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## **WP 3 – Energy planning – Scenarios selection and simulation D3.3 – Energy demand simulator - Transport sector**

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## Table of Contents

List of abbreviations / Nomenclature .....	4
1 Introduction .....	5
2 General overview of the transport simulation module .....	6
3 Model description .....	8
3.1 Reference and future year energy consumption.....	8
3.2 Hourly relative distributions creation .....	8
3.3 Hourly charging simulation.....	9
4 Simulation results example.....	10
4.1 Relative hourly distributions .....	10
4.2 Electrical vehicle charging hourly distributions .....	12
5 Conclusion .....	13
Annex .....	14



## List of Figures

Figure 1 Electrical transport sector simulation module .....	6
Figure 2 Weekday relative distribution .....	10
Figure 3 Weekend relative distribution .....	10
Figure 4 Week relative distribution .....	11
Figure 5 Weekly seasonality .....	11
Figure 6 Yearly relative distribution .....	12
Figure 7 Electrical vehicles charging distribution .....	12



## List of abbreviations / Nomenclature

Abbreviation	Definition
EV	Electrical vehicle
V2G	Vehicle-to-grid
UNIZAG FSB	University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
RINA-C	RINA Consulting

# 1 Introduction

This document presents second part of the deliverable D3.3 – Energy demand simulator – Transport sector. It consists of two parts: the code which will be integrated in the PLANHEAT simulation module and the accompanying document which discusses the transport simulation model in detail. The deliverable is part of work package WP3 - Energy planning - Scenarios Selection and Simulation. The main objective of this work package is to develop planning and simulation module of the PLANHEAT integrated tool, which will be capable of creating end-user's defined scenarios according to the mapping module outputs. Furthermore these scenarios will be additionally analysed and evaluated on hourly level. Goal of the simulation module is to provide results on technical feasibility of the proposed system. It is important to mention that simulation module will be available only if the end-user decided to map heating and cooling demand on hourly level. For this reason, simulation module also provides hourly result on hourly level for a whole year horizon.

Simulation module consists of three parts: hourly simulation of heating and cooling demand, hourly simulation of heating and cooling supply, and finally, hourly simulation of electrical transport demand. The last part is shown in detail through this document. The main purpose of this submodule is to provide hourly data on electrical vehicle (EV) charging load. This will also give the idea to end-user on the size of available additional storage for electrical energy which could be used through usage of EVs. Cities will be crucial part of the future smart energy systems, which will be capable of integrating power, heating, cooling and transport sector. Important part will be both-way connection between power and transport sector, through so called vehicle-to-grid (V2G) system, which will enable charging and discharging of EVs connected to the power grid in order to provide power balancing. Vehicles could be charged during surplus of electricity and discharged during insufficient power supply. Since PLANHEAT integrated tool is focused on development of heating and cooling sectors, detailed analyses of such a complex interaction won't be possible. PLANHEAT integrated tool will provide the end-user with EV charging distributions which could be used further for more detailed study.

Partner responsible for development of this deliverable is UNIZAG FSB, while integration of the code into QGIS platform will be carried through task T3.5 - Development of planning and simulator modules and validation.

This document is divided into several chapters. In the following one, general overview of the transport simulation module will be shown. In the third chapter, detailed description of the model is displayed, including all equations, assumptions and simplifications. In the fourth chapter, first simulation results are presented and briefly discussed. In the conclusion, future steps have been outlined, while Annex of the document provides the Python code itself.

The draft of the deliverable has been shared with the rest of WP3 partners. The final version has been delivered on time on June 30 2018.

## 2 General overview of the transport simulation module

Electrical transport sector simulation module overview is shown in Figure 1. The whole process could be divided in several steps. In the beginning, end-user has to define characteristics of the current state of the transport sector, usually based on fossil fuels, i.e. gasoline or diesel. It is important to notice that only personal vehicles are taken into account in the PLANHEAT simulation module. End-user has to define: yearly fossil fuel consumption, number of fossil fuel vehicles, fuel type, number of kilometres per vehicle, specific consumption, fuel heating value and specific emissions. In the next step, end-user has to define characteristics of the future year, where integration of electrical vehicles is planned. End-user should provide data on total numbers of electrical vehicles (or share), specific electrical energy consumption (kWh/km), battery capacity and specific emissions of the national power sector. After these first two steps of input are completed, total fossil fuel consumption for reference year and electricity consumption, including the additional electricity storage capacity, for the future scenario can be calculated.

In order to create hourly charging simulation, relative electrical vehicle charging distribution has to be created. End-user could easily choose one of the already existing relative hourly charging distributions. Furthermore, end-user could also create their own set of hourly distributions by using guidelines which will be defined and integrated in the PLANHEAT simulation module. Once the distributions are defined, end-users can simulate hourly charging of electrical personal vehicles. Additionally, they can analyse the hourly availability of additional electricity storage in a shape of personal vehicles' batteries.

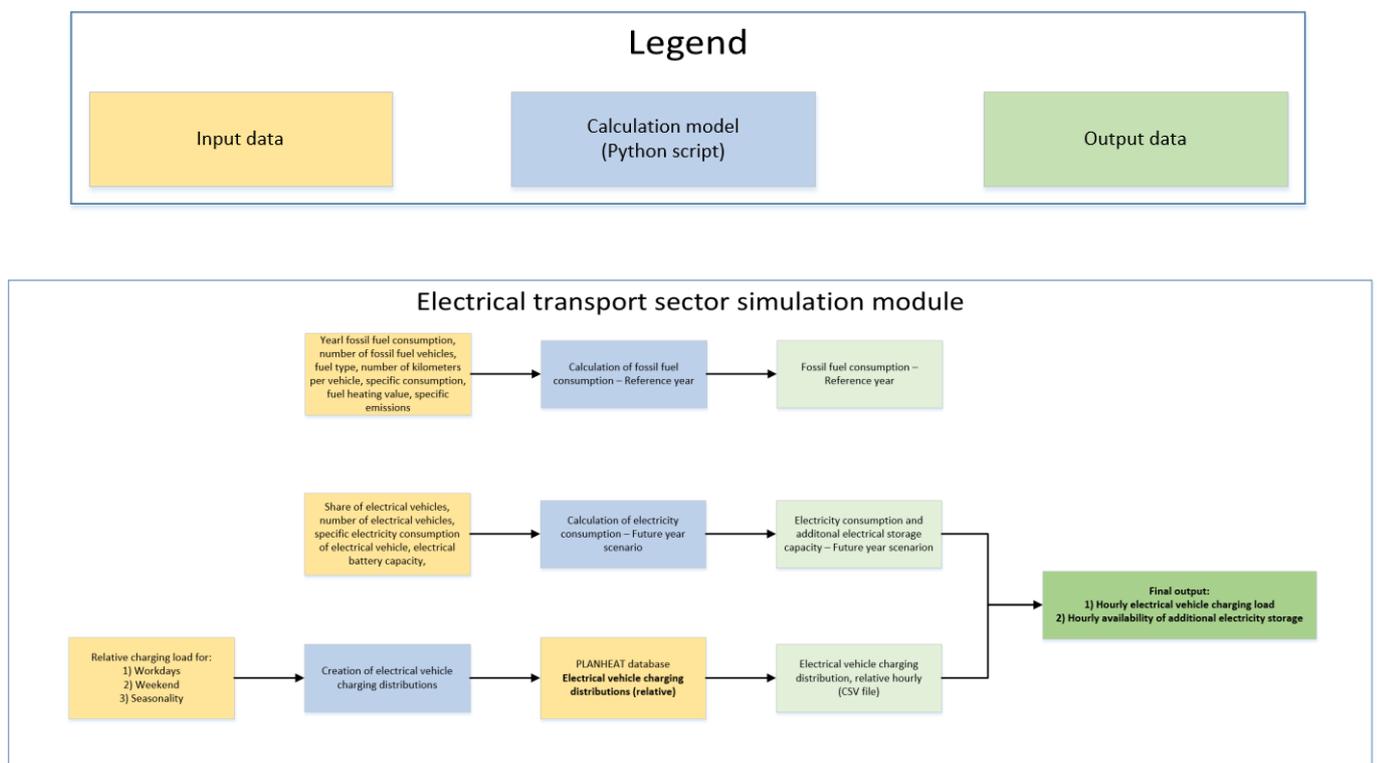


Figure 1 Electrical transport sector simulation module



Due to the fact that PLANHEAT integrated tool will be open-source and free, commercial tools aren't available for development of this module. Furthermore, PLANHEAT integrated tool will be developed in the QGIS platform which is partially written in the Python. Because of that, code for transport sector simulation module is also written in Python by using Numpy package which allows relatively simple handling of large amount of structured data, such as array, since distributions have 8760 hourly values, i.e. the simulation is carried for every hour of the year. The code is shown in the Annex of this document. It is additionally delivered in the file form as a second part of this deliverable.

### 3 Model description

#### 3.1 Reference and future year energy consumption

In order to acquire reference year energy consumption related to the fossil fuelled personal vehicles, Equation (1) should be used.

$$Q_{fossil,i} = D_{yearly,i} \cdot c_{fossil,i} \quad (1)$$

Where  $Q_{fossil,i}$  is yearly final energy consumption for reference year [Wh] calculated by using yearly overall distance of all personal vehicles  $D_{yearly,i}$  [km] and specific consumption  $c_{fossil,i}$  [kWh/km]. Furthermore,  $i$  represents personal vehicle type, which could be diesel or gasoline.  $D_{yearly,i}$  is calculated by using end-user's data on number of personal vehicles and average daily/yearly travelled distance.  $c_{fossil,i}$  is obtained by using technical data such as average consumption of the vehicle and fuel calorific value.

Once reference year energy consumption, end-user can define future year final energy consumption for electrical vehicles in the similar manner, by using Equation (2).

$$Q_{EV} = D_{yearly,EV} \cdot c_{EV \text{ consumption}} \quad (2)$$

Where  $Q_{EV}$  is final yearly electrical energy consumption of electrical vehicles [Wh], which is calculated by using yearly travelled distance  $D_{yearly,EV}$  [km] and specific consumption  $c_{EV \text{ consumption}}$  [kWh/km]. Total travelled distance is acquired by using share of EV in the future personal vehicles fleet and average yearly distance per vehicle.

#### 3.2 Hourly relative distributions creation

Creation of hourly relative distributions can be done in three simple steps:

- 1) Define workday relative charging distribution
- 2) Define weekend relative charging distribution
- 3) Define weekly seasonality for a whole year

Workday relative charging distribution is constituted of 24 values which represent relative charging demand for each hour in a day. This distribution is repeated five times, i.e. for every workday in the week. It is important to notice that these values are in range from 0 to 1. Weekend relative charging distribution could be different or same as workday relative distribution. It is repeated 2 times, for every day of the weekend. These two distributions are merged and define a typical week in the year. If the end-user is aware of transport seasonality effect in the city, i.e. that during summer months people tend to use cars more often, they can create weekly seasonality. It includes 53 values for every week in the year. These values multiply general week of the year and can increase or decrease charging load in different seasons of the year. Once all of the inputs are defined, hourly relative distribution curve could be created. It has 8760 values, i.e. for every hour in the year.

### 3.3 Hourly charging simulation

Once the total yearly final energy consumption of electrical vehicles is known, i.e.  $Q_{EV}$ , including the hourly relative distribution curve  $EV_{rel\ charge,t}$  [-], hourly charging simulation could be carried out by using Equation (3).

$$EV_{charging_t} = \frac{Q_{EV} \cdot \frac{EV_{rel\ charge,t}}{\sum_{t=1}^{t=8760} EV_{rel\ charge,t}}}{\sum_{t=1}^{t=8760} EV_{rel\ charge,t}} \quad (3)$$

Where  $EV_{charging_t}$  represents hourly absolute charging distribution [W].

## 4 Simulation results example

### 4.1 Relative hourly distributions

In this section, first results of the transport sector demand simulation are presented. In order to calculate EV consumption, generic (“dummy”) data have been used. Furthermore, one of the default charging distributions have been used. Figure 1 shows relative charging distribution for a weekday, i.e. from Monday to Friday. The relative values are in range from zero to one. If relative load is equal to one, it means that all EV are connected and charging, e.g. 2:00 am. In the morning, people are leaving their houses and travelling to work, charging load decreases. In the noon is peak again, since some EV are charging outside their houses. In the afternoon, people are coming back home and in the evening start charging their EVs again. Figure 3 shows similar data but only for weekend days, i.e. Saturday and Sunday. The distribution usually differs from the working day relative charging distribution but if the end-user wants to make it the same, he/she will be able to do it.

Weekday relative distribution

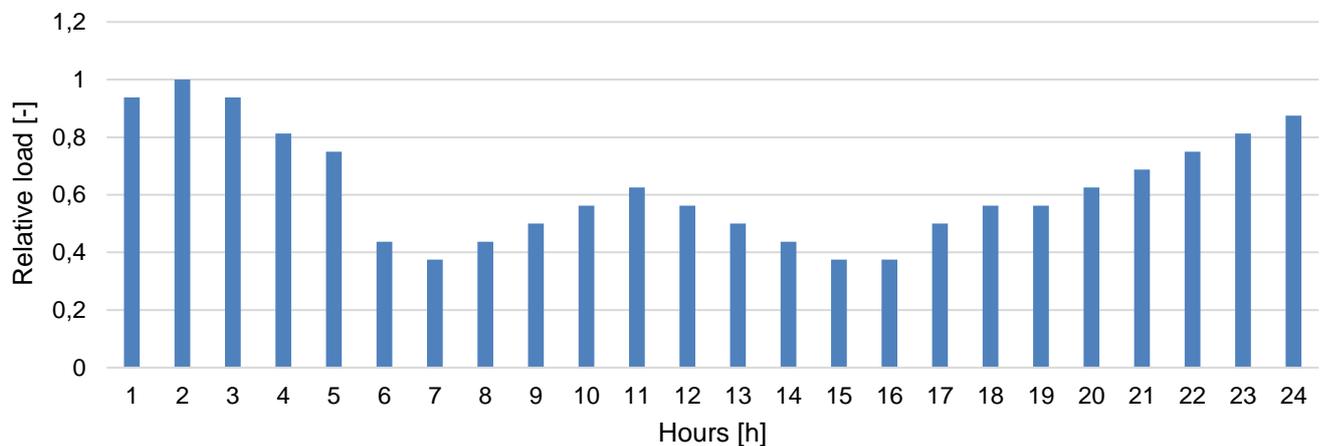


Figure 2 Weekday relative distribution

Weekend relative distribution

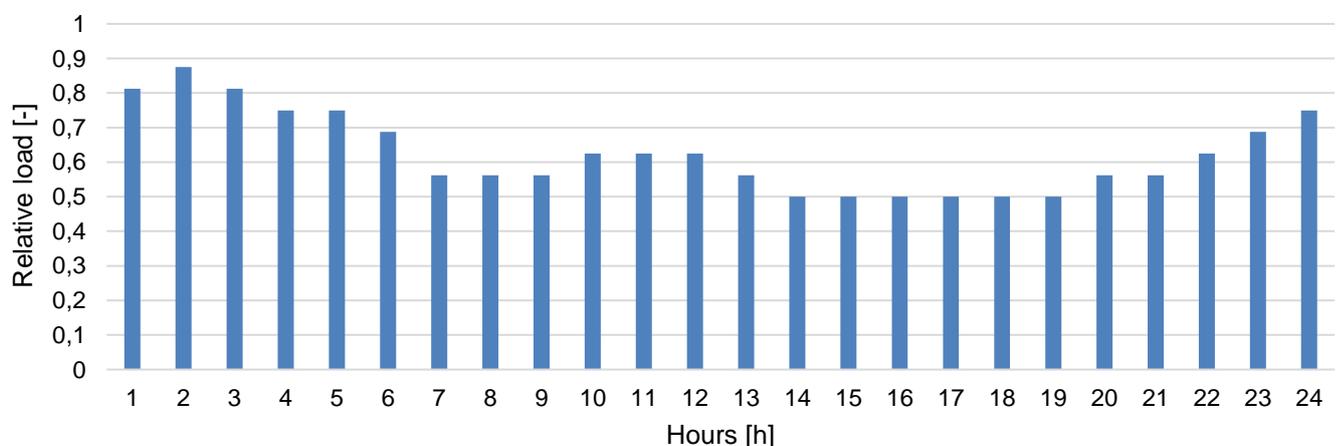


Figure 3 Weekend relative distribution

Once, workday and weekend distributions have been defined, a whole week could be generated. From above shown daily distributions, the relative distributions for a whole week has been created as shown in Figure 4. Sometimes, there is seasonal differences in charging load. If the end-user would like to simulate this, they could use weekly seasonality. The example of weekly seasonality relative distribution is shown in Figure 5. These relative values can be higher than 1. If the value is equal to one, then that week is equal to week relative distribution, as shown in Figure 4.

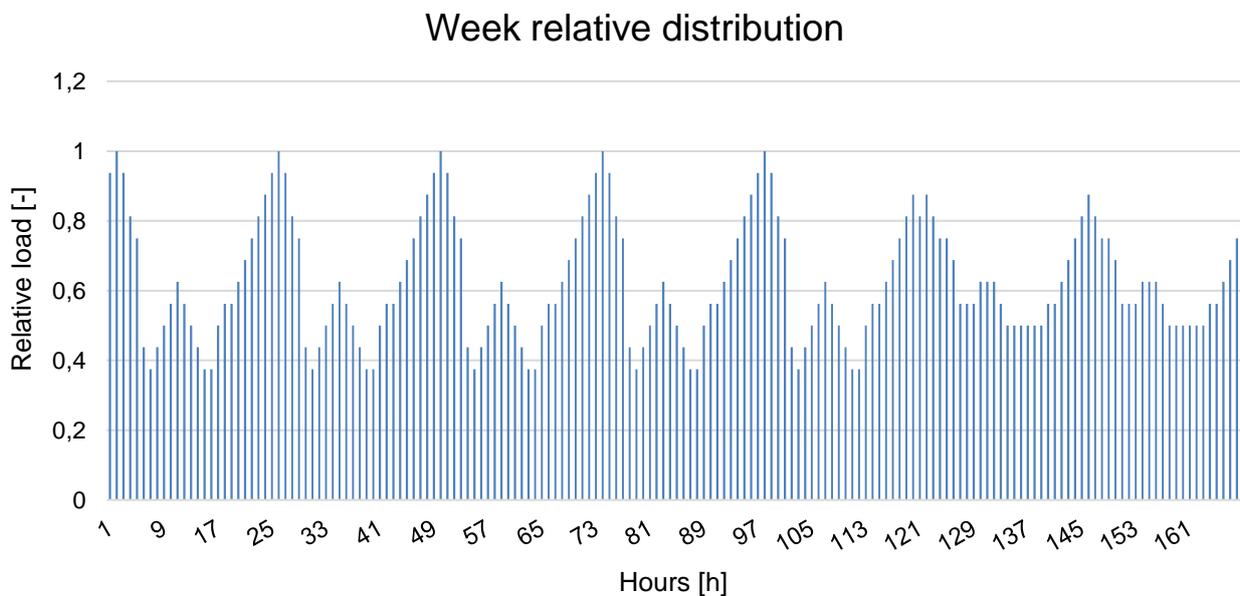


Figure 4 Week relative distribution

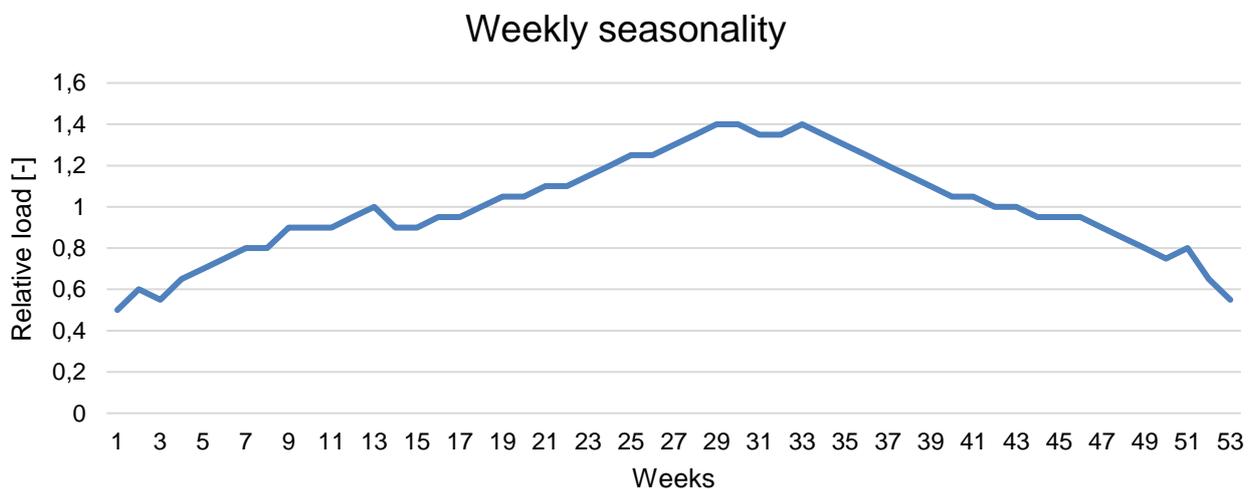


Figure 5 Weekly seasonality

Once week relative distribution and seasonality effect have been defined, these data can be used to develop a charging pattern for a whole year. Yearly relative charging distribution mentioned input data is shown in Figure 6. It could be observed that a shape of the curve is similar to the one shown in Figure 5.

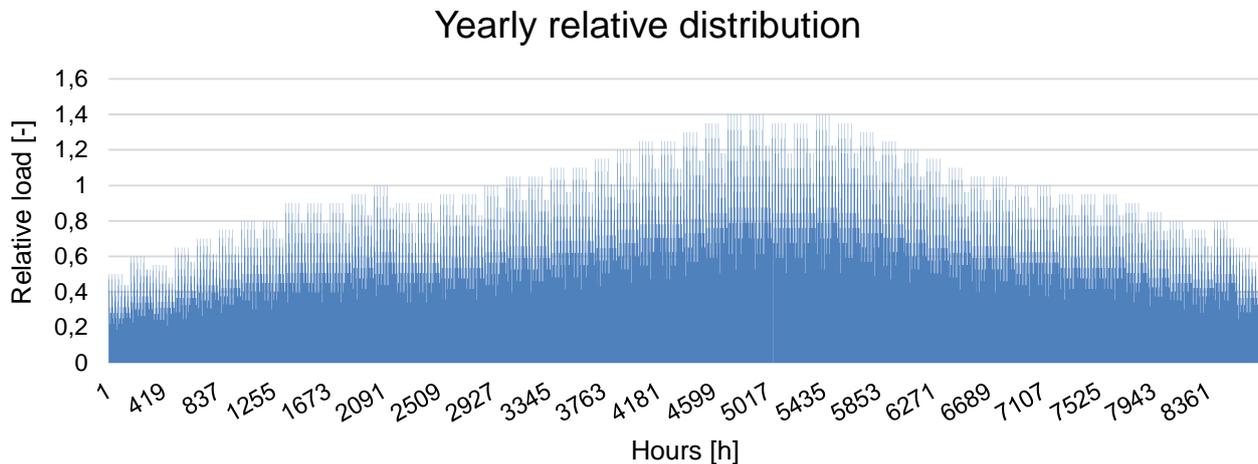


Figure 6 Yearly relative distribution

## 4.2 Electrical vehicle charging hourly distributions

According to the generic data, total yearly electrical energy needed for EV charging is equal to 5.000 MWh. When this value is distributed to 8760 values, according to the yearly relative hourly charging distributions, absolute EV charging load could be acquired, as shown in Figure 7. Peak load is equal to 1,2 MW, obtained during summer months, due to the seasonality effect. Baseload is equal to around 0,2 MW.

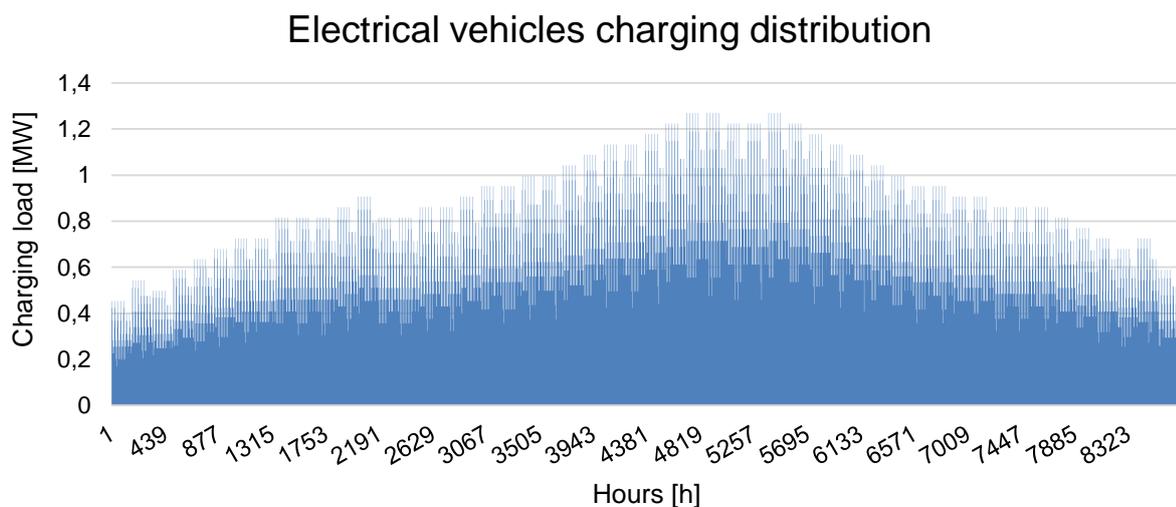


Figure 7 Electrical vehicles charging distribution



## 5 Conclusion

This document presents one part of the D3.3 – Energy demand simulator - Transport sector. Second part is the code which will be used to acquire hourly simulation of the electrical transport demand, i.e. charging pattern. In the document detailed description of the model is shown, including equations, crucial assumptions and simplifications.

The model firstly calculates consumption of the fossil and electrical vehicles in terms of final energy consumption. In the second step, relative charging distribution is created according to the input provided by the end-user: weekday relative distribution and weekend relative charging distribution. These two inputs define a whole week which is repeated in order to acquire 8760 values, i.e. a whole year distribution. Furthermore, end-user could define seasonality effect on weekly level. As the part of the PLANHEAT integrated tool, set of default distributions will be available for the end-user, but they will also be able to develop their own. This data is then used to calculate absolute charging load for a whole year.

Code is written in Python, by using Numpy package which is used for relatively easy handling of large data arrays. The code is shown in the Annex of this document, while the code, including default distributions are also delivered as part of this deliverable.

In the next steps, this code will be integrated in the QGIS platform through task T3.5 - Development of planning and simulator modules and validation.



# Annex



```
import numpy as np
import matplotlib.pyplot as plt
```

```
" Calculation of final energy consumption "
```

```
#Average consumption of gasoline PV [L/100 km]
```

```
cons_avg_gas=7.5
```

```
#Gasoline lower calorific value [kWh/L]
```

```
cal_value_gas=8.89
```

```
#Average energy consumption of gasoline PV [kWh/km]
```

```
en_cons_avg_gas=cons_avg_gas*cal_value_gas/100
```

```
#Average CO2 emissions - gasoline cars [gCO2/km]
```

```
CO2_avg_gas=110
```

```
#Average consumption of diesel PV [L/100 km]
```

```
cons_avg_diesel=6.5
```

```
#Diesel lower calorific value [kWh/L]
```

```
cal_value_diesel=10.83
```

```
#Average energy consumption of diesel PV [kWh/km]
```

```
en_cons_avg_diesel=cons_avg_diesel*cal_value_diesel/100
```

```
#Average CO2 emissions - diesel cars [gCO2/km]
```

```
CO2_avg_diesel=115
```

```
#Number of personal vehicles
```

```
N_PV=50000
```

```
#Gasoline vehicles share
```

```
share_gas=0.7
```

```
#Diesel vehicles share
```

```
share_diesel=0.3
```

```
#Number of gasoline personal vehicles
```

```
N_gas=N_PV*share_gas
```

```
#Number of diesel personal vehicles
```

```
N_diesel=N_PV*share_diesel
```

```
#Estimated daily distance per PV [km/day]
```

```
dist_day=20
```

```
#Estimated yearly distance per PV
```

```
dist_year=dist_day*365
```

```
#Total distance - gasoline PV
```

```
total_distance_gas=dist_year*N_gas
```

```
#Total distance - diesel PV
```

```
total_distance_diesel=dist_year*N_diesel
```

```
#Final energy consumption - gasoline [MWh]
```

```
fin_en_gas=en_cons_avg_gas*total_distance_gas
```

```
#Final energy consumption - diesel [MWh]
```

```
fin_en_diesel=en_cons_avg_diesel*total_distance_diesel
```

```
#CO2 emissions [tonnes CO2]
```

```
total_CO2_fossil=(CO2_avg_gas*total_distance_gas+CO2_avg_diesel*total_distance_diesel)/1000000
```

```
"Electrical vehicles"
```

```
#Share of personal electrical vehicles
```

```

EV_share=0.1
#Number of EVs
N_EV=EV_share*N_PV
#Specific EV energy consumption [Wh/km]
en_cons_avg_EV=220
#Specific CO2 emissions of electricity sector [gCO2/kWh]
power_sector_CO2=276
#Average battery capacity [kWh]
bat_capacity=20
#Average charging/discharging capacity [kW]
EV_capacity=20
#Total electricity consumption [MWh]
fin_en_EV=en_cons_avg_EV*dist_year*N_EV/1000000
#Total CO2 emissions
total_CO2_EV=fin_en_EV*1000*power_sector_CO2/1000000

" input basic distribution data "

hours=np.linspace(1,8760,8760)
hours_24=np.linspace(1,24,24)

base_distribution=np.genfromtxt("transport_electrical_vehicles.txt")

" plot base_distribution data "

plt.figure(1)
plt.plot(hours_24,base_distribution)
plt.xlabel('Hours [h]')
plt.ylabel('Relative demand [-]')
plt.title('Relative transport electric vehicles demand')
plt.show

" weekend and seasonal characteristics input data"
#weekend consumption increase/decrease [-]
weekend=1
#seasonal consumption increase/decrease [-]
winter=1.0
spring=1.0
summer=1.0
autumn=1.0

" weekly distribution creation"

week_1=np.tile(base_distribution,5)
week_2=np.genfromtxt("transport_electrical_vehicles_weekend.txt")
week_2=np.tile(week_2,2)
week=np.concatenate((week_1,week_2),axis=0)

plt.figure(2)
plt.plot(week)
plt.show
plt.xlabel('Hours [h]')

```

```

plt.ylabel('Relative demand [-]')
plt.title('Relative transport electrical vehicles demand')

" yearly distribution creation"

year_1=np.tile(week*winter,11)
year_2=np.tile(week*spring,13)
year_3=np.tile(week*summer,13)
year_4=np.tile(week*autumn,13)
year_5=np.tile(week*winter,2)
year_6=base_distribution*winter

year=np.concatenate((year_1,year_2,year_3,year_4,year_5,year_6),axis=0)
plt.figure(3)
plt.plot(hours,year)
plt.xlabel('Hours [h]')
plt.ylabel('Relative demand [-]')
plt.title('Relative transport electrical vehicles demand')
plt.show

"yearly distribution update with weekly correction"
year_update=np.concatenate((year_1,year_2,year_3,year_4,year_5),axis=0)
year_update=np.reshape(year_update,(52,168))
n=np.genfromtxt("transport_electrical_vehicles_weekly.txt")
#n=np.ones(53)
year_update=year_update*n[:52][:,np.newaxis]
year_update=np.reshape(year_update,(8736,1))
year_6_update=np.reshape(year_6,(24,1))*n[52]
year_update=np.concatenate([year_update,year_6_update])

plt.figure(4)
plt.plot(n)
plt.xlabel('Weeks')
plt.ylabel('Weekly correction [-]')
plt.title('Weekly correction for transport electrical vehicles demand')
plt.show

plt.figure(5)
plt.plot(year_update)
plt.xlabel('Hours [h]')
plt.ylabel('Updated relative demand [-]')
plt.title('Updated relative transport electric vehicles demand')
plt.show

"Hourly distribution of final consumption"
#Total final energy consumption [MWh]
Total_final=fin_en_EV

year_update_sum=np.sum(year_update)

Total_final_distribution=Total_final*(year_update/year_update_sum)

```



```
plt.figure(6)
plt.plot(hours,Total_final_distribution)
plt.xlabel('Hours [h]')
plt.ylabel('Final demand [MW]')
plt.title('Transport electrical vehicles final demand')
plt.show

np.savetxt("Result_Transport_electrical_vehicles.csv",Total_final_distribution, delimiter=".")
```