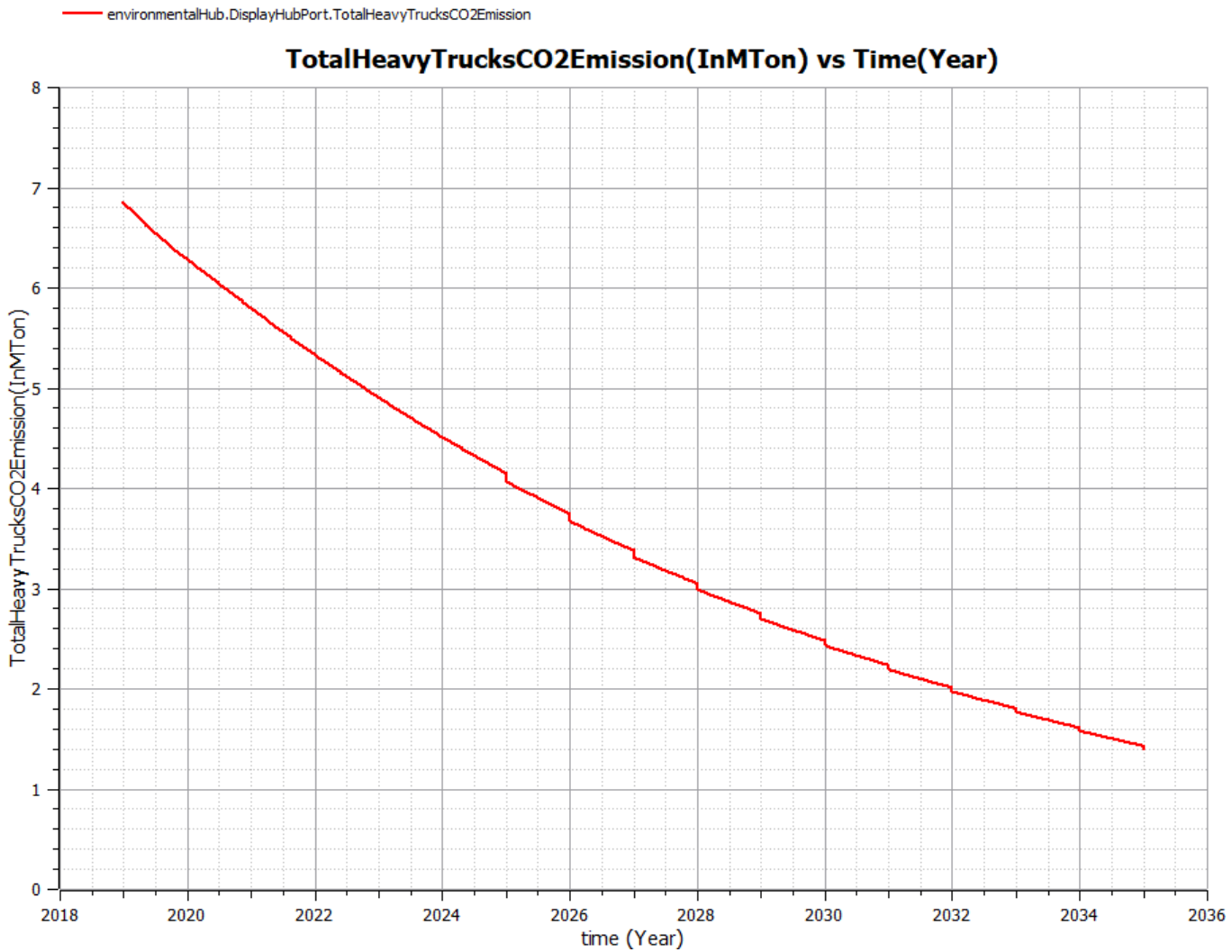


Results Scenario 3 – CO2 Fossil Emissions of Heavy Truck

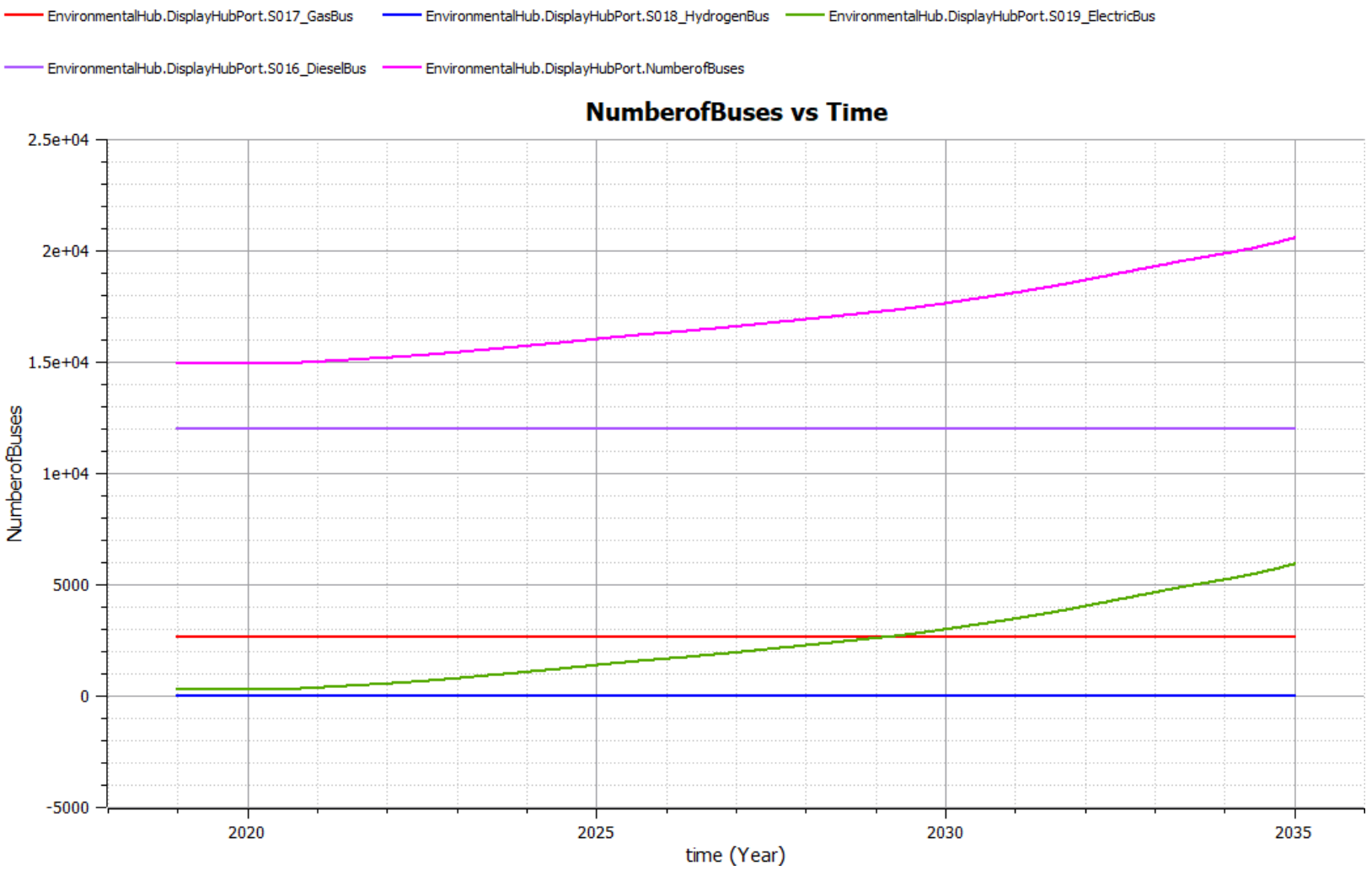
– Ex: HeavyDieselTruck – Fossil Ban Year -2025, Average driving range km Reduction – 2%



Results Scenario 3 – CO2 Emissions of Heavy Truck incl upstream and biofuels – Ex: HeavyDieselTruck – Fossil Ban Year -2025, Average driving range km Reduction – 2%

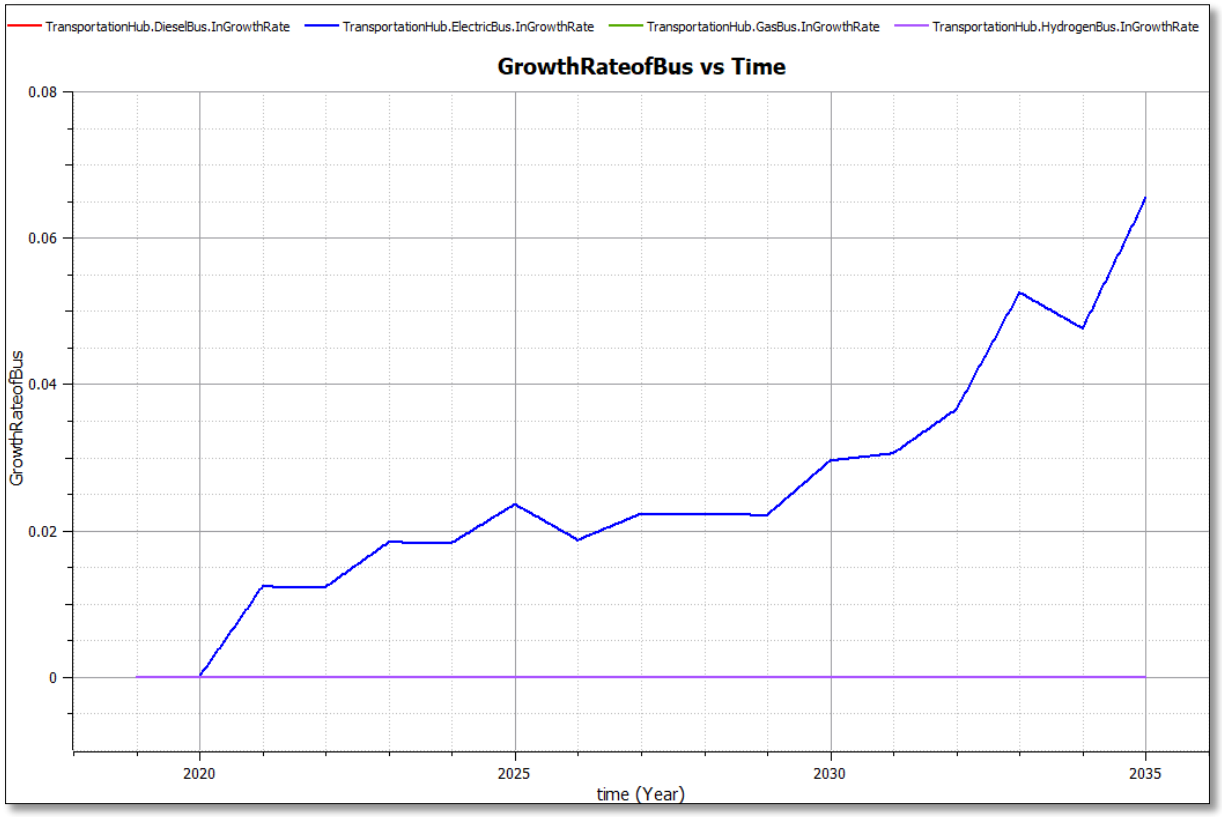


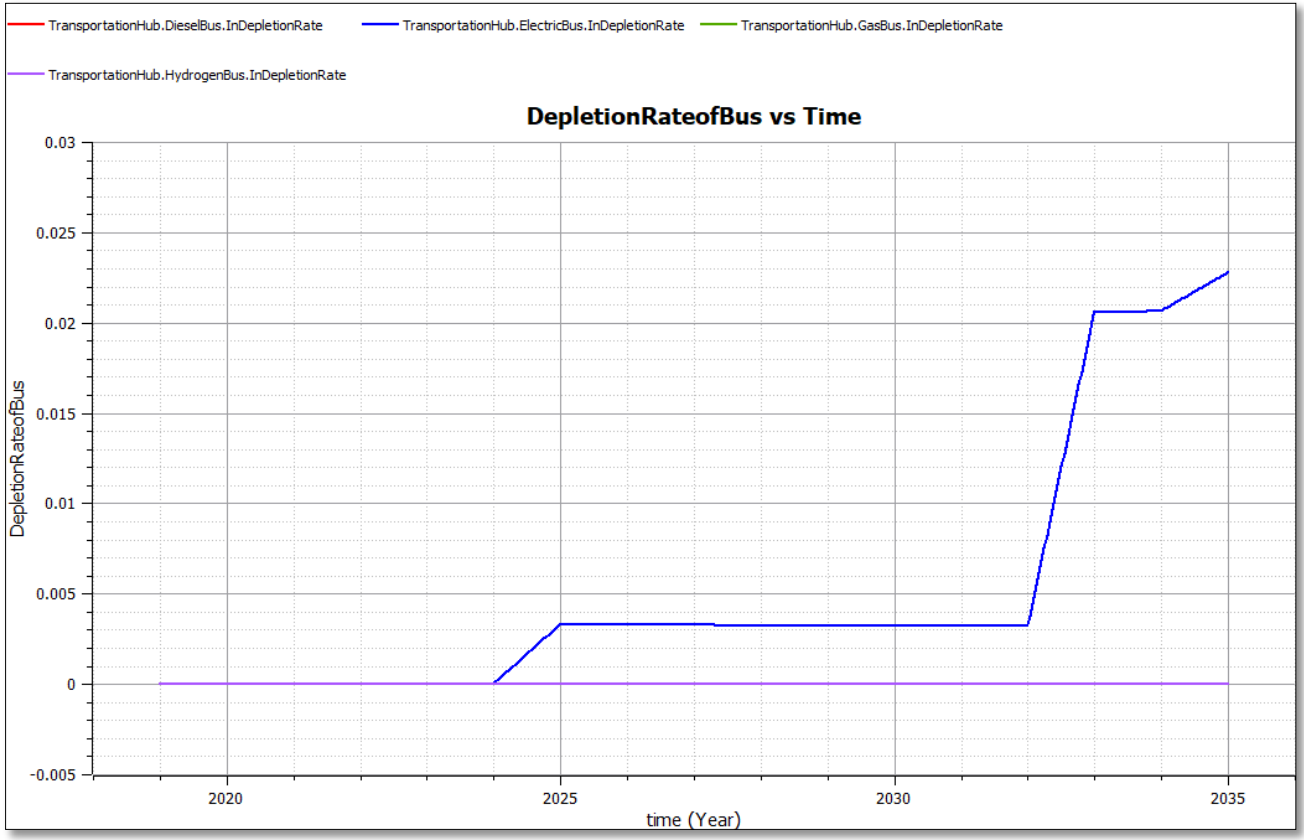
Results Scenario 3 – Bus New Combi-table Data - True



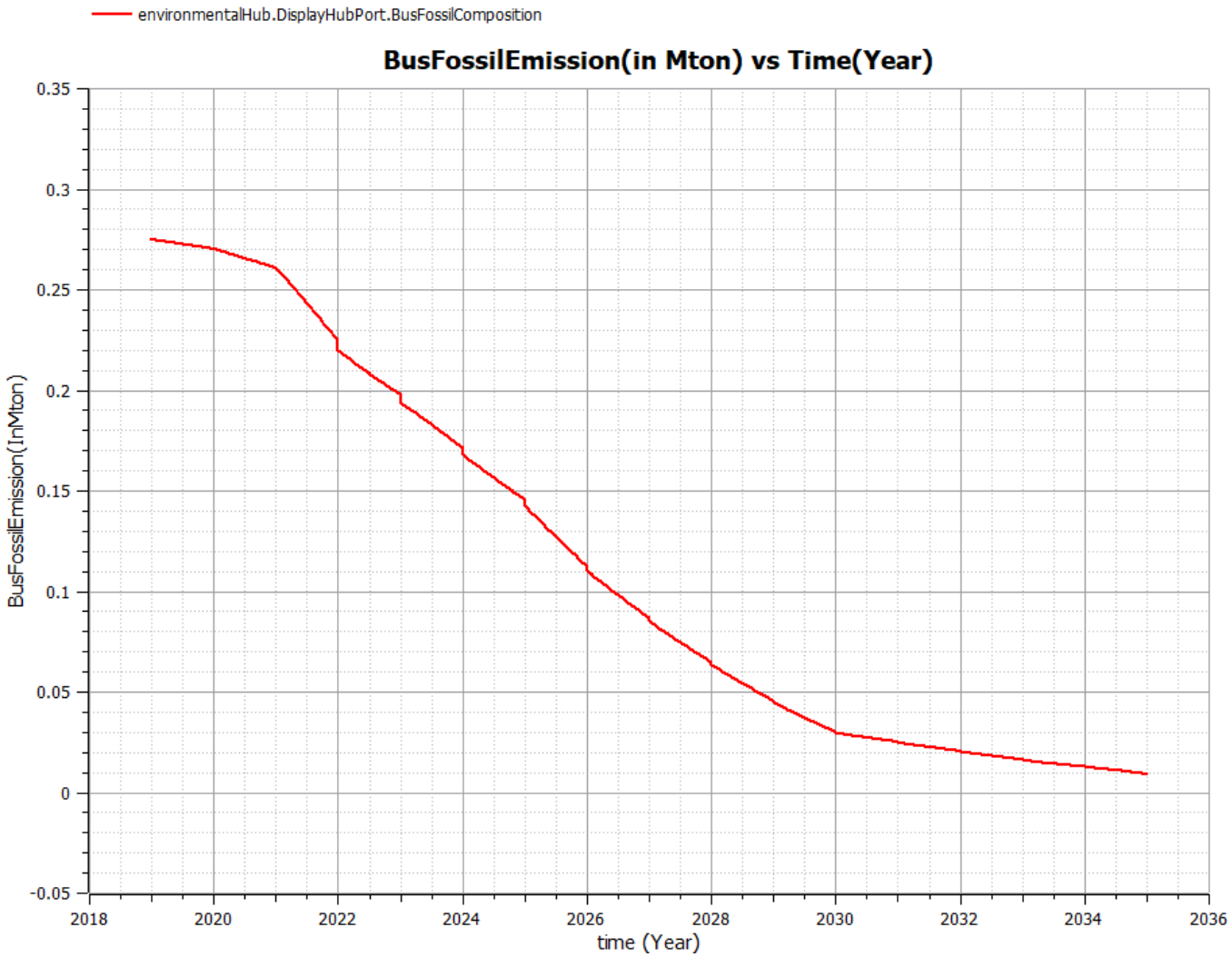
Bus	Fossil Ban Year
Diesel	2025
Biogas	2030
H2	2030

Results Scenario 3 – Number of Buses Growth and Depletion Rate

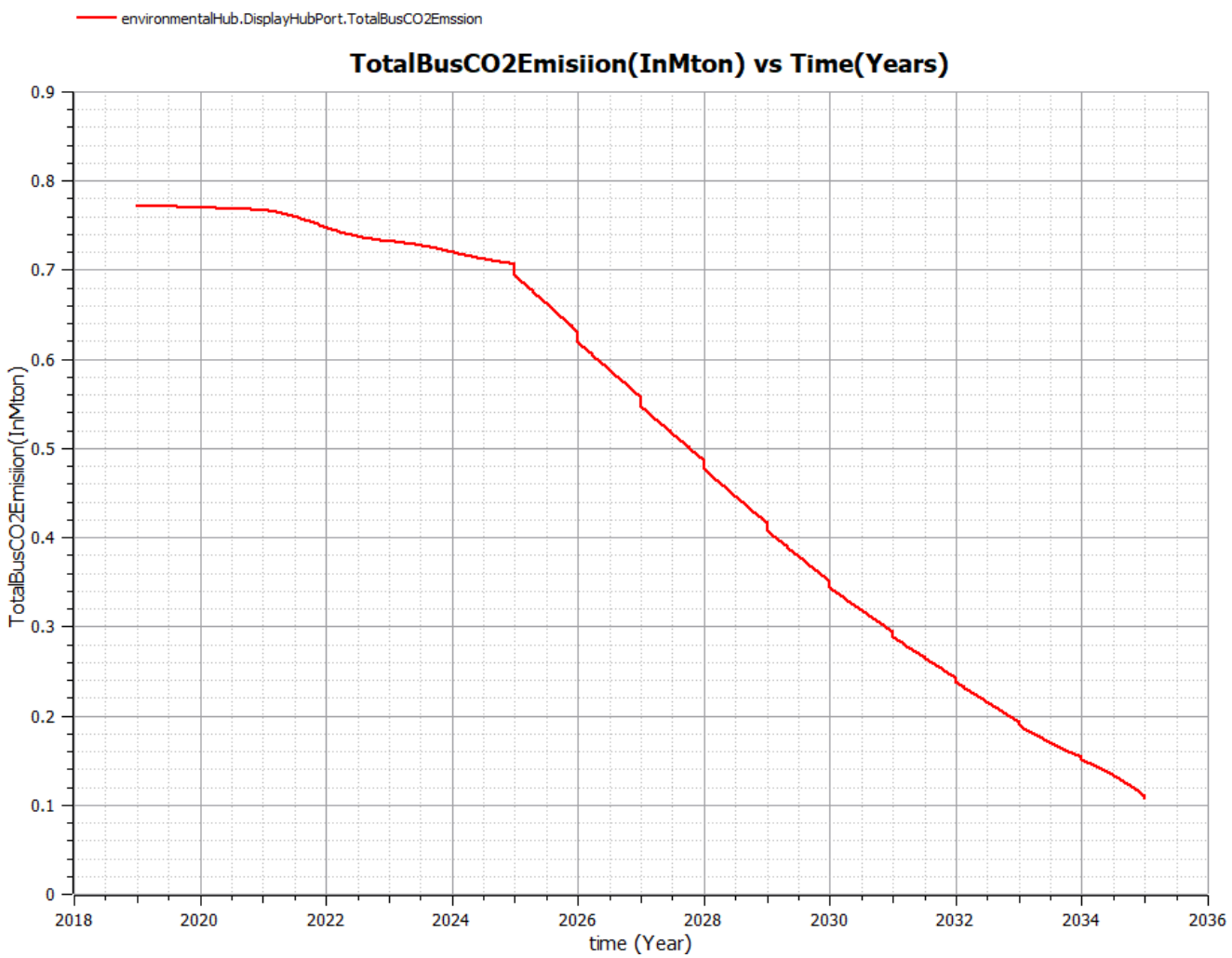




Results Scenario 3 – Bus CO2 Fossil Emissions

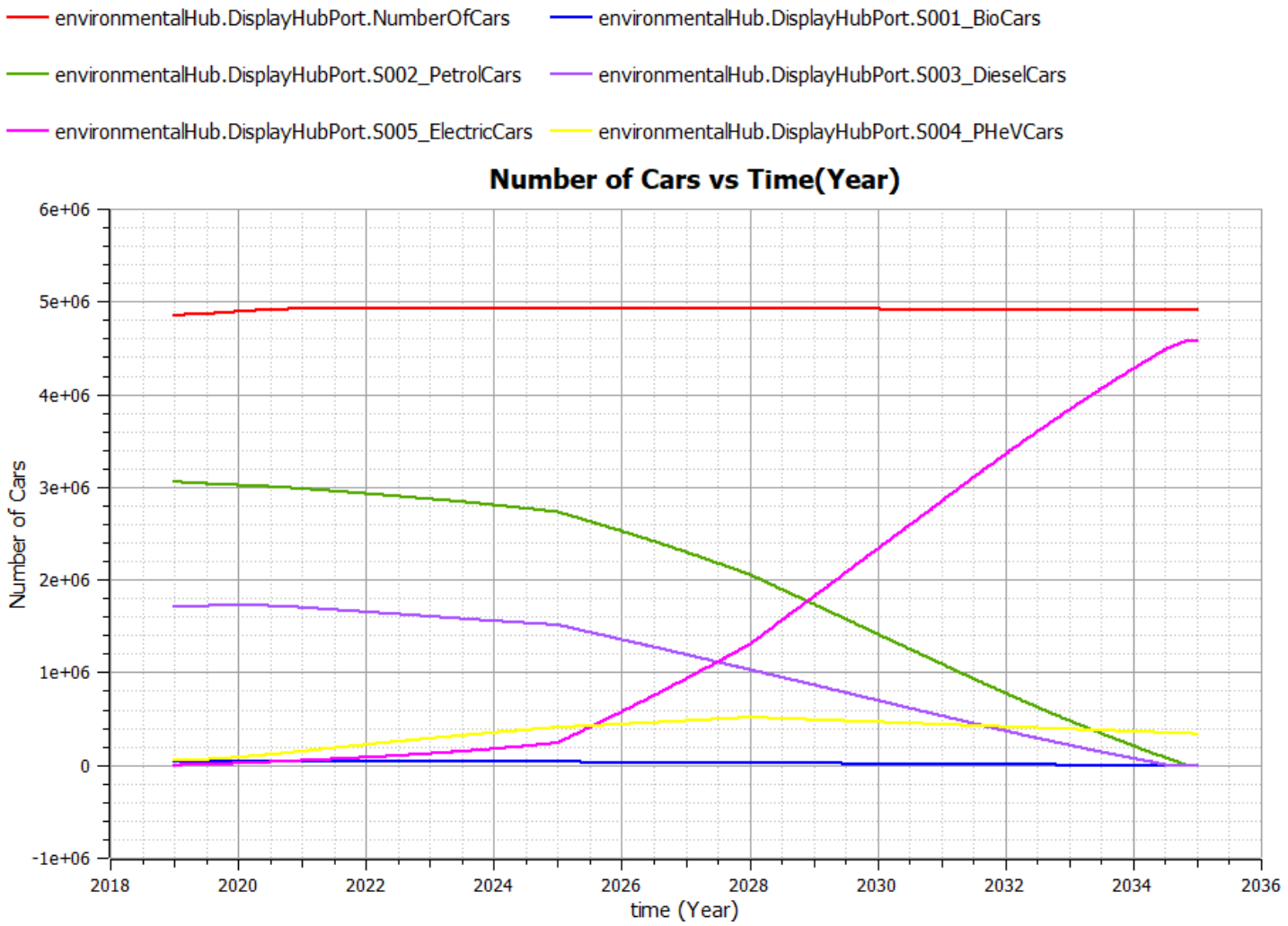


Results Scenario 3 – Bus CO2 Emissions incl upstream and biofuels



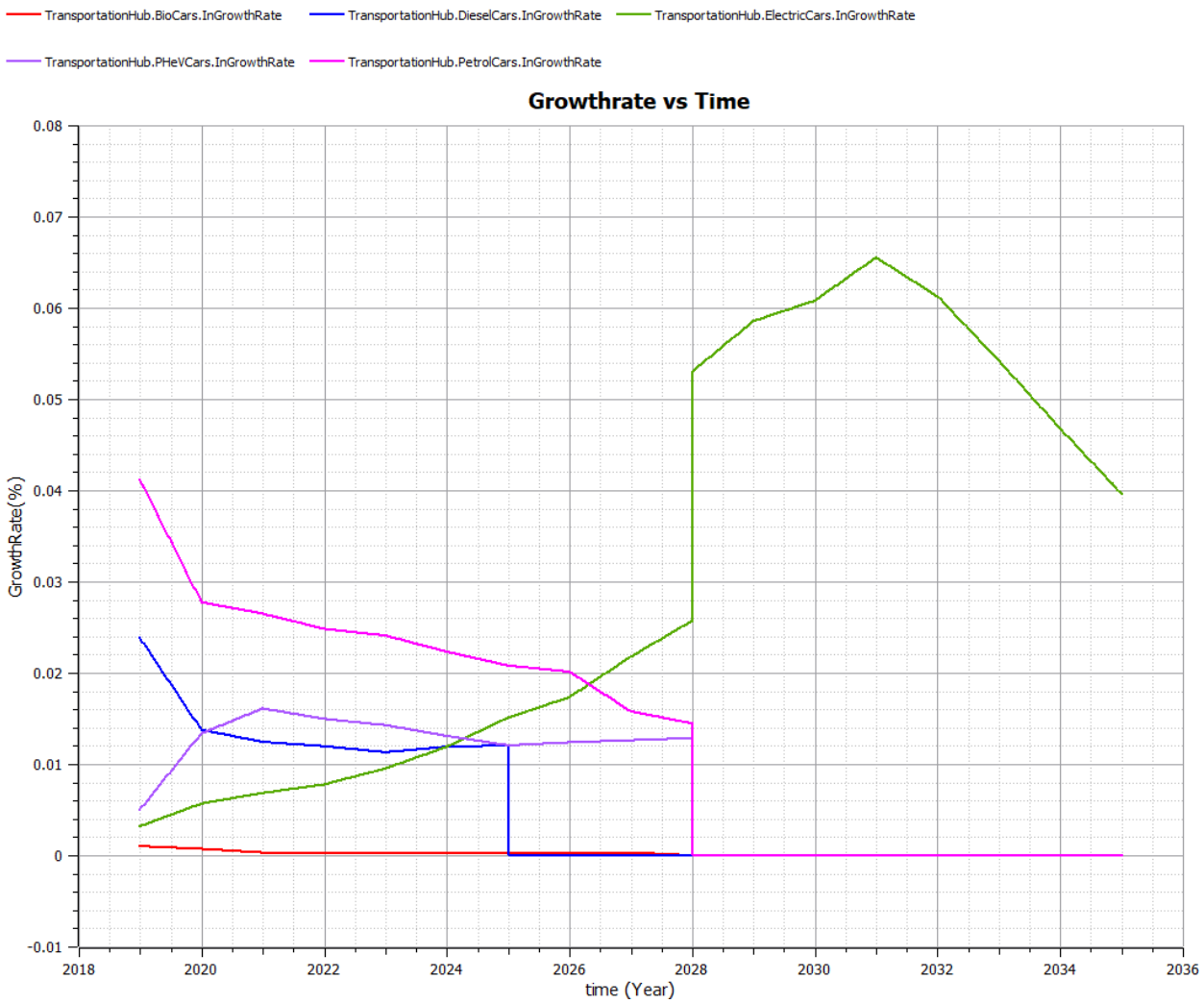
Results Scenario 4 – Cars

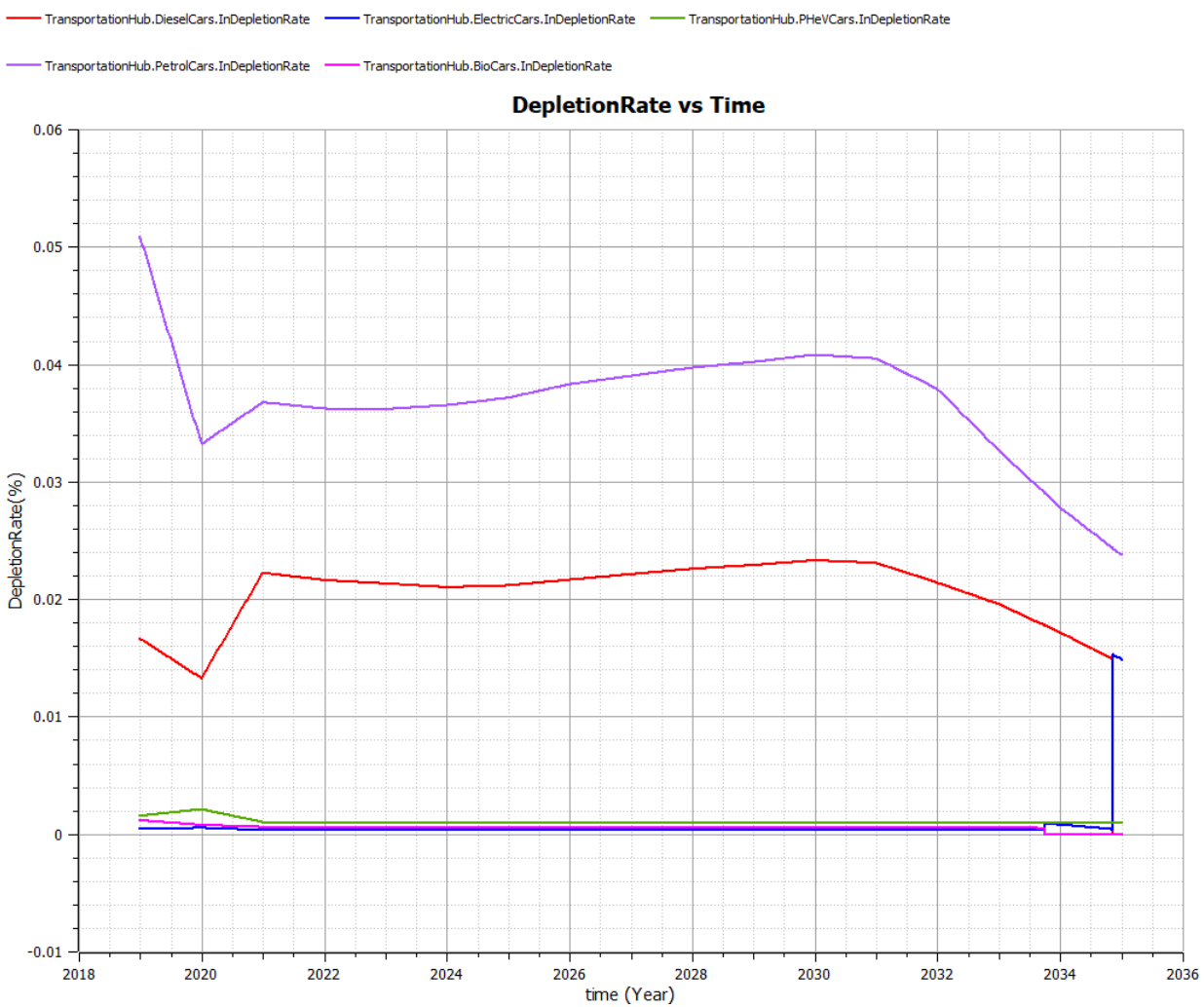
Conversion start Year - 2025 , Average driving range km Reduction – 2%, annually



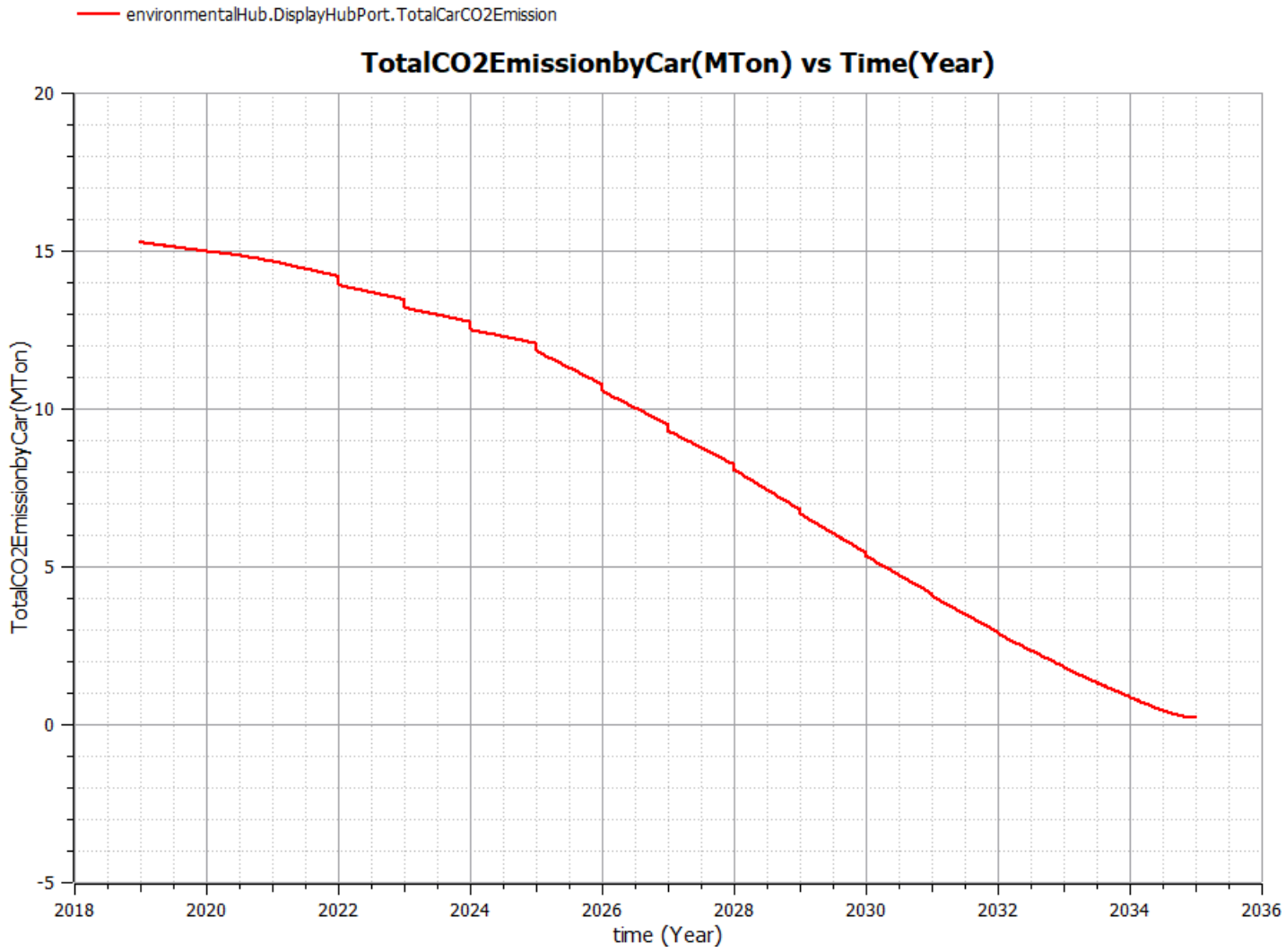
Vehicle Type	Conversion %	Fossil Ban Year
Petrol	4.5	2025
Diesel	3.5	2025
Bio	4.5	2028
PHeV	13	2028

Results Scenario 4 –Cars Growth and Depletion Rate

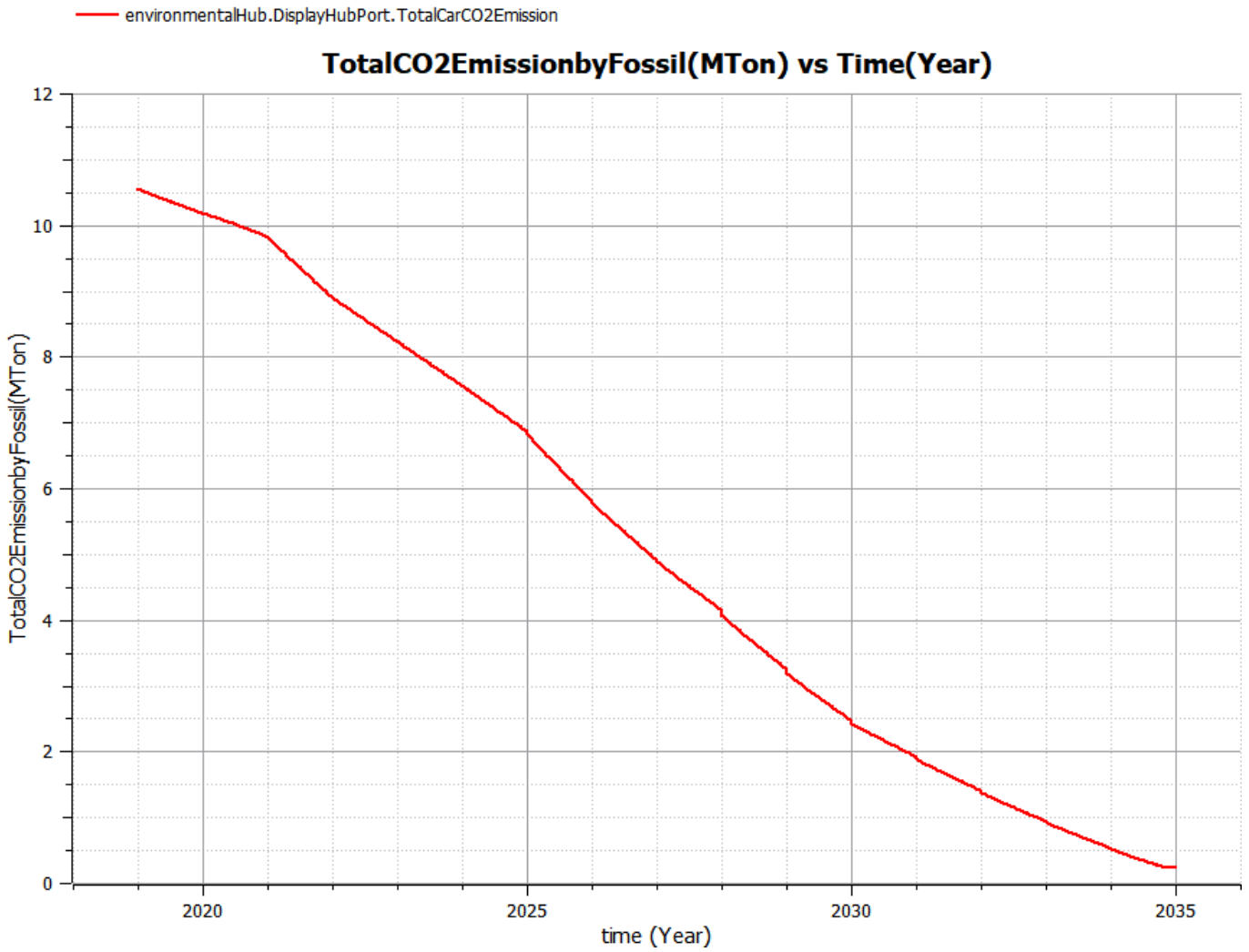




Scenario 4 – Total Car CO2 Fossil Emission including upstream and biofuels

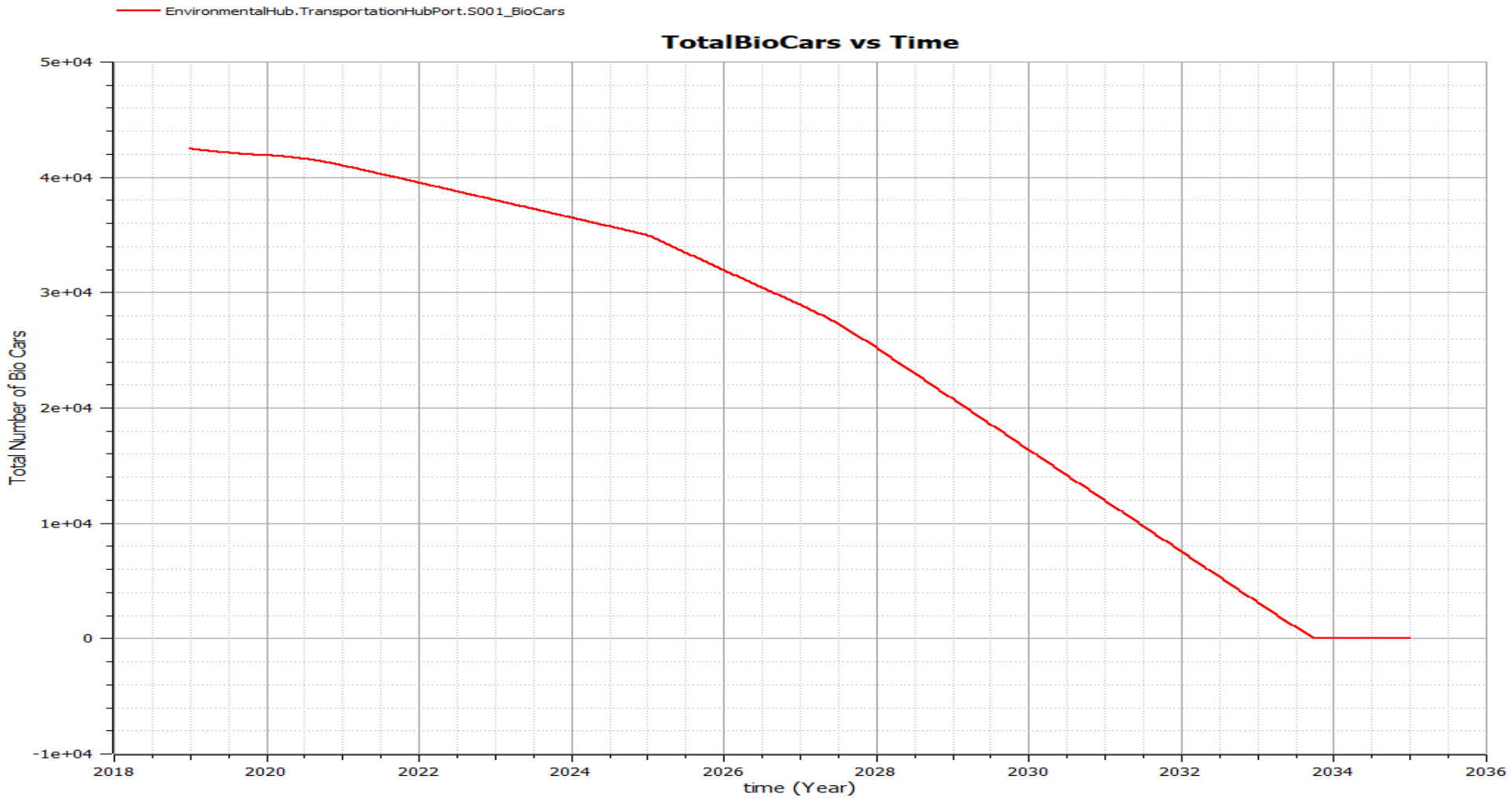


Scenario 4 – Total Car CO2 Fossil Emission



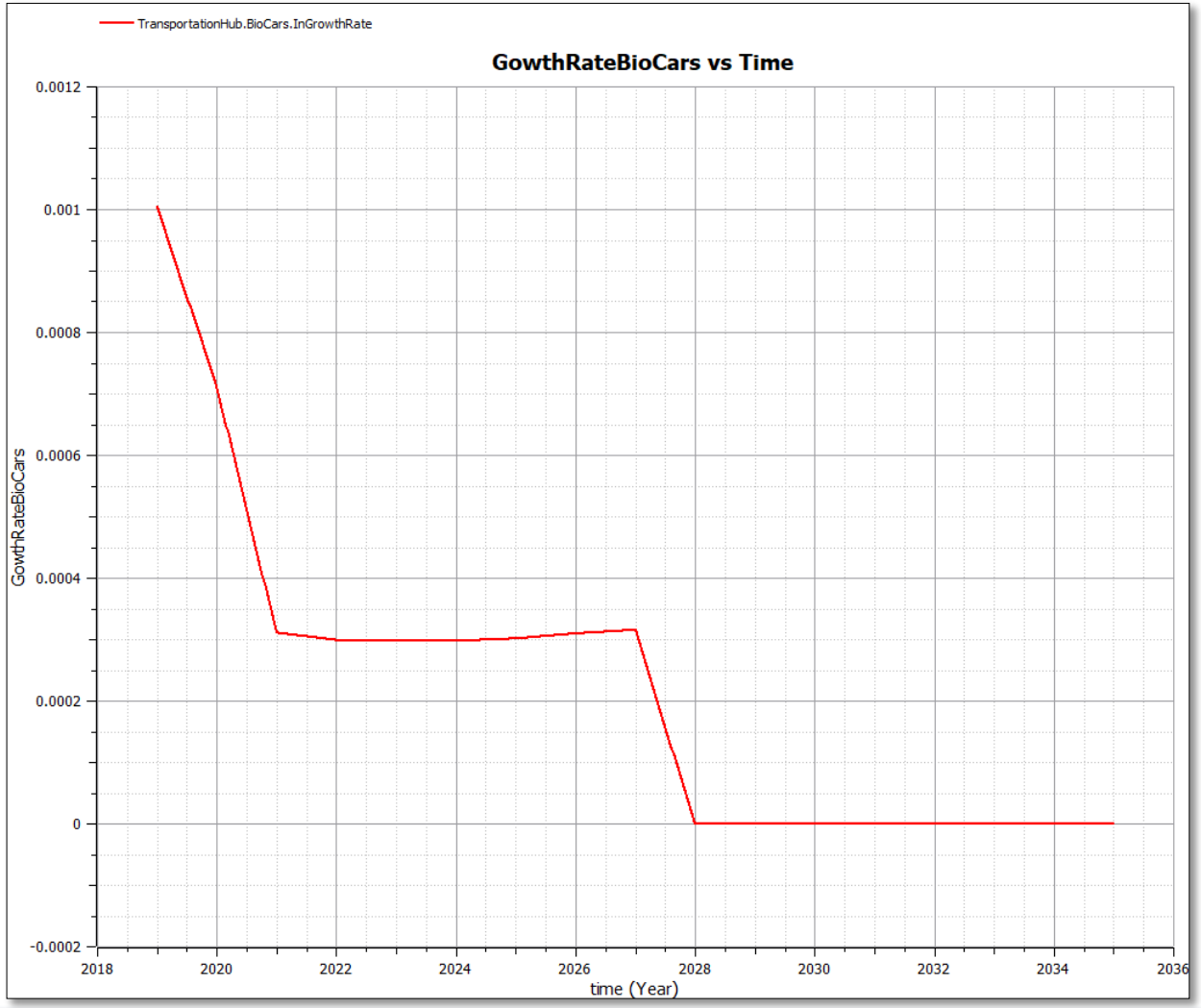
Results Scenario 4 – Total Number of Cars BioGas

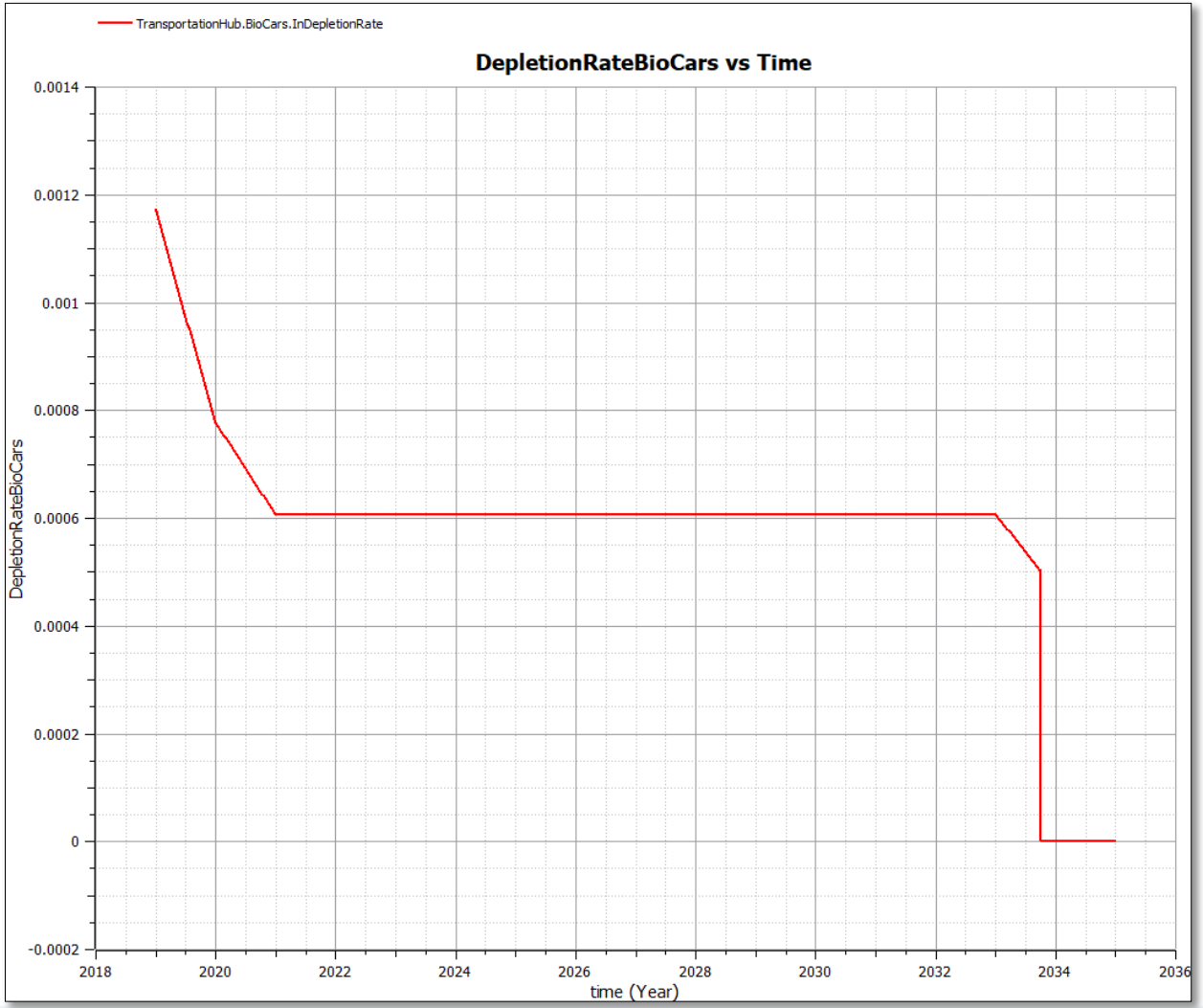
– Ex: BioGasCars – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage – 4.5%, Average driving range km Reduction – 2% per year



Results Scenario 4 – Car Growth and depletion rate

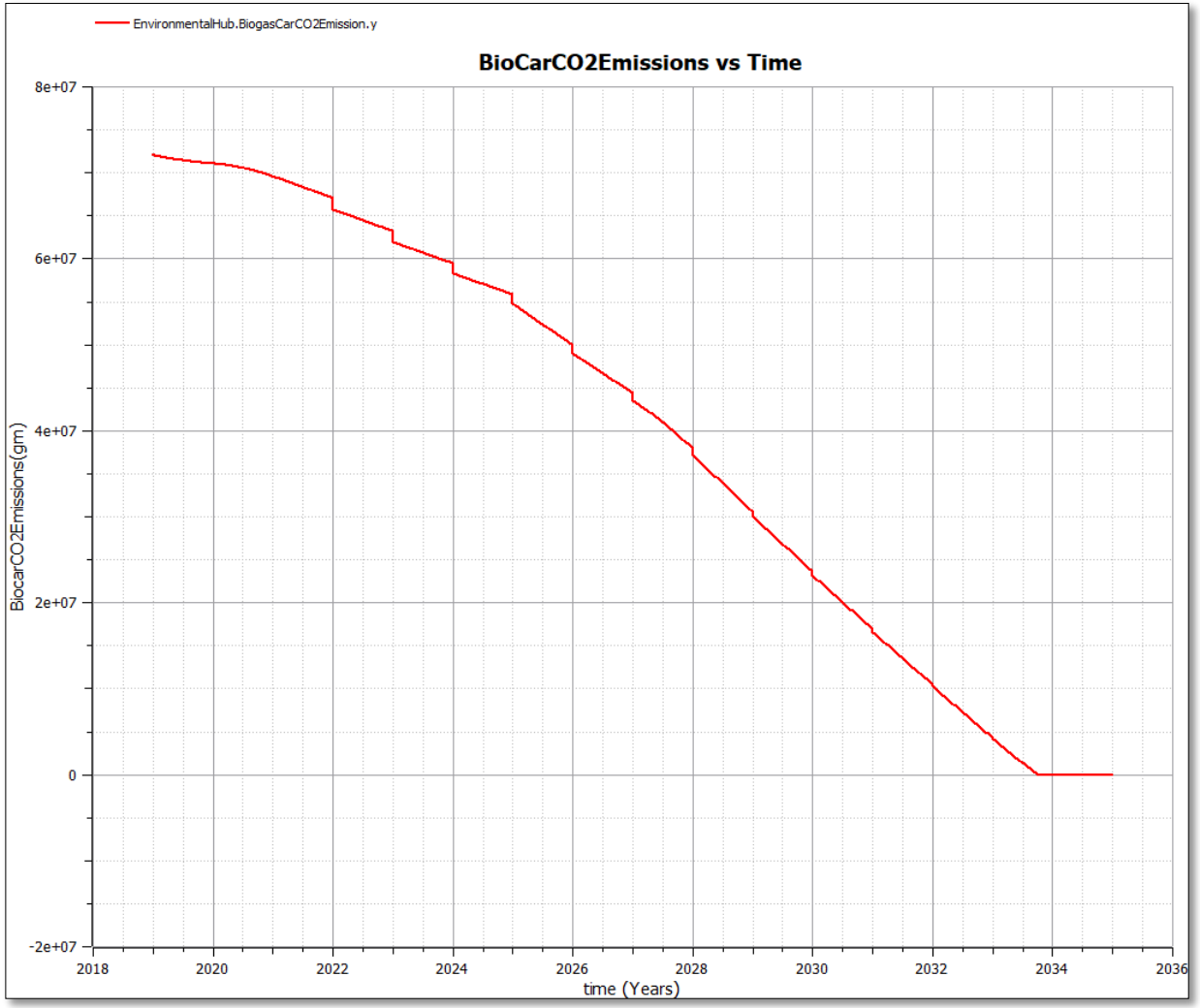
– Ex: BioGasCars – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage – 4.5%, Average driving range km Reduction – 2%,





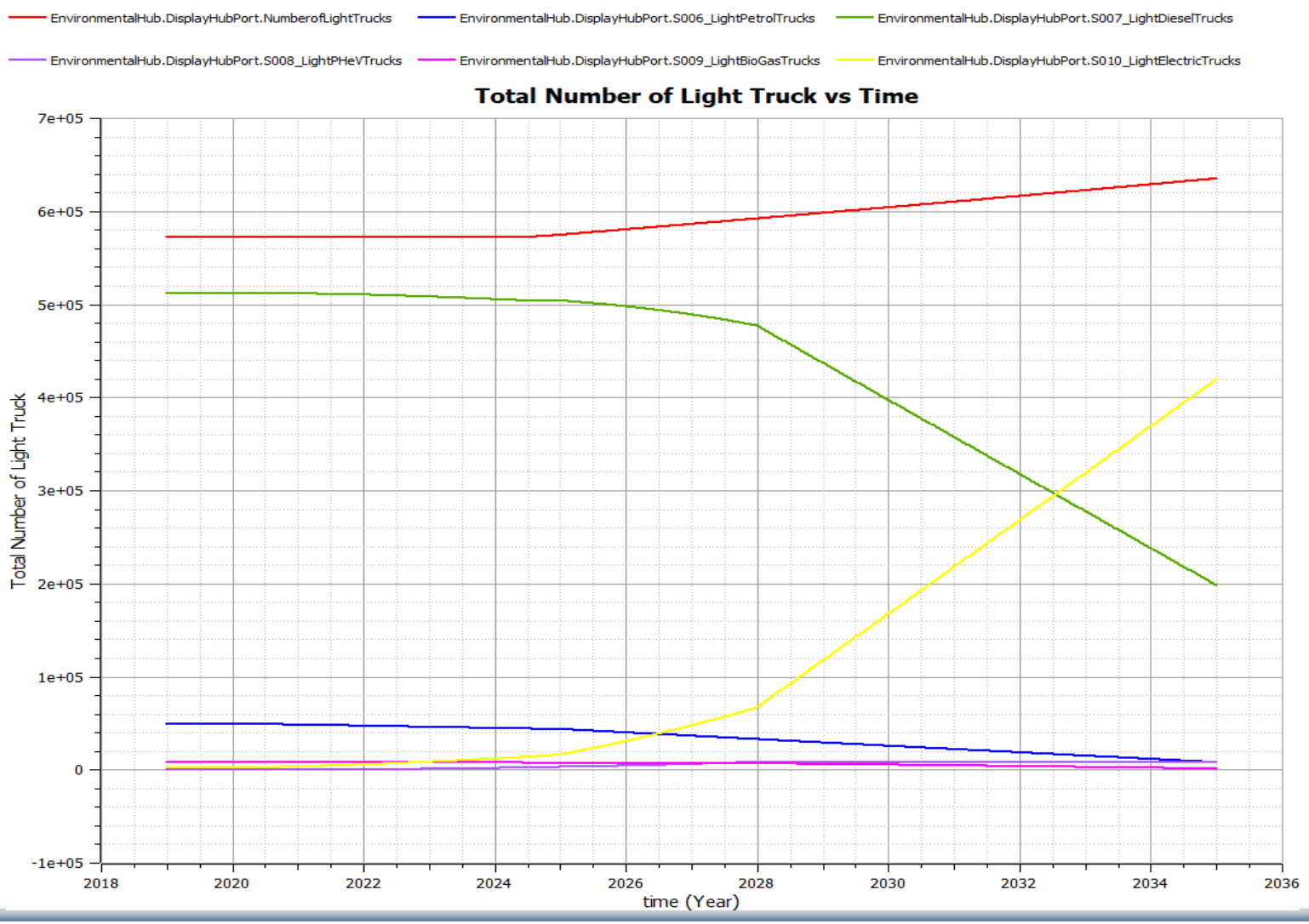
Results Scenario 4 – Car CO2 Emission BioGas

– Ex: BioGasCars – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage – 4.5%, Average driving range km Reduction – 2%,



Results Scenario 4 – Light Trucks-

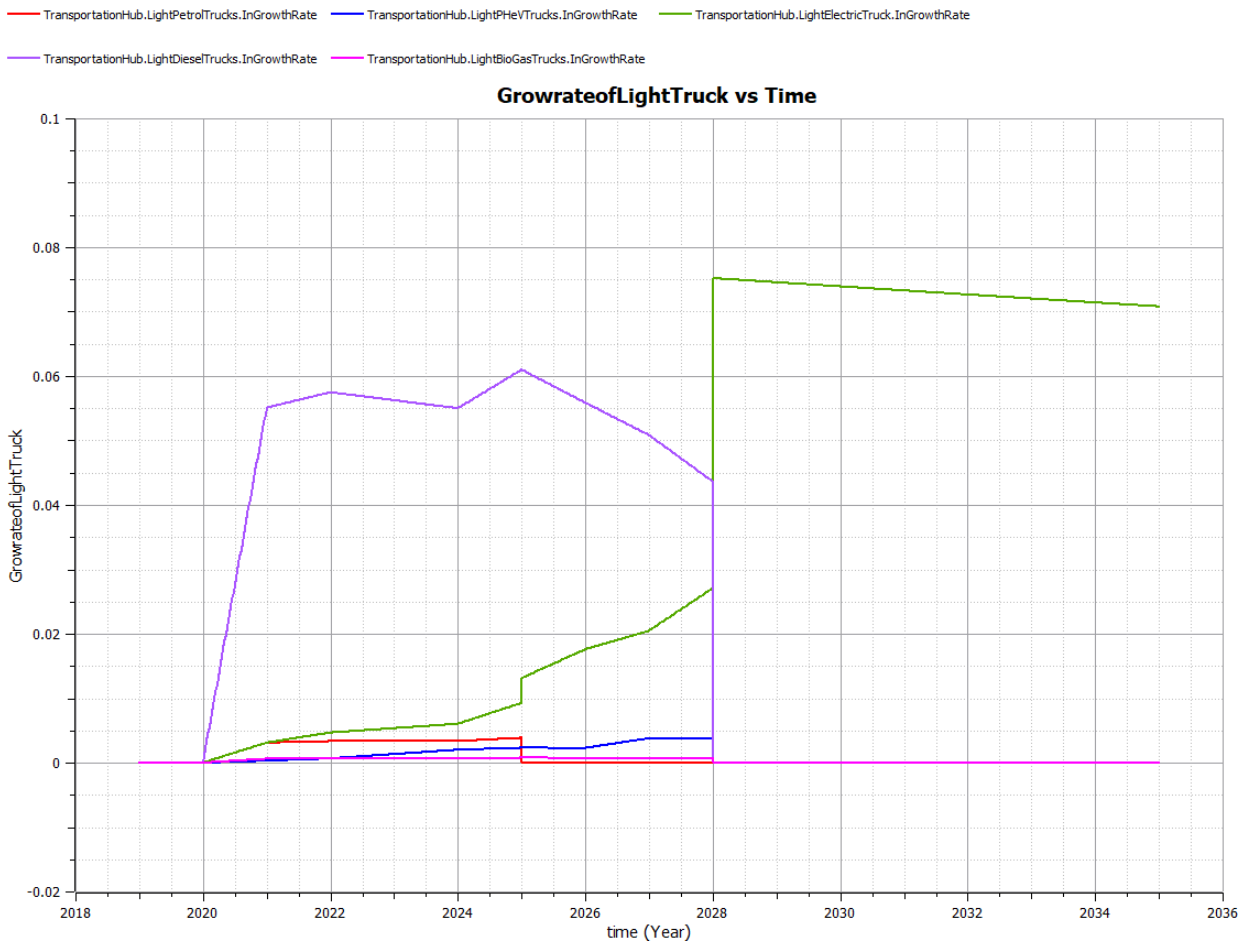
Hw Conversion start Year – 2025 , Average driving range km Reduction – 2%, annually

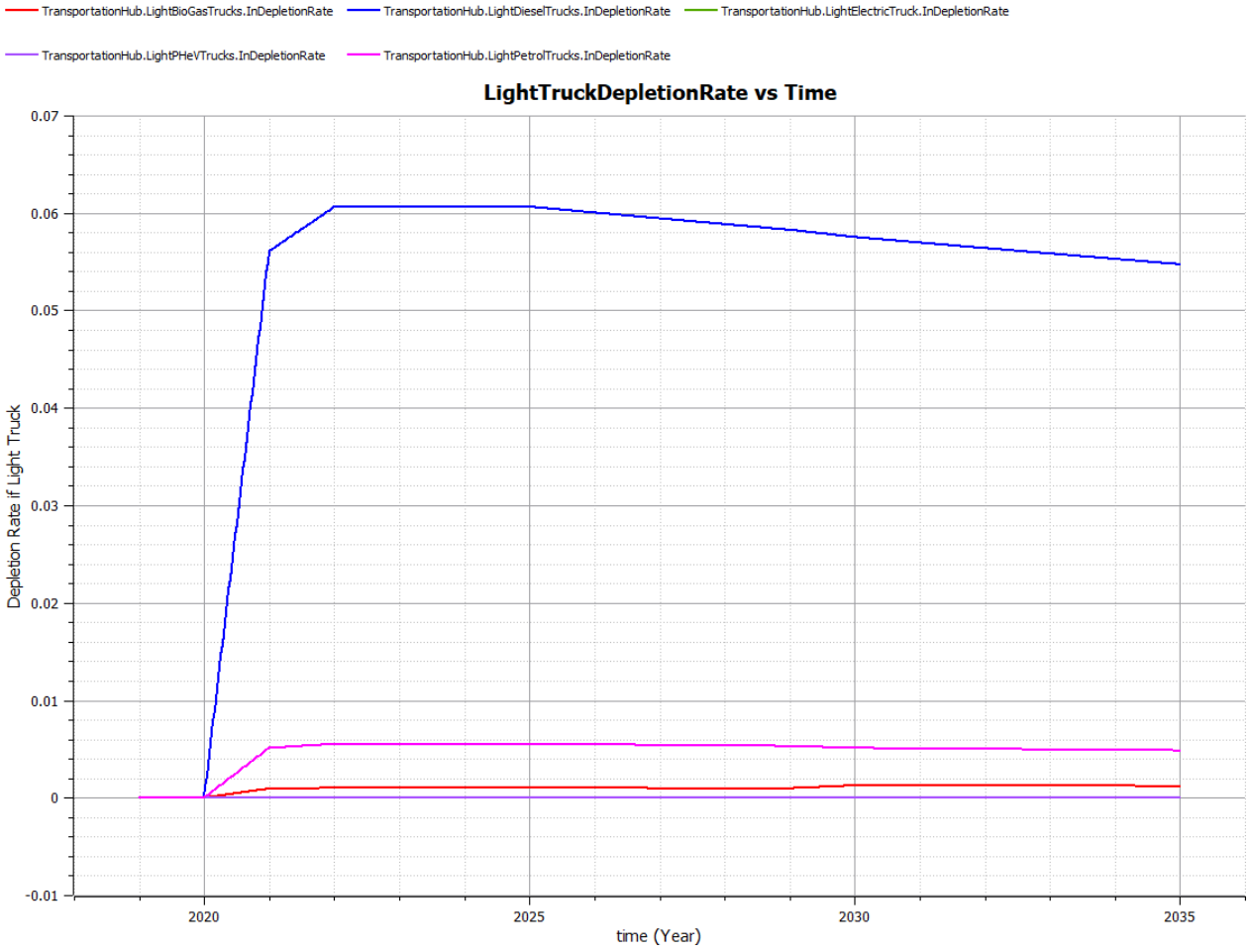


Car	Conversion %	Fossil Ban Year
Petrol	1	2025
Diesel	1	2028
Bio	1	2028
PHeV	1	2028

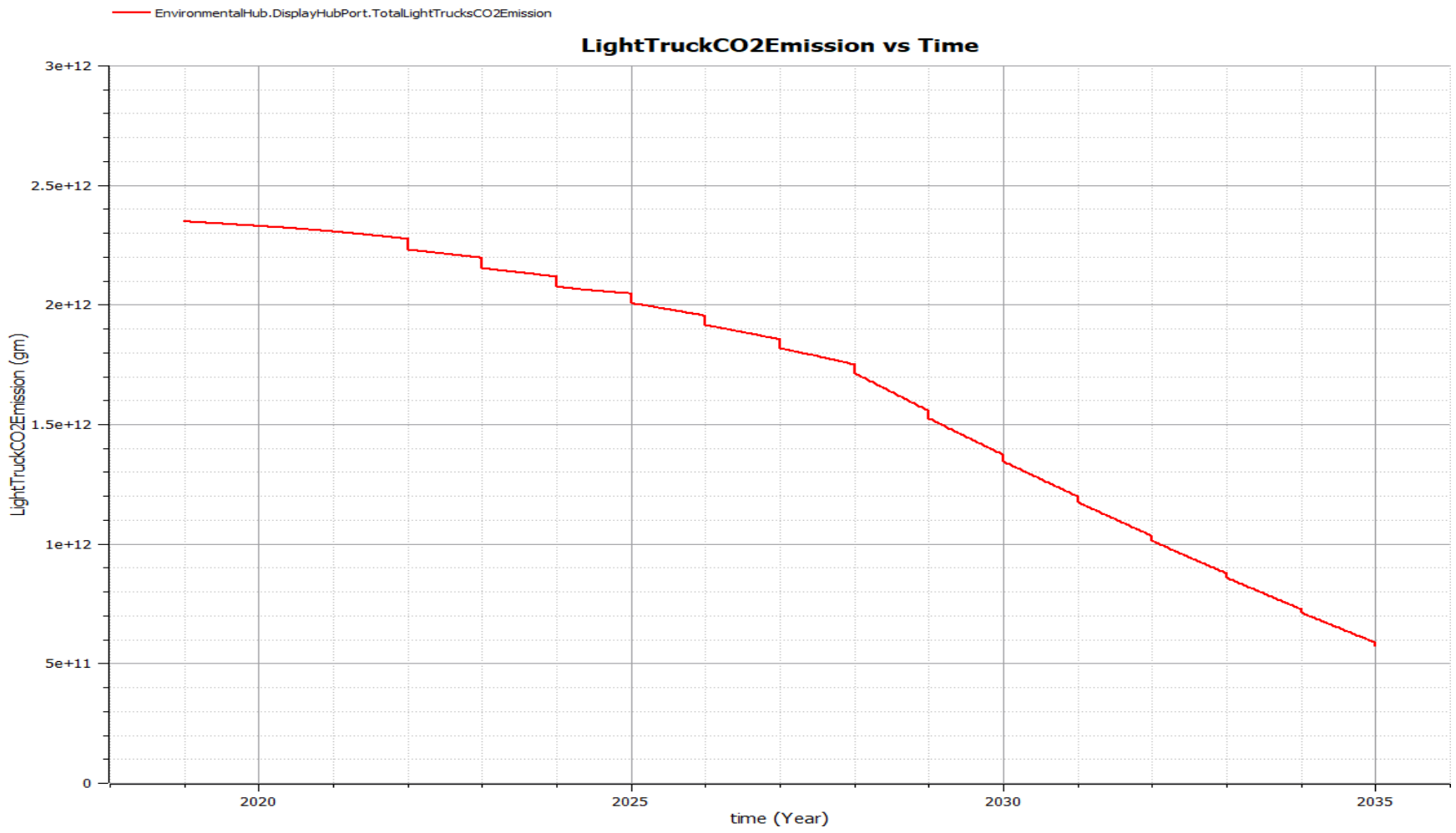
Results Scenario 4 – Light Trucks-

Growth and Depletion Rate Conversion Percentage – 1%, Average driving range km Reduction – 2%



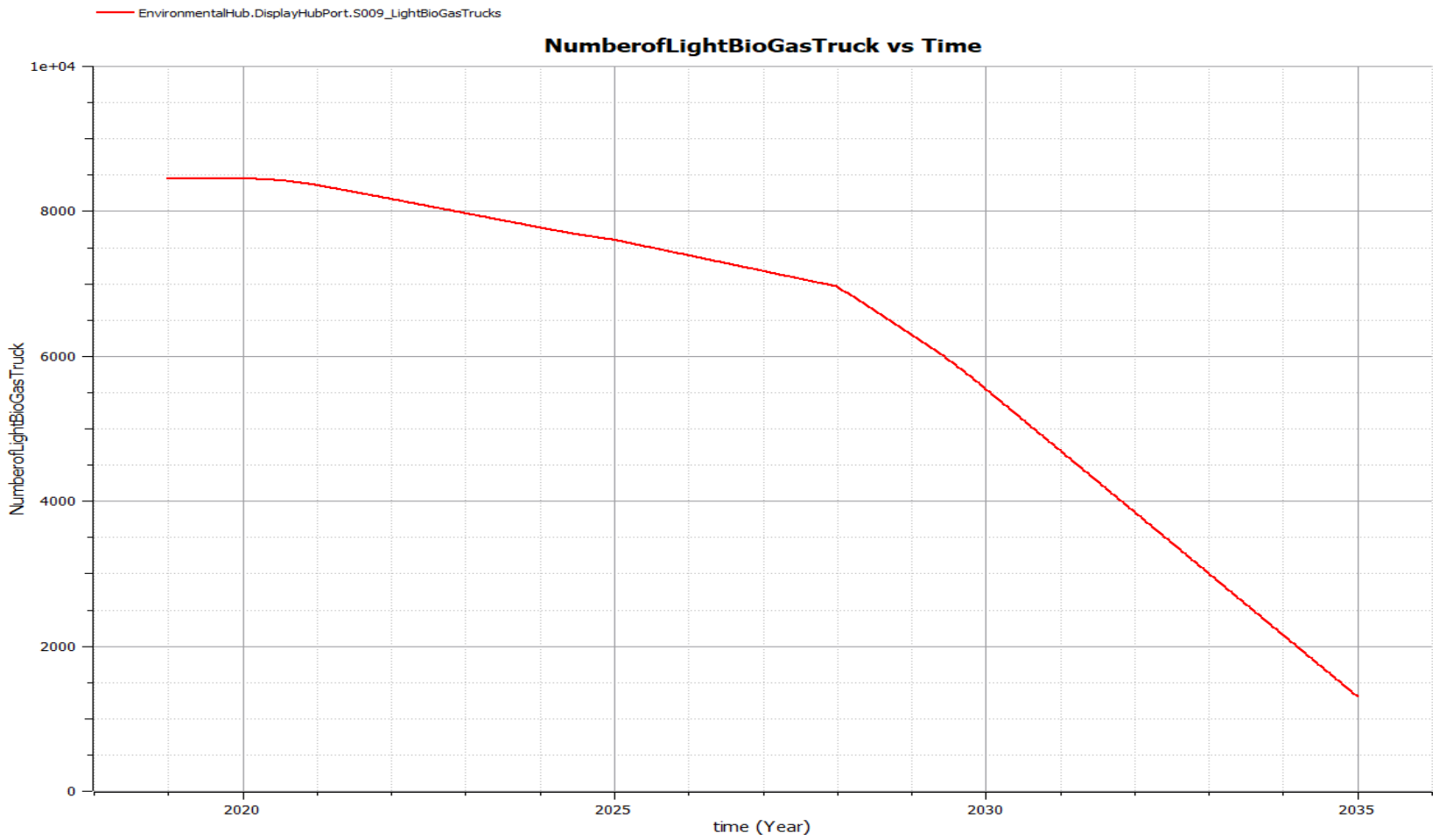


Results Scenario 4 – Light Trucks CO2 Emissions



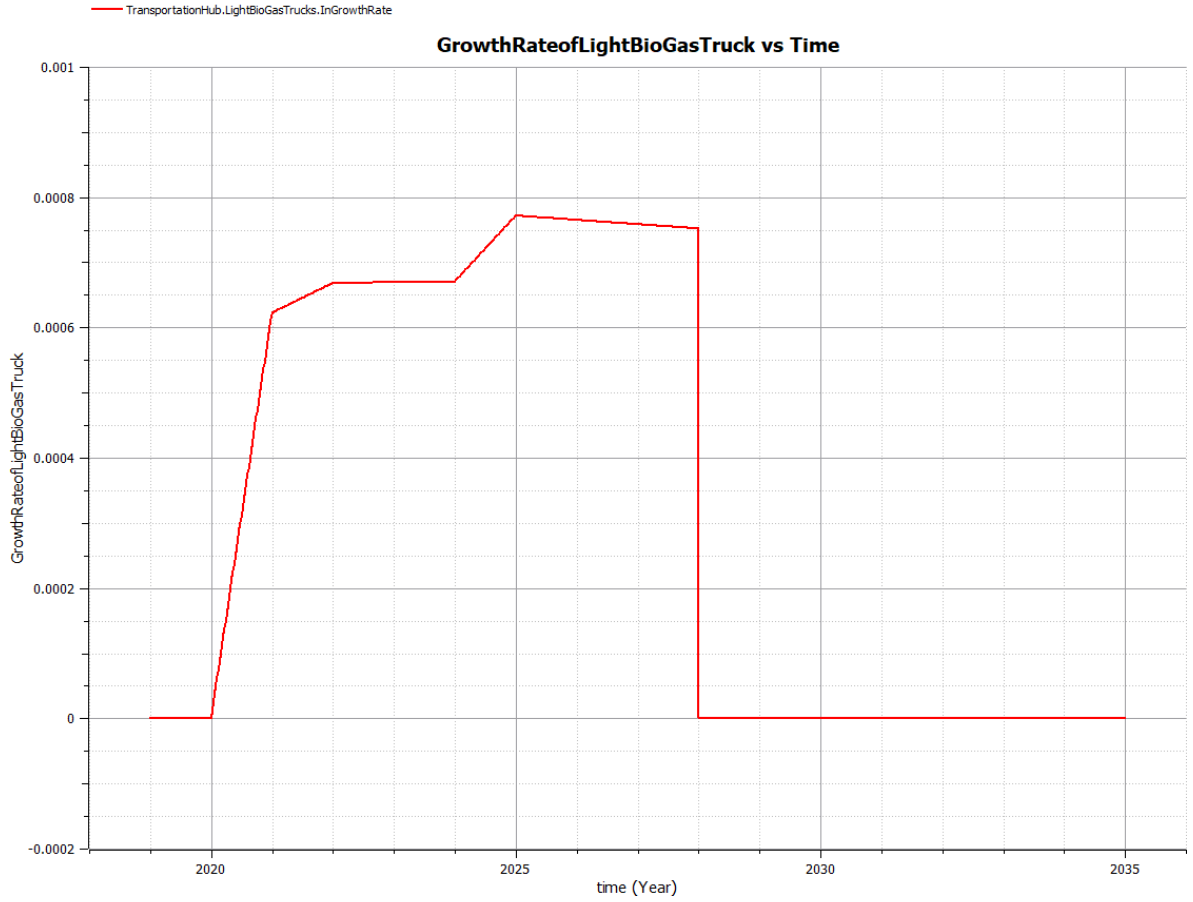
Results Scenario 4 – Total Number of Light Trucks

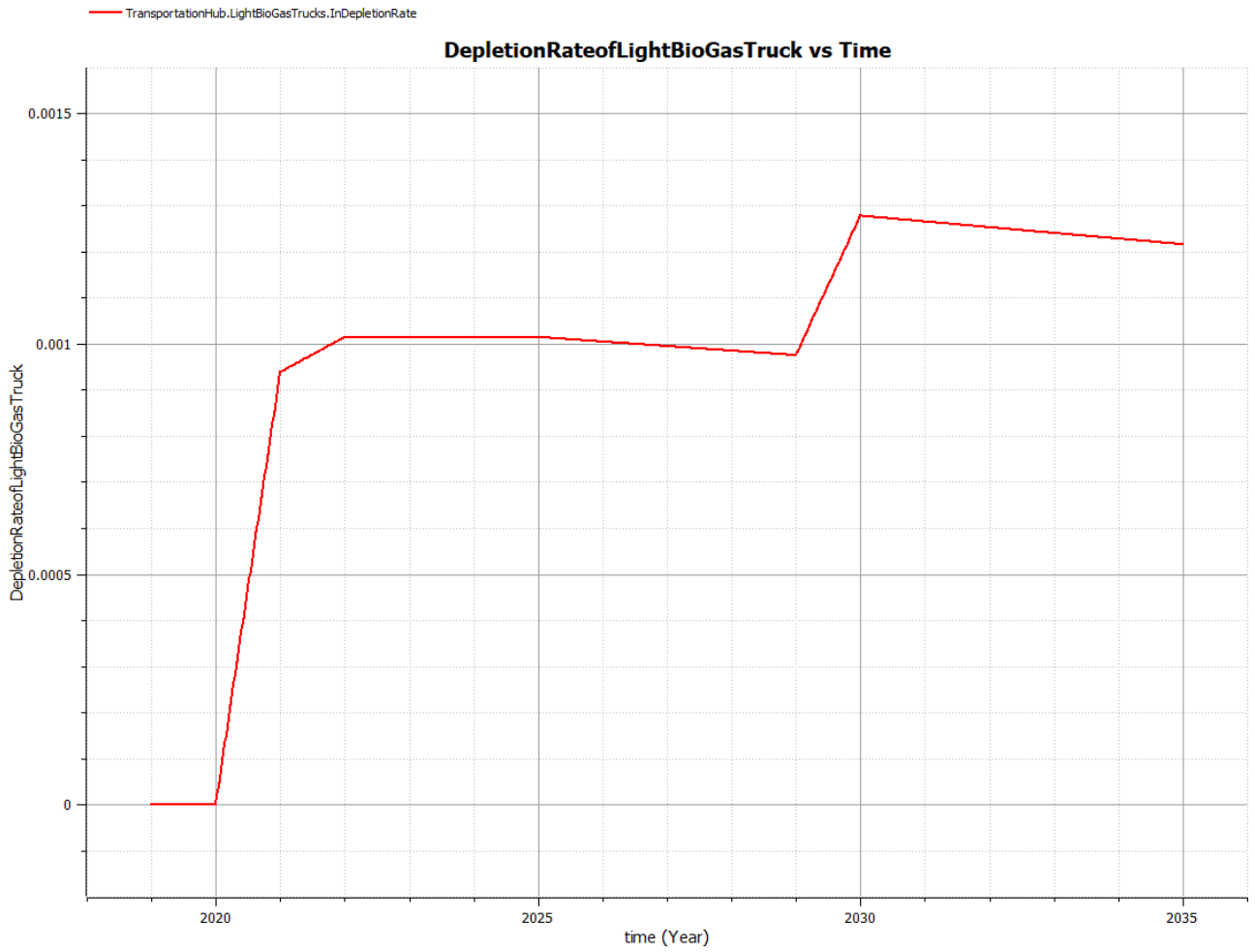
– Ex: LightBioTruck – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage –1% Average driving range km Reduction – 2% annually



Results Scenario 4 – Growth and Depletion Rates of Light Trucks

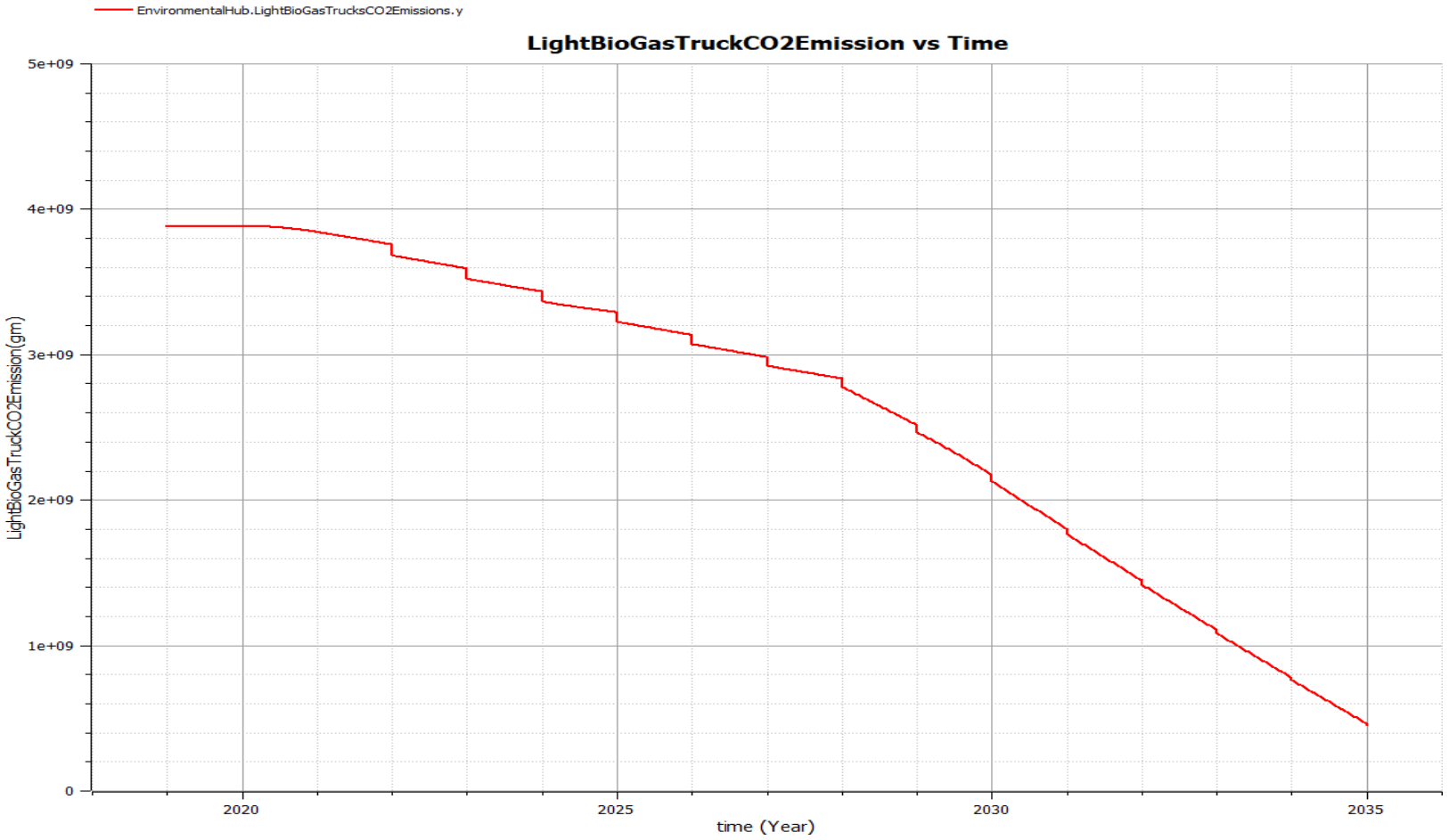
– Ex: LightBioTruck – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage –1%, Average driving range km Reduction – 2%





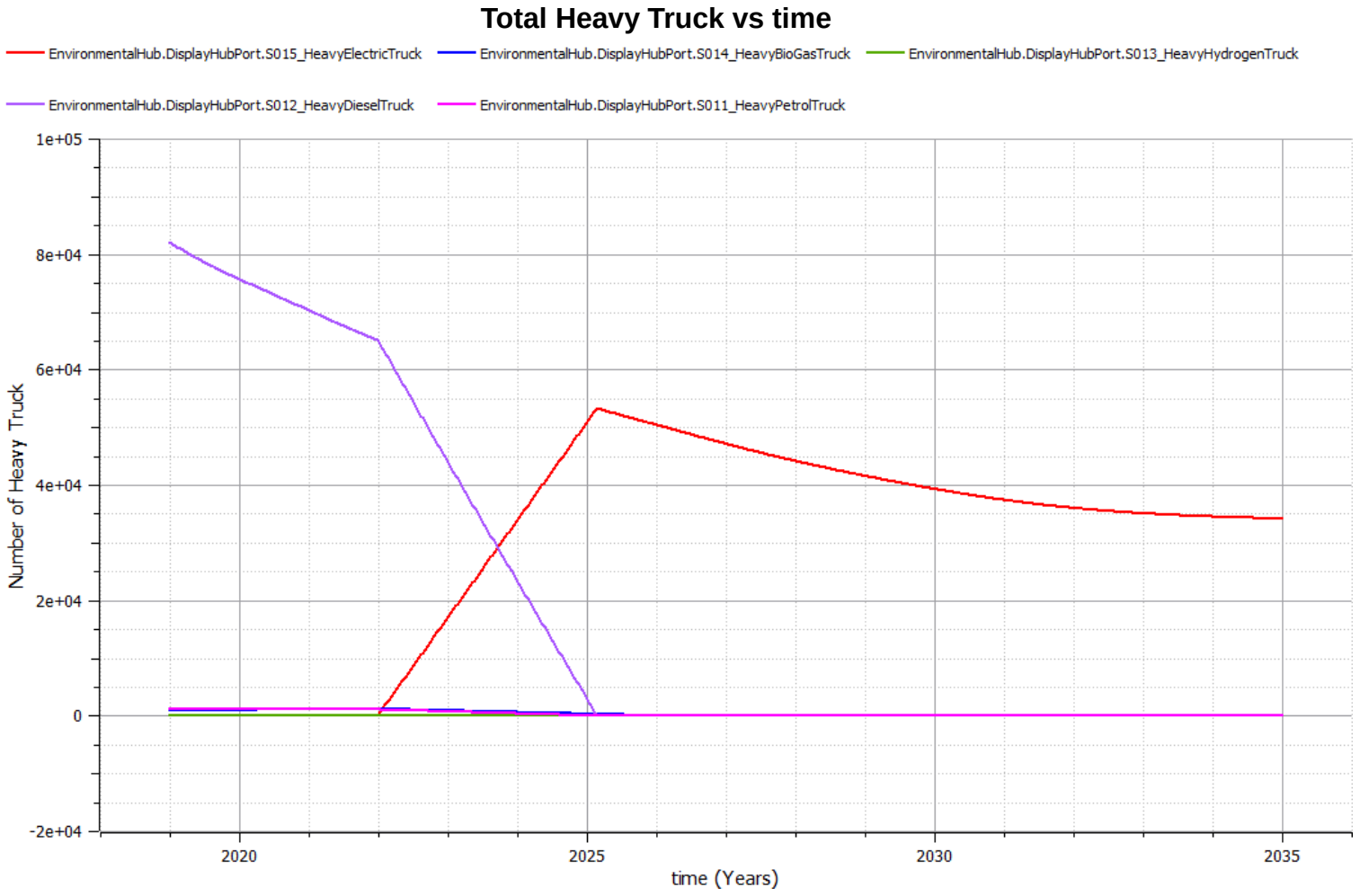
Results Scenario 4 – CO_2 Emissions of Light Trucks

– Ex: LightBioGasTruck – Fossil Ban Year -2028, Conversion start Year – 2025, Conversion percentage –1%, Average driving range km Reduction – 2% annually



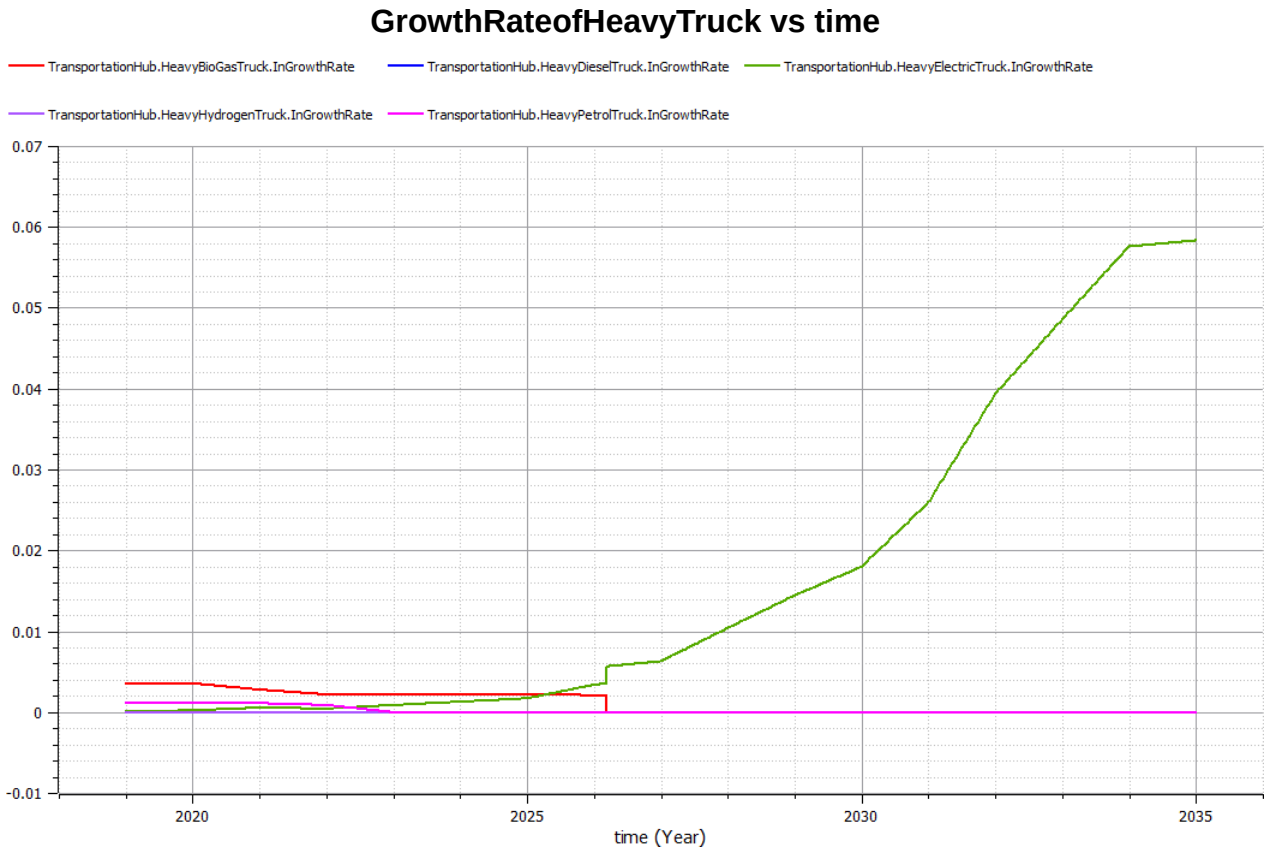
Results Scenario 4 – Heavy Trucks

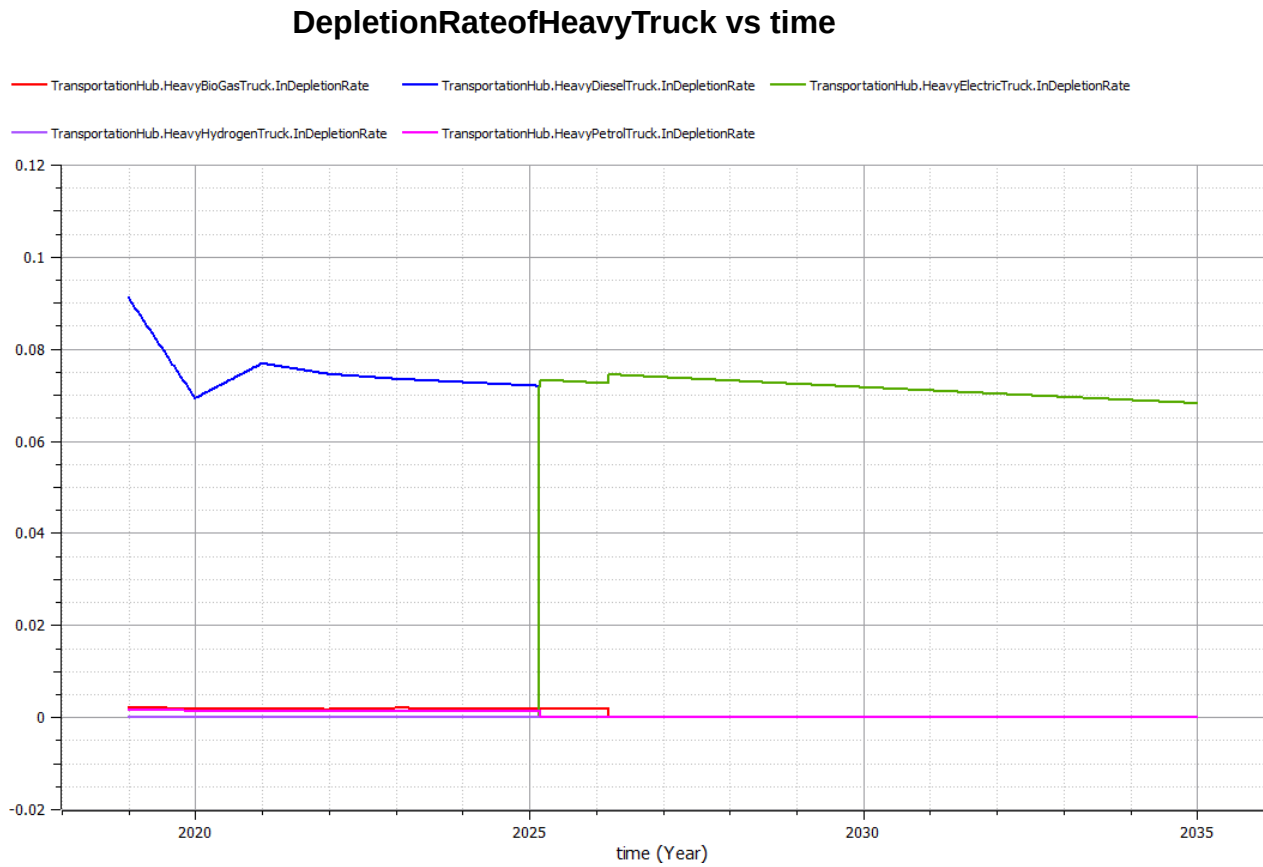
Conversion Percentage -1% , Average driving range km Reduction – 2% annually



Car	Conversion %	Fossil Ban Year
Petrol	1	2028
Diesel	1	2025
Bio	1	2028
H2	1	2028

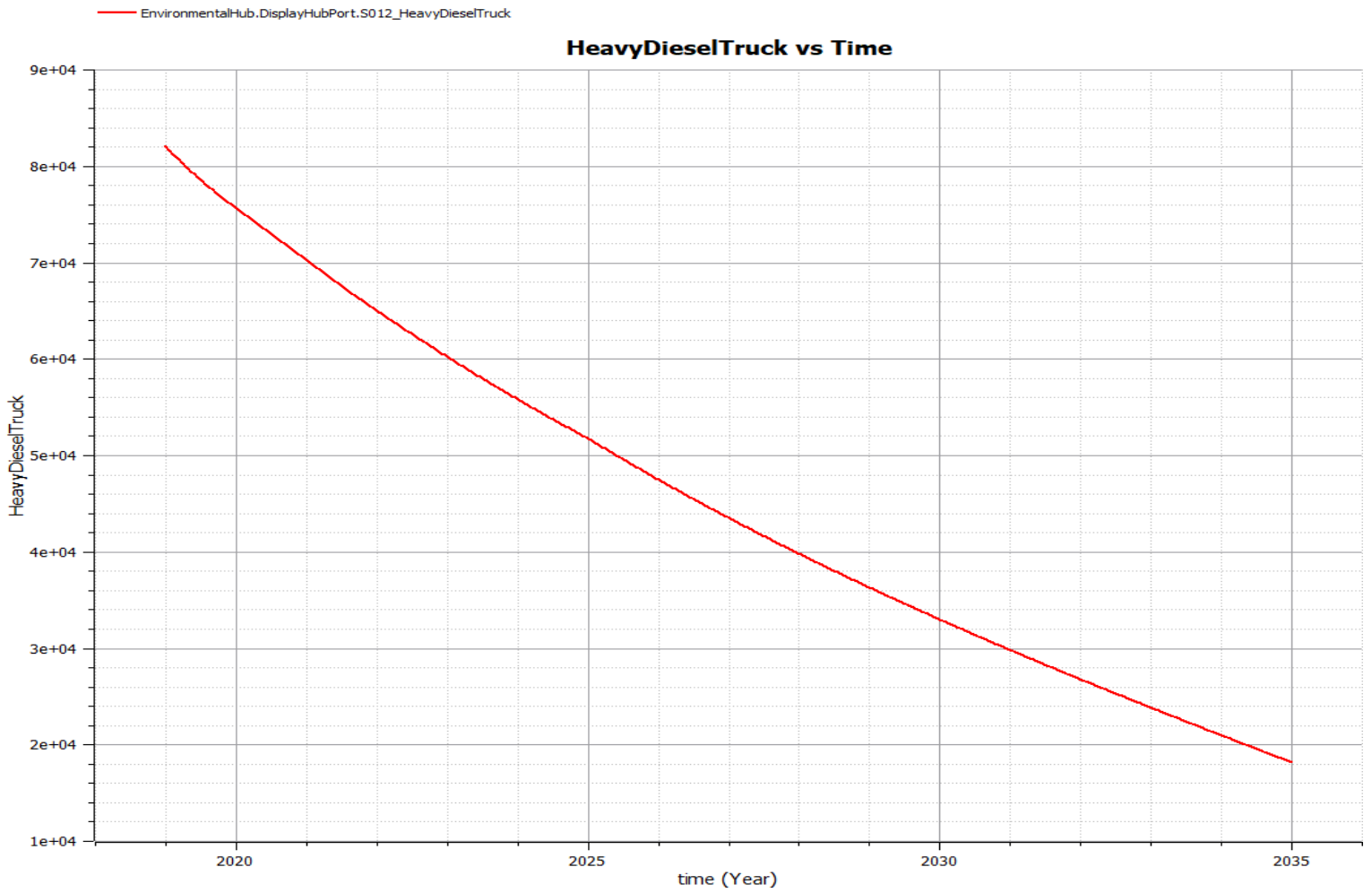
Results Scenario 4 – Heavy Truck Growth and Depletion Rate





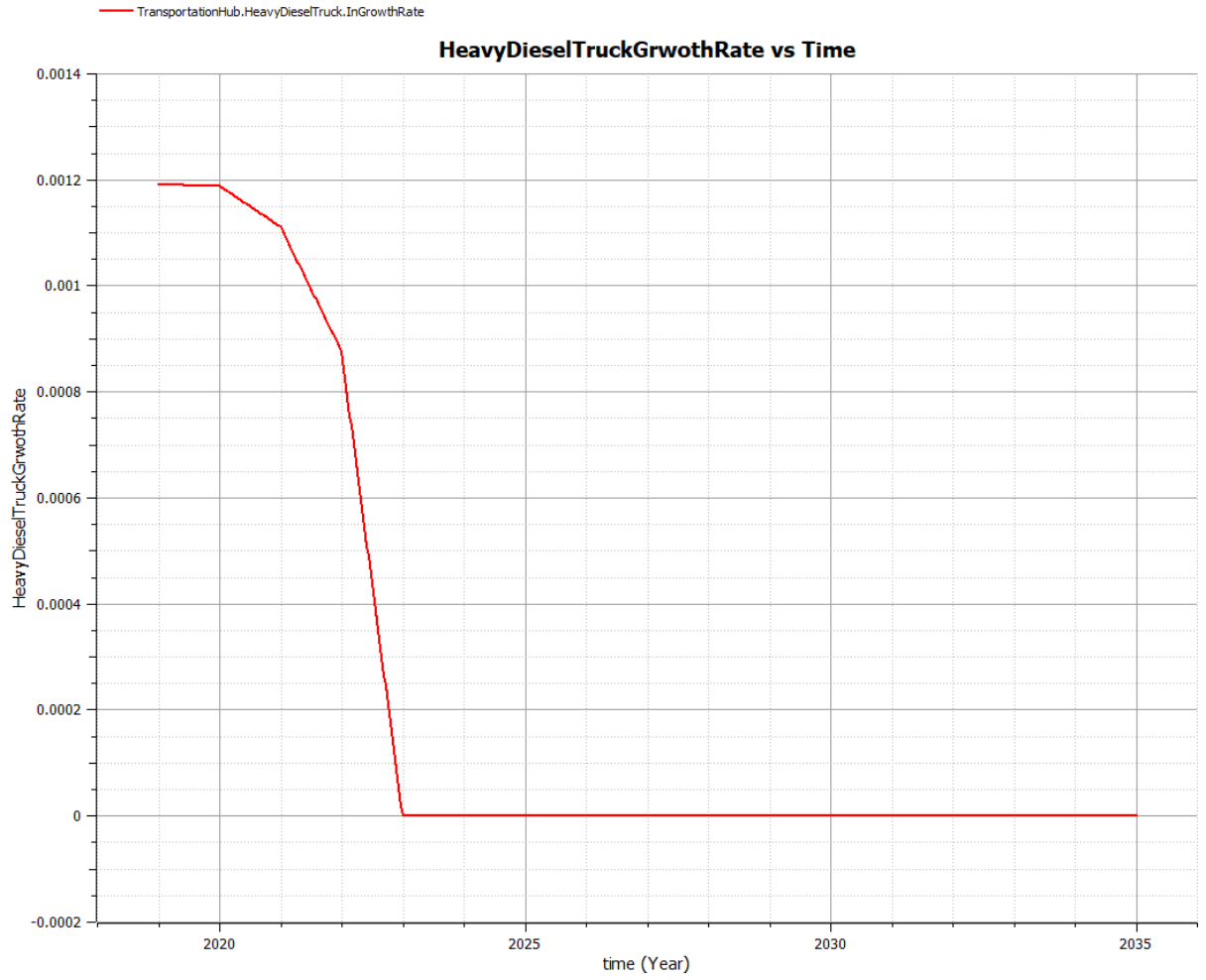
Results Scenario 4 – Total Number of Heavy Truck

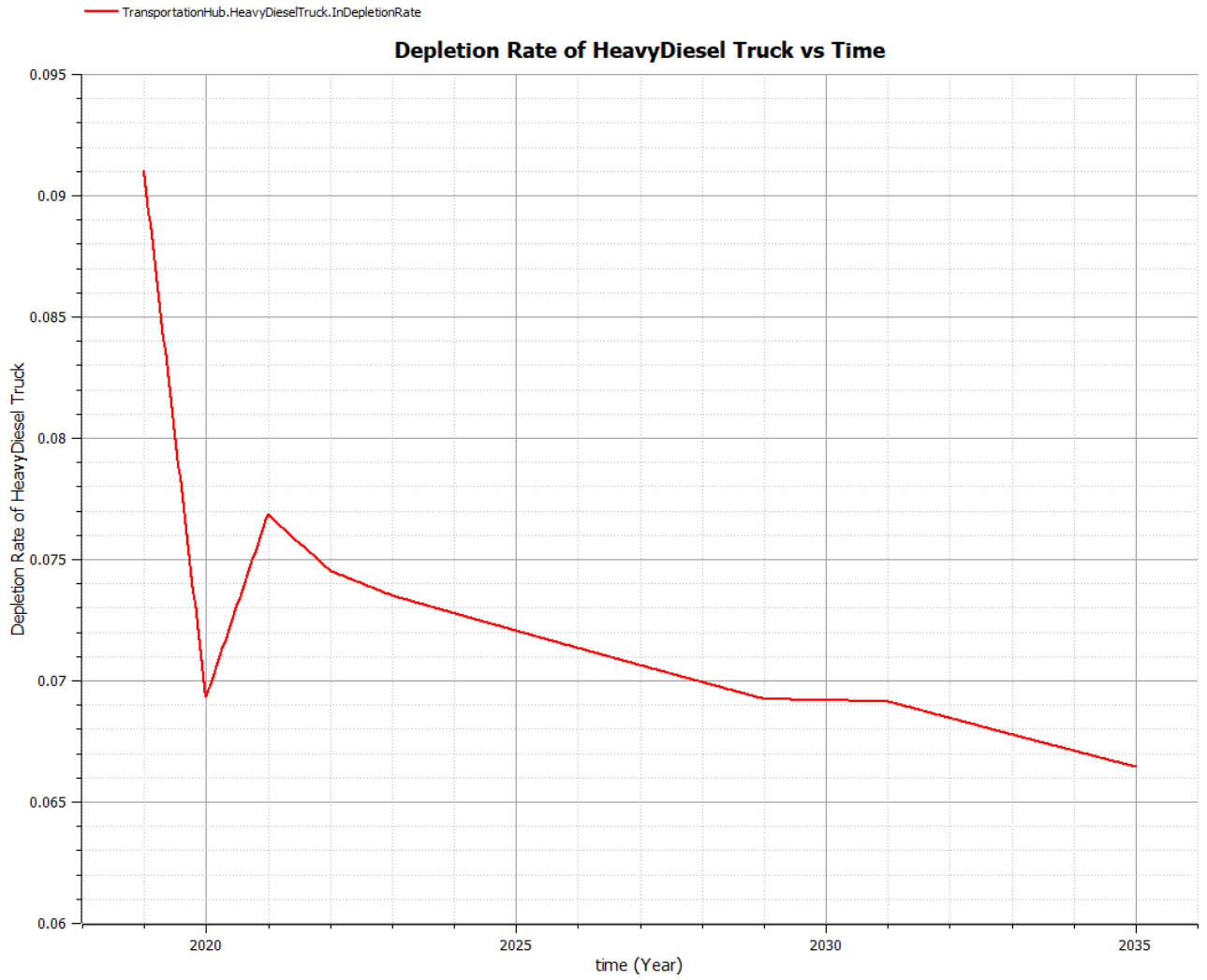
– Ex: HeavyDieselTruck – Fossil Ban Year -2028, Conversion start Year – 2025, Conversion percentage –1% , Average driving range km Reduction – 2% annually



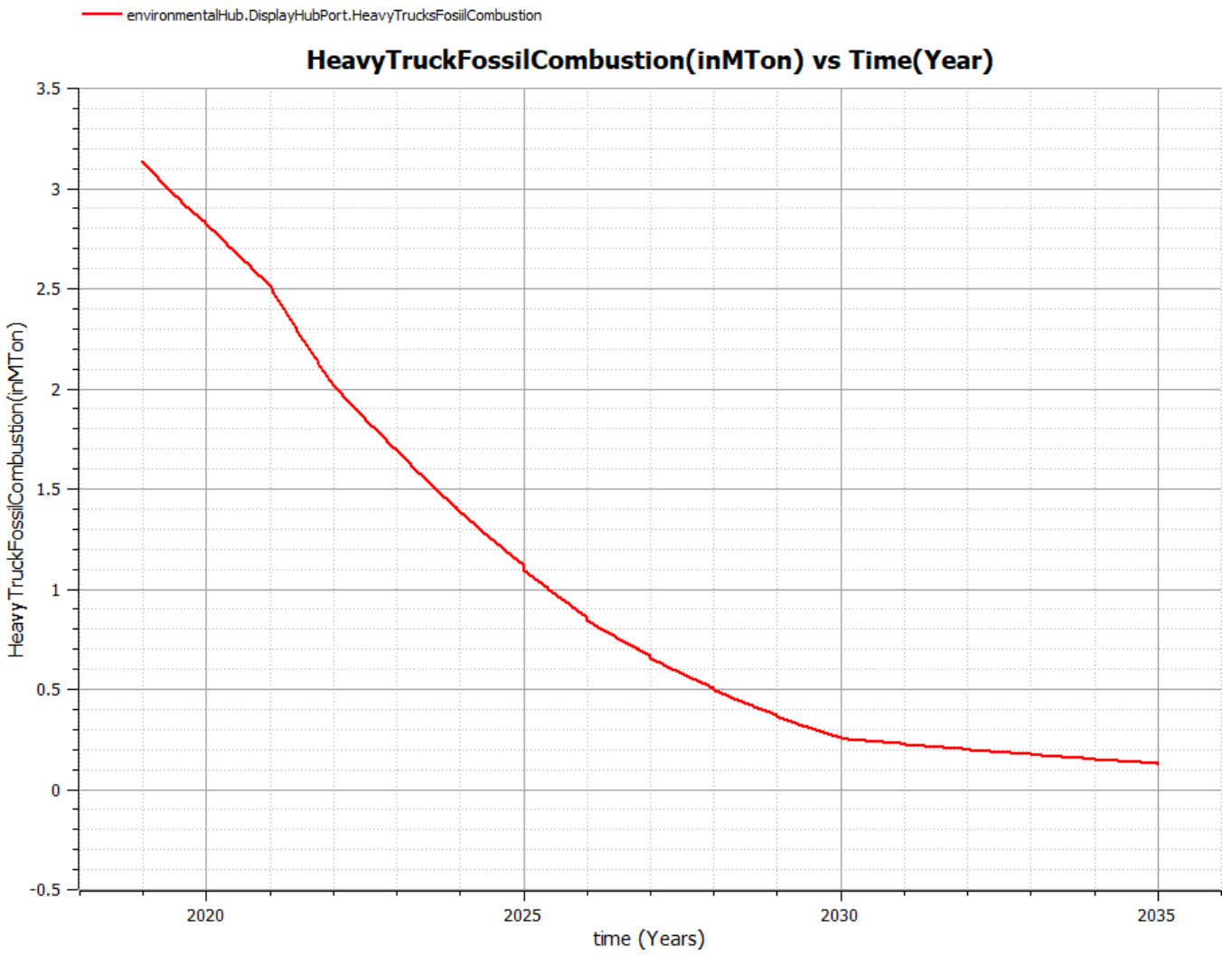
Results Scenario 4 – Growth and Depletion Rates of Heavy Truck–

Ex: HeavyDieselTruck – Fossil Ban Year -2028, Conversion start Year – 2025, HW Conversion percentage –1%, Average driving range km Reduction – 2% annually

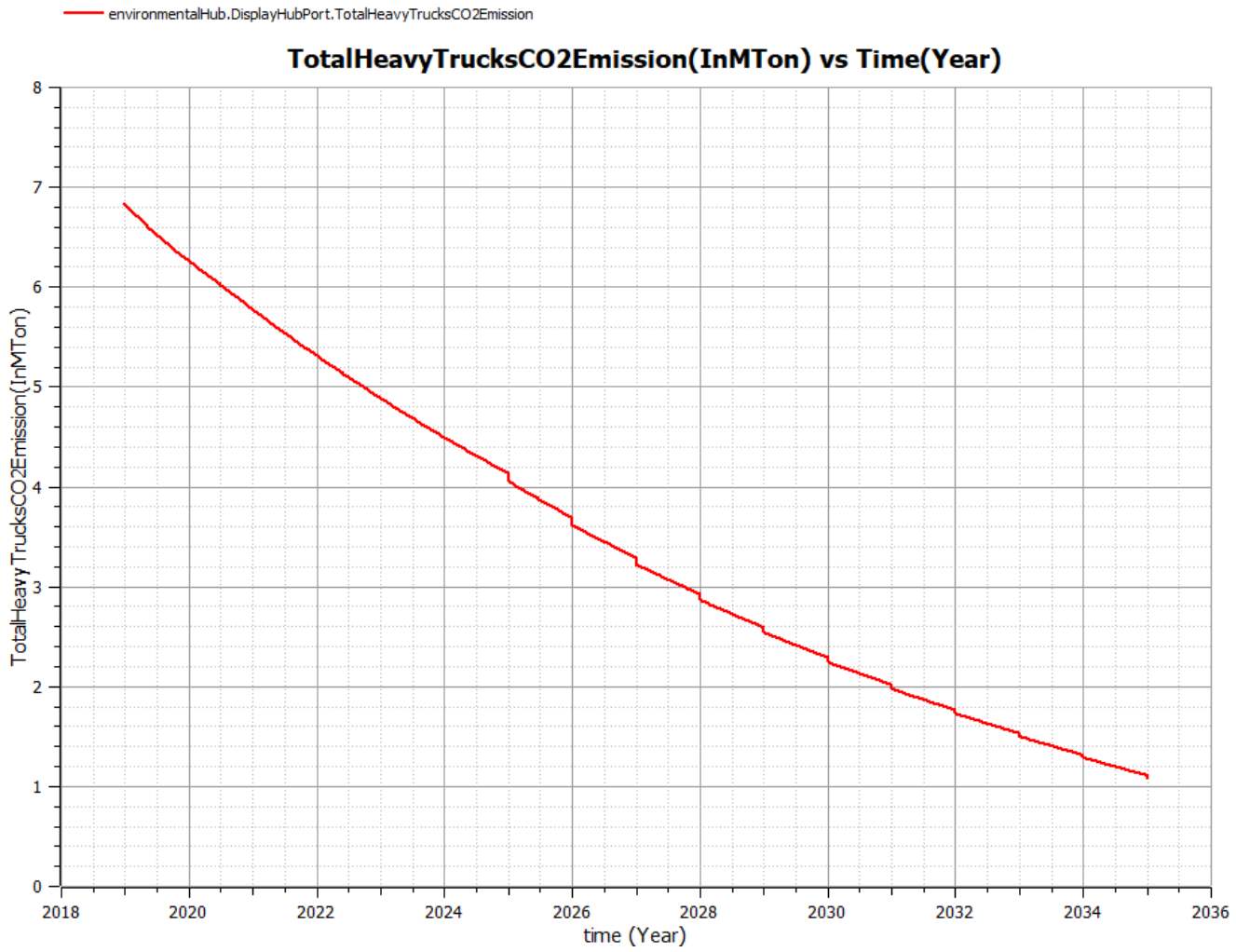




Results Scenario 4 – CO2 Fossil Emissions of Heavy Truck – Ex: HeavyDieselTruck – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage –1%, Average driving range km Reduction – 2%

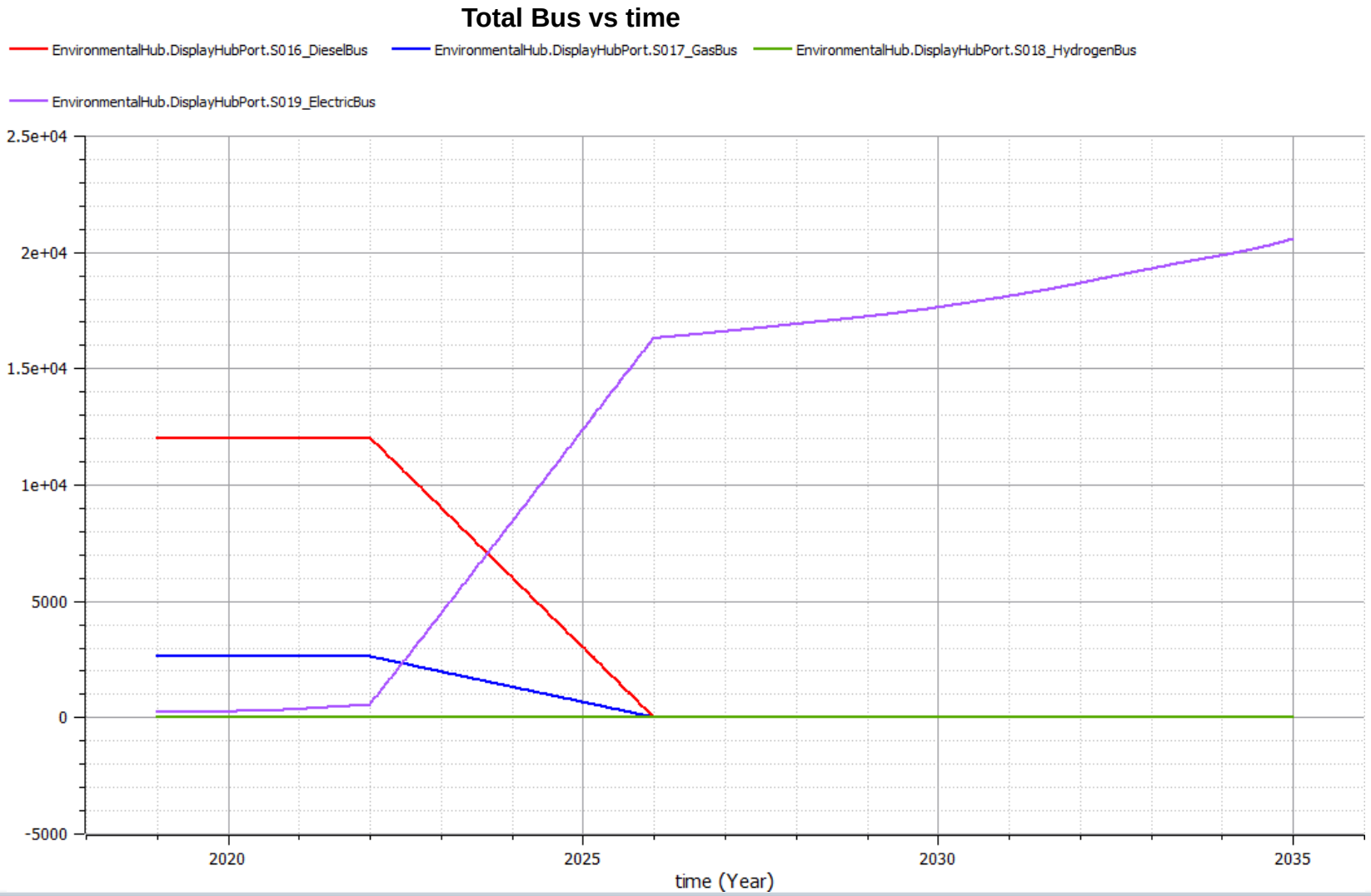


Results Scenario 4 – CO2 Emissions of Heavy Truck incl upstream and biofuels – Ex: HeavyDieselTruck – Fossil Ban Year -2028, Conversion Year – 2025, Conversion percentage –1%, Average driving range km Reduction – 2%

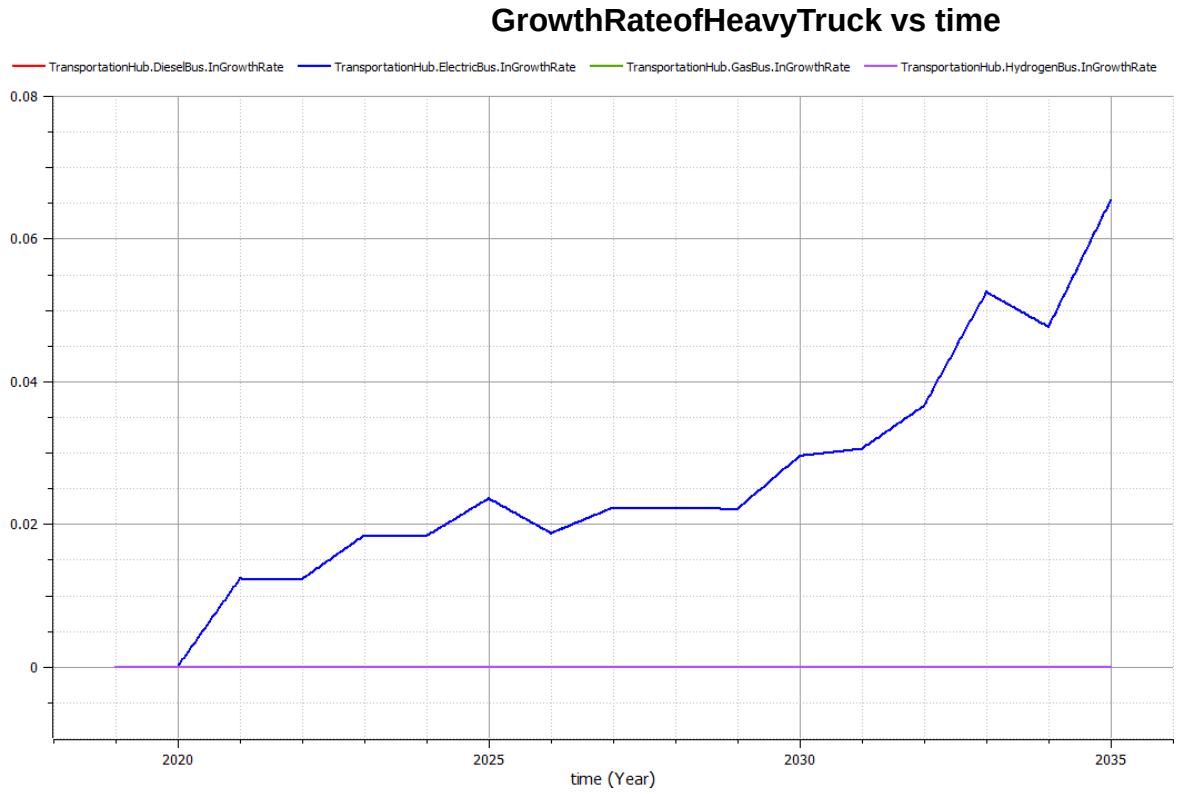


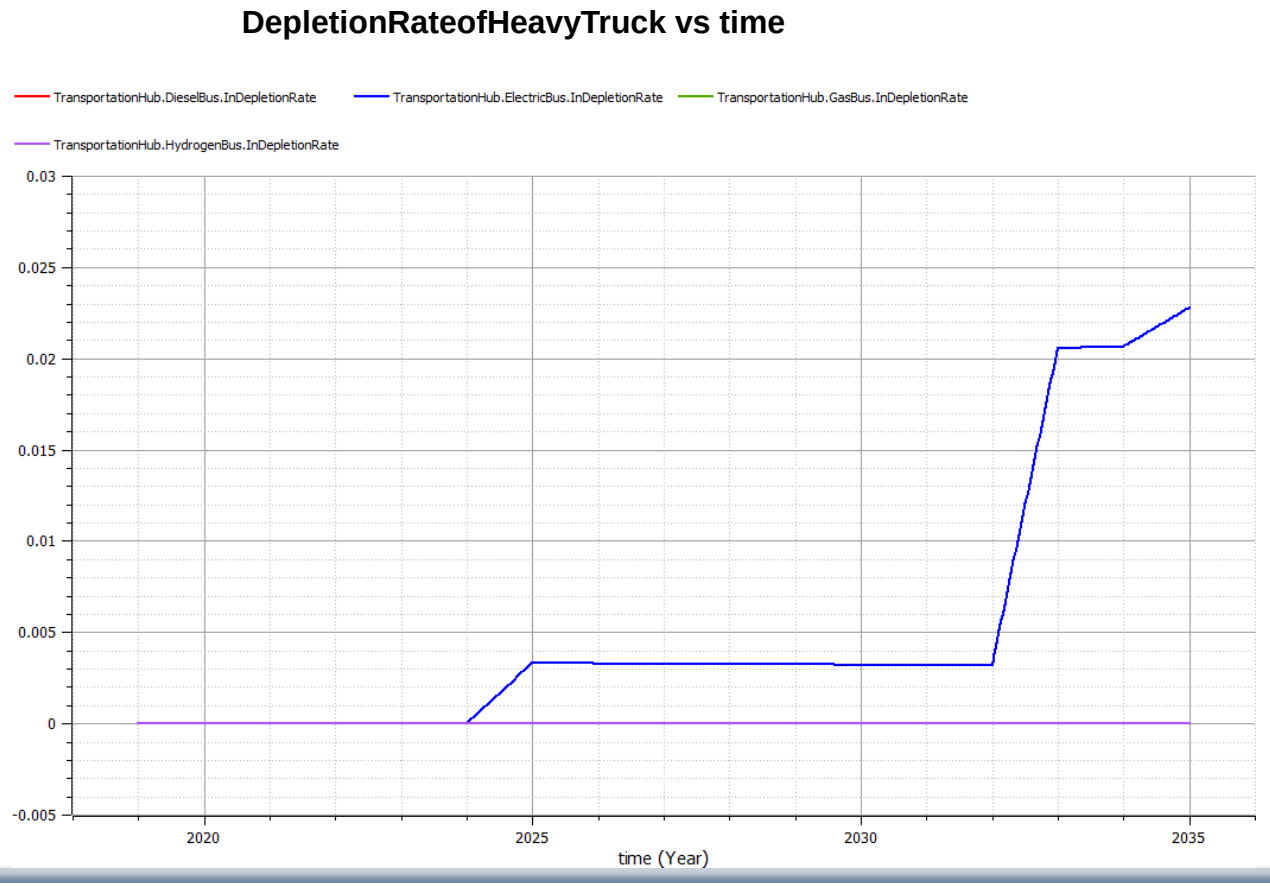
Results Scenario 4 – Buses -

Conversion Percentage – 0.01 (1% per year) , New Combi-table Data for Growth Rate

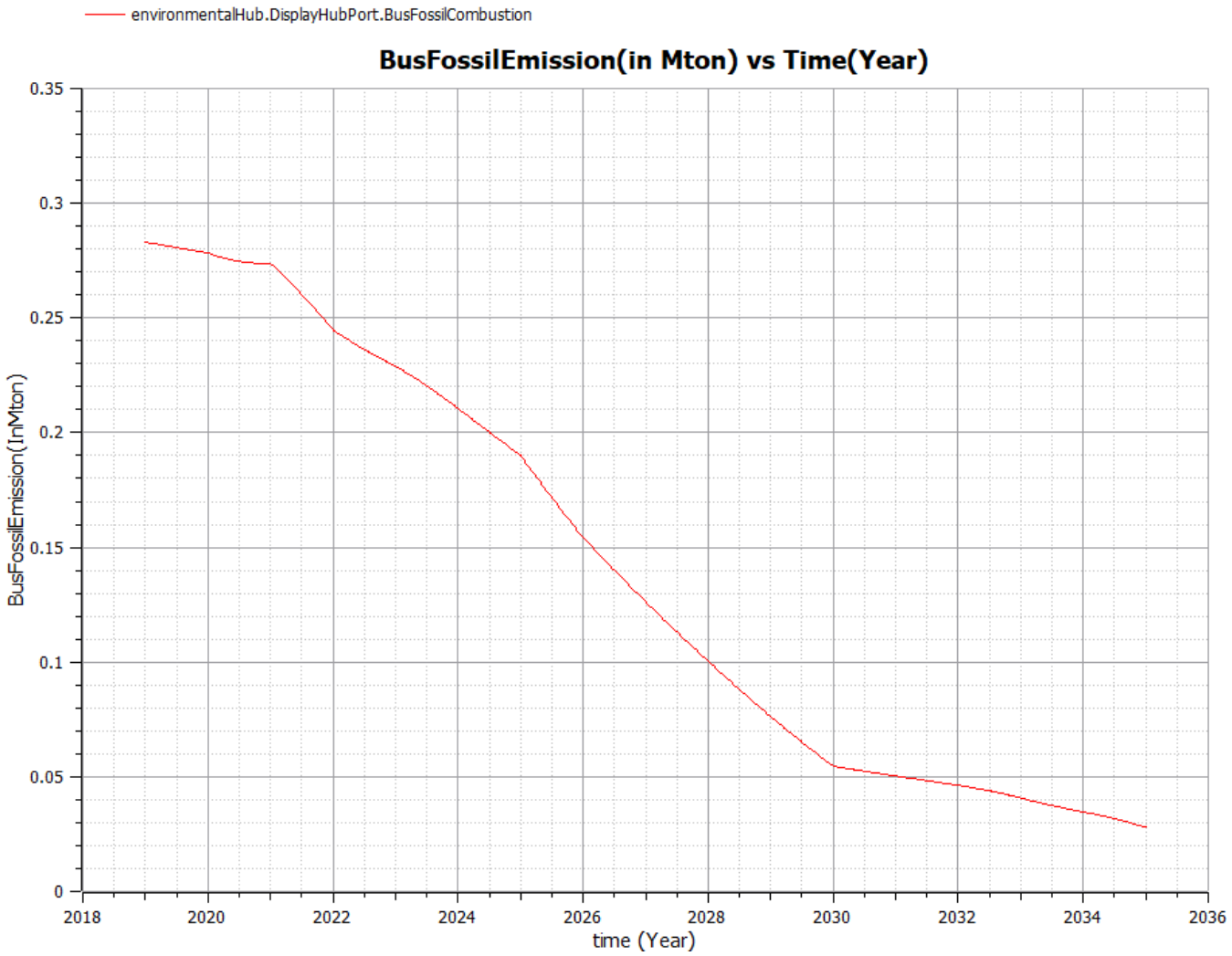


Results Scenario 4 – Bus Growth and Depletion Rate

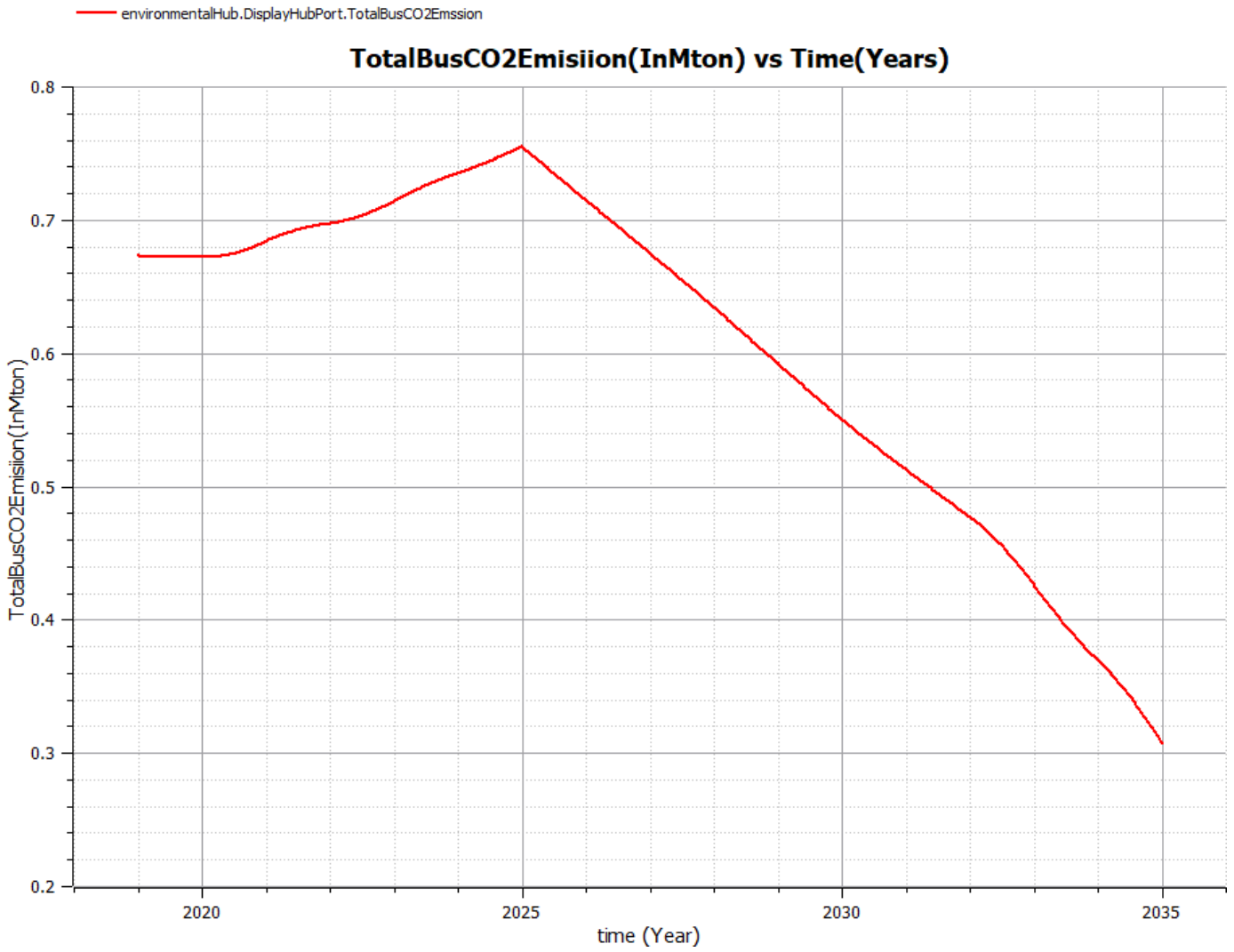




Results Scenario 4 – Bus CO2 Fossil Emissions



Results Scenario 4 – Bus CO2 Emissions including upstream and biofuels



Conclusion

A **transportation library for simulating the transition from fossil to electric** has been developed. It is very adaptable, and available as **open source**, OSMC-PL license

Four transition **Scenarios** for Sweden simulated for years **2019 - 2035**

- Scenario 1 – Gradual transition increase
- Scenario 2 – Faster transition, with fossil ban year for fossil cars 2025, similar for other vehicles
- Scenario 3 – Also doubling public transport like buses, reducing fossil cars correspondingly
- Scenario 4 – Hardware conversion of remaining fossil cars to electric

- **Not enough with gradual transition, government plan (Scenario 1)**
- **Not enough with new fossil car sales ban year 2025 (Scenario 2)**
- **Not enough with new fossil car sales ban year 2025 + double bus/train (Scenario 3)**
- **Only when adding hardware conversion of fossil cars, we get down to zero CO2 emission from cars 2035 (Scenario 4)**