

CACTUS

Models and Methods for the Evaluation and the Optimal Application of Battery Charging and Switching Technologies for Electric Busses



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1 Introduction

The global trend towards clean and energy-efficient vehicles is driven by concerns regarding the impacts of fossil-fuel-based road transport on energy security, climate change and public health. Electrification in particular is understood as providing a potential multitude of opportunities for the use of energy from renewable sources and for the reduction of local emissions and greenhouse gas emissions like no other. In 2009, the European Commission presented the Green Cars Initiative aimed at encouraging the development and market uptake of clean and energy-efficient vehicles. This strategy will enable the environmental impact of road transport to be reduced and will boost the competitiveness of the automobile industry.

1.1 Problem

The use of public transport is an environmentally friendly way to travel. If more and more passenger cars will be powered by electrical energy in the future, public transport companies will be forced to convert their diesel busses into electric busses in order not to lose this advantage.

The requirements of busses are different to those of passenger cars. A bus covers an average distance of 250 to 300 km each day. The bus itself has a weight of, for example, 14-17.5 t (Solaris Urbino 18), 28 t (MAN NG 313) or 26.6 t (Mercedes O 405 GN). A suitable battery that would enable the bus to run for such a long distance without having to be recharged would be far too big, heavy and expensive. In order to overcome this problem, several approaches are currently being investigated, for example switching the battery and the short inductive charging of super capacitors at bus stops. With these technical solutions, which combine vehicles and infrastructure, fully electric busses should be enabled for use in public transportation.

Assumptions:

1. In the near future, there will be no batteries for fully electric busses which provide the daily output of 300 km without needing to be recharged and which would be acceptable in terms of their size, weight and cost.
2. No technical approach that is currently being investigated will be equally suitable for all public transport companies.
3. In any case, investment costs for vehicles, in-vehicle components and infrastructures (e. g. battery charging or battery switching facilities) will be very high for public transport companies.

The following conclusion is drawn: The available technical approaches and solutions must be considered separately against the prerequisites and requirements of every single public transport company in terms of transportation, technical, economic and environmental aspects. Only on this basis can a decision for a technology that optimally meets the requirements of a public transport company be made.

1.2 Objectives

Technical solutions to enable fully electric busses should be evaluated so that they reflect the prerequisites and requirements of the participating public transport companies. The ultimate goal of the project is to find the best technical solution for the participating public transport companies HVB, MVB, PVGS and PKM depending on their real input data (timetable, vehicle operation plan, etc.), which in most cases may mean minimising the investment and operational costs. Of course, the best solution may vary between the participating public transport companies due to the strongly different prerequisites, assignments and aims. The best solution does not only involve a technology, but also its optimal application.

To achieve this aim, models of all relevant transportation, technical, economic and ecological values will be elaborated. Methods will be developed with which the question as to the most suitable technical solution (depending on the input values) can be answered and which help to apply the technical solution found in an optimal way. A software tool will be developed with which the different solutions can be easily compared. It should be possible to study the gradual integration of fully electric busses into existing fleets of diesel, natural gas and hybrid busses.

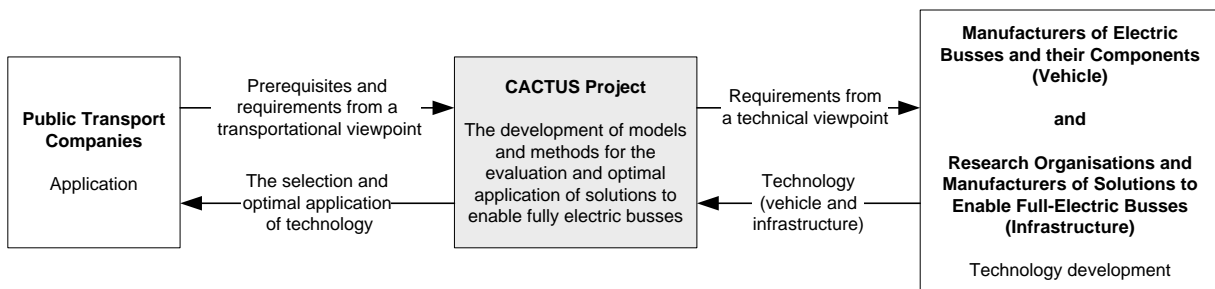


Figure 1: The role of the CACTUS project

The preliminary studies with the participating public transport companies will lead into recommendations for the actors in the field of technology development, namely the manufactures and researchers of fully electric busses and the corresponding infrastructure. The role of the CACTUS project can be seen in Figure 1.

1.3 Concept

In the CACTUS project, considerations concerning techniques for fully electric busses will be made to decide which best fits a public transport company's needs. This requires a series of detailed questions to be answered. Some general questions are:

- Is it possible to keep to the timetable with a given configuration (all technical and strategic elements requiring the operation of fully electric busses), a given vehicle fleet (including those with mixed engines) and a given vehicle operation plan?

- How high are the investment and operational costs?

In this context, several optimisation issues arise, some of which are listed here:

- What should the operation plan look like so the timetable can be kept to?
- Where the charging or exchanging facilities have to be located?

In the CACTUS project, methods that can be used to answer these will be developed.

1.4 Scope of this Deliverable

On the basis of collected issues the necessary input variables will be identified and the output variables will be specified. The output variables allow a quantitative assessment and comparability to transportation, technical, economic and ecological aspects. If required input variables are not yet available in electronic form will be collected and prepared, so that they can be electronically processed. All variables and their relations to each other will be modelled, so the methods to be developed in WP3 can work with. In Deliverable 1.1 the questions have been collected which will be answered within the CACTUS project. The Deliverable 1.1 only mentioned 'what is the problem' not 'how will the problem be solved' (this is part of Deliverable 2.1 and moreover Deliverable 3.1).

Deliverable 1.2 provides a large collection of current technologies for enabling fully electric buses as well as a broad overview to current available electric buses. The technologies includes lithium-ion batteries, inductive charging, charging via pantograph on the run, exchanging the battery and the application of super capacitors.

The models presented in this Deliverable 2.1 are simplified images of the reality. They are divided into transportation, technical, economic and ecological complexes. Some will be considered as input values and some as output values. Methods to be developed in WP3 work with input values and delivers output values. Models are the basis of the methods to be developed in WP3. The models are a pre-stage of implementation. That means it is aimed to write the models in source code.

Deliverable 3.1 provides several methods in order to answer the questions from Deliverable 1.1. There are simulation and optimization for transportation and technical issues as well as special methods of consideration for economic and ecological issues. Depending on the question one or more of them will be applied.

This Deliverable 4.1 describes the function of developed CACTUS tool in which all models and methods have been implemented and integrated. Beside the tool itself, a central issue of this Deliverable is the description of the input files in Chapter 5 as well as the description of the different built-in tools for preparing the input files in Chapter 3 for optimizing the charging and exchanging infrastructure and for simulation.

2 Installation

2.1 General

The CACTUS tool requires:

- Java Runtime Environment 7
- Octave Interpreter (see next section)

The CACTUS tool is included in the `CACTUS.zip` archive. It can be unpacked to any folder.

2.2 Octave Interpreter for Windows

1. Download the Octave version 3.8.2 or higher

 <http://mxеоctave.osuv.de/octave-3.8.2-4-portable.zip>

2. Extract the file into a folder <octave_home> of your choice
3. Edit the file “Optimizer.bat” in the “bin” folder of your CACTUS tool and change the lines 6 and 7:

```
01: @echo off
02: REM -----
03: REM Please adjust the paths OCTAVE_HOME and CACTUS_HOME to suit your needs
04: REM (please do not add a trailing backslash)
05: REM -----
06: set OCTAVE_HOME=C:\usr\Octave\Octave-3.8.2
07: set CACTUS_HOME=D:\var\CACTUS\Models-Octave
08: REM -----
09: pushd %CACTUS_HOME%
10: %OCTAVE_HOME%\bin\octave %CACTUS_HOME%\integrationTest.m 1>output.txt 2>error.txt
11: popd
```

4. Up to this point the optimizer should be able to run. You can check this by execute the Optimizer.bat file with the parameter “testopt” from any terminal window:

```
> Optimizer testopt
```


3 Using the tool

3.1 Open the files

Select `File | Open...` from the menu or press `STRG+O` in order to open the files described above. If you do not have prepared the input files you can use the build-in-tools coming with the CACTUS tool for preparing the input files easily. See Chapter 2 for more details.

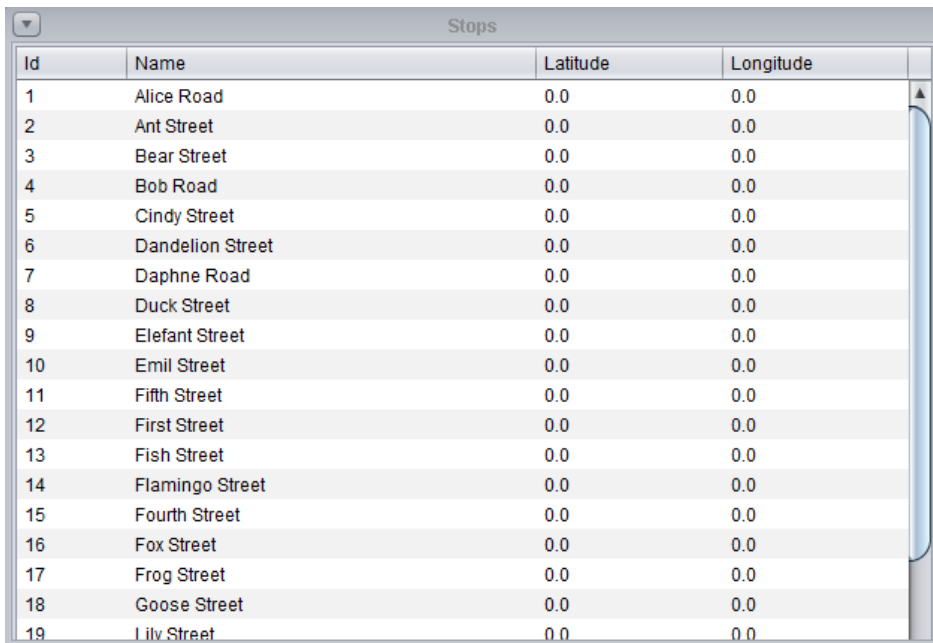
3.2 Views

There are several views which all are internal windows. They can be placed side by side or one above the other. The following subsections describe all available views.

3.2.1 Stops

The stops frame shows all bus stops including id, name, latitude and longitude.

Select `View | Stops` from the menu or press `ALT+1` to bring the stops frame to the foreground.



Id	Name	Latitude	Longitude
1	Alice Road	0.0	0.0
2	Ant Street	0.0	0.0
3	Bear Street	0.0	0.0
4	Bob Road	0.0	0.0
5	Cindy Street	0.0	0.0
6	Dandelion Street	0.0	0.0
7	Daphne Road	0.0	0.0
8	Duck Street	0.0	0.0
9	Elefant Street	0.0	0.0
10	Emil Street	0.0	0.0
11	Fifth Street	0.0	0.0
12	First Street	0.0	0.0
13	Fish Street	0.0	0.0
14	Flamingo Street	0.0	0.0
15	Fourth Street	0.0	0.0
16	Fox Street	0.0	0.0
17	Frog Street	0.0	0.0
18	Goose Street	0.0	0.0
19	Lily Street	0.0	0.0

3.2.2 Runs

The runs frame shows all runs from the timetable including detailed information about all the bus stops the runs as well as departure and arrival times.

Select `View | Runs` from the menu or press `ALT+2` to bring the runs frame to the foreground.

Route Green (1)	Departure Stop	Arrival Stop	Depart...	Arrival ...
Route Green (2)	Ant Street	Bear Street	5:51	5:52
Route Green (3)	Bear Street	Duck Street	5:52	5:53
Route Green (4)	Duck Street	Fourth Street	5:53	5:54
Route Green (5)	Fourth Street	Goose Street	5:54	5:55
Route Green (6)	Goose Street	Elefant Street	5:55	5:56
Route Green (7)	Elefant Street	Frog Street	5:56	5:57
Route Green (8)	Frog Street	Fish Street	5:57	5:58
Route Green (9)	Fish Street	Fox Street	5:58	5:59
Route Green (10)	Fox Street	Flamingo Street	5:59	6:00
Route Green (11)				
Route Green (12)				
Route Green (13)				
Route Green (14)				
Route Green (15)				
Route Green (16)				
Route Green (17)				
Route Green (18)				
Route Green (19)				
Route Green (20)				

If you would like to see the details of a certain run, simple select it on the left side. The details of the run immediately become visible on the right side.

3.2.3 Energy Storage Types

The energy storage types view shows all energy storage types including their attributes. The attributes cannot be changed here.

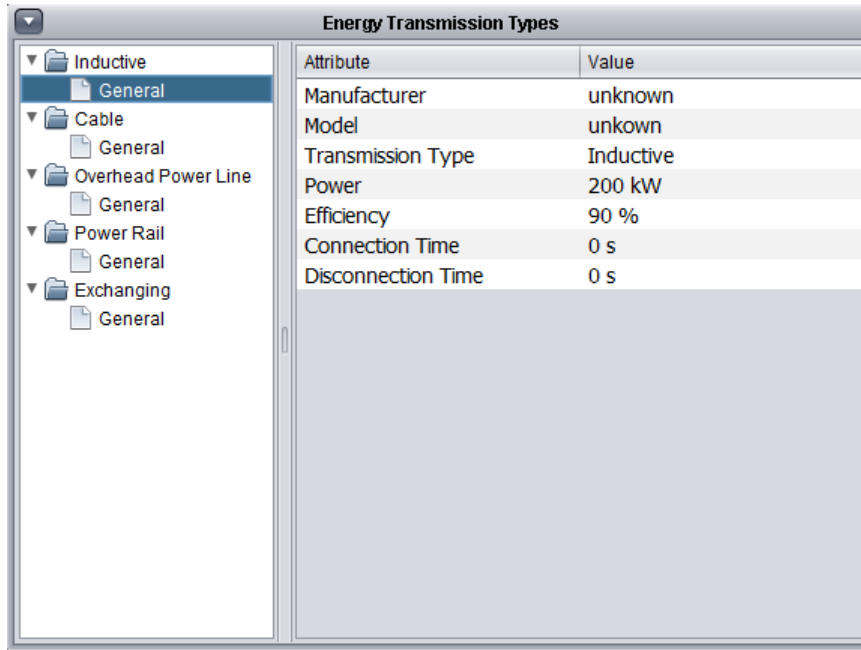
Select View | Energy Storage Types from the menu or press ALT+3 to bring the energy storage types frame to the foreground.

Attribute	Value
Chemical Composition	Lithium-Ion
Manufacturer	unknown
Model	unknown
URL	unknown

3.2.4 Energy Transmission Types

The energy transmission types view shows all energy transmission types including their attributes. The attributes cannot be changed here.

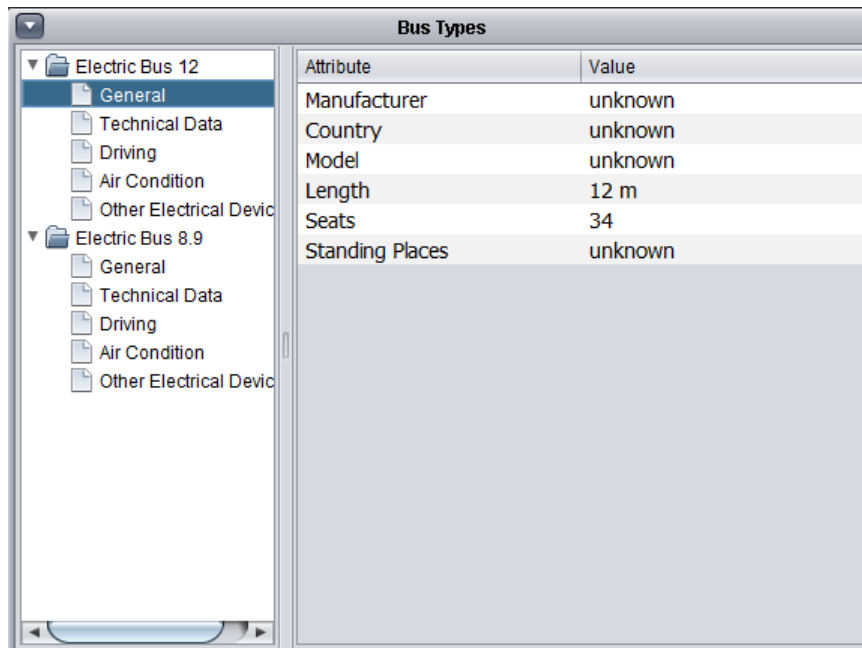
Select **View | Energy Transmission Types** from the menu or press **ALT+4** to bring the energy transmission types frame to the foreground.



3.2.5 Bus Types

The bus types view shows all bus types including their attributes. The attributes cannot be changed here.

Select **View | Bus Types** from the menu or press **ALT+5** to bring the bus types frame to the foreground.



3.2.6 Busses

The busses view shows all busses including their main attributes like the id, the type, the capacity of the energy storage, the charging level of the energy storage, the distance covered so far and messages.

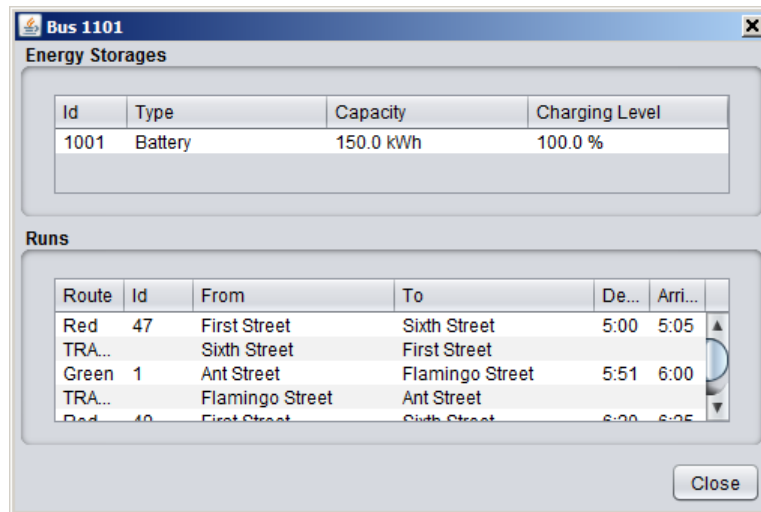
Select **View | Busses** from the menu or press **ALT+6** to bring the busses frame to the foreground.

The screenshot shows a window titled "Busses" containing a table with the following data:

Id	Type	Capacity	Charging Level	Distance	Messages	...
1101	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>
1102	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>
1103	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>
1104	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>
1105	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>
1106	unknown	150.0 kWh	100%	0.0 km	no	<input type="text"/>

You can switch to the bus type by clicking the right mouse button and following the appearing popup menu.

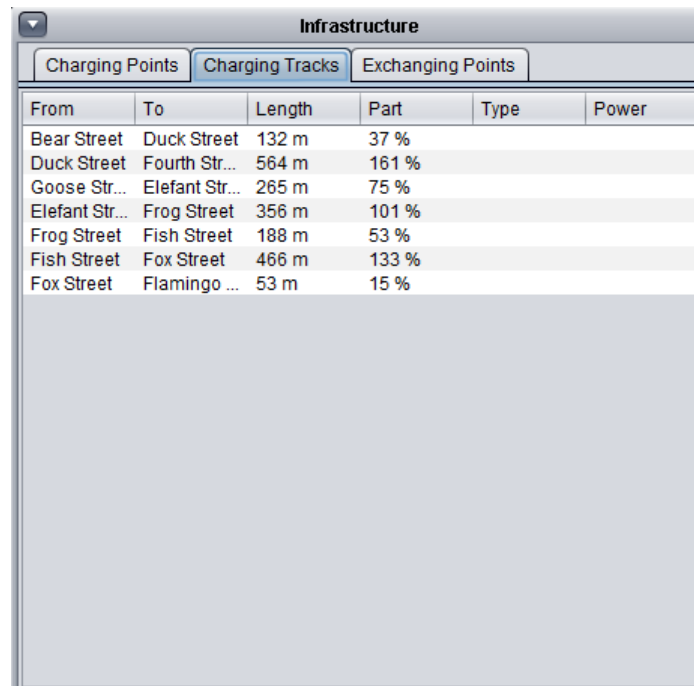
By clicking the button in the right column a window opens with further information on the energy storages of the bus and the list of the runs.



3.2.7 Infrastructure

The infrastructure view shows the charging points, the charging tracks and the exchanging points within the public transport network.

Select View | Infrastructure from the menu or press ALT+7 to bring the infrastructure frame to the foreground.



You can switch to the energy transmission type by clicking the right mouse button and following the appearing popup menu.

3.3 Run simulation

After reading the input files successfully you are ready to start the simulation. There are several simulation variants available (see Chapter 4 for details).

4 Tools within the CACTUS tool

There are several tools available for preparing the input files. For the first time please use them in the right order as described below. The following figure illustrates the most important tools including the input files needed.

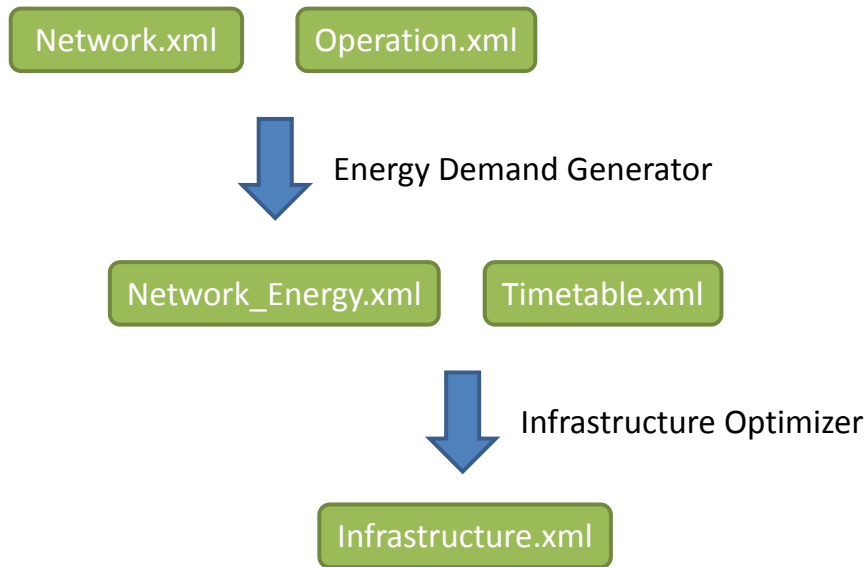


Figure 2: Process of input file preparation

The process of preparing the input files is demonstrated on a sample public transport network as follows:

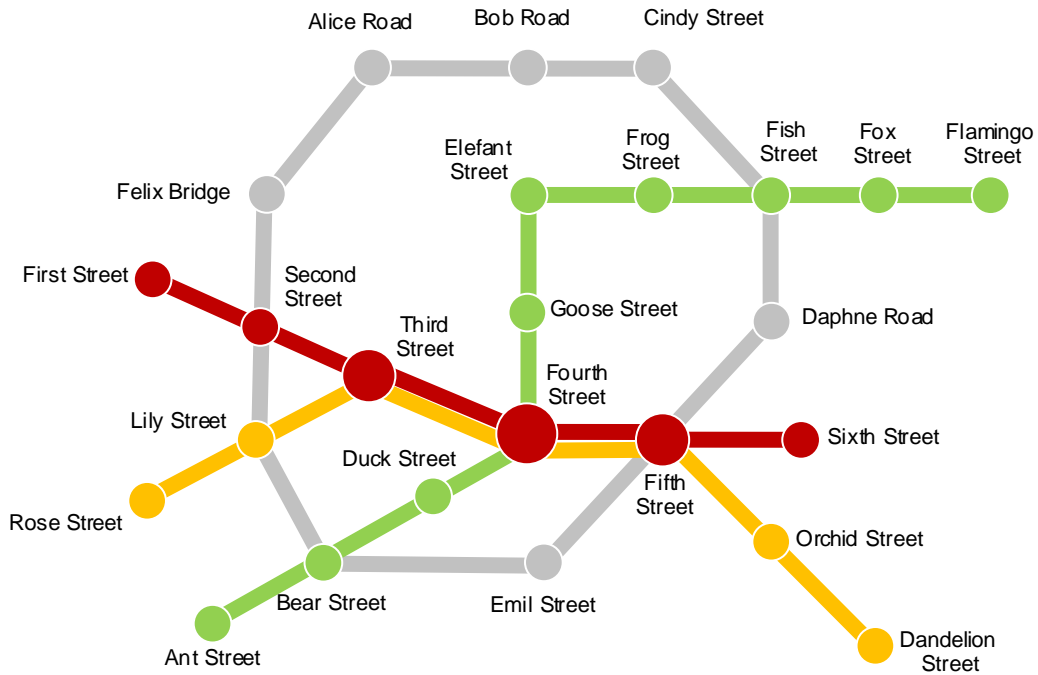


Figure 3: Sample public transport network

4.1 Network and Timetable Generator

The tool Network and Timetable Generator can be used for generating the files Network.xml (including stops and ways) and Timetable.xml (including runs) easily. The starting point is the timetable of the starting stop of a certain bus route. This timetable contains the stops of the route in the right order, the travel times between the stops in minutes and the departure times for the whole day.

From this, the names of the stops, the travel time between the stops and the departure times have to be (manually) extracted and to be written into a plain text file in the following format:

```
*ROUTE
Green
direction regular

*Stops
Ant Street
Bear Street
Duck Street
Fourth Street
Goose Street
Elefant Street
Frog Street
Fish Street
Fox Street
Flamingo Street
```


*Times

0 1 2 3 4 5 6 7 8 9

*Departures

05:51

06:11 06:31 06:51

07:11 07:31 07:51

08:11 08:41

09:11 09:41

10:11 10:41

11:11 11:41

12:11 12:41

13:11 13:31 13:51

14:11 14:31 14:51

15:11 15:31 15:51

16:11 16:31 16:51

17:11 17:37 17:57

18:11 18:37 18:57

19:11 19:37 19:57

20:17 20:47

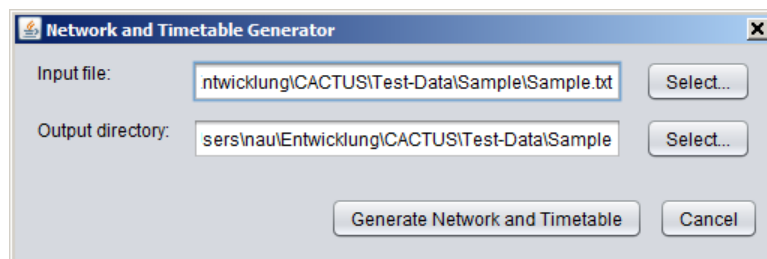
21:20 21:50

22:20 22:50

23:20 23:50

Please note: the data only contains the departures from Monday to Friday. The data of several timetables have to be written into the same plain text file.

Select **Tools** | **Network and Timetable Generator** from the menu or press STRG+N. The following dialog window opens:

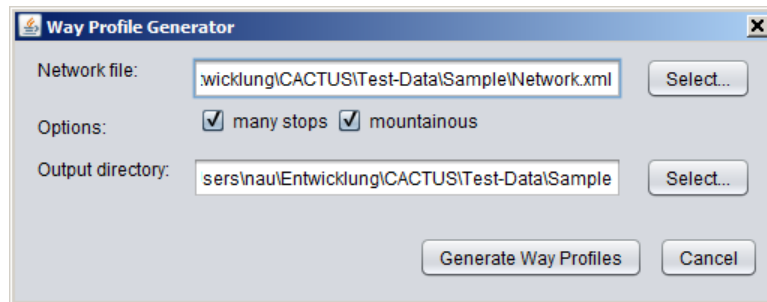


Choose the plain text input file as defined above and the output directory and press the Button **Generate Network and Timetable**. The files **Network.xml** and **Timetable.xml** are generated.

4.2 Way Profile Generator

The **Network.xml** file now does not contain any way profiles. In order to add them to the **Network.xml** file, the tool **Way Profile Generator** can be used. An alternative variant to the **Way Profile Generator** is the **Way Profile Logger** which helps to record real way profile data from the bus and which is explained in the next section.

Select Tools | Way Profile Generator from the menu or press STRG+W. The following dialog window opens:



Choose the network file and the output directory and press the Button Generate Way Profiles. You can also determine the speed profile by selecting the check box many stops and the topography by selecting the check box mountainous.

The Way Profile Generator derives the distance between two successive stops from the travel time. A travel time of 1 minute is equal to 350 m. A travel time of 1 minute is equal to 700 m and so on. If the check box many stops is not selected the bus accelerates to 36 km/h from the first stop, runs with constant speed of 36 km/h to the second stop and decelerates down to 0 km/h. If the check box many stops is selected the bus stops always after 150 m. If the check box mountainous is selected the gradient randomly changes. If the check box mountainous is not selected there is no gradient at all. The Way Profile Generator cannot generate the locations (latitude and longitude). The way profiles are added to the Network file.

All ways of the Network file now contains:

```
<Way from="2" to="3" comment="Ant Street -> Bear Street" distance="350">
  <Profile>
    <Entry time="0" latitude="0.0" longitude="0.0" elevation="0"
speed="0.0" distance="0"/>
    <Entry time="1" latitude="0.0" longitude="0.0" elevation="0"
speed="1.0" distance="1"/>
    <Entry time="2" latitude="0.0" longitude="0.0" elevation="0"
speed="2.0" distance="4"/>
    <Entry time="3" latitude="0.0" longitude="0.0" elevation="0"
speed="3.0" distance="7"/>
    <Entry time="4" latitude="0.0" longitude="0.0" elevation="0"
speed="4.0" distance="12"/>
    ...
    <Entry time="48" latitude="0.0" longitude="0.0" elevation="0"
speed="7.0" distance="335"/>
    <Entry time="49" latitude="0.0" longitude="0.0" elevation="0"
speed="6.0" distance="342"/>
```

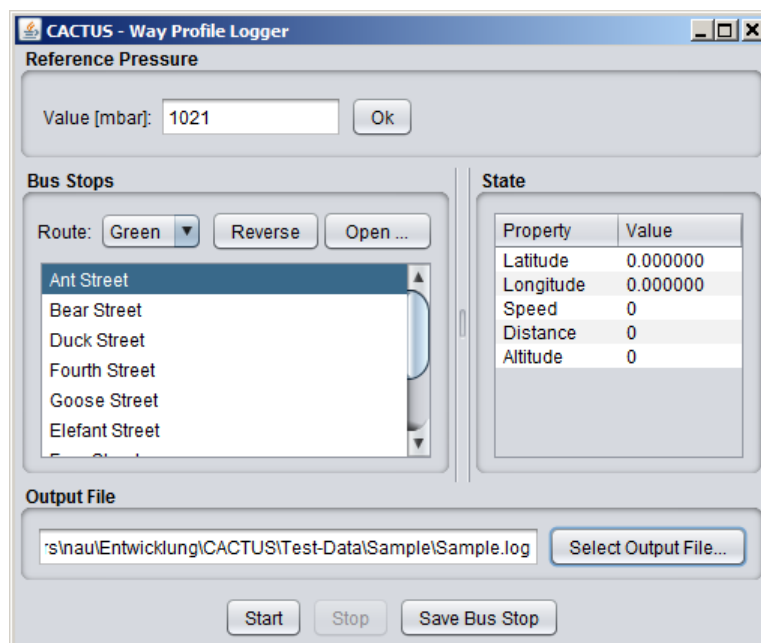
```
<Entry time="50" latitude="0.0" longitude="0.0" elevation="0"
speed="5.0" distance="347"/>
</Profile>
</Way>
```

The origin Network file is renamed to Network_without_WayProfiles.xml.

4.3 Way Profile Logger

There is a further tool coming with the CACTUS tool. It allows logging the speed profile and the elevation profile of busses. For that, you only have to sit in the bus as a regular passenger and to run the Way Profile Logger on your laptop. However, a GPS receiver and a barometer are required for using the Way Profile Logger. The Way Profile Logger processes NMEA strings coming from the GPS receiver. For measuring the air pressure we used the demonstration board STEVAL-MKI120V1 (LPS331AP). If you would like to use another barometer you have to implement and add the respective class.

Select **Tools | Way Profile Logger...** from the menu or press **STRG+L** in order to run the Way Profile Logger. The following window appears:



On the top area of the window you can enter the reference pressure. This value can be retrieved from <https://aviationweather.gov/adds/metars/> by entering the code for the nearest airport for example.

The middle right area shows the current state of the position, the speed, the distance and the altitude. These values are directly taken from the GPS receiver and the barometer.

The middle left side shows a list of bus stops. These bus stops are expected to be reached in this order. When the button `Save Bus Stop` is clicked the name of the currently selected bus stop is inserted into the log file and the selections switches to the next bus stop.

The log file can be selected by clicking the button `Select Output File...` When the button `Start` is clicked, the logging starts to write the time, the latitude, the longitude, the elevation, the speed and the distance to the log file every second. Here is an example of such an entry:

```
<Entry time="608" latitude="52.147890" longitude="11.583675" elevation="57"
speed="0" distance="4"/>
```

The time and the distance are always reset to 0 when the button `Save Bus Stop` is pressed. Click the button `Stop` to finish the logging process.

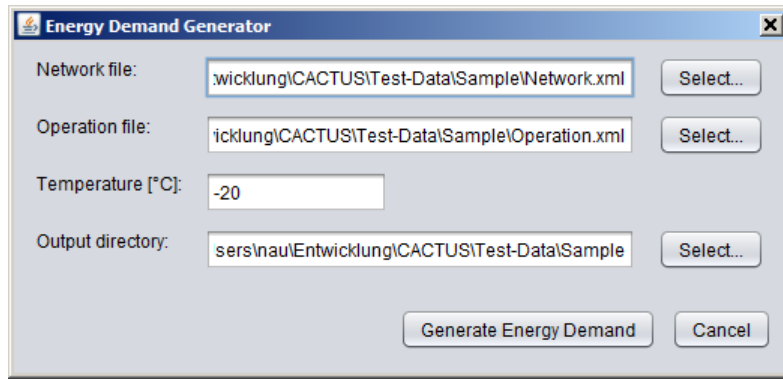
All settings are automatically stored into a file named `ProfileLogger.cfg`. It is a plain text file that can be edited using any text editor. Here is a sample content of the `ProfileLogger.cfg` file:

```
selected_route=Green
routes=C:\\Users\\nau\\Entwicklung\\CACTUS\\Test-
Data\\Sample\\Sample_ProfileLogger.txt
output_file= C:\\Users\\nau\\Entwicklung\\CACTUS\\Test-
Data\\Sample\\Sample.log
reverse_route=false
pressure-sensor_port=COM10
gps-receiver_port=COM9
ref_pressure=1021
```

So far, there is no other way to change the COM ports of the GPS receiver and the barometer than manually editing the `ProfileLogger.cfg` file.

4.4 Energy Demand Generator

Select `Tools | Energy Demand Generator...` from the menu or press `STRG+E` in order to run the Energy Demand Generator. The following window appears:



Select the Network.xml file by clicking the `Select...` button in the first row. Select the Operation.xml file by clicking the `Select...` button in the second row. Enter the outside temperature. The value should be very low. And finally select the output directory by clicking the `Select...` button in the fourth row. Press the button `Generate Energy Demand` to start the generation process.

The bus types including their masses are taken from the Operation.xml file. All ways (that is the profiles of the ways) of the Network.xml file are simulated with each bus type during the generation process. So, the energy consumption is determined for all types of busses. The result is written into the Network_Energy.xml file:

```
<Way from="2" to="3" comment="Ant Street -> Bear Street" distance="350">
  <EnergyConsumption>
    <BusType id="201" name="Electric Bus 12" value="0.06" unit="kWh"/>
    <BusType id="202" name="Electric Bus 8.9" value="0.031"unit="kWh"/>
  </EnergyConsumption>
</Way>
```

4.5 Infrastructure Optimizer

The Infrastructure Optimizer is an external tool which is integrated into the CACTUS tool and can be invoked by `select Tools | Infrastructure Optimizer...` from the menu or press `STRG+I` in order to run the Infrastructure Optimizer.

This tool optimizes the locations of the charging points, charging tracks or exchanging points. It is assumed that all required input files are available in the project directory. A file `Infrastructure.xml` is generated and stored in the project directory.

A specific method must be chosen as shown in the following table:

Method \ File	Charging at points	Charging on tracks	Changing batteries
Input for all methods:			

Network_Energy.xml Operation.xml Timetable.xml	As described above	As described above	As described above
Input for specific methods: Economic.xml	<ul style="list-style-type: none"> • Costs for installation charging facilities for each bus stop 	<ul style="list-style-type: none"> • Costs per installation for each track • Costs per meter of installation for each track 	<ul style="list-style-type: none"> • Costs for installation swapping facilities for each bus stop • Costs per swap for each bus stop • Capacity measured in batteries per hour for each bus stop
Output for specific methods: Infrastructure.xml	<ul style="list-style-type: none"> • Bus stops which must be equipped with charging facilities • Costs per charging station • Total costs 	<ul style="list-style-type: none"> • Ways which must be equipped with charging facilities • Costs per way • Total costs 	<ul style="list-style-type: none"> • Bus which must be equipped with charging facilities • Costs per charging station • Total costs

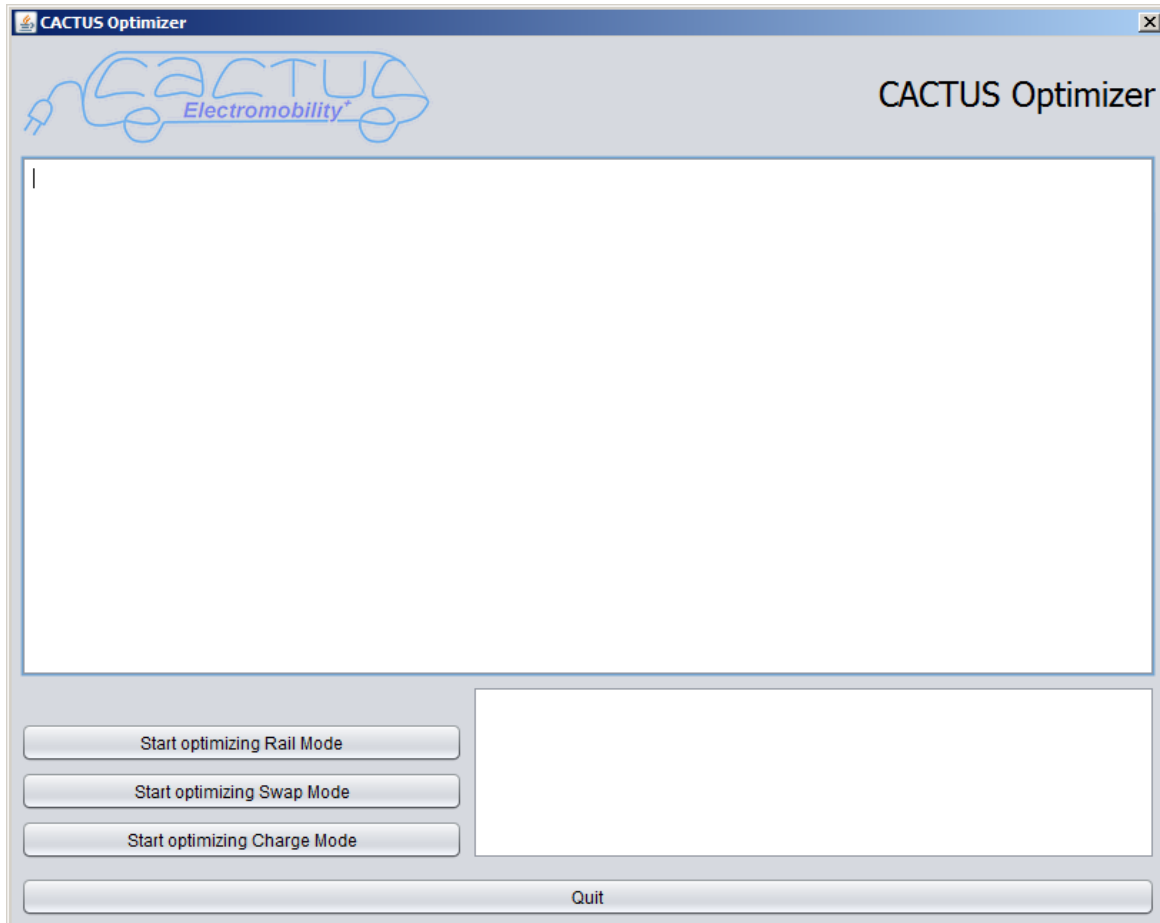
In some cases of insufficient input data, optimization has no solution. Typical examples are:

- Very low battery capacities: A bus with even fully charged batteries cannot drive between two bus stops.
- Too many bus stops or ways are excluded from the selection process: It might be not possible to charge the batteries at the remaining bus stops or on the remaining ways.
- Swapping capacity is too low: There are not enough batteries available to satisfy the all demands.

If any of the circumstances listed below occurs, it will be reported in plain text form.

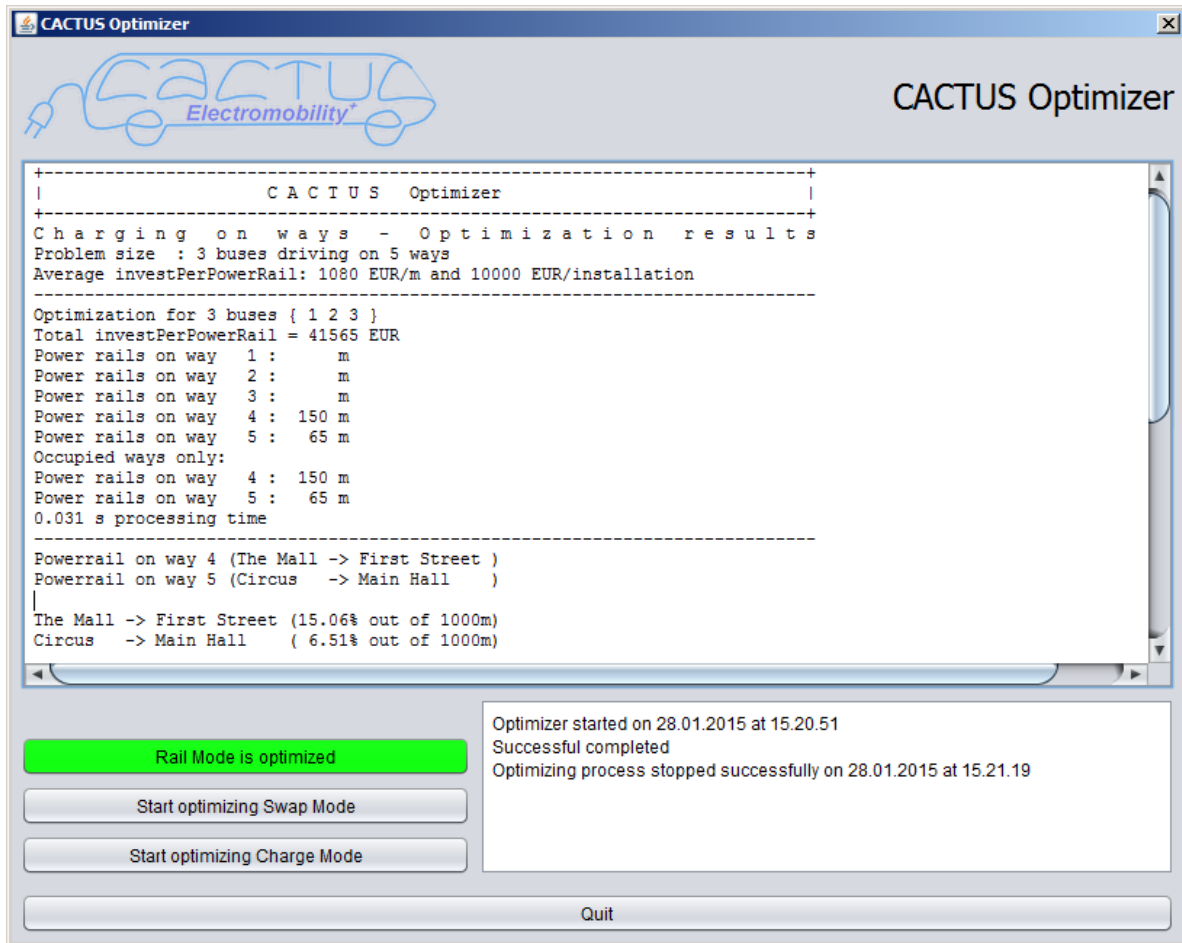
The Infrastructure Optimizer is written in OCTAVE¹ and it uses the GNU Linear Programming Kit “glpk”.

After starting the Infrastructure Optimizer the following Dialog comes up and allows starting the three different modes. After a button press the associated optimizer will be started.



Since the calculation takes up to several minutes the button background color changes to red and the button text changes from “Start optimizing xxx Mode” to “Optimizing xxx Mode...”. The start time and the stop time are logged in the smaller text area. There are also all error messages logged. When the optimization has finished successfully, the button background color changes to green, the button text changes to “xxx Mode is optimized” and a summary of the results is shown in the upper text area.

¹ GNU OCTAVE is a high-level interpreted language, primarily intended for numerical computations and with libraries for optimization. Octave is distributed under the terms of the GNU General Public License.

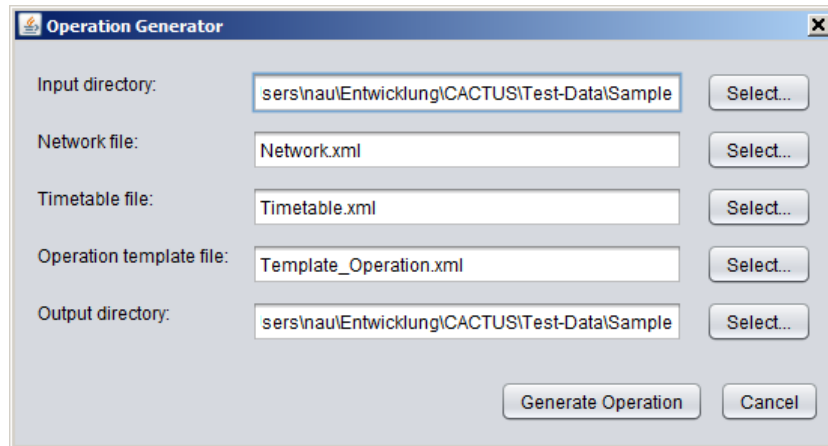


Optimization can be run for all three modes depending on the requirements. The “Quit” button closes the dialog but the results are stored internally in a xml file (see section 5.5) for further use. The results can be looked up easily by the infrastructure frame (see section 2.2.7).

4.6 Operation Generator

The Operation Generator is a tool which helps to rapidly and simply generate a set of busses with operation plans. The generated busses and operation plans might not have much to do with real operation plans, because work schedules of the bus drivers are not considered here. Of course, in reality the work schedules have to be considered. The algorithm assumes a list of all runs from the Timetable.xml ordered by the departure time. For each run a free bus is taken from the list of busses. If there is more than one bus free, the bus with the lowest number of runs is taken. If there is no bus free, a new bus is created. A bus becomes free when its current run is finished.

Select Tools | Operation Generator from the menu or press STRG+P. The following dialog window opens:



Select the input directory, the network file, the timetable file, the operation template file and the output directory and press the button `Generate Operation`. The file `Operation.xml` is generated containing all busses with their operation plans. The generated `Operation.xml` file is ready to use for simulation.

5 Simulation variants

There are several simulation variants available. They are described in the following subsections.

5.1 All busses for one day

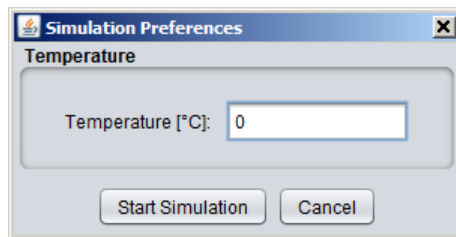
5.1.1 Objective

The objective of this simulation variant primarily is for visualizing the bus movements and for verifying the capacities of the batteries are sufficient.

In order to run this simulation variant select `Simulation | All busses for one day` from the menu or press `STRG+R`. The following dialog window opens:

5.1.2 Input

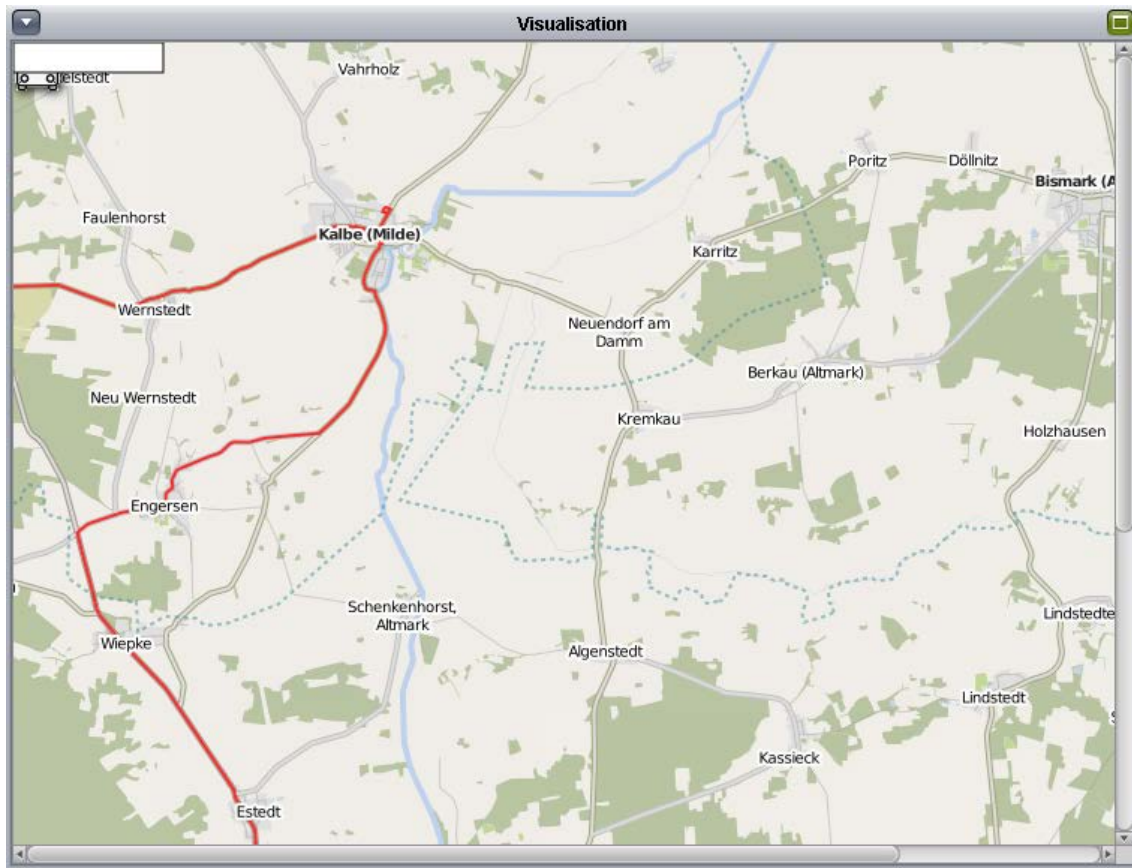
The timetable definition (Timetable.xml file) comprises only one uncertain day. That means there is no distinction between working days and weekend days. You can assume the defined Runs descend from working days. When all busses should be simulated for one day the definitions of the Operation.xml will be simulated exactly once.



Enter the outside temperature in °C at which the simulation should run and start the simulation by clicking the button `Start Simulation`.

5.1.3 Result

There are two frames revealing the simulation results. The first is a visualization of the bus movements which is only possible at this simulation variant.



This is only possible if Ways contains Profiles which contains the GPS log of the ways. Alternatively, the locations of the bus stops (latitude, longitude) can be used for direct movement (not according to real ways).

The second frame shows the states of the busses. It is the same view as described in section 2.2.6. The column `Capacity` shows the total capacity of all energy storages of the bus. The column `Charging Level` shows the current charging level of the energy storages. If any bus runs into an empty battery fault, this is highlighted by red color in the column `Charging Level`. Additionally, an error is raised in the column `Status`. The column `Distance` shows the total covered distance of the bus.

5.2 All busses for one year

5.2.1 Objective

The objective is to retrieve the economic and ecological impacts. That is why the simulation is performed for a whole year. This is the only simulation variant in which economic and ecological impacts are calculated and presented. The following figure illustrates which input files are needed for that type of simulation.

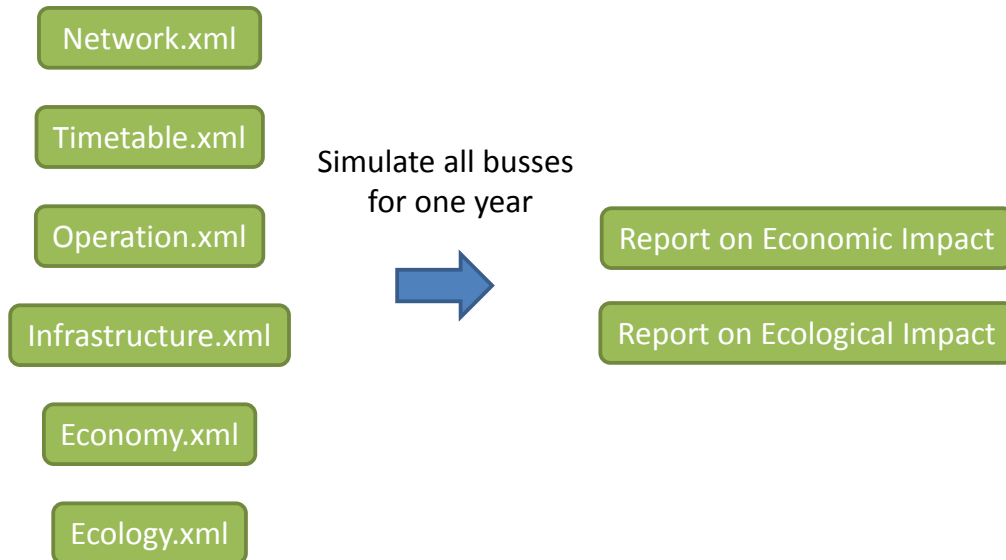


Figure 4: Input files required for the simulation of all busses for one year

In order to run this simulation variant select `Simulation | All busses for one year` from the menu or press `STRG+Y`. The following dialog window opens:

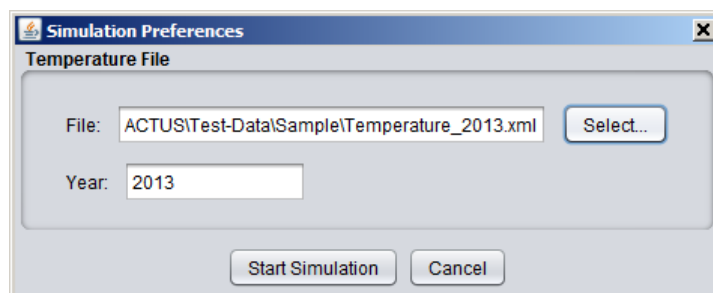
5.2.2 Input

Enter the year. Select the temperature file. The temperature file must have the following format (extract):

```
<weste:station name="Magdeburg">
<weste:wert datum="2013-01-01T00:00:00Z" einheit="Grad C" qualitaetsni-
veau="high" geobreite="52.1029" geolaenge="11.5826" hoehe="76" hoehenein-
heit="m" geoqualitaetsniveau="certain">6.1</weste:wert>
```

It can be retrieved from the Deutscher Wetterdienst [3]. The file must contain the temperature value in °C from hour 0 of 1/1/year to hour 23 of 31/12/year for every hour.

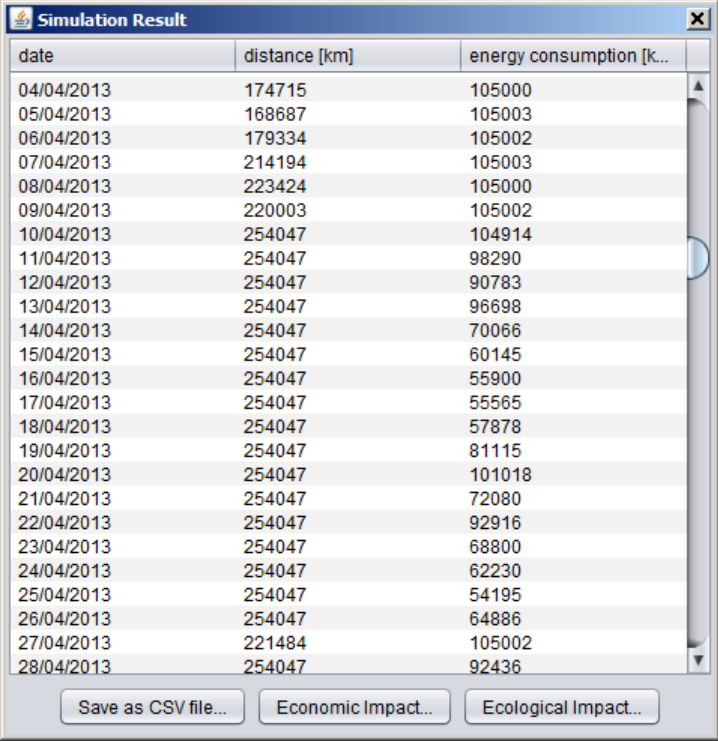
Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.2.3 Result

The result window shows the result of each simulation run. The left column shows the date. The middle column shows the distance covered by all simulated busses. The right column shows the energy consumption in kWh.



The screenshot shows a window titled "Simulation Result" with a table containing simulation data. The table has three columns: "date", "distance [km]", and "energy consumption [k...". The data rows show dates from 04/04/2013 to 28/04/2013, with varying distances and energy consumption values. At the bottom of the window, there are three buttons: "Save as CSV file...", "Economic Impact...", and "Ecological Impact...".

date	distance [km]	energy consumption [k...]
04/04/2013	174715	105000
05/04/2013	168687	105003
06/04/2013	179334	105002
07/04/2013	214194	105003
08/04/2013	223424	105000
09/04/2013	220003	105002
10/04/2013	254047	104914
11/04/2013	254047	98290
12/04/2013	254047	90783
13/04/2013	254047	96698
14/04/2013	254047	70066
15/04/2013	254047	60145
16/04/2013	254047	55900
17/04/2013	254047	55565
18/04/2013	254047	57878
19/04/2013	254047	81115
20/04/2013	254047	101018
21/04/2013	254047	72080
22/04/2013	254047	92916
23/04/2013	254047	68800
24/04/2013	254047	62230
25/04/2013	254047	54195
26/04/2013	254047	64886
27/04/2013	221484	105002
28/04/2013	254047	92436

The result can be written into a CSV file for further processing using other tools.

When the button `Economic Impact...` is clicked a report on the economic impact is generated and presented. When the button `Ecological Impact...` is clicked a report on the ecological impact is generated and presented. How both reports are generated is described in the following two subsections.

5.2.3.1 Economy

The economic impacts are calculated based on economic model and use `Economic.xml`. The results are total cost of ownership in the use of electric buses and adapt to their needs and way to exchange and charging the battery less for present value of the proceeds of liquidation. The components of value of total costs are:

- present value of the acquisition costs of bus with components:
 - nominal acquisition costs,
 - acquisition costs taking into account subsidies,
 - self-financed acquisition costs,

- external acquisition costs,
- annual annuity acquisition costs,
- discounted annual annuity acquisition costs,
- discounted costs of the spare battery,
- and present value of the acquisition costs per passenger,
- total annual operating costs with components:
 - annual energy costs,
 - annual tire costs,
 - annual costs of the daily supply of the vehicles,
 - annual maintenance costs,
 - annual salary,
 - annual insurance costs,
 - discounted annual operating costs,
 - and present value of operating costs per passenger,
- infrastructure costs with components:
 - nominal infrastructure costs,
 - costs of battery swapping,
 - infrastructure costs taking into account subsidies,
 - self-financed infrastructure costs,
 - external infrastructure costs,
 - annual annuity infrastructure costs,
 - discounted annual annuity infrastructure costs,
 - discounted annual infrastructure maintenance costs,
 - and present value of infrastructure costs per passenger,
- external costs with components:
 - annual noise emission costs,
 - annual pollutant emission costs,
 - total annual external costs,
 - discounted annual external costs,
 - and present value of external costs per passenger,
- value of the proceeds of liquidation:
 - nominal proceeds of liquidation,
 - and present value proceeds of liquidation per passenger.

5.2.3.2 Ecology

The file Ecology.xml contains definitions of energy carriers (here synonymous with energy sources) (see section 5.7). In order to calculate the emissions caused by different energy sources (e.g. diesel, gas, electricity mix of a certain year, electricity 100% renewables) firstly the amount of an energy source required to produce 1 kWh of electrical energy is determined. If there is a mix of electricity this is done for all concerned energy sources. For example, approximately 1.2 kg of brown coal or 0.3 kg of black coal has to be burned to generate 1 kWh of electricity [1]. Secondly and finally, the amount of emissions is calculated when a certain amount of an ener-

gy source is converted to electricity. For example, [2] mentions an output of 3.25 t of CO₂ when 1 t of brown coal is burned, 2.68 t of CO₂ when 1 t of black coal is burned and 2.30 t of CO₂ when 1 t of oil is burned. Figure 2 shows some more emissions caused by different energy sources.

	SO ₂ g/kWh	NO _x g/kWh	CO ₂ kg/kWh	Staub g/kWh
GuD	0,125	0,351	0,398	0,037
Steinkohle KW	0,351	0,696	0,896	0,064
Braunkohle KW	0,401	0,830	1,054	0,263
IGCC (ohne CO ₂ -Abtrennung)	0,041	0,189	0,653	0,026
IGCC (mit CO ₂ -Abtrennung)	0,034	0,174	0,074	0,027
Solarzellen (multikristallin)			0,089	
Wasserkraft			0,039	
Atomkraft			0,031	
Windkraft			0,023	

Quellen:
 Öko-Institut: Treibhausgasemissionen und Vermeidungskosten der nuklearen, fossilen und erneuerbaren Strombereitstellung, März 2007

IER: Ganzheitliche Bilanzierung der Energie- und Stoffströme von Energieversorgungstechniken, August 2000

Cost and Performance Baseline for Fossil Energy Plants, DOE/NETL-2007/1281, Mai 2007

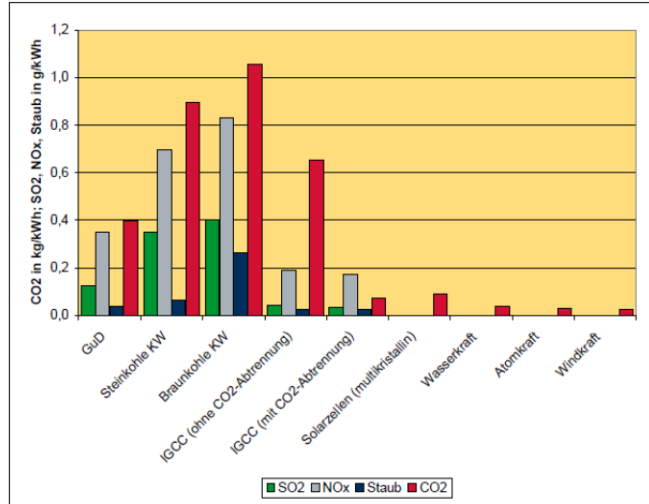
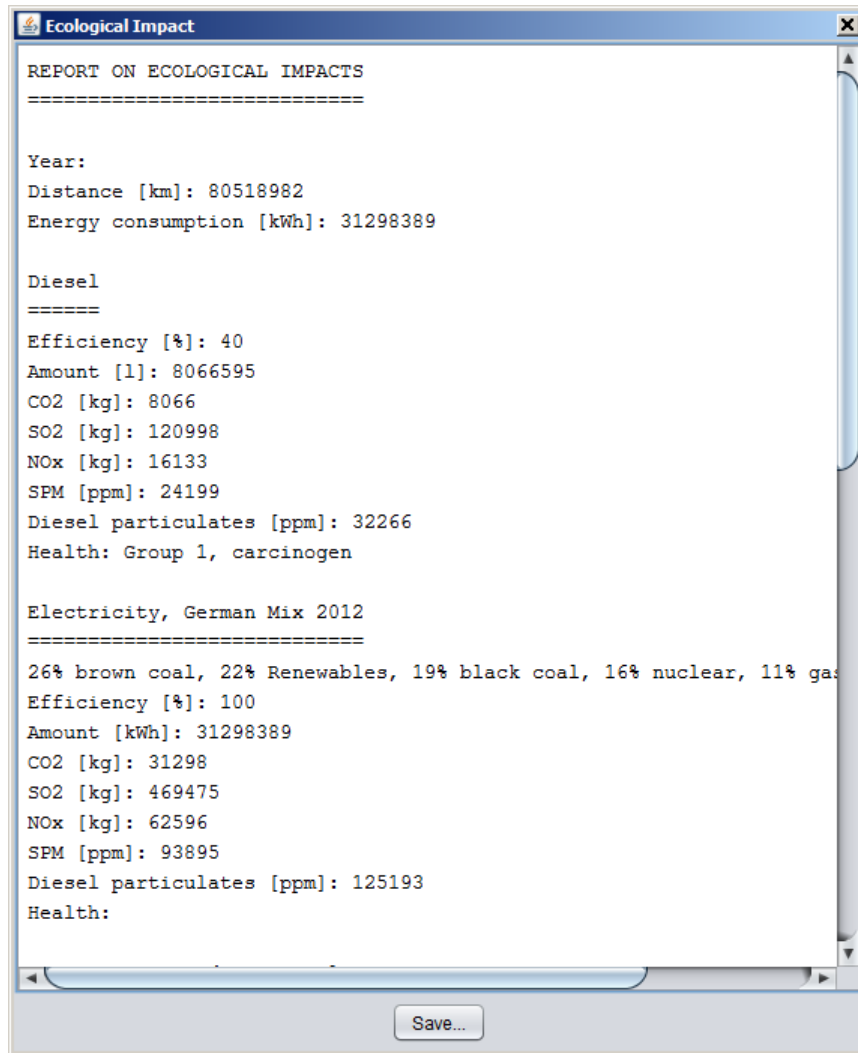


Figure 5: Emissions of different energy sources [2]

The ecological impact is shown in the appearing window formatted as a plain text report.



The report includes the total covered distance within the simulated year as well as the total consumed amount of electrical energy. For all defined energy sources the total emission of carbon dioxide, sulfur dioxide, nitrogen oxide, and suspended particulate matter and diesel particulates is calculated and listed in the report. Savings in emissions or a higher amount of emissions of each energy source compared to all other energy sources are calculated in total and as percentage as well.

5.3 Influence of mass

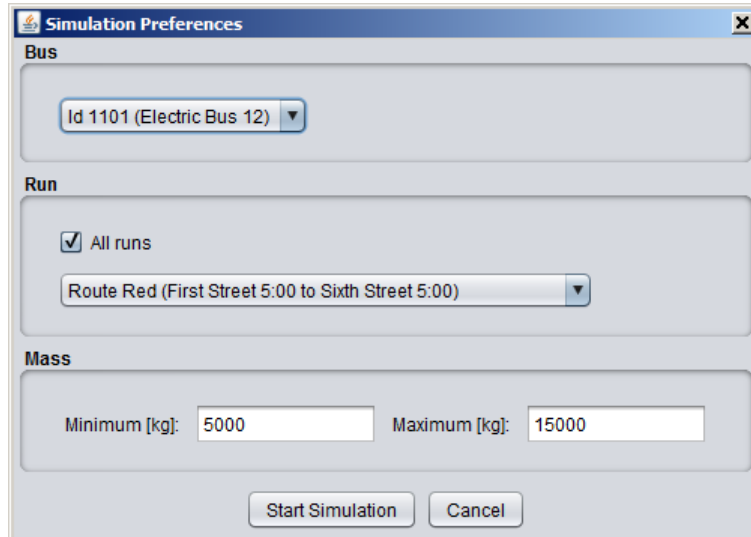
5.3.1 Objective

The objective is to find out the influence of the mass on the energy consumption. For this, several simulation runs are performed while the mass is varied.

In order to run this simulation variant select Simulation | All busses for one day from the menu or press STRG+N. The following dialog window opens:

5.3.2 Input

Select the bus to be simulated from the combo box. Select the run of the bus to be simulated or select the checkbox `All runs` if all runs of the bus should be simulated. Select the minimum and the maximum outside temperature in °C. Start the simulation by clicking the button `Start Simulation`.



The image shows a dialog box titled "Simulation Preferences" with a close button (X) in the top right corner. The dialog is divided into three sections: "Bus", "Run", and "Mass".

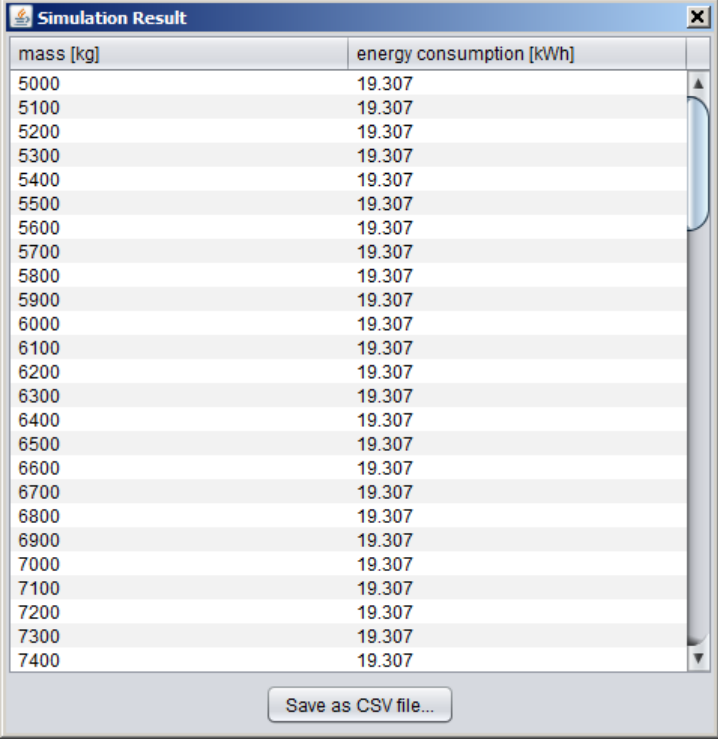
- Bus:** A dropdown menu is set to "Id 1101 (Electric Bus 12)".
- Run:** A checkbox labeled "All runs" is checked. Below it, a dropdown menu is set to "Route Red (First Street 5:00 to Sixth Street 5:00)".
- Mass:** Two input fields are present: "Minimum [kg]" with the value "5000" and "Maximum [kg]" with the value "15000".

At the bottom of the dialog, there are two buttons: "Start Simulation" and "Cancel".

A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.3.3 Result

The result window shows the result of each simulation run. The left column shows the mass in kg and the right column shows the energy consumption in kWh.



The screenshot shows a dialog window titled "Simulation Result" with a close button (X) in the top right corner. The window contains a table with two columns: "mass [kg]" and "energy consumption [kWh]". The table lists mass values from 5000 to 7400 in increments of 100, with a corresponding energy consumption of 19.307 kWh for each. A "Save as CSV file..." button is located at the bottom center of the dialog.

mass [kg]	energy consumption [kWh]
5000	19.307
5100	19.307
5200	19.307
5300	19.307
5400	19.307
5500	19.307
5600	19.307
5700	19.307
5800	19.307
5900	19.307
6000	19.307
6100	19.307
6200	19.307
6300	19.307
6400	19.307
6500	19.307
6600	19.307
6700	19.307
6800	19.307
6900	19.307
7000	19.307
7100	19.307
7200	19.307
7300	19.307
7400	19.307

The result can be written into a CSV file for further processing using other tools.

5.4 Influence of speed profile

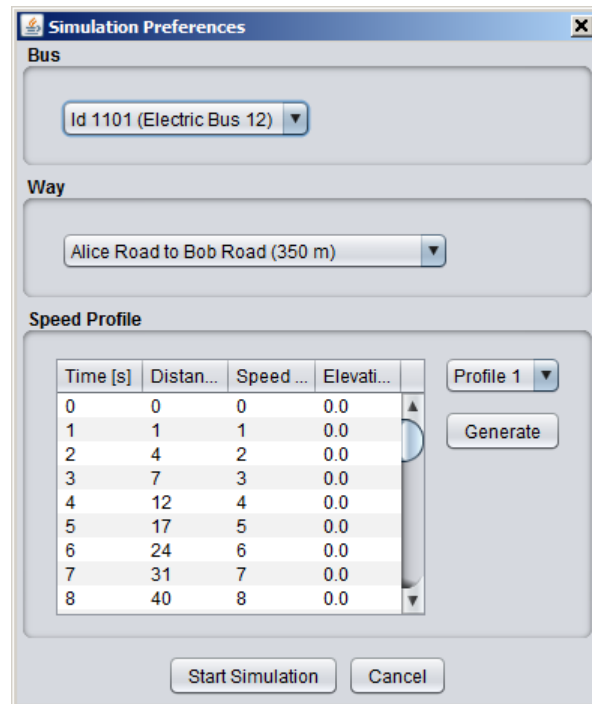
5.4.1 Objective

The objective is to find out the influence of the speed profile on the energy consumption. For this, several simulation runs are performed while the speed profile is varied.

In order to run this simulation variant select `Simulation | Influence of Speed Profile` from the menu or press `STRG+S`. A dialog window for setting the simulation preferences appears.

5.4.2 Input

Select the bus to be simulated from the combo box. Select the way from the combo box. Select the speed profile or generate a new one by clicking the `Generate` button. Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.4.3 Result

The result window shows the energy consumption of the simulated speed profile.

5.5 Influence of elevation profile

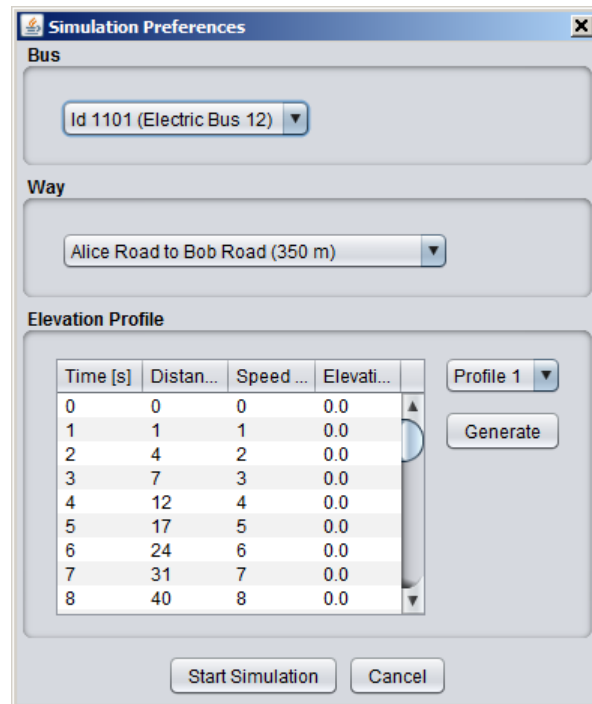
5.5.1 Objective

The objective is to find out the influence of the elevation profile on the energy consumption. For this, several simulation runs are performed while the elevation profile is varied.

In order to run this simulation variant select `Simulation | Influence of Elevation Profile` from the menu or press `STRG+H`. A dialog window for setting the simulation preferences appears.

5.5.2 Input

Select the bus to be simulated from the combo box. Select the way from the combo box. Select the height profile from the combo box or generate a new one by clicking the `Generate` button. Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.5.3 Result

The result window shows the energy consumption of the just simulated speed profile.

5.6 Influence of the outside temperature

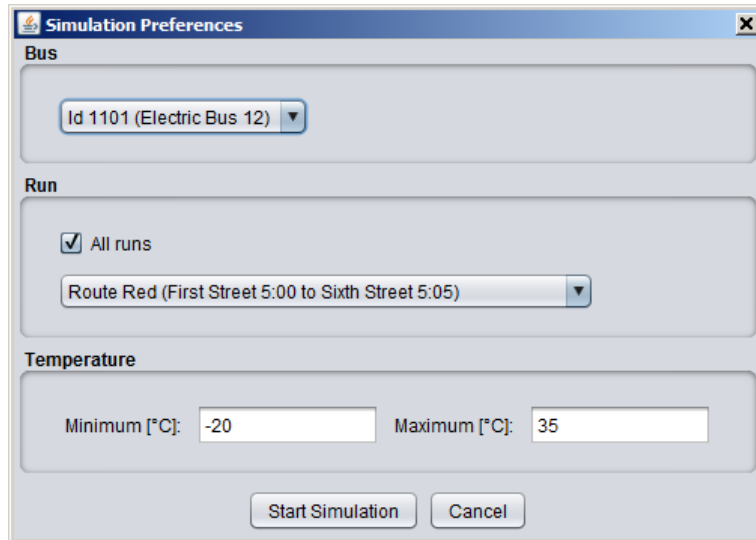
5.6.1 Objective

The objective is to find out the influence of the outside temperature on the energy consumption. For this, several simulation runs are performed while the outside temperature is varied.

In order to run this simulation variant select `Simulation | Influence of the Outside Temperature` from the menu or press `STRG+T`. The following dialog window opens:

5.6.2 Input

Select the bus to be simulated from the combo box. Select the run of the bus to be simulated or select the checkbox `All runs` if all runs of the bus should be simulated. Select the minimum and the maximum outside temperature in °C. Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.6.3 Result

The result window shows the result of each simulation run. The left column shows the outside temperature in °C and the right column shows the energy consumption in kWh.

temperature [°C]	energy consumption [kWh]
-20	105.24
-19	105.008
-18	105.007
-17	105.008
-16	105.005
-15	105.009
-14	105.008
-13	105.012
-12	105.007
-11	105.01
-10	105.01
-9	105.012
-8	105.009
-7	105.011
-6	105.01
-5	105.01
-4	105.012
-3	105.012
-2	105.014
-1	105.012
0	105.013
1	105.011
2	105.012
3	105.016
4	105.015

The result can be written into a CSV file for further processing using other tools.

5.7 Influence of energy recovery

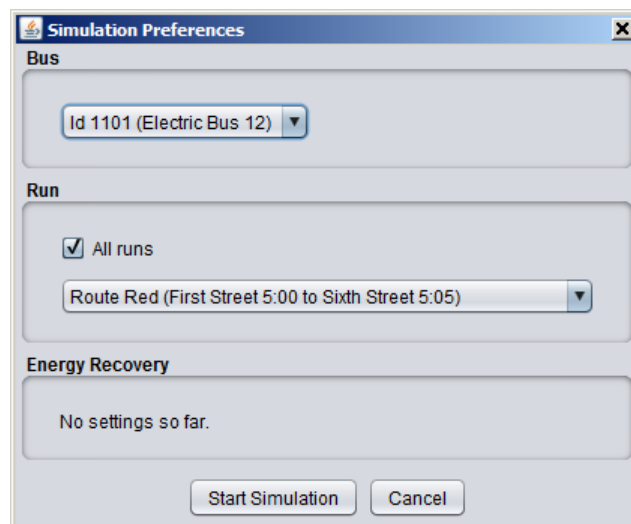
5.7.1 Objective

The objective is to find out the influence of energy recovery on the battery charging level and on the energy consumption. For this, two simulation runs are performed: one with energy recovery and one without.

In order to run this simulation variant select `Simulation | Influence of Energy Recovery` from the menu or press `STRG+E`. The following dialog window opens:

5.7.2 Input and progress

Select the bus to be simulated from the combo box. Select the run of the bus to be simulated or select the checkbox `All runs` if all runs of the bus should be simulated. The outside temperature is fixed at 20 °C. Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.7.3 Result

The result window shows the result of each simulation run. The left column shows whether energy recovery is used or not. The right column shows the minimum charging level reached during the simulation. The result can be written into a CSV file for further processing using other tools.

5.8 Minimize battery capacity

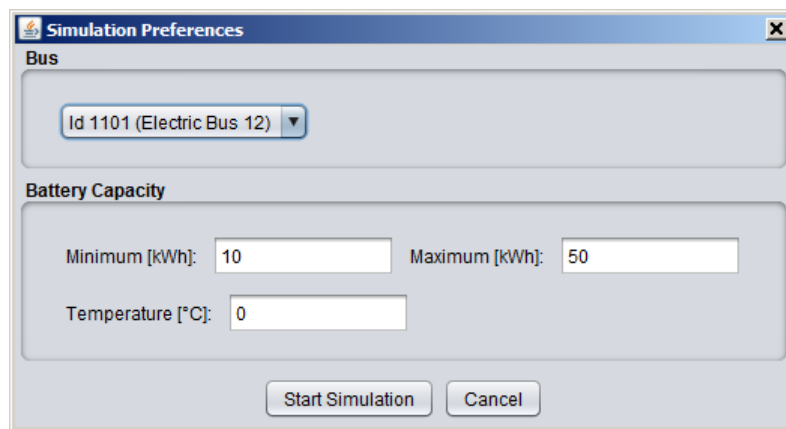
5.8.1 Objective

The objective is to find out the lowest possible battery capacity for a certain bus. This means, the battery capacity is big enough for not to run in an empty battery fault. For this, several simulation runs are performed while the battery capacity is varied.

In order to run this simulation variant select `Simulation | Minimize Battery Capacity` from the menu or press `STRG+B`. A dialog window for entering further preferences opens.

5.8.2 Input and progress

Select the bus to be simulated from the combo box. Enter the minimum and the maximum battery capacity in kWh. Enter the outside temperature in °C. Start the simulation by clicking the button `Start Simulation`.



A progress window appears showing the simulation progress. When the simulation is finished, the simulation progress window closes and a result window appears.

5.8.3 Result

The result window shows the result of each simulation run. The left column shows the battery capacity and the right column shows the minimum charging level reached during the simulation.

capacity [kWh]	minimum charging level
10	0.13071744277754335
11	0.13071744277754335
12	0.13071744277754335
13	0.13071744277754335
14	0.13071744277754335
15	0.13071744277754335
16	0.13071744277754335
17	0.13071744277754335
18	0.13071744277754335
19	0.13071744277754335
20	0.13071744277754335
21	0.13071744277754335
22	0.13071744277754335
23	0.13071744277754335
24	0.13071744277754335
25	0.13071744277754335
26	0.13071744277754335
27	0.13071744277754335
28	0.13071744277754335
29	0.13071744277754335
30	0.13071744277754335
31	0.13071744277754335
32	0.13071744277754335
33	0.13071744277754335
34	0.13071744277754335

The result can be written into a CSV file for further processing using other tools.

6 Input files

There are several input files required by the CACTUS tool.

All files contain a header. This is the enclosing tag `<CACTUS>`. The second row is the format. The attribute name is always CACTUS. The subname is {Network | Timetable | Operation | Infrastructure | Economy | Ecology} is equal to the name of the file. The type is {input | output}. At last the version. The third row contains the name and the abbreviation of the public transport company.

```
<CACTUS>
  <Format name="CACTUS" subname="Network" type="input" version="1.0" />
  <Company name="" short="" />
```

6.1 Network.xml

This file contains all the bus stops and all the ways between them.

6.1.1 Stops

All stops are enclosed in the `<Stops>` tag. A stop has an id and a name. The definition of latitude and longitude is optional.

```
<Stop id="1" name="Alice Road" latitude="" longitude="" />
```

Stops must not be real bus stops. Depots and charging points for instance are also modelled as stops.

6.1.2 Ways

A way is a direct connection between two stops. The attribute from contains the id of the stop at which the way starts. The attribute to contains the id of the stop at which the way ends. The attribute distance contains the length of the way in [m]. The attribute comment only shows the names of the connecting stops.

```
<Way from="2" to="3" comment="Ant Street -> Bear Street" distance="350">
```

All ways are enclosed in the `<Ways>` tag.

A way must have at least one profile. A profile represents for each second of the run on the way the time [s], the latitude and the longitude, the elevation [m], the speed [km/h] and the distance [m]. The distance on a way always starts at 0.

```
<Profile>
  <Entry time="0" latitude="52.111751" longitude="11.632158" elevation="45"
  speed="0" distance="0" />
  <Entry time="1" latitude="52.111744" longitude="11.632149" elevation="46"
  speed="1" distance="0" />
  <Entry time="2" latitude="52.111738" longitude="11.632147" elevation="45"
  speed="2" distance="0" />
```

6.1.3 TransitWays

TransitWays are special ways. They connect stops without having passengers. Those are runs from and to the depot.

All ways are enclosed in the <TransitWays> tag. They have the same structure as normal ways.

```
<TransitWay from="22" to="1" comment="Second Street -> Alice Road" distance="5000">
```

Each transitway should also have a profile.

6.2 Timetable.xml

This file contains all the runs of the busses. Here is a sample of a run. The stops refer to the definitions in the Network.xml file.

```
<Run id="1" route="Green" vehicleType="Bus">
  <Stop id="2" name="Ant Street" arrival="" departure="5:51"/>
  <Stop id="3" name="Bear Street" arrival="5:52" departure="5:52"/>
  <Stop id="8" name="Duck Street" arrival="5:53" departure="5:53"/>
  <Stop id="15" name="Fourth Street" arrival="5:54" departure="5:54"/>
  <Stop id="18" name="Goose Street" arrival="5:55" departure="5:55"/>
  <Stop id="9" name="Elefant Street" arrival="5:56" departure="5:56"/>
  <Stop id="17" name="Frog Street" arrival="5:57" departure="5:57"/>
  <Stop id="13" name="Fish Street" arrival="5:58" departure="5:58"/>
  <Stop id="16" name="Fox Street" arrival="5:59" departure="5:59"/>
  <Stop id="14" name="Flamingo Street" arrival="6:00" departure=""/>
</Run>
```

Each run has an id, a route number and a vehicle type. Each stop within a run refers to the stop defined in the Network.xml file by its id and name. The attribute arrival contains the arrival time at the stop in the form 'hh:mm'. The attribute departure contains the departure time from the stop in the form 'hh:mm'.

6.3 Operation.xml

This file contains definitions of energy storage types, energy transmission types and bus types as well as busses and their runs. Each type has at least an id and a name.

Energy storage types, energy transmission types and bus types are described by key value pairs. Here each pair is described by the tag <Property> with the attributes key and unit. The value of <Property> is the value. This generic variant has been chosen because it is easier to add information and to display them in the tool. A set of properties can be encapsulated in a so-called category (tag <Category>) whose only attribute is the name.

6.3.1 Energy storage types

Energy storage types are meant to be in the bus or in exchanging points. Examples for energy storage types are lithium ion batteries with different chemical compositions, ultra-capacitors or flywheels.

```
<EnergyStorageType id="1" name="Battery">
  <Category name="General">
    <Property key="Chemical Composition">Lithium Iron Phos-
phate</Property> <!-- Lithium-Polymer, Lithiumtitanat, Lithium-Mangan,
Lithium-Luft -->
    <Property key="Manufacturer">unknown</Property>
    <Property key="Model">unknown</Property>
    <Property key="URL">unknown</Property>
  </Category>
  <Category name="Operation">
    <Property key="Voltage" unit="V">600</Property>
    <Property key="Power" unit="kW">160</Property>
    <Property key="Efficiency" unit="%">90</Property>
  </Category>
  <Category name="Charging">
    <Property key="Charging Power" unit="kW">3.3</Property>
    <Property key="Charging Time" unit="h">8</Property>
    <Property key="Charging Efficiency"
unit="%">90</Property>
    <Property key="Minimum Charging Level"
unit="%">30</Property>
  </Category>
  <Category name="Auxiliary">
    <Property key="Aging Factor" unit="year">1.0</Property>
    <Property key="Exchangeable">yes</Property>
  </Category>
</EnergyStorageType>
```

Some properties are optional. They only have an informal character. Some values are mandatory. They are used within the simulation. These mandatory properties are the Charging Power, Charging Time, Charging Efficiency and the Minimum Charging Level.

6.3.2 Energy transmission type

An energy transmission type describes the how the energy is transferred to the bus. Examples are inductive energy transmission, energy transmission via cable and battery exchanging point.

```
<EnergyTransmissionType id="101" name="Inductive">
  <Category name="General">
    <Property key="Manufacturer">unknown</Property>
    <Property key="Model">unknown</Property>
    <Property key="Transmission Type">Inductive</Property>
    <Property key="Power" unit="kW">200</Property>
  </Category>
</EnergyTransmissionType>
```

```
<Property key="Efficiency" unit="%">90</Property>
<Property key="Connection Time" unit="s">0</Property>
<Property key="Disconnection Time" unit="s">0</Property>
</Category>
</EnergyTransmissionType>
```

Mandatory properties of energy transmission types are Power and Efficiency.

6.3.3 Bus type

The sense of bus types is obviously. Every bus type is a type of a pure electric bus.

```
<BusType id="201" name="Electric Bus 12">
  <Category name="General">
    <Property key="Manufacturer">unknown</Property>
    <Property key="Country">unknown</Property>
    <Property key="Model"> electric</Property>
    <Property key="Length" unit="m">12</Property>
    <Property key="Seats">34</Property>
    <Property key="Standing Places">unknown</Property>
  </Category>
  <Category name="Technical Data">
    <Property key="Mass" unit="kg">12000</Property>
    <Property key="Range" unit="km">150</Property>
    <Property key="Engine Efficiency" unit="%">99</Property>
    <Property key="Energy Recovery While Braking"
unit="%">99</Property>
  </Category>
  <Category name="Driving">
    <Property key="Acceleration" unit="m/s2">1.0</Property>
    <Property key="Deceleration" unit="m/s2">1.0</Property>
    <Property key="Maximum Speed" unit="m/s">13.89</Property>
  </Category>
  <Inventory>
    <Device name="Ticket Machine" power="250" unit="W"/>
    <Device name="Lights" power="500" unit="W"/>
    <AirCondition>
      <Power temperature="-20" unit="W">8000</Power>
      <Power temperature="-10" unit="W">7000</Power>
      <Power temperature="0" unit="W">6000</Power>
      <Power temperature="10" unit="W">4000</Power>
      <Power temperature="20" unit="W">0</Power>
      <Power temperature="30" unit="W">4000</Power>
      <Power temperature="35" unit="W">8000</Power>
    </AirCondition>
  </Inventory>
</BusType>
```

Mandatory properties are Mass, Engine Efficiency, Seats and Standing Places, Acceleration, Deceleration, Maximum Speed, and Inventory. The tag AirCondition within Inventory describes the energy consumption of the air condition (heating and cooling) depending on the outside temperature.

6.3.4 Bus

A bus is an instance of a bus type. It has an id. The attribute type contains the id of the bus type. The attribute nameOfType contains the name of the bus type.

```
<Bus id="1101" type="201" nameOfType="Electric Bus 12">
  <EnergyStorage id="1002" type="2" nameOfType="Ultracapacitor" capaci-
ty="0.325" unit="kWh"/>
  <EnergyStorage id="1001" type="1" nameOfType="Battery" capacity="150.0"
unit="kWh"/>
  <Sequence>
    <Run id="47" comment="First Street -> Sixth Street (5:00 ->
5:05)"/>
    <Transit from="23" to="12"/>
    <Run id="1" comment="Ant Street -> Flamingo Street (5:51 ->
6:00)"/>
  </Sequence>
</Bus>
```

6.4 Network_Energy.xml

This file is a temporary file only. It is generated by the CACTUS tool using the files Network.xml and Operation.xml. From the file Operation.xml the bus type definitions are taken. The file Network_Energy.xml works as input for the optimization of the charging infrastructure.

The difference to the Network.xml file is the energy consumption which is given for each way and bus type. The value represents the energy consumption for the related bus type on the related way.

```
<Way from="16" to="14" comment="Fox Street -> Flamingo Street" dis-
tance="350">
  <EnergyConsumption>
    <BusType id="201" name="Electric Bus 12" value="0.013" unit="kWh"/>
    <BusType id="202" name="Electric Bus 8.9" value="0.008"
unit="kWh"/>
  </EnergyConsumption>
</Way>
```

6.5 Infrastructure.xml

This file contains the charging points, charging tracks and exchanging points calculated by the optimization component. This file is generated by the optimisation.

Charging tracks are enclosed in the tag <PowerRails>. Each way is described by the attributes from and to which are the ids of the corresponding stops and the length of the electrified track.

```
<PowerRails>
  <Way from="0056" to="0075" power="0132" unit="m" comment="(100.00%
out of 132m)"/>
</PowerRails>
```

Charging points are enclosed in the tag <PowerStops>. Each stop contains the id of the corresponding stop as defined in the Network.xml file.

```
<PowerStops>
  <Stop id="058" power="0010" unit="kW"/>
```

Exchanging points are enclosed in the tag <ExchangingStops>. Each stop contains the id of the corresponding stop as defined in the Network.xml file.

```
<ExchangingStops>
  <Stop id="057" power="0010" unit="kW"/>
```

Each infrastructure element must be bind to an energy transmission type as defined in the Operation.xml file.

6.6 Economy.xml

The file contains definitions of different types of costs: acquisition costs, operating costs, infrastructure costs, and external costs which are enclosed in tag <CostType>. Extended properties for energy storage types referring to economical aspect of the project are enclosed in <EnergyStorageType>

6.6.1 Acquisition costs

General acquisition costs are the costs of the bus fleet: bus costs itself and the costs double-layer capacitor taking into account subsidies and external finance rate. Units for costs are Euro (EUR), which will be later converted into Polish Zloty (PLN).

```
  <Category name="General Costs">
    <Property key="Bus Cost" unit="EUR" variable="KN_bus">2.17</Property>
    <Property key="Double-layer Capacitor Cost" unit="EUR" variable="K_kond">0</Property>
    <Property key="Subsidies For Bus" unit="EUR" variable="DA">1.302</Property>
    <Property key="External Finance Rate" variable="u_kred_A">0.5</Property>
  </Category>
```

Category “annuity costs” refers to financial conditions of investment in electric buses. Credit period, loan interest rate, market interest rate and repayment terms are taken into account.

```
<Category name="Annuity Costs">
  <Property key="Credit Period" unit="year" variable="N">5</Property>
  <Property key="Loan Interest Rate" variable="s">0.07</Property>
  <Property key="Market Interest Rate" variable="i">0.02</Property>
  <Property key="Repayment Term" unit="year" variable="M">5</Property>
</Category>
```

6.6.2 Operating costs

Energy costs, such as energy consumption or costs rate energy are the subject of the Economy.xml. Different types of propulsion extort different units: [kWh/km], [EUR/kWh] for e-buses, [l/km], [EUR/l] for diesel buses (for petrol and AdBlue). Annual operational use is taken into account.

```
<Category name="Energy Costs" unit="EUR" variable="KO_en">
  <Property key="Energy Consumption" unit="[kWh/km]/[l/km]" variable="Z_en">2</Property>
  <Property key="Cost Rate Energy" unit="[EUR/kWh]/[EUR/l]" variable="k_en">3</Property>
  <Property key="Tax Relief" unit="EUR/l" variable="r_en">2</Property>
  <Property key="Cost Rate AdBlue" unit="EUR/l," variable="k_en_AdB">4</Property>
  <Property key="Consumption AdBlue" unit="l/km" variable="Z_en_AdB">3</Property>
  <Property key="Operational Use" unit="km/year" variable="PE">5</Property>
</Category>
```

Costs of maintenance are the subject of category „Maintenance Costs“. These costs depend on the size of the fleet (number of buses), additional equipment, age of the fleet, etc.

```
<Category name="Maintenance Costs" variable="KO_en">
  <Property key="Average Annual Operational Use" unit="km/year" variable="pe_sr">2</Property>
  <Property key="Additional m-Type Bus Equipment Cost" unit="EUR" variable="w_kdw_m">2</Property>
  <Property key="Number Of Buses" unit="" variable="L_a">1</Property>
  <Property key="Additional Bus Equipment Type" unit="" variable="m">2</Property>
  <Property key="Number Of Buses With m-Type Equipment" unit="" variable="L_a_dw_m">4</Property>
  <Property key="Staff Index" unit="man-year/vehicle/year" variable="w_pw">3</Property>
  <Property key="Cost Rate Workshop Staff" unit="EUR/man-year" variable="k_pw">3</Property>
  <Property key="Maintenance Costs Independent Of Operational Use" unit="" variable="w_knz">3</Property>
  <Property key="Vehicle Age Factor" unit="" variable="W_w">2</Property>
  <Property key="Weight Of Age Factor" unit="" variable="t_a">3</Property>
  <Property key="Scheduled Speed Factor" unit="" variable="w_v">0</Property>
</Category>
```

Wage costs are in category „Salary“ which contains of bus drivers costs as well as training and maintenance.

```
<Category name="Salary" variable="KO_k">
  <Property key="Bus Driver Costs" unit="EUR/year" variable="K_wyn">3</Property>
  <Property key="Training And Maintenance Costs" unit="EUR/year" variable="K_szk">3</Property>
</Category>
```

Tire costs depend on the schedule speed expressed in [km/h].

```
<Category name="Tire Costs" variable="KO_op">
  <Property key="Scheduled Speed" unit="km/h" variable="V_roz">25</Property>
</Category>
```

These costs which were not assigned to categories presented above are presented in category „Other costs“. The above mentioned are the costs of insurance, costs of supply and costs of vitality of the fleet.

```
<Category name="Other Costs">
  <Property key="Insurance Cost Rate" unit="" variable="k_ubezp">3</Property>
  <Property key="Useful Life Of Bus" unit="Years" variable="T">3</Property>
  <Property key="Bus Age and Type Factor" unit="" variable="W_wt">0</Property>
  <Property key="Daily Supply Cost Rate" unit="EUR/km" variable="k_en_dost">1</Property>
</Category>
```

6.6.3 Infrastructure costs

In category „Battery Swapping Costs" numbers of additional batteries, battery capacity and the costs of the battery capacity are defined.

```
<Category name="Battery Swapping Costs" variable="KI_zm_bat">
  <Property key="Number Of Additional Batteries" unit="" variable="L_bat">1</Property>
  <Property key="Battery capacity" unit="kWh" variable="P_bat">1</Property>
  <Property key="Battery Capacity Cost" unit="EUR/kWh" variable="k_pbat">306000</Property>
</Category>
```

Two types of charging costs are defined which refers to inductive and conductive charging.


```
<Category name="Charging Costs" variable="">
  <Property key="Costs Of Inductive Charging" unit="EUR" variable="KI_lad_ind">75000</Property>
  <Property key="Costs Of Conductive Charging" unit="EUR" variable="KI_lad_przew">210000</Property>
</Category>
```

Maintenance of infrastructure as well as funding of infrastructure costs are „Other costs“.

```
<Category name="Other Costs" variable="">
  <Property key="Subsidies For Infrastructure" unit="EUR" variable="DI">354600</Property>
  <Property key="Annual Conductive Maintenance Costs" unit="EUR/year" variable="KI_u_przew">21000</Property>
  <Property key="Annual Inductive Maintenance Costs" unit="EUR/year" variable="KI_u_ind">7500</Property>
  <Property key="External Finance Rate Infrastructure" unit="" variable="u_kred_i">0.5</Property>
</Category>
```

6.6.4 External costs

Noise and pollution emissions are assigned to the category „External costs“. The unit is [EUR/km].

```
<CostType id="4" name="External Costs" variable="KZ">
  <Category name="General Costs" variable="">
    <Property key="Noise Emission Cost Rate Per Bus" unit="EUR/km" variable="k_halas">3</Property>
    <Property key="Pollutant Cost Rate Per Bus" unit="EUR/km" variable="k_pow">4</Property>
  </Category>
</CostType>
```

6.6.5 Extended properties for energy storage types

Necessary economic values for three types of energy storage (which are the same like in „Operation.xml“) are given in this tag. Costs and lifetime of the battery (and spare battery) as well as the capacity of the battery are important from the view of further calculations in the model.

```
<EnergyStorageType id="1" name="Battery">
  <Category name="Extended Properties">
    <Property key="Capacity" unit="kWh">0</Property>
    <Property key="Cost" unit="EUR">0</Property>
    <Property key="Lifetime" unit="year">10</Property>
    <Property key="Spare Battery Cost" unit="EUR">0.306</Property>
  </Category>
</EnergyStorageType>
<EnergyStorageType id="2" name="Ultracapacitor">
```

```
        <Category name="Extended Properties">
        <Property key="Capacity" unit="kWh">0</Property>
        <Property key="Cost" unit="EUR">0</Property>
        <Property key="Lifetime" unit="year">10</Property>
        <Property key="Spare Battery Cost"
unit="EUR">0.306</Property>
        </Category>
    </EnergyStorageType>
    <EnergyStorageType id="3" name="Flywheel">
    <Category name="Extended Properties">
        <Property key="Capacity" unit="kWh">0</Property>
        <Property key="Cost" unit="EUR">0</Property>
        <Property key="Lifetime" unit="year">10</Property>
        <Property key="Spare Battery Cost"
unit="EUR">0.306</Property>
    </Category>
    </EnergyStorageType>
```

6.7 Ecology.xml

This file contains definitions of energy carriers. Examples for energy carriers are diesel, gas, 100% renewables or the mix of electricity.

From these definitions is calculated how much [kg, l] of an energy carrier is required to generate a certain amount of electrical energy. See section 4.2.3.2 for more information. Furthermore the efficiency of the engine is defined as well as a list of pollutants and how much of them are produced when one unit of the energy carrier is burned.

```
<EnergyCarrier id="2001" name="Diesel">
    <Description></Description>
    <Unit>l</Unit>
    <Efficiency>0.4</Efficiency>
    <EnergyDensity unit="kWh/l">9.7</EnergyDensity>
    <CarbonDioxide abbreviation="CO2" unit="g">1</CarbonDioxide>
    <SulfurDioxide abbreviation="SO2" unit="g">15</SulfurDioxide>
    <NitrogenOxide abbreviation="NOx" unit="ppm">2</NitrogenOxide>
    <SuspendedParticulateMatter abbreviation="SPM"
unit="ppm">3</SuspendedParticulateMatter>
    <DieselParticulates unit="ppm">4</DieselParticulates>
    <Health>Group 1, carcinogen</Health>
</EnergyCarrier>
```

7 References

[1] Information Center for the Application of Electricity (original: Hauptberatungsstelle für Elektrizitätsanwendung e.V.)

[2] Association for the Environment and Nature Protection (original: Bund für Umwelt und Naturschutz – BUND), National Association of North Rhine-Westphalia: Brown coal and climate, http://www.bund-nrw.de/themen_und_projekte/braunkohle/braunkohle_und_umwelt/braunkohle_und_klima/

[3] German Meteorological Service (original: Deutscher Wetterdienst), <http://www.dwd.de/WESTE>