Notice

Some errors have been discovered in some diagrams, updated versions of the presentation will be uploaded soon.
A Modelica Library and Scenarios for Sweden’s Conversion from fossil powered to electric transportation

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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

• 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 increase
  • Scenario 2 – Faster transition, with fossil ban year for sales of new fossil cars 2025
  • Scenario 3 – Also doubling collective 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

<table>
<thead>
<tr>
<th>Car</th>
<th>Fossil Ban Year</th>
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<tbody>
<tr>
<td>Petrol</td>
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</tr>
<tr>
<td>PHeV</td>
<td>2100</td>
</tr>
</tbody>
</table>

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 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 Scenario 4.
  - 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
    ![Level component diagram]
  • Rate_1
    ![Rate_1 component diagram]
  • Source
    ![Source component diagram]
  • Sink
    ![Sink component diagram]

• From Modelica Blocks library:
  • Switch
    ![Switch component diagram]
  • Greater Threshold
    ![Greater Threshold component diagram]
  • Combitable
    ![Combitable component diagram]
### Block Name | Block Symbol | Block Diagram | Explanation
--- | --- | --- | ---
Level | ![Block Symbol](image) | ![Block Diagram](image) | • This block gives a continuous change in the level of the tank

Rate_1 | ![Block Symbol](image) | ![Block Diagram](image) | • 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 | ![Block Symbol](image) |  | y = if u2 then u1 else u3;
y is real output
u2 is Boolean Input
u1 and u3 is real input
### Modeling Components - continued

<table>
<thead>
<tr>
<th>Block Name</th>
<th>Block Symbol</th>
<th>Block Diagram</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GreaterThreshold</td>
<td><img src="image" alt="GreaterThreshold Symbol" /></td>
<td><img src="image" alt="GreaterThreshold Diagram" /></td>
<td>$y = u &gt; \text{threshold}$; Where $y$ is Boolean Output $u$ is Real Input.</td>
</tr>
</tbody>
</table>
| Combi-Table         | ![Combi-Table Symbol](image) | ![Combi-Table Diagram](image) | • It helps to import 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. |
<p>| variableAverageKM   | <img src="image" alt="variableAverageKM Symbol" /> | <img src="image" alt="variableAverageKM Diagram" /> | • It gives average km vehicle driving range that reduce w.r.t time with a given percentage. |
| VehicleOutput       | <img src="image" alt="VehicleOutput Symbol" /> | <img src="image" alt="VehicleOutput Diagram" /> | • If $\text{VehicleIn}$ will be less than or equal to zero then $\text{VehicleOut}$ value will be zero. Else it will be normal $\text{VehicleLevel}$ values. |</p>
<table>
<thead>
<tr>
<th>Block Name</th>
<th>Block Symbol</th>
<th>Block Diagram</th>
<th>Explanation</th>
</tr>
</thead>
</table>
| startConversionSwitch  | ![Symbol]    | ![Diagram]    | • 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    | ![Symbol]    | ![Diagram]    | • 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**

- **GenerationRate**
- **VehicleLevel**
- **DepletionRate**
- **VehicleNos**
- **Input port for Growth Rate and Depletion Rates from Combi-table**
- **InGrowthRate**
- **InDepletionRate**
- **Total Vehicle Calculation Input Port**
- **Total Vehicle Output port**
- **Conversion**
- **Converted Vehicle from fossil to Electric Vehicle**
- **To eV**

**Electric Vehicles**

- **VehicleLevel**
- **GenerationRate**
- **DepletionRate**
- **Input port for Growth Rate and Depletion Rates from Combi-table**
- **InGrowthRate**
- **InDepletionRate**
- **Total Vehicle Calculation Input Port**
- **Total Vehicle Output port**
- **VehicleNos**
- **FromFossilVehicles**
- **VehicleNos**

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*Usage: Creative Commons with attribution CC-BY*
Model Components – Model for Growth Rate and Depletion Rate

• Rate model for Fossil Vehicle:

  Symbol of Rate Model for Fossil Cars

  Combitable Switch Flag

  Growth and Depletion Rate Switch Between Combi-Table

  Input Growth Rate and Depletion Rate Combi-tables

  Growthrate

  Switch For Growth to Electrical Vehicle

  GrowthRateToElectricalVehicle

  DepletionRate

  StartSimulationTime

• Rate model for Electric Vehicles:

  Symbol of Electric Vehicle Rate

  Combi-Table Switch Flag

  Growth and Depletion Rate Switch Between Combi-Table

  Input Growth Rate and Depletion rate Combi-tables

  Growthrate

  GrowthSwitch

  CombiTableSwitch

  DepletionSwitch

  CombiTableSwitch

  DepletionRate

  StartSimulationTime

Growth and Depletion Rate Switch Between Combi-Table
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

- Rate model For Fossil Vehicles:
- Rate model for Electric Vehicles:
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

- **Energy used 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*Energypk) and if Variable averagekm is used, variableavgeagekm 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
Scenario Model- TransportationParameter

- 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 increase
- Scenario 2 – **Faster** transition, with **fossil ban year** for fossil cars 2025, similar for other vehicles
- Scenario 3 – Also doubling **collective 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

<table>
<thead>
<tr>
<th>Car</th>
<th>Fossil Ban Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>2100</td>
</tr>
<tr>
<td>Diesel</td>
<td>2100</td>
</tr>
<tr>
<td>Bio</td>
<td>2100</td>
</tr>
<tr>
<td>PHeV</td>
<td>2100</td>
</tr>
</tbody>
</table>

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 Emissions
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 | 
PHeV Cars | 
Electric Cars | 

Vehicle Legends:
Results Scenario 2 – Cars Growth and Depletion Rate

![GrowthRate vs Time](chart1)

![DepletionRate vs Time](chart2)
Results Scenario 2 – Total Cars CO2 Emissions
Results Scenario 3 – Cars- Average driving range km Reduction – 2%

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

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Legends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Cars</td>
<td>Total Number of Cars</td>
</tr>
<tr>
<td>Bio Gas Cars</td>
<td>Bio Gas Cars</td>
</tr>
<tr>
<td>Petrol Cars</td>
<td>Petrol Cars</td>
</tr>
<tr>
<td>Diesel Cars</td>
<td>Diesel Cars</td>
</tr>
<tr>
<td>PHeV Cars</td>
<td>PHeV Cars</td>
</tr>
<tr>
<td>Electric Cars</td>
<td>Electric Cars</td>
</tr>
</tbody>
</table>
Results Scenario 3 – Number of Cars Growth and Depletion Rate
Results Scenario 3 – Total Cars CO2 Emission 2019 - 2035
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 – Total Number of Cars
- Ex: BioGasCar – Fossil Ban Year - 2030, Average driving range km Reduction – 2% per year

![Graph showing the total number of BioGasCars over time from 2020 to 2035.](image-url)
Results Scenario 3 – Car CO2 Emission
- Ex: BioGasCar – Fossil Ban Year -2028, Average driving range km Reduction – 2%
Results Scenario 3 – Light Trucks - Average driving range km Reduction – 2%

<table>
<thead>
<tr>
<th>Trucks</th>
<th>Fossil Ban Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>2028</td>
</tr>
<tr>
<td>Diesel</td>
<td>2025</td>
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<tr>
<td>BioGas</td>
<td>2030</td>
</tr>
<tr>
<td>PHeV</td>
<td>2028</td>
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</tbody>
</table>
Results Scenario 3 – Light Trucks-Growth Rate and Depletion Rate

![Graph showing Light Trucks Growth Rate vs Time](image1)

![Graph showing Light Trucks Depletion Rate vs Time](image2)
Results Scenario 3 – Light Trucks - CO2 Emissions

![Graph showing Total Light Truck CO2 Emissions vs Time](image-url)
Results Scenario 3 – Total Number of Light Trucks
- Ex: LightBioTruck – Fossil Ban Year -2030, Average driving range km Reduction – 2% per year

![Graph showing total number of LightBioTruck vs time](image-url)
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

<table>
<thead>
<tr>
<th>Heavy Truck</th>
<th>Fossil Ban Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>2028</td>
</tr>
<tr>
<td>Diesel</td>
<td>2025</td>
</tr>
<tr>
<td>Bio</td>
<td>2028</td>
</tr>
<tr>
<td>Hydro</td>
<td>2028</td>
</tr>
</tbody>
</table>
Results Scenario 3 – Heavy Truck - Growth and Depletion Rate

HeavyTruckGrowthRate vs Time

HeavyTruckDepletionRate vs Time
Results Scenario 3 – Heavy Truck CO2 Emissions
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 Emissions of Heavy Truck
– Ex: HeavyDieselTruck – Fossil Ban Year -2025, Average driving range km Reduction – 2%
Results Scenario 3 – Bus New Combi-table Data - True

<table>
<thead>
<tr>
<th>Bus</th>
<th>Fossil Ban Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>2025</td>
</tr>
<tr>
<td>Biogas</td>
<td>2030</td>
</tr>
<tr>
<td>H2</td>
<td>2030</td>
</tr>
</tbody>
</table>
Results Scenario 3 – Number of Buses Growth and Depletion Rate

Growth Rate of Buses vs Time

Depletion Rate of Buses vs Time
Results Scenario 3 – Bus CO2 Emissions

![Total Bus CO2 Emission vs Time](image)

- Graph showing the Total Bus CO2 Emission over time from 2020 to 2035.
Results Scenario 4 – Cars
Conversion start Year - 2025, Average driving range km Reduction – 2%, annually

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Conversion %</th>
<th>Fossil Ban Year</th>
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</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>4.5</td>
<td>2028</td>
</tr>
<tr>
<td>Diesel</td>
<td>3.5</td>
<td>2025</td>
</tr>
<tr>
<td>Bio</td>
<td>4.5</td>
<td>2028</td>
</tr>
<tr>
<td>PHeV</td>
<td>13</td>
<td>2028</td>
</tr>
</tbody>
</table>
Results Scenario 4 – Cars Growth and Depletion Rate
Results Scenario 4 – Car Pool CO2 Emission
Results Scenario 4 – Total Number of Cars
– 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
– 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

<table>
<thead>
<tr>
<th>Car</th>
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<th>Fossil Ban Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>1</td>
<td>2025</td>
</tr>
<tr>
<td>Diesel</td>
<td>1</td>
<td>2028</td>
</tr>
<tr>
<td>Bio</td>
<td>1</td>
<td>2028</td>
</tr>
<tr>
<td>PHeV</td>
<td>1</td>
<td>2028</td>
</tr>
</tbody>
</table>
Results Scenario 4 – Light Trucks - Growth and Depletion Rate Conversion Percentage – 1%, Average driving range km Reduction – 2%

[Graphs showing growth and depletion rate conversion for light trucks.]
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 – CO2 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

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</tr>
<tr>
<td>Diesel</td>
<td>1</td>
<td>2025</td>
</tr>
<tr>
<td>Bio</td>
<td>1</td>
<td>2028</td>
</tr>
<tr>
<td>H2</td>
<td>1</td>
<td>2028</td>
</tr>
</tbody>
</table>
Results Scenario 4 – Heavy Truck Growth and Depletion Rate
Results Scenario 4 – Heavy Trucks CO2 Emissions

![Graph showing heavy trucks CO2 emissions vs time. The graph indicates a decrease in emissions over time, with the y-axis representing CO2 emissions in units of 10^12 kg CO2 and the x-axis representing years from 2015 to 2025.](image-url)
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 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 – Buses -
Conversion Percentage – 0.01 (1% per year) , New Combi-table Data for Growth Rate
Results Scenario 4 – Bus Growth and Depletion Rate

GrowthRateofHeavyTruck vs time

DepletionRateofHeavyTruck vs time
Results Scenario 4 – Bus CO2 Emissions
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 collective 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)