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DESENT

Smart Decision Support System for Urban Energy and Transportation

DELIVERABLE 8.3

Implementation and evaluation of DESENT

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Changes History

VERSION	DATE	DESCRIPTION	PARTNER
V 0.1	28/02/2019	First contents for Weiz	4ER, WEIZ, RSG, City of Weiz
V 0.2	05/04/2019	Added description of Helmond and ALBATROSS tool	TU/e
V 0.3	29/04/2019	Revised description of Helmond and ALBATROSS tool	TU/e
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Executive Summary

The present document is a deliverable within WP 8 “Implementation and evaluation” of the DESENT project, within the framework of JPI Urban Europe, reporting the results of the activities carried out by the entire consortium.

The purpose of this deliverable is to:

> *Implement and evaluate the proposed integrated models and tools through case studies in three pilot cities, Weiz, Helmond and Steijnker. With the specific goals to serve a wide penetration of new energy development and solutions from different stakeholders and to verify the feasibility of the approaches through implementation and evaluation*

This deliverable sets the focus purely on the implementation of the tools and models and describes in detail the challenges and benefits of the implementation as well es the results from the implementation itself.

The implementation process lead to insight on mobility and electric vehicle charging behaviour for the City of Helmond. For the City of Weiz, the implementation was done to generate results on the Weiz Energy System as well as to verify the functionality of the tools developed and furthermore demonstrate the applicability. In each case special attention is paid to the issues arising while use the tools or preparing their use. This can also be seen as one of the major results, aside of the tools itself.

The main objective of this deliverable is to present the how the tools and models developed in the project DESENT can be implemented in different demonstration cities by presenting use cases for Helmond and Weiz. To create a better understanding of the work necessary the whole process of data preparation and tool implementation is discussed. Additionally, results of the tool implementations are shown as can be seen by the structure of this deliverable:

Section 2: Data preparation for demonstration: Elaborates on the key issues that arose while gathering or trying to gather the data necessary for the implementation of the tools. For a better understanding of data gathering methodologies please refer to Deliverable 8.1.

Section 3: Implementation of Albatross: Describes in detail the results of the application of the Tool Albatross (see Deliverables 2.3 and 3.1) for the City of Helmond.

Section 4: Implementation of the DESENT energy tool box: This section will explain in depth the implementation of the DESENT energy tool box (see Deliverables 4.1, 4.2, 5.1 and 5.2) in the City of Weiz. While the results of the implementation for different use cases and application cases is presented, special attention is also paid to the performance and applicability of the tools and models.

Section 5: Implementation of the mobility energy calculation: Within this section a exemplary calculation of energy consumption bases on GPS tracked trip data is presented.

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1 Introduction and objectives

The project DESENT aims at capturing and displaying the energy situation of urban areas for policy makers and city planners to better understand the energy demand and generation capacities of cities.

The objective of WP8 is to:

> *The main objective of WP8 is to implement and evaluate the proposed integrated models and tools through case studies in three pilot cities, Weiz, Helmond and Steijnker.*

with the detailed objectives:

- *to serve wide penetration of new energy development and solutions from different stakeholders*
- *to verify the feasibility of our approaches through implementation and evaluation*

This deliverable discusses the implementation the DESENT energy tool box and the tool ALBATROSS in the demonstration cities of the DESENT project. The purpose is to not only obtain results from the application of the tools but also gain insight in the necessary steps required to get those tools and models to work and also the challenges arising from it. Special emphasis is also set on the applicability of the tools itself.

Since data availability and quality are two of the main factors for the quality of results obtained by the tools, it was expected that some challenges will occur during the acquisition of these data. This is described in detail in section 2 with focus on the two demonstration cities Weiz and Helmond.

The tool ALBATROSS, which can be used to simulate the mobility behaviour of an entire synthetically generated population was implemented for the city of Helmond, the results being presented in section 3.

The DESENT energy tool box, which consists of multiple different tools for energy system analysis, was tested in the city of Weiz. For the implementation different scenarios for energy system development and uncertainty reduction were investigated. The applicability of the tools alongside the results of the investigation are presented in section 4.

The final tool to be implemented in the demonstration cities is the mobility energy consumption tool, which allows the user to calculate energy consumption resulting from mobility and travel actions. The implementation and results of the tool are shown in section 5.

2 Data preparation for demonstration

2.1 Weiz

Within this chapter, issues during the demonstration phase at the demonstrator in Weiz are discussed.

2.1.1 Mobility data issue

This chapter is about the problems that occured and the solutions that were found during the execution of D 8.3 in DESENT. In chapter 2.1.2 it is pointed out which problems occured during the test phase of the GPS-Dataloggers. 2.1.3 shows the problems arising with the SINTEF app and which solutions were found for those problems. Chapter 2.1.4 and 2.1.5 show the alternative apps that were found and used for the study and which problems we had with those. The Chapters 2.1.6 and 2.1.7 show a short and summarized timetable how the overall process took place. After that a short conclusion is presented. Chapter 2.1.8 shows different manuals which were given out to the probands in Weiz.

2.1.1.1 Issues with the GPS-Loggers

The first idea for executing the study was to use tiny GPS-Loggers which had to be carried around by the probands (see at Figure 1). In addition to that the people had to fill out a mobility diary where they wrote down which vehicle has been used to get from point A to point B.

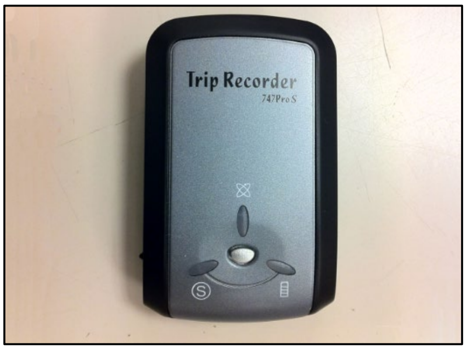

Figure 2-1: GPS-Logger

After testing the GPS-Loggers some serious issues arose. At first, many people didn´t want to provide those sensible data. Although the people which tried to fill out the diary didn´t make it to fill it out seamlessly. So, there were many gaps in the data we gathered this way. The next problem was that the GPS-Loggers needed to be switched on and off from time-to-time. If the Logger had no or bad satellite reception, they made annoying noises. Also, the battery only lasted for about 2,5 Days and the Logger must be recharged. The manual for the appropriate data collection for those GPS-Loggers was about 20 pages and very complicated. People with no or low technical knowledge or people with no access to a PC or Laptop would have serious problems to complete the study. Because of all the mentioned reasons we decided to execute the study via smartphone. The big advantage of this solution is, that the participants didn´t have to carry around the GPS-Logger and don´t have to visit our department every 2-3 Days to recharge the logger and cleaning the limited memory.

2.1.1.2 Sintef – Smiling Earth App Test phase

After Sintef delivered the App .apk File, which was on the 15th of October 2018, a testing phase of the App was started to see if it meets the requirements of the study. The next chapter will give an overview of the problems during the test phase, which solutions SINTEF came up with and which problems couldn´t be solved at all. Those problems resulted in a change of strategy and the app with which the study was executed in the municipality of Weiz. The overall process took about 3 months.

2.1.1.2.1 The .apk File-Problem

To install the App via the external (not via Google Play Store) .apk file was the first problem that occured during the test phase. The app and the installation should be as simple as possible for the end-users. Installing an App via external sources requires lower security standards on the user's mobile phone. In the fist place this causes uncertainty amongst the probands and second, this means more effort to participate in the study. The next problem is, that the "Settings-"menue differs due to different Android versions and smartphone manufacturers. Therefore, composing an appropriate instruction for the app installation is a big challenge. Nevertheless, the App was installed and tested.

2.1.1.2.2 GPS – Tracking and Activity recognition (data quality)

The main functionality of the app should be the GPS – tracking and the automatic activity recognition. Those functions were tested with as many smartphones as possible. Some study participants also tried to use the App. More than 70 % of the tested Smartphones weren´t able to send the tracked data. If the activity recognition "worked" the output data wasn´t correct at all. For example: If you would track your car journey to work with the app, the data indicated that the participant took his bike. The main problem here is, that the GPS module of many smartphones isn´t delivering precise enough data to ensure that the activity recognition works appropriate.

```
Data log:
Time [ms],dd/MM/yyyy hh:mm:ss.SSS,Longitude,Latitude,Speed,AccelerationX,AccelerationY,AccelerationZ,activity
1543322920077,27/11/2018 01:48:40.077,0.0,0.0,0.0,0.0,0.0,0.0,STILL
1543323913073,27/11/2018 02:05:13.073,0.0,0.0,0.0,0.0,0.0,0.0,WALKING
1543323919077,27/11/2018 02:05:19.077,0.0,0.0,0.0,0.0,0.0,0.0,WALKING
1543323925077,27/11/2018 02:05:25.077,0.0,0.0,0.0,0.0,0.0,0.0,WALKING
1543323928614,27/11/2018 02:05:28.614,15.4486452,47.0789964,0.0,0.0,0.0,0.0,WALKING
1543323931078,27/11/2018 02:05:31.078,0.0,0.0,0.0,0.0,0.0,0.0,WALKING
1543323937077,27/11/2018 02:05:37.077,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323939267,27/11/2018 02:05:39.267,15.4487404,47.0790205,0.0,2.5570073,4.2999864,5.535394,WALKING
1543323942540,27/11/2018 02:05:42.540,15.4487133,47.0790246,0.104598,2.8060043,4.7405195,12.181698,WALKING
1543323943077,27/11/2018 02:05:43.077,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323949079,27/11/2018 02:05:49.079,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323959005,27/11/2018 02:05:59.005,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323974076,27/11/2018 02:06:14.076,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323974346,27/11/2018 02:06:14.346,15.4486945,47.0791893,0.0,-0.61291564,-11.549629,-0.17238252,WALKING
1543323978089,27/11/2018 02:06:18.089,15.4487921,47.0792941,0.537305,1.9728222,2.3463178,3.371036,WALKING
1543323980079,27/11/2018 02:06:20.079,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323981956,27/11/2018 02:06:21.956,15.4488999,47.079375,0.545197,2.4420857,3.3997664,12.018892,WALKING
1543323985476,27/11/2018 02:06:25.476,15.4489193,47.0793683,1.144744,1.8579005,2.2888567,15.840038,WALKING
1543323986080,27/11/2018 02:06:26.080,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323992001,27/11/2018 02:06:32.001,15.4489609,47.0793553,0.0,1.7908629,4.012682,14.518439,WALKING
1543323992079,27/11/2018 02:06:32.079,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543323998081,27/11/2018 02:06:38.081,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543324231334,27/11/2018 02:10:31.334,0.0,0.0,0.0,0.0,0.0,0.0,ON_FOOT
1543324778925,27/11/2018 02:19:38.925,15.4480013,47.0811299,0.0,0.18195933,-0.019153614,9.911995,WALKING
1543328751611,27/11/2018 03:25:51.611,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,STILL
1543328757597,27/11/2018 03:25:57.597,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,WALKING
1543328763596,27/11/2018 03:26:03.596,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,WALKING
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1543328775597,27/11/2018 03:26:15.597,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,WALKING
1543328781596,27/11/2018 03:26:21.596,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,WALKING
1543328787597,27/11/2018 03:26:27.597,15.447936538750941,47.08121071939637,0.44128492,0.0,0.0,0.0,WALKING
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Figure 2-2: Screenshot – Data structure Smiling Earth Logfile

Figure 2-2 shows the data structure of a successfully exported logfile. The last column named "activity" shows constantly "walking", "foot" and "still". Indeed, the user of the App was riding his bike.

Looking at Figure 2-3 the tracking data is not precise enough to show the actual way of the app user. This is also a problem on other tracking apps. But those apps use algorithms which minimize these problems. Without reasonable data quality the gathered data were worthless in the sense of further processing and analyzing.

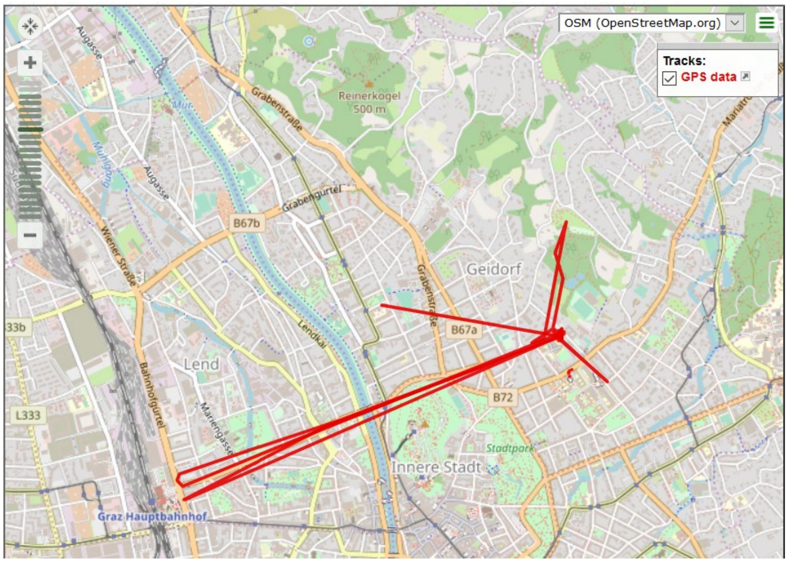


Figure 2-3 Tracking sample - Smiling Earth App, Basemap: Open Street Map

2.1.1.2.3 Sending the data (data access)

Besides the mentioned problems many participants had the problem that they couldn´t send the data with the provided button (Figure 2-4 – right bottom). After clicking on that button, the button disappeared and nothing happened. This wouldn´t be a big problem if the data were stored locally on the smartphone in .csv or .gpx file format. But they weren´t, which leads to the problem that those data couldn´t be accessed to the tracked data without actually sending it via E-Mail. Another problem was that the sending button vanished after clicking and wouldn´t reappear until restarting the smartphone. In some cases, participants had to reinstall the app on their smartphone to make the button reappear. 3 out of 4 participants faced this problem and couldn´t send any data. After those bugs appeared, strong doubts occured that the study would be executable with this app.

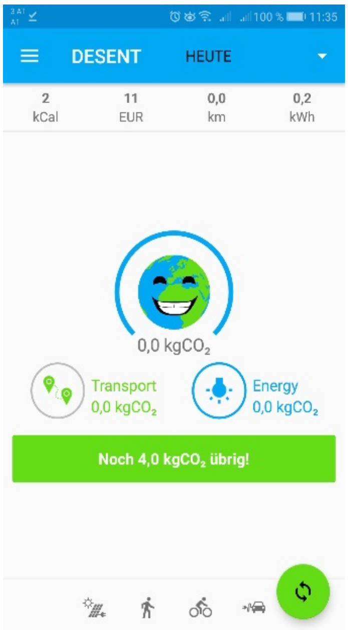


Figure 2-4: Landing Page - Smiling Earth App

2.1.1.2.4 Further Problems

It took SINTEF about 1 month to implement the sending button and about 3 weeks to translate the app from English to German. The calculations about how much CO_2 the app user is saving aren´t correct till now. The app also is getting killed by Android's energy saving algorithm. There was never a sign on the smartphone if the app is running or not (like a symbol in the menu bar) so the participants didn´t know that the app got killed and the data gathering is interrupted. Even though the app delivered bad GPS precision it took a lot of battery power. The app also crashed in many cases and couldn´t get launched until the participant reboots his/her smartphone. Another problem was, that the app is only provided for android, which reduces the chances of acquiring the 300 participants for our study.

2.1.1.2.5 Solutions

SINTEF published the app on the Google Play Store which made it easier to participate in the study and solved the problem mentioned in chapter 2.1.1.2.1. But due to the problem of data access, lack of data quality, the insufficient app performance and the lingering communication with Sintef, the decision was made to change the app and execute the study with another GPS tracking app. The alternative apps used (Alpenverein aktiv for IOS and GPS Logger for Android) also have their advantages and disadvantages which will be discussed in the following chapters.

2.1.1.3 GPS Logger for Android

The GPS-Logger for Android (short: GPSfA) was published by Mendhak and is free available on Google´s Playstore[1].

2.1.1.3.1 Advantages

At first, the app is free available on the PlayStore which made it much easier for the participants to take part in our study. The GPSfA was chosen because it comes with various options which support the data gathering. The most relevant advantage is the possibility to transfer the data automatically after a certain time interval. This configuration minimizes the chances that the participants forget to send their data. Also, the overall configuration options allow many variations about accuracy, data logging and which information should be logged.

2.1.1.3.2 Disadvantages

With all the provided settings the setup of the app is getting more and more complex. So, the manual for the setup finally had four pages, which was nevertheless 5 times shorter than the manual for the GPS-Loggers. Also, we needed much more time to test the optimal settings for the data gathering. Also, the participants have no possibility to take a look at their tracks on their smartphone. The data has to be transferred to a laptop or pc with a .gpx viewer on it (or some online-based equivalent The app was tested over a longer period and also faced some problems which will be discussed in the next chapter.

[1] Click here to show the app in Google PlayStore.

2.1.1.3.3 Issues

As already mentioned, the biggest problem was also the biggest advantage of the app. Due to the many possible settings and the overall complexity of the app many participants had problems to setup the app. It also took a long time to find the right configuration for the best data quality and less expenditure for the participants. The automatic data sending was the most complex option to set up. The reason for that is that every participant has to configure his/her E-Mail account to allow this option. For example: Gmail-User had to lower the security standards of their mail-account to ensure the app (GPSfA) is able to send E-Mails from this account the evaluation email address (desent@weiz.at). Another problem was that different smartphones had different GPS-modules which are very different in accuracy. It was hard to find settings which run on nearly every device. Due to the energy saving settings of android the app also got killed after a short time logging.

2.1.1.3.4 Solutions

To minimize the effort for the proband´s the decision was made to setup an E-Mail account from which every proband automatically sends his data to said mail address. Thanks to this step the proband´s didn´t have to lower the security settings of their private mail account. The only solution we found to bypass the energy saving settings of android was to change the energy management plan for the app. The problem here was that not every proband had the same smartphone with the same android version on it. So, every smartphone has different energy settings and different paths to change those. Focus was set on Samsung and Huawei smartphones, for those a guide to change the energy saving settings was provided.

2.1.1.4 Alpenverein aktiv for IOS

The “Alpenverein Aktiv (short: AVA)”-App was chosen to extend our study-range to non-android users.[2]

2.1.1.4.1 Advantages

As already mentioned, it was decided to extend the range of possible probands by executing the study on Android and IOS. After short research it was found out that this app met the requirements of the study best. The app is, in comparison to the GPSfA, very simple and easy to understand. As a result, the finished manual for this app was about 2 Pages (without screenshots).

[2] Click here to view the Apple App Store.

2.1.1.4.2 Disadvantages

The biggest disadvantage to mention is that the app doesn't have the option to send the gathered data automatically via E-Mail. In this case all IOS users had to send the gathered data manually on a daily basis or after the whole tracking week.

2.1.1.4.3 Issues

The problems faced on that app are very similar to the problems that occured with the GPSfA app on Android. The app is getting killed by IOS and there is no chance to disable that because the app uses a big amount of hardware resources. Another problem was that the app developer (Outdooractive GmbH & Co. KG) released a new version of the app and stopped updating the old version. Also, the tracking got stuck in the old version after the last update. After changing to the new version of the app, it´s now necessary to create a free user account. The new version was also not very stable and crashed occasionally.

2.1.1.4.4 Solutions

The manual was extended with an instruction to create the required free account and added a bunch of screenshots from the app to the manual. For the problems faced on the AVA-App no solution could be found. The only thing that could be done was hoping that the developer fixes the bugs and releases a more stable version in the near future.

2.1.1.5 Study Timetable (Technical part)

Date	What happened?
26.04.2018	Sintef delivered the English version of the app to the project partners
	Testing the app
25.09.2018	Reporting to Sintef
01.08. – 01.10.2018	Get in touch with local businesses for vouchers
16.11.2018	New Version from Sintef (no german, many bugs)
21.11.2018	Another Update from Sintef
27.11.2018	Upload into google play store (app translated in german but many bugs still exist)
03.09. – 07.09.2018	Writing the instructions for the alternative apps

03.09. – 01.11.2018	Testing the alternative apps, improving the instructions and starting the study
01.11.2018 – 20.02.2019	Executing the study with 2 alternative apps (promotion and support for the participants)

2.1.1.6 *Study timetable (proband acquisition)*

Date	**Activity**	**reached Persons**
Okt. 2018	Article about the study in the newspaper "Weizer Woche"	Number of copies: 43.647
Nov. 2018	Article about the study in the community newspaper (Weiz Präsent) – this Newspaper goes to all households of the municipality of Weiz.	12.900 Households
11.12.2018	E-Mail to all tenants of the Innovation-Centre of Weiz	200-300
17.12.2018	E-Mail to all employees of the municipality of Weiz	~400
17.01.2019	E-Mail to all employees of a company (ANS)	~50
17.01.2019	Posting on the Facebook-Page of the Municipality of Weiz	~3500
24.01.2019	Talking about the Project in front of 4 school classes within the IT-branch of the school.	80
31.01.2019	Reminder E-Mail to all pupils	
01.10.2018 – 15.02.2018	Personal contact over other channels like phone, personal conversation	~100
	Sum	Households: ~56.547 People direct: ~4430 Actual probands: 75 Response rate (basis: people direct): ~1,7 %

2.1.1.7 Conclusion

After the long process of configuring and testing the alternative apps and waiting for SINTEF to complete the smiling earth app much time was lost for the study. The modifications and uncertainties led to a decreasing amount of probands and a slow overall progress. The main issue which SINTEF faced was, that Google changed its awareness API in short intervals which led to the problem that the app got instable, see Deliverable 6.1. Much time was invested to find accurate workarounds or solutions for every problem which has been mentioned in this report. There were also problems which went through the entire study like no budget for goodies and the protracted process to setup appropriate manuals for the different apps. Executing the study with smartphones instead of the tested GPS loggers had the big advantage that the probands didn´t have to carry around the tiny loggers which were easy to forget. Also, the tested GPS loggers had the problem that they weren´t precise and often had no or bad satellite reception. The disadvantage about executing the study via smartphones was, that there are many smartphone manufacturers and different operating system versions which differ in design and user interface. Therefore, a very long test phase was necessary to identify the problems with every app we wanted to use. Another big problem was the battery usage of the gps-logging apps. Due to that and after changing the app multiple times, due to the various mentioned reasons, not enough probands for the study were found. As can be seen in Chapter 2.1.1.6 many channels were used to acquire the required number of study participants. Free vouchers were given away and Facebook was used as well as the local community newspapers, schools and other institutions like local companies as communication channels. Unfortunately, despite our efforts, we weren´t able to find the required number of participants. The low response rate of 1,7 % lead to a total of 75 participants which completed the study.

2.1.2 Building data issue

Available building data is the foundation for the DESENT energy tool box, as such this data needs to be of high quality for the results of the tools to be representative. The data for the city of Weiz originates from the “Gebäude- und Wohnungsregister (GWR)” which is a database for building data, that needs to be filled by the municipalities. While the basic data from the database is of good quality it still had to be checked for errors or blank spots, for this purpose the standardisation and imputation tool described in D5.1 were developed. Aside from erroneous and missing data two key issues with the data in the GWR were identified:

- Data might be outdated:
  It is very likely, that the GWR is, at least in certain parts, outdated as it is often poorly maintained. While the GWR of Weiz is well maintained there is no information on the update date of single buildings. Thus, changes in the building infrastructure such as renovations or changes in the heating systems etc. might not be represented in the data. While this is not as critical in the city of Weiz, as the data was updated recently
- Not all data required is in the GWR:
  The energy tool box requires a substantial range of information, see D5.1 for the detailed description of the data required. The problem is, that the GWR has focus mostly on building infrastructure and information on the heating energy. The electricity and mobility sector are heavily underrepresented in that database.

2.2 Helmond

2.2.1 Mobility data issue

In Netherlands, most of the mobility data are published open annually, which provides a good basis for research and practices. The data is normally at the national level where respondents are random samples across the country. This means the number of populations for the city of Helmond could be actually small.

In addition, ALBATROSS tool is created for predicting activity and travel demand at the post code level, which means the decision tree model embedded needs sufficient data at zone level from the specific city when it is applied to the city level. In Helmond, the number of 6-digit post codes are limited because of the city scale. This limitation applies to many places within ALBATROSS. For example, the population synthesis will require detailed zonal data from the city which is in general not available. Because of the various limitation in data at detailed level, in the implementation, a model learned from national level is applied to the city level.

2.2.2 Building data issue

Implementation of building energy consumption tool needs a list of building data and related energy consumption data. The building data is partly available from BAG data source. We extracted the detailed building data for the Helmond city. The data includes building related information only, such as year of the building, size, location, etc. However, the energy consumption data in the city of Helmond related to the buildings are not available. The city of Helmond does not own any energy consumption data related to the detailed information, although many houses installed smart meters, the data are normally owned by different energy suppliers who actually own the data.

3 Implementation of Albatross

Considering the limited input for Helmond city, we calibrated the model based on the data from the Netherlands. The synthetic population of the metropolitan area of Eindhoven is used for show the implementation of Albatross, which includes Helmond.

The output of the Albatross for all activities and trips can be put into any data file. It can also be visualized in figure 3-1. The synthetic population of Eindhoven metropolitan area (5704 households) conducted 20970 trips on a day. As you can see that most trips are conducted around Eindhoven metropolitan area. There are still some long distance trips which go through the whole country. Based on the prediction of work location as shown in figure 3-2, it can be explained.

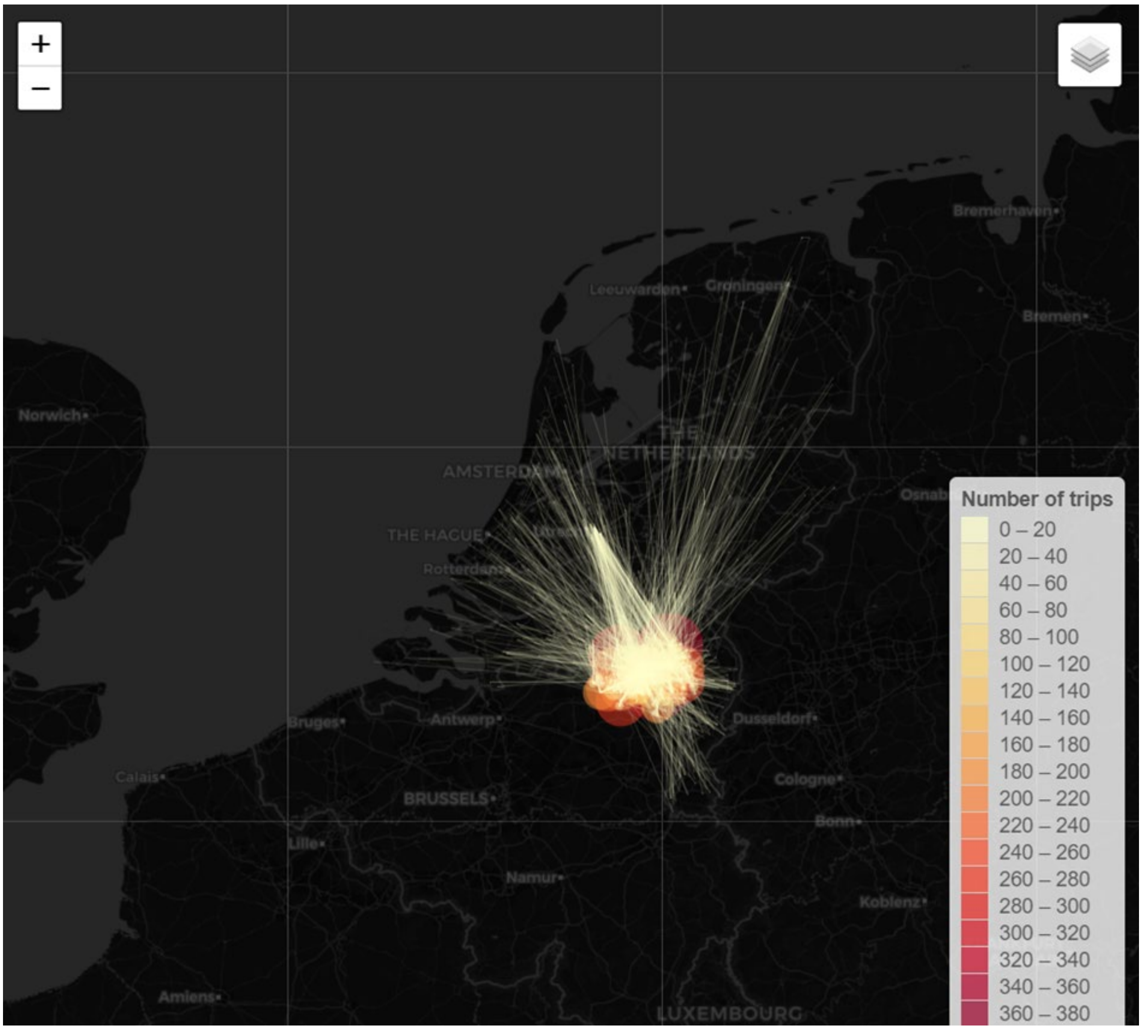


Figure 3-1 O-D flow at four digital postcode level for the synthetic population in Eindhoven metropolitan area

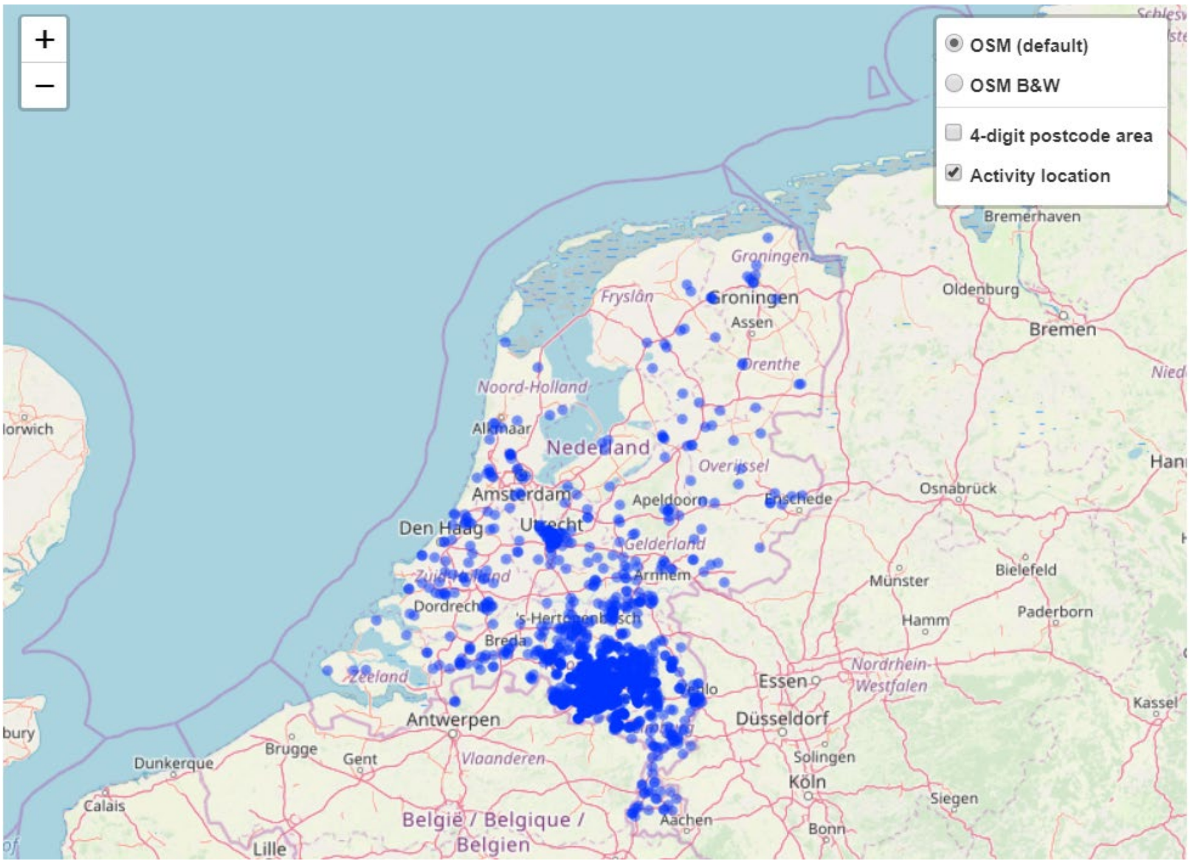


Figure 3-2 Work location distribution in 4-digital postcode

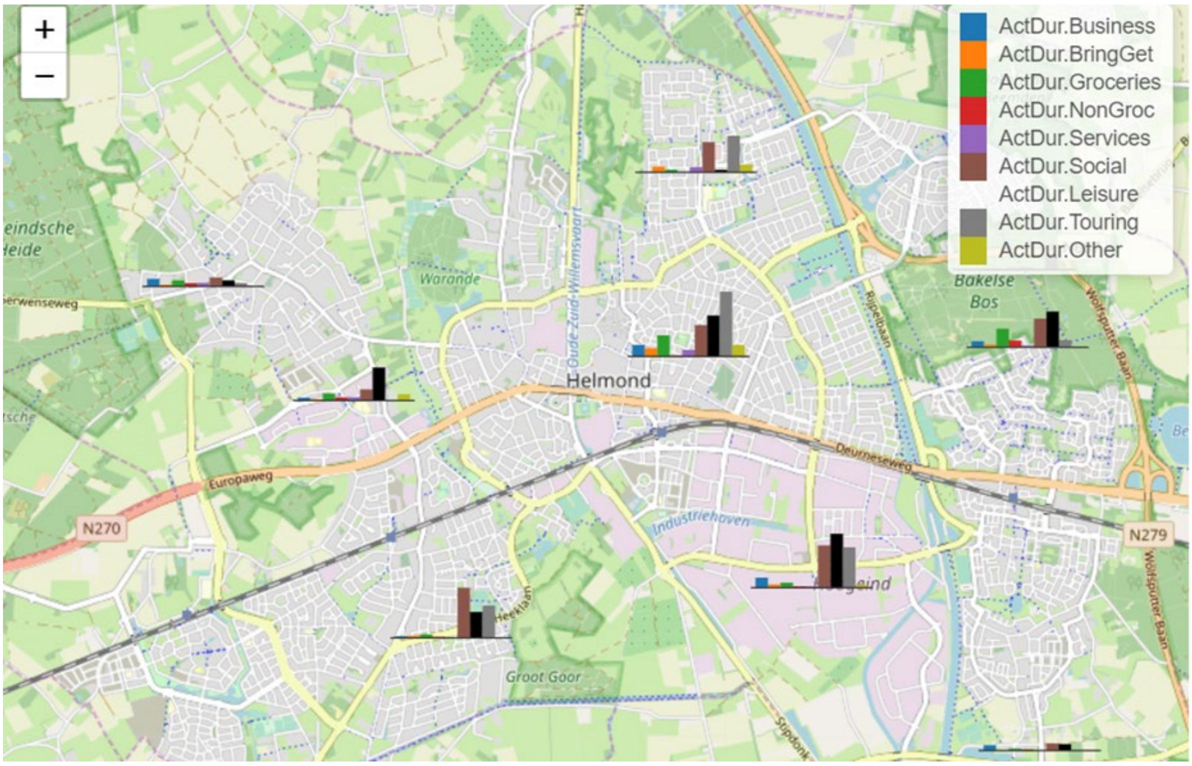


Figure 3-3 Activity duration distribution for non-work out-of-home activities

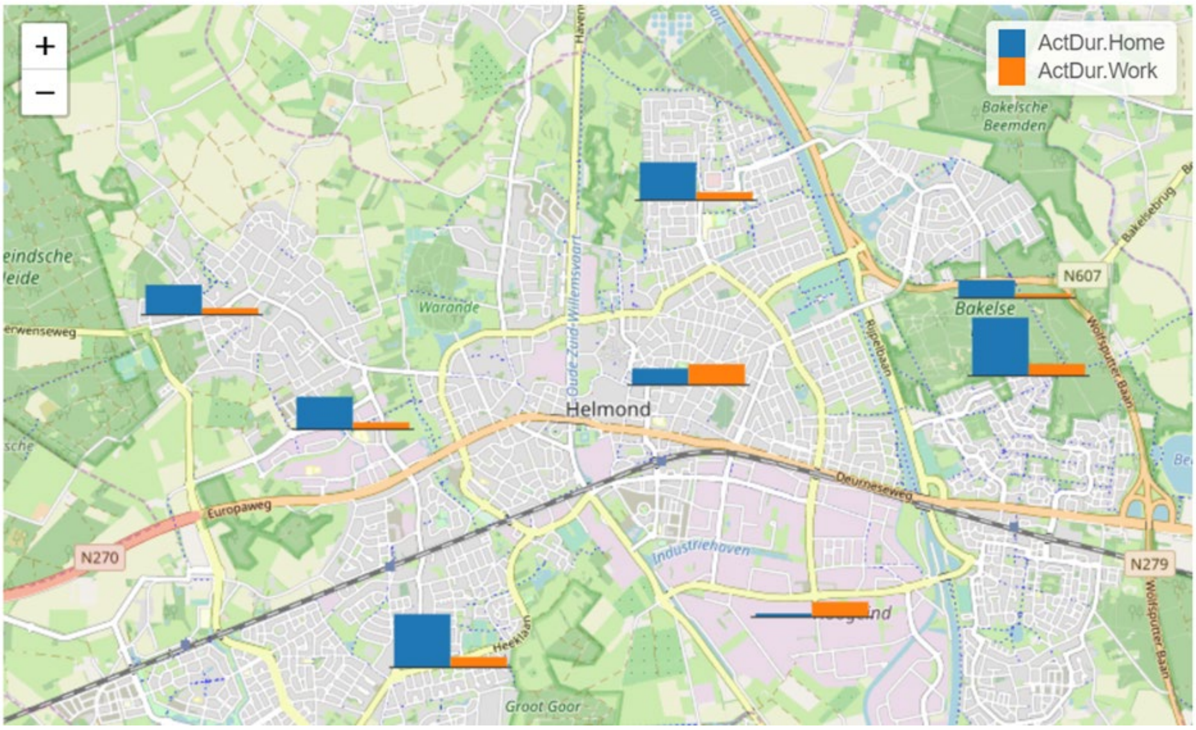


Figure 3-4 Work and home activity duration distribution

The activity duration for the city of Helmond is shown in figure 3-3 and figure 3-4 based on the location of such activity at four digital postcodes. It can be seen that many people are living in the Helmond especially out of the city center of Helmond, while few people are working in Helmond. Social, leisure and touring activity durations are relatively higher comparing to other activities, which follows the common sense.

For charging activities, most of them are predicted as a parallel activity to an existing activity. Only fast charging is anticipated as a separate trip. As shown in figure 3-5, 3-6, and 3-7, the charging activity is predicted at four digital post code level together with trips. The fast charging activity is shown in 3-7. It can be seen that there are not many fast charging activities based on the data collection described in delivery 3.3. Since fast-charging stations are increasing, the current prediction might have to be updated in a near future to catch up with the further development of fast charging infrastructure. Figure 3-8 displays an electricity consumption based on the current prediction of charging activities and assumed the charging rate per type of charging facilities. It can be seen that so far in most areas slow charging consumes most of the electricity while in some area fast charging also require a high demand for electricity.

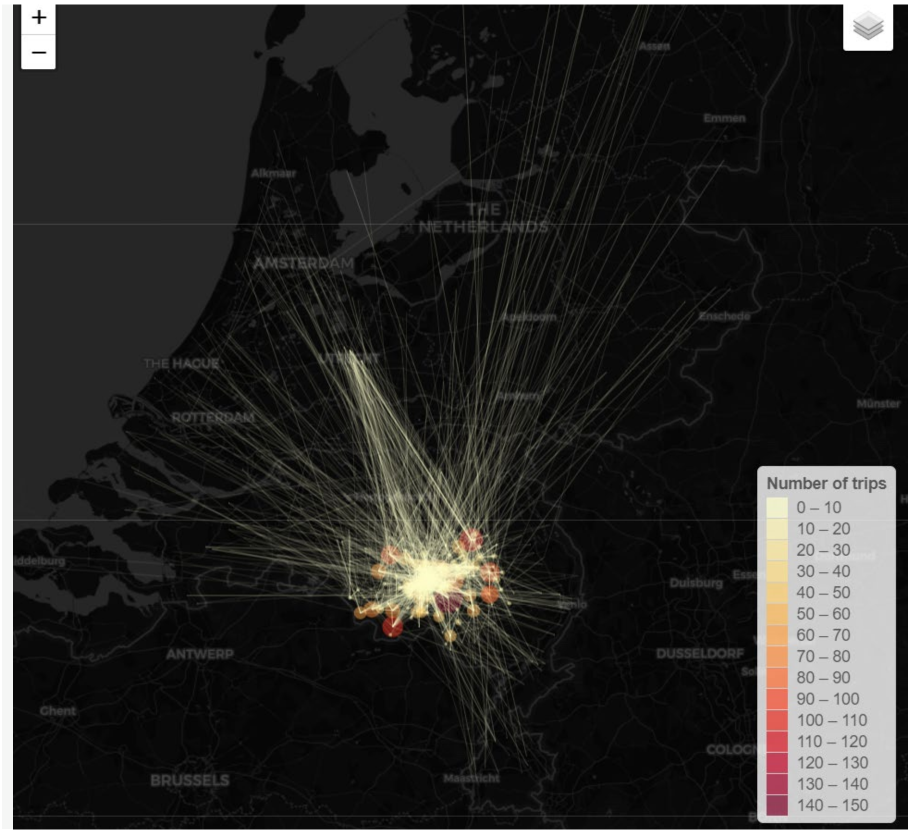


Figure 3-5 Charging activity together with trips at four digital postcode level

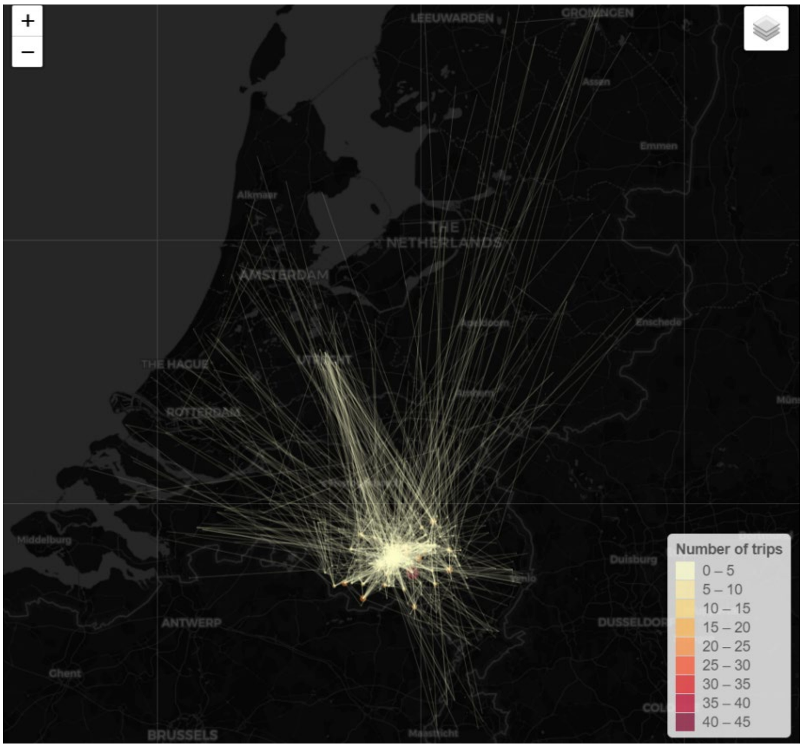


Figure 3-6 slow charging trips for 4-digital post code level

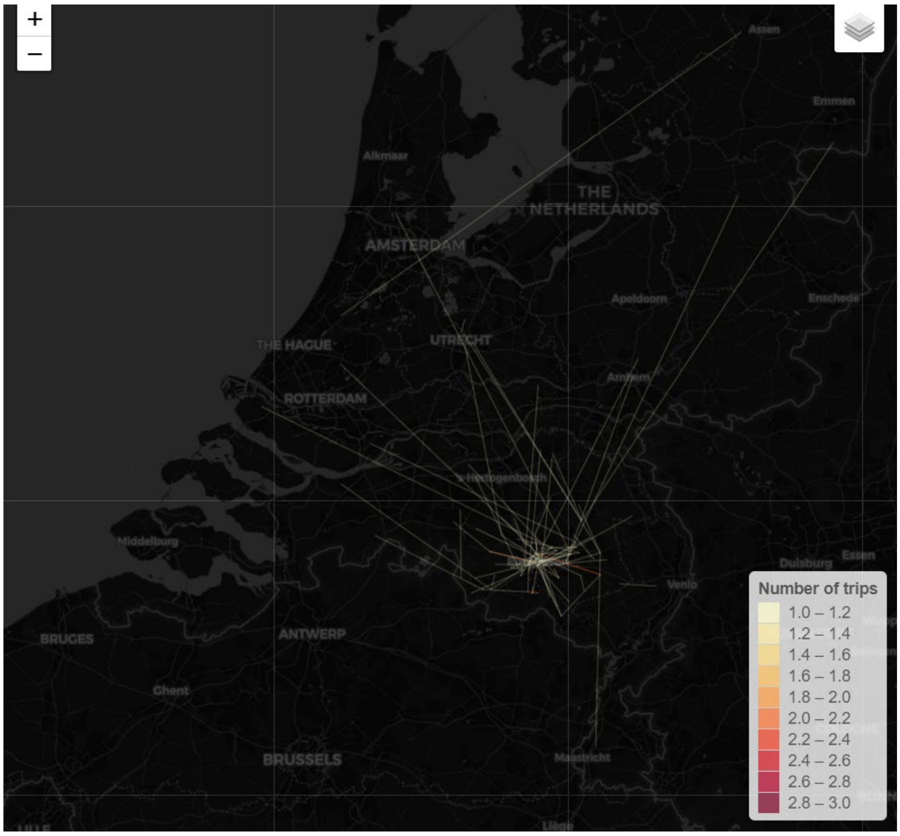


Figure 3-7 Fast charging trips for 4 digital post code level

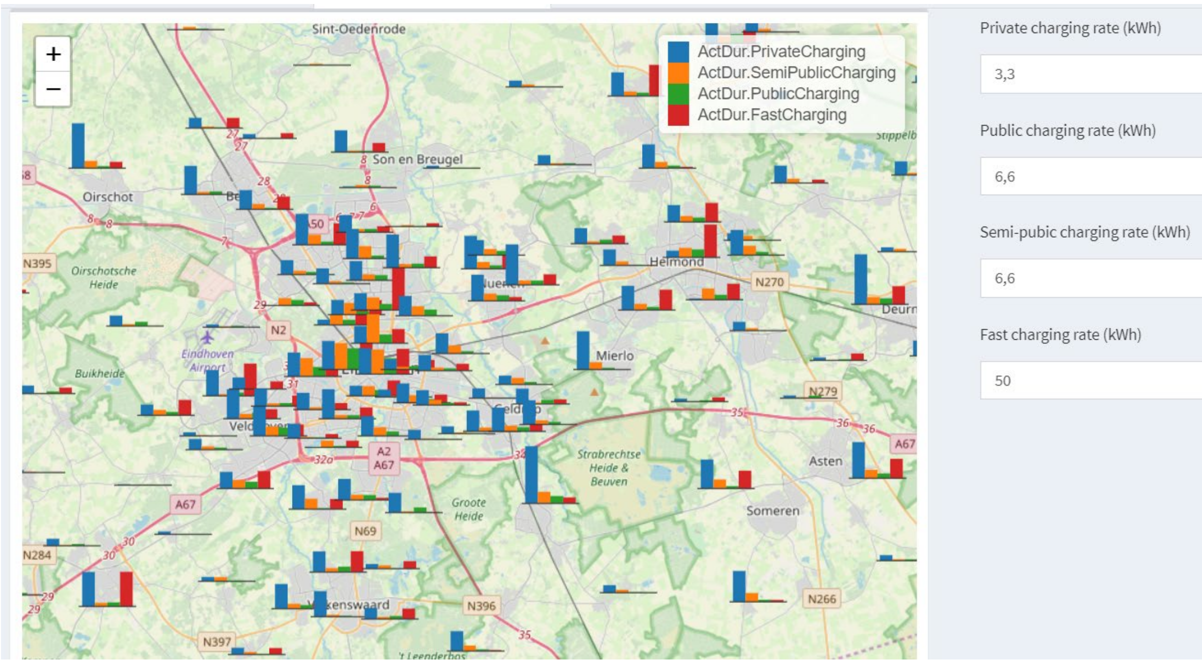


Figure 3-8 The prediction of electricty consumption (KWh) for 4 digital postcode level

4 Implementation of DESENT energy tool box

One key feature of the DESENT project is the development on the DESENT energy tool box with which simulations of a district energy system can be made in order to better analyse and understand such a system and to fully understand the effects of changes on the system. The tool and its underlying components are described in detail in Deliverable 4.1, 4.2, 5.1 and 5.2.

The developed tools are tested for the demonstration city of WEIZ where the energy system will be analysed and presented in the following chapters. The testing procedure contains the following steps, which were done in order to obtain the results:

- **Data Gathering and Preparation:**
  To calculate the energy system data, already existing data of the city of Weiz was analysed and prepared for the simulations. This process is one of the key steps for the energy system analysation as the quality of the data is fundamentally important for the quality of the results.
- **Data and system validation:**
  The prepared data was validated and fed to the tools. Each tool and sub-tool was tested with the finalised data and their corresponding operation validated. Where required, additional modifications to the tools were made.
- **Scenario definition:**
  As the tools allow for a vast amount of options to be analysed and simulated (see Deliverables 5.1 and 5.2) and the amount of results would exceed the scope of this deliverable distinct scenarios were defined to prove the operation of the tools.
- **Scenario calculation and evaluation:**
  The before defined scenarios are simulated, the results derived and discussed below.

This general approach can be replicated for any analysation using the DESENT energy tool box.

Each tool iteration is tested toward to aspects:

- **Functionality of the tool:**
  The first test sets focus on how the tools functions from data input to result evaluation, how easy it is to use and how easily the results can be obtained.
- **Results of the tool:**
  The second test is an evaluation of the results. While this is definitely harder to do, as the complexity of the data and the results is hard to comprehend, a general feasibility check is made.

4.1 Analysation of the current situation in Weiz

For the first analysation with the DESENT energy tool box in the demonstration city Weiz the current situation with focus on households was chosen. The sets of data provided information on non-household buildings as well, but since the data quality for households was supreme in comparison to the other buildings, focus is set on households.

The goal of the first analysation is to better understand the energy consumption of households within the region of Weiz and to be able to locate energy consumption centres and identify areas with potential for improvements. Focus is set on both the geographical distribution of the energy consumption as well as the resulting load profiles for the region.

4.1.1 Analysation with geo-political reference

Using the data for households on the lowest geographical resolution and calculating the entire energy consumption for heating and electricity yields the results shown in Figure 4-1, depicting the regions of Krottendorf (semi-rural region) and the city-region of Weiz (rural region).

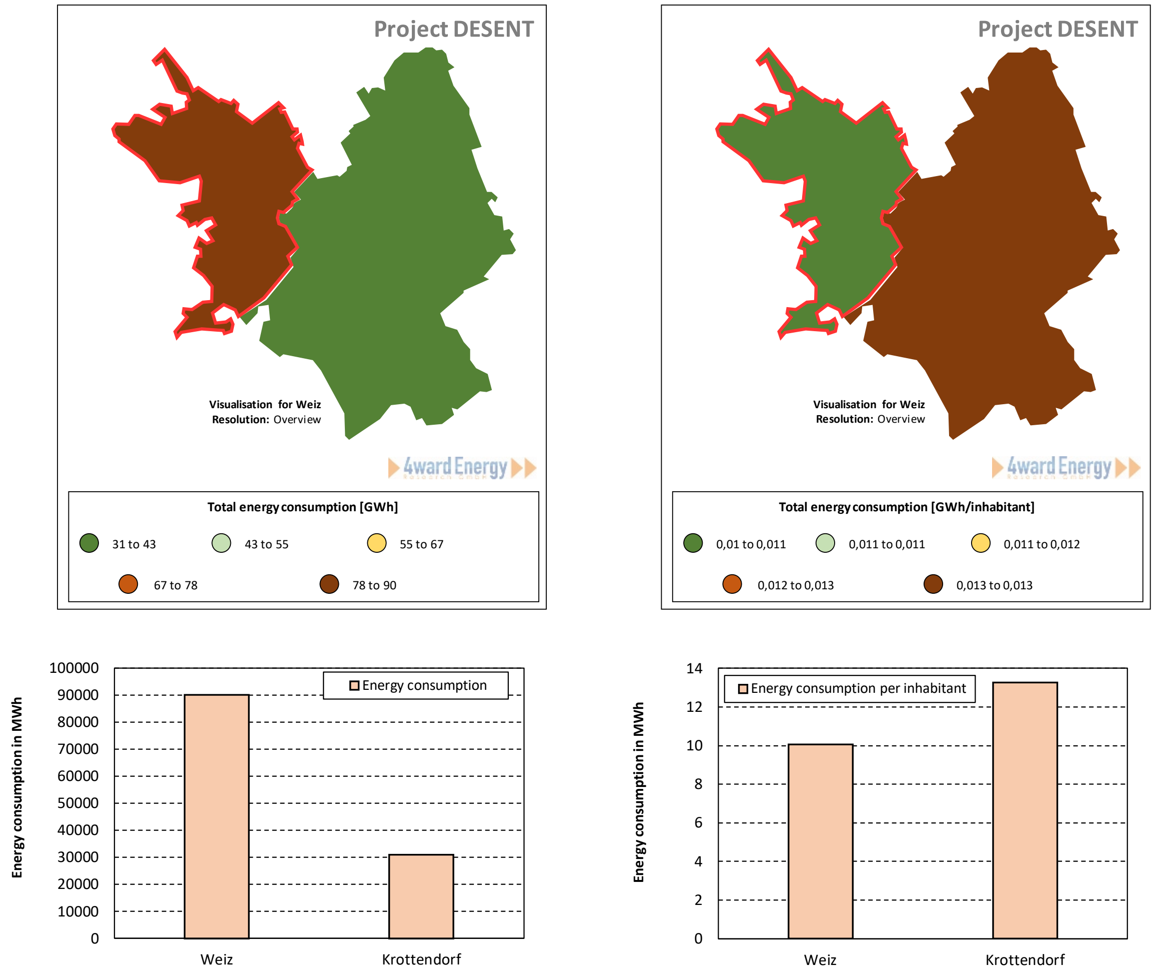


Figure 4-1: Analysation of the energy consumption of the region of Weiz – Resolution: Overview

As can be seen in the figure, the rural region of Weiz shows a by far higher total energy consumption, than the semi-rural region Krottendorf. In the city region of Weiz approximately 3 times as much energy is consumed than in the semi-rural region of Krottendorf. This result is actually not really surprising as the urban region of Weiz shows a by far higher population density than the region of Krottendorf. The data sets provided to the tool indicate a total of 11.300 people living in the entire region, of which 9.000 can be assigned to the rural and 2.300 to the semi-rural region. This data matches the official numbers for the area of 11.627 as of 2018[3]. Therefore, the population of the rural region amounts to approximately 26% of the population of the urban region. The total energy consumption of the rural region (31.000 MWh) amounts to 34 % of that of the urban region (90.200 MWh).

To compensate for the population density aside from the total energy consumption also the energy consumption per inhabitant is analysed. The results show, that in the region of Krottendorf the energy consumption per inhabitant is larger than the energy consumption per inhabitant in Weiz (+31,6 %). The main driver for this higher consumption per inhabitant is a higher heating demand due to worse building standards in combination with more energy intensive heating systems.

[3] Statistik Austria: Bevölkerung am 1.1.2018 nach Ortschaften (Gebietsstand 1.1.2018),

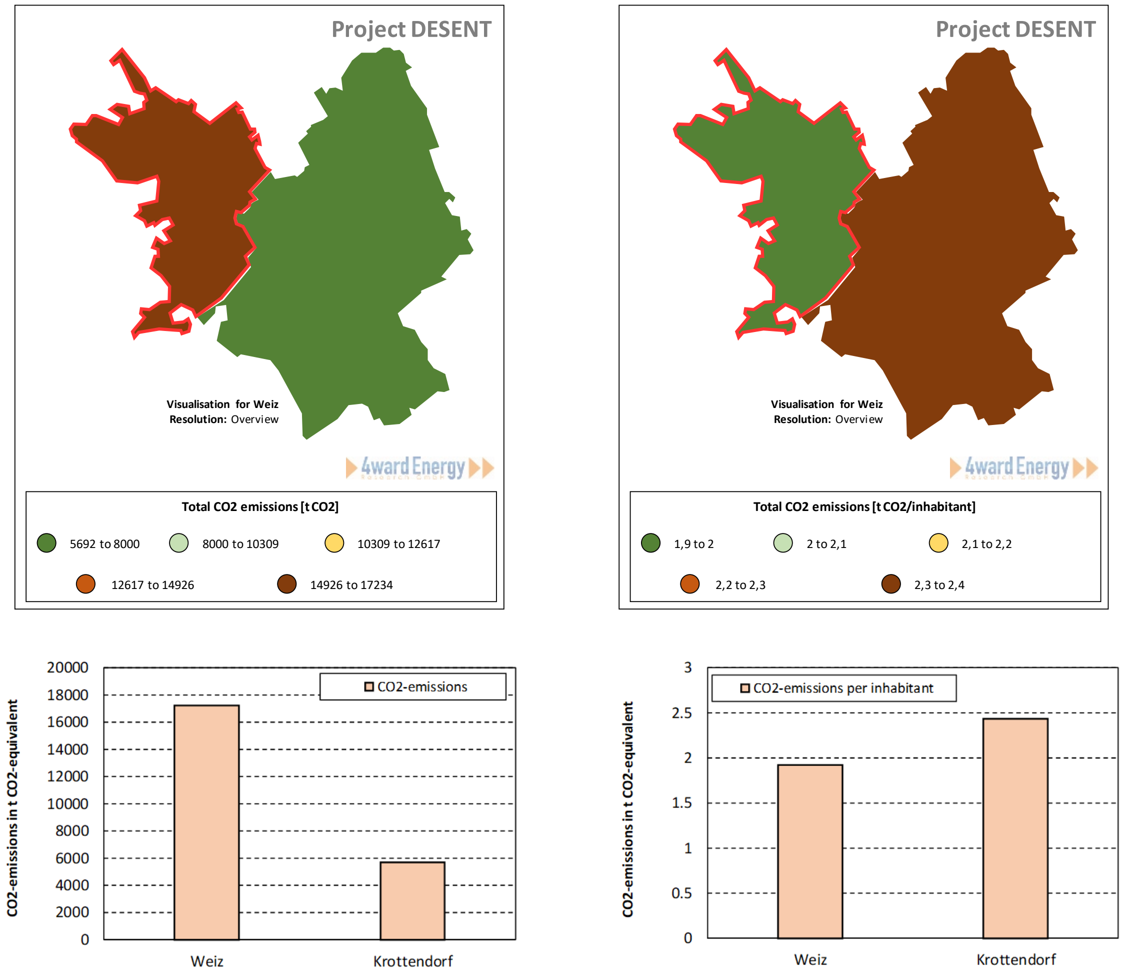


Figure 4-2: Analysation of the CO_2 emissions of the region of Weiz – Resolution: Overview

A similar conclusion can be obtained when considering the CO_2 emissions of the households, see Figure 4-2. It needs to be considered, that the data presented here only includes heating and electrical consumption but no CO_2 emissions from the transport sector or the food consumption sector.

On average Austria has a CO_2 emission of 7,19 tons of CO_2 equivalent per inhabitant[4]. While the region "Weiz" shows a higher total CO_2 emission than Krottendorf the CO_2 emissions per capita are smaller. In Germany, which shows a similarities to consumption structures as Austria, the average CO_2 emissions for heating are around 1.97 tons of CO_2, where electricity consumption comes up to 0.29 tons of CO_2[5].

4 https://de.statista.com/statistik/daten/studie/167877/umfrage/co-emissionen-nach-laendern-je-einwohner/

5 http://www.energie-weblog.de/co2-emissionen-pro-kopf/

The urban part of the Weiz region is below that average with 1.92 t CO_2-equivalent per inhabitant, the region Krottendorf is above the average with 2.44 t CO_2-equivalent. Again, this indicates, that in the urban part of the region facilitates better building standards and more eco-friendly heating are in place.

By increasing the resolution and dividing the 2 main regions into 12 sub regions, see Figure 4-3, new insights can be gained on the energy consumption and CO_2 emissions. The main region of Weiz is divided into 4 sub-regions (Altstadt, Neustadt, Wegscheide and Radmannsdorf) the main region of Krottendorf is divided into 8 sub-regions (Nöstl, Büchel, Krottendorf Ost and West, Reggersstätten, Farcha, Preding Nord and Süd)

Figure 4-3: Separation of the Weiz Demonstration area into 12 sub-regions

The urban region of Weiz, which has the highest consumption, has two distinct subregions (Radmannsdorf and Neustadt) which show significantly higher consumption values, see Figure 4-4. Which, given the average consumption per capita, can be traced to the higher number of inhabitants of these subregions. Interestingly enough one of the rural subregions (Preding) shows the lowest average consumption per capita, whereas the other rural subregions show higher average consumption values than the subregions of the urban centre.

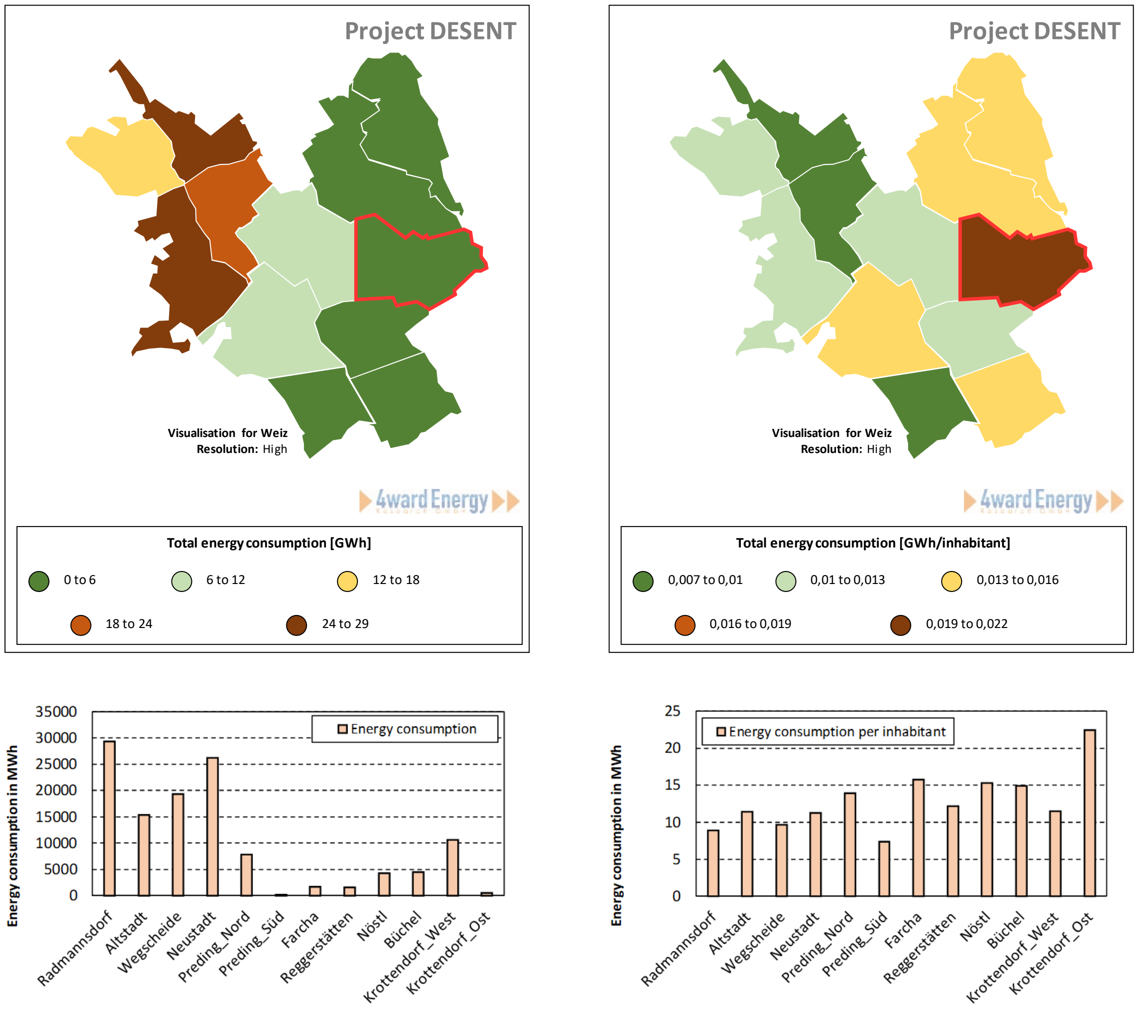


Figure 4-4: Analysation of the energy consumption of the region of Weiz – Resolution: High

The largest part of the energy consumption is due to heating, depending on the building standard, ranging from 180 kWh/m² to 15 kWh/m² [6]. The high extremely high value for the region of Krottendorf_Ost of 22.46 MWh / per capita for total energy consumption can be traced back to very few people living in rather large buildings with poor building standards. A total of 23 people are registered within that area. As a comparison, the region Radmannsdorf (urban part) has a population of approximately 3.000 inhabitants.

[6] Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden

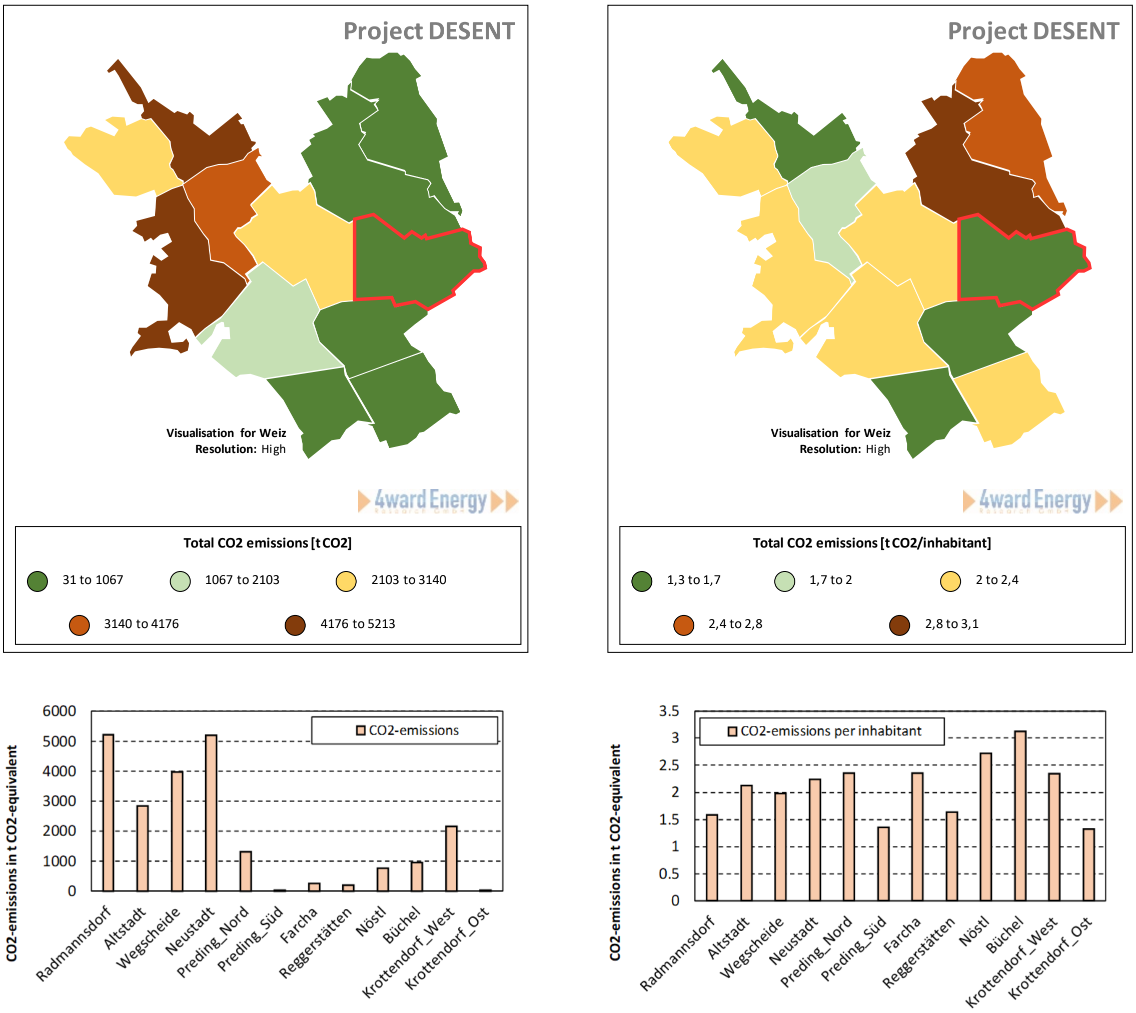


Figure 4-5: Analysation of the CO_2 emissions of the region of Weiz – Resolution: High

A similar situation presents itself when analysing the CO_2 emissions caused by the energy consumption for heating and electricity. While the urban region of Weiz shows vey higher total numbers for CO_2 emissions, the average values per capita are around the 2 t CO_2-equivalent mark, with Radmannsdorf having the lowest average values. A result that is quite surprising is the comparison of energy consumption per capita and CO_2 emissions per capita in the subregion Krottendorf_Ost. With an energy consumption of 22.46 MWh/capita this sub region has the highest relative energy consumption but the lowest relative CO_2 emissions, with a value of 1.33 t CO_2-equivalent. The high energy consumption can be explained by poor building standards which lead to a high energy demand for heating. But as often the case in rural regions, the demand is satisfied by heating with wood, wood chips or wood pellets. The subregion of Büchel, which shows the highest relative CO_2 emissions (3.13 t CO_2-equivalent), has a above average relative energy consumption.

This goes to show, that you cannot directly link energy consumption to CO_2 emissions as the driving factor is the technology used for the satisfaction of the energy demand. The results indicate that of the 12 considered subregions a total of 6 subregions have a lower than average relative CO_2 consumption (3 of them from the urban region) and 6 subregions have a higher than average value.

Another conclusion that can be drawn from these graphs is that while the information of on the map in the different special resolutions helps to better emphasise the distribution of the energy consumptions, the additional bar-graphs are required to get the final degree of detail required to fully understand the situation. Another result that can be obtained from this analysation is, that, at least for the demonstration city of Weiz, the relative energy consumption per capita and the relative CO_2 emissions per capita are lower for the urban region than for the rural region.

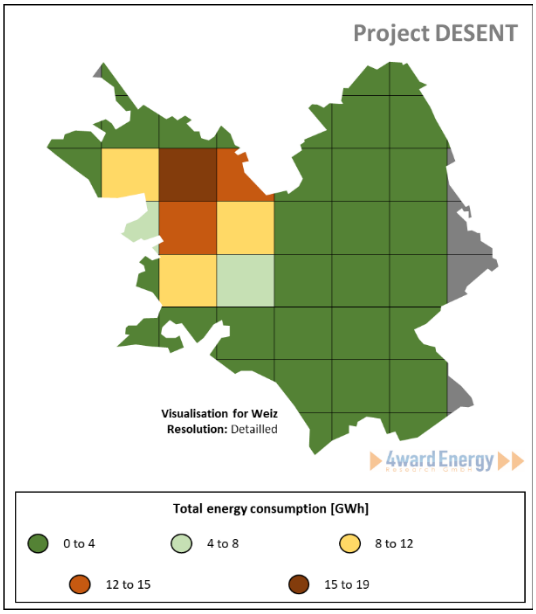
4.1.2 Analysation with cadastre reference

The great drawback of the lower resolutions is the lack of possibilities to pinpoint consumption hot spots or emission hot spots. A general overview can be obtained, but an in-detail analysation is not possible. Apart from the geo-political maps, showing borders of different regions, a cadastre approach for visualisation can be chosen. There are two options at hand, a 750 x 750m resolution or alternatively a 75 x 75 m resolution, see Figure 4-6 for total energy consumption.

The maps use the approach, that each building within the database is assigned to one specific area. If a building is on the borders of one or more areas, it is assigned to the area with the highest proportion of building surface in it. The grey areas indicate, that there is not a single building in that specific area.

One of the first conclusions that can be drawn from the 750x750 resolution is, that even in the rural region of Weiz city there are substantial areas without any household buildings. This explains, why the subregion “Altsadt” has a comparatively low energy consumption in comparison to the other subregions of the urban area. What can also be taken from the Figure 4-6 is the fact, that there is one core consumption hot spot for household energy consumption in the centre of the urban area, with the adjacent region showing also increased consumption values which are then getting smaller as the distance to the city centre increases. This effect is in direct correlation with the amount of people living in that area.

Even more information on the energy consumption and the urban structure can be obtained from the 75x75m resolution analysation. Aside from the information on consumption hotspot it also shows the geographical distribution of households in the area. From that figure it can easily be explained, why the rural region has a by far lower energy consumption than urban region as the density of building is substantially lower. Additionally, this type of visualisation provides insight into the consumption structure as consumption hotspots can be very precisely pin pointed. The general conclusion about the energy consumption is similar to that of the 750x750 m resolution.



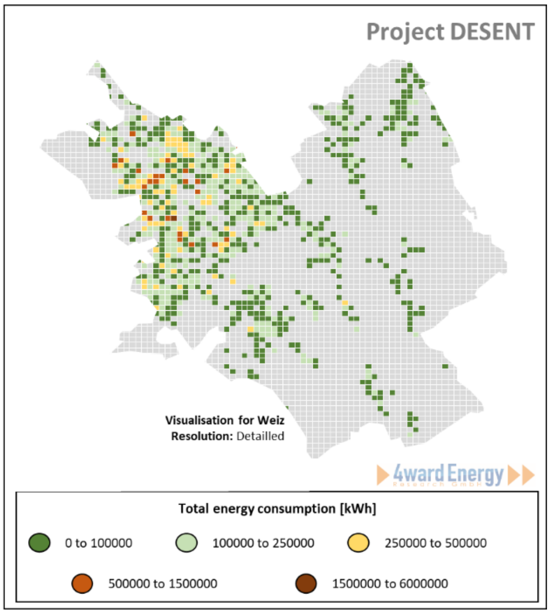
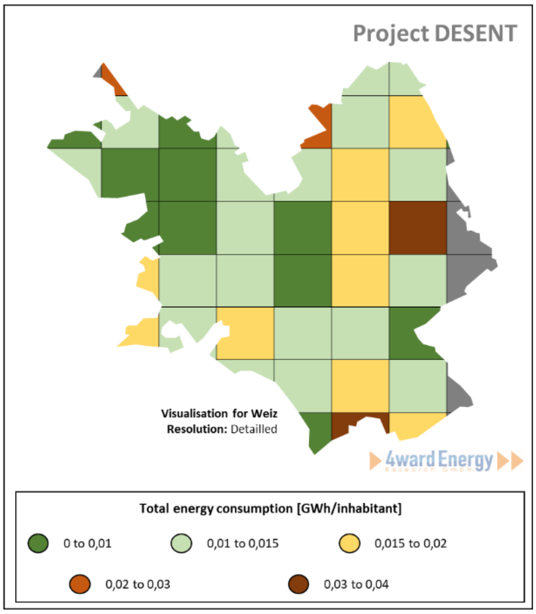


Figure 4-6:Analysation of the energy consumption in the demonstration area of Weiz. Left: 750x750 m resolution, Right: 75m x 75m resolution.

While the results for the general energy consumption seem quite obvious, as they are linked to the population numbers of the urban areas, the specific energy consumption per capita yields a different insight. Similar to the results from the analysis with the geo-political borders, the conclusion can be drawn, that the highest specific consumption values are not necessarily found within the urban region. The results of Figure 4-7 show, that higher specific results are found in the rural areas – which is in line with the conclusion from the analysations above.

One interesting conclusion can be drawn from the comparison of the 750x750 and the 75x75 resolution. While the lower resolution results suggest, that the urban area has an overall very low specific consumption the more detailed resolution clearly shows, that there are fields with a rather high specific consumption within that area.

What is also interesting to mention is that in case of the rural regions many parts actually show a rather low specific energy consumption, a conclusion the results of the 750x750 resolution wouldn't suggest.



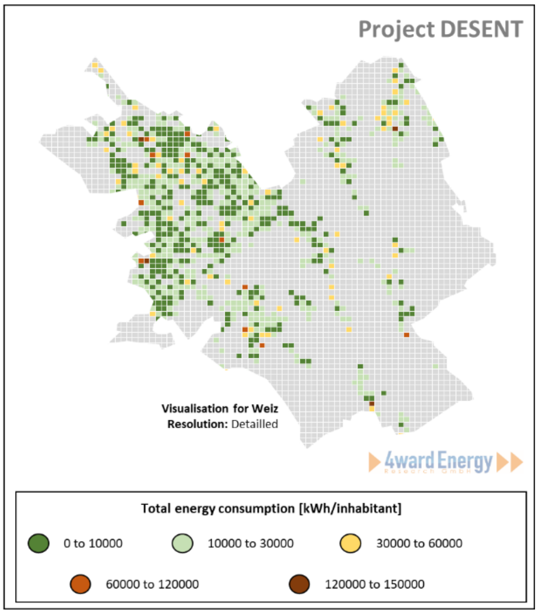
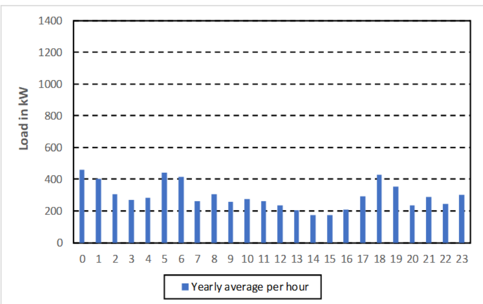


Figure 4-7: Analysation of the energy consumption in the demonstration area of Weiz. Left: 750x750 m resolution, Right: 75m x 75m resolution.

4.1.3 Analysation of load profiles

Aside from the annual energy consumption values, the tool provides the possibility to analyse data with a higher temporal resolution. Building on the knowledge about the parameters of the different households considered, load profiles are generated. This is especially important when looking a potential dispatch of decentralised generation capacities. The tool provides the user with load values for each quarter hour of the day for the selected region.

For the demonstration purpose of the DESENT toolbox, load profiles for the sub regions (12 regions) were created. For more comparable results, these profiles where then aggregated to show the average hourly load values throughout the year for each region. As the demonstration only considers households, these profiles are looking similar in those cases where non-electrical heating plays a minor role – as is the case for most regions.



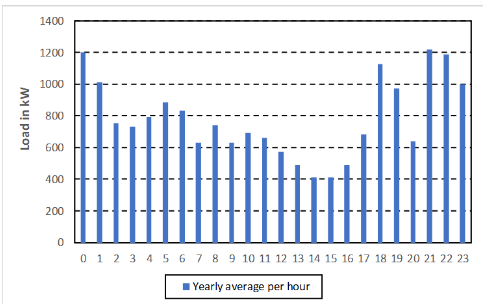


Figure 4-8: Load profile of the region Altstadt

Figure 4-9: Load profile of the region Radmannsdorf

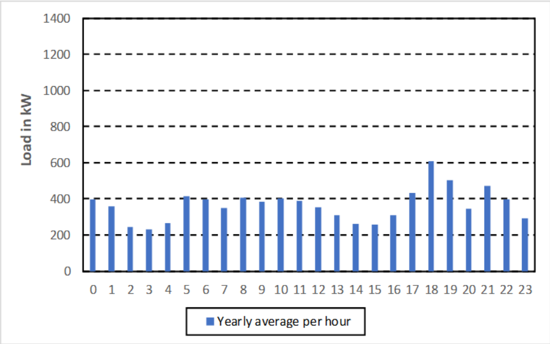


Figure 4-10: Load profile of the region Wegscheide

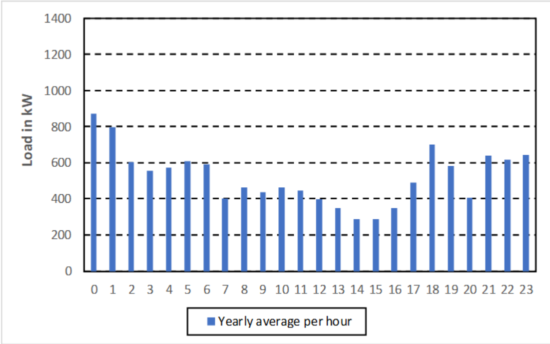


Figure 4-11: Load profile of the region Neustadt

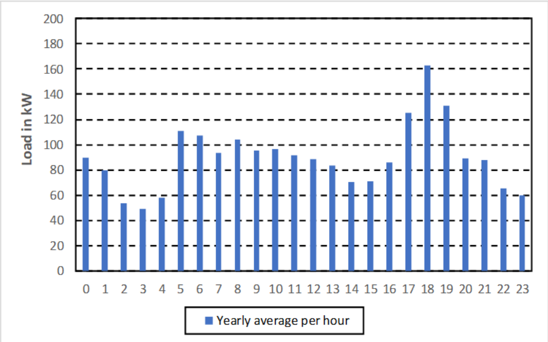


Figure 4-12: Load profile of the region Preding Nord

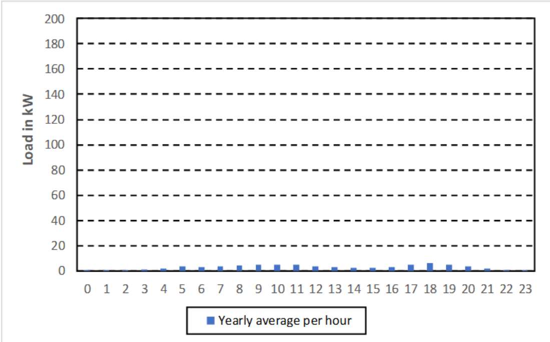


Figure 4-13: Load profile of the region Preding Süd

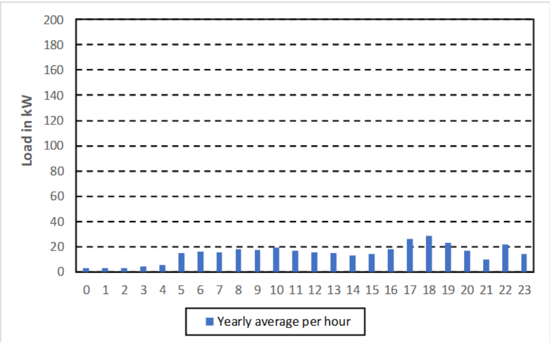


Figure 4-14: Load profile of the region Farcha

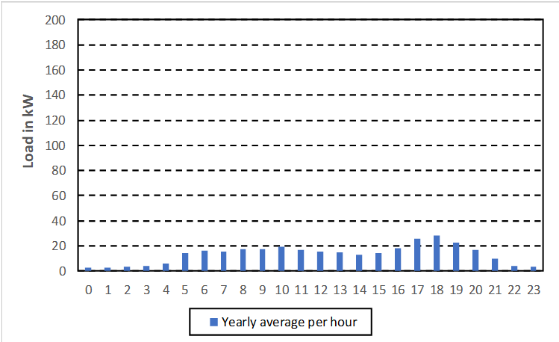


Figure 4-15: Load profile of the region Reggersstätten

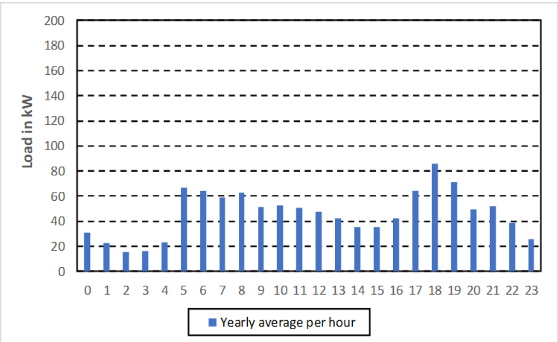


Figure 4-16: Load profile of the region Nöstl

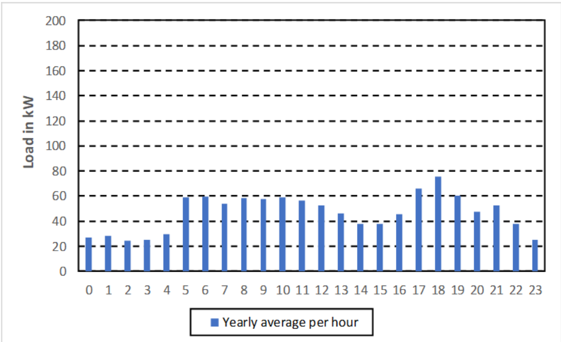


Figure 4-17: Load profile of the region Büchel

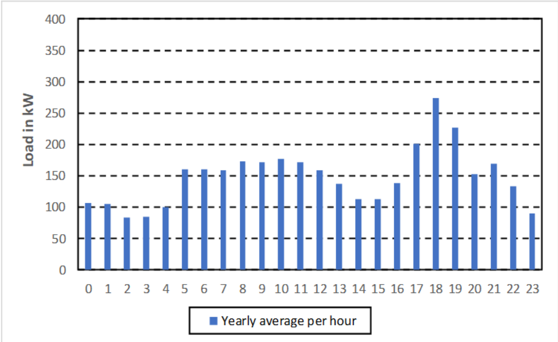


Figure 4-18: Load profile of the region Krottendorf West

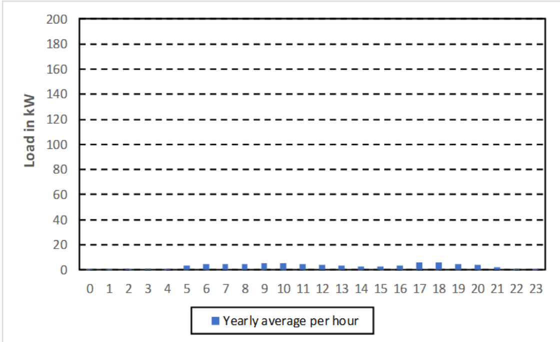


Figure 4-19: Load profile of the region Krottendorf Ost

The annual averages of the hourly values show a generally similar curve in each region, although the details differ from region to region, depending on whether electrical heating is an option or not. As only household loads are considered these results is not too surprising. Single households differ greatly from one another, but once more households are considered, the single load profiles start to overlap, and the difference start to even out – this is even more true for when average hourly values throughout the year are considered.

Nevertheless, the demonstration shows, that a potential improve in the methodology of the load profile generation can be achieved by using even more base-load profiles for each set of parameters for the households, although it is to be expected, that they will even out nevertheless.

The analysation of the load profiles leads to the conclusion that two peaks can be found throughout the day. Peak one is the around 11 to 12 o'clock, which represents the timeframe for cooking, the second peak, which is higher in most cases, occurs in the afternoon, which represents both cooking and leisure activities. Additionally, the results show, that during the winter months the consumption and peak loads are significantly higher than during the summer months. Although magnitude of this increase cannot be observed in each of the sub regions. While in the urban region the difference in peak loads is about 20 % this is not true for the suburban regions where the difference can increase to up to 30 % or even 40 %. This effect can be the result of the additionally required electrical energy required for heat pumps, which traditionally are rather found in the rural and semi-urban regions. Apart from that difference, the energy demand – which can be retrieved from load profiles – increases with the amount of people living in the region.

4.1.4 Evaluation of the tool use

As stated above, the use of the tool is evaluated toward two criterions: usability and results.

Usability:
The general usability of the tool is satisfying. It was observed, that the most manual effort needs to be put into creating the raw data for the tools, especially for geo-referencing. With the first demonstration trials the error was made, that a substantial amount of buildings was

referenced to multiple areas, leading to multiple duplicates of buildings in the raw data. To prevent that from happening a raw data input routine was created.

After the raw data was created the effort of the user is limited to managing the tool, no further data manipulation is required. During the demonstration phase different errors in the operation of the tool were identified as erroneous calculations were spotted or errors in the code observed. Over multiple iterations, these errors were corrected, resulting in a smooth operation of the tool. At the end of the demonstration phase, the tool is in a state, where it can be offered to the operators in Weiz.

For other regions additional work would be necessary especially on the visualisation part, where currently only the areas of Weiz are visualised.

Results:
To check on the results, a limited set of data was used, and all calculations were made manually and with the tool. As the energy calculation tools were already validated in Deliverables 4.1 and 4.2 only the general operation in the demonstration mode was checked. By manually calculating the operation steps of the tool, certainty about the automatic calculation can be gained. As mentioned, a control calculation with a limited data set was made, leading to satisfying results.

4.2 Energy System Development

To core feature of the tool is the possibility of analysing the effects of substantial changes in the energy system. The changes can either be politically induced (by funding or prohibitions) or made through changes in the general attitude of the population. Regardless of the reason for a change, it is hard to fully comprehend, what effects such a change would have on the energy system, especially when it comes to a technology switch.

But understanding the effects of changes is crucial for reducing the long-term uncertainty in the energy system. Additionally, decision makers should have the necessary tools to provide them with the means to assess these effects in order to make profound and sustainable changes.

But not only long-term effects are of value, but also the imminent effects that these technology switches have on the dispatch at the generation side. As these technology switches often will lead to a systematic change, also for instance the load profiles are affected, leading to changing challenges for the energy dispatch.

To simulate this effect and test the functionality of the tool a scenario was defined in which the demonstrator Weiz will be faced with an extensive exchange of heating systems. For each building within the urban region of Weiz the existing heating system will be changed to district heating. This of course is by no means a sensible approach as the necessary infrastructure for such an approach is not available. For the rural region (Krottendorf) all heating systems are swapped for heat pumps of fitting size to satisfy the heat and warm-water demand. Again, this scenario is very unlikely to occur in reality. But since the purpose of this simulation run is to prove the functionality of the tool, it is not necessary to build a sensible scenario.

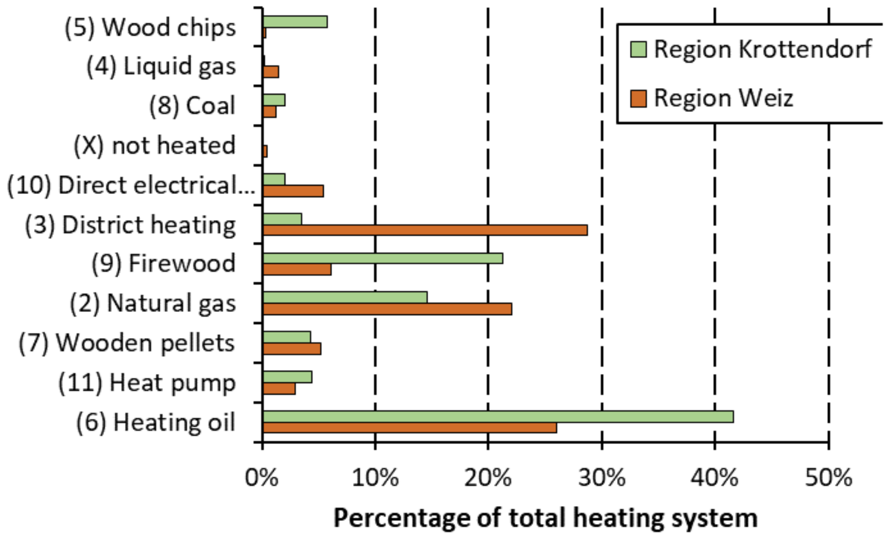


Figure 4-20:Distribution of heating systems in the base case scenario for the regions Krottendorf and Weiz

Figure 4-20 shows the distribution of the heating system in the different regions. The main conclusion, that can be drawn from the analysation is, that the urban area has a high share of district heating, heating oil and natural gas, while the rural region shows high shares of heating oil. Natural Gas and Firewood. This situation builds the baseline for the further analysation of the technology switch.

4.2.1 Effects on the energy consumption and CO_2 emissions

First off, the effects of the technology swap in the two regions on the annual energy consumption is investigated. As the tools state (see Deliverable 4.1 and 4.2) the energy consumption values shown consider the efficiency of the of the heating technologies, thus showing the energy contained in the fuel. This needs to be considered for the energy analysation as substantial parts of the total energy consumption are for heating and the heating energy demand depends on the building structure and not on the heating system. Whereas the energy contained in the fuel strongly depends on the heating system.

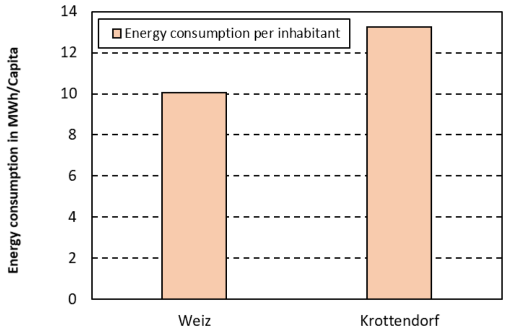


Figure 4-21: Total energy demand before the exchange of the heating system

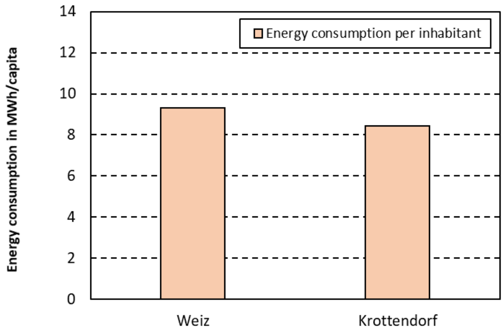


Figure 4-22: Total energy demand after the exchange of the heating system

The effects of the exchange of the heating system are investigated via the specific energy demand per capita. For the urban region "Weiz" the change is rather limited, dropping to approximately 93 % of its former value. The drop shows, that from an energy perspective district heating has a slightly better efficiency than the average heating system installed before the exchange. More effects are expected for the CO_2 emission.

A higher reduction of specific energy consumption can be found in the rural region (Krottendorf), which can easily be explained through the change to heat pumps. Heat pumps show a by far higher efficiency than the other heating systems and therefore result in this massive drop of energy consumption. In total a drop to 63 % of the original value can be seen.

An even stronger effect can be observed when looking at the CO_2 emissions reduction caused by the change in the heating system. For the urban region of Weiz the exchange towards district heating leads to a drop of around 0.5 t CO_2 equivalent per capita, which is around 27 % of the original value. This massive drop can easily be explained by the smaller specific CO_2 emission of district heating in t CO_2 / kWh in comparison to other heating systems. Before the change the unweighted average value was around 0.21 t CO_2 equivalent / kWh and goes down to 0.18 t CO_2 equivalent / kWh with the district heating system.

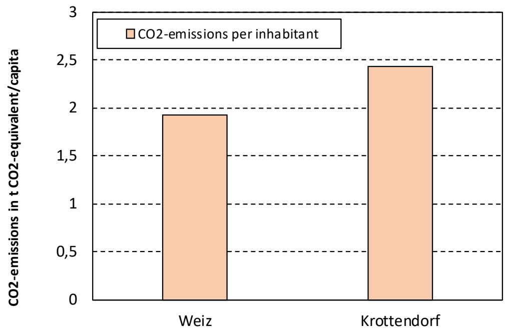


Figure 4-23: Specific CO_2 emissions before the exchange of the heating system

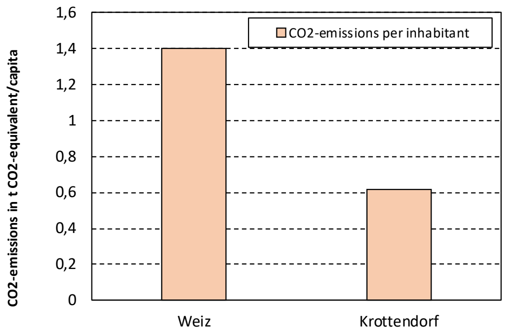


Figure 4-24: Specific CO_2 emissions after the exchange of the heating system

Even more drastic is the effect for the rural region, where the unweighted value of specific CO_2 emissions was around 0.2 t CO_2 equivalent / kWh and went down to 0.13 t CO_2 equivalent / kWh due to the changes toward heat pumps.

But changing the heating system also has follow up effects, as the electricity consumption increases and the load profile changes.

4.2.2 Effects on the load profiles

Changing the heating system in the region Krottendorf to an alternative system (heat pumps) lead to a high reduction of energy demand, as heat pumps have a higher efficiency than conventional heating systems. But they do use electricity to generate the heat thus leading to an added strain on the electricity grid. To investigate those sector coupling effects, the DESENT energy tool box is capable of calculating the electricity load profiles after the exchange and comparing them to the ones before the exchange. Figure 4-25 to Figure 4-29 show examples of the effects on the load profiles.

Apart from the fact that exchanging all heating systems for heat pumps isn’t the least bit feasible, the effects on the electricity system would be tremendous. The electricity consumptions rises significantly as all buildings would generate their heat with electricity. This would result in a enormous increase of the peak load by the factor 3 to 4, which would result in a very strong stress on the electricity grid.

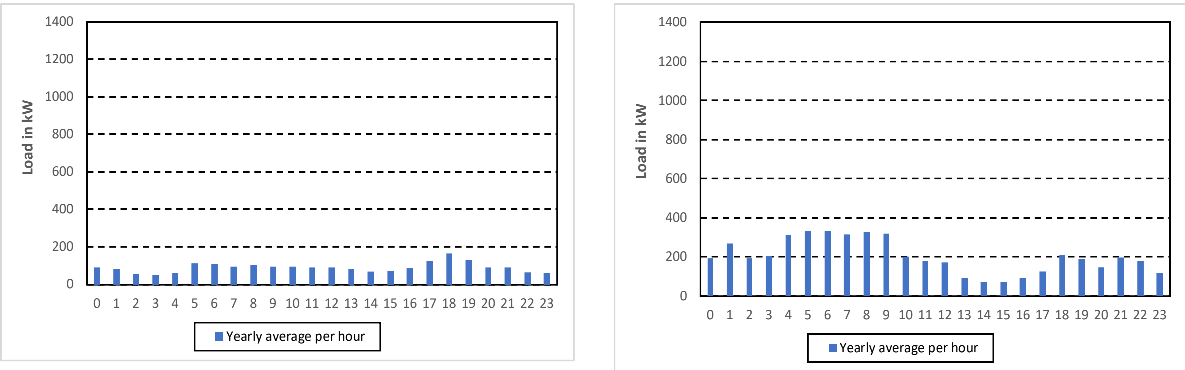


Figure 4-25: Change in the average load profile in the region Preding Nord

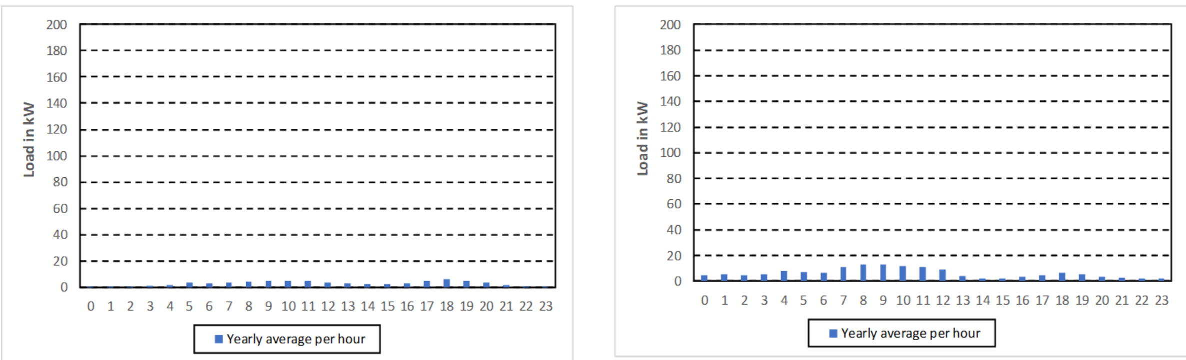


Figure 4-26: Change in the average load profile in the region Preding Süd

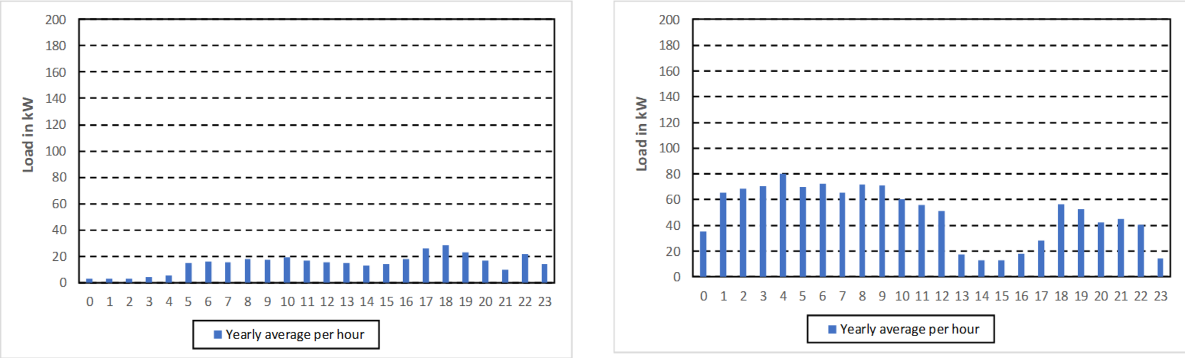


Figure 4-27: Change in the average load profile in the region Regersstätten

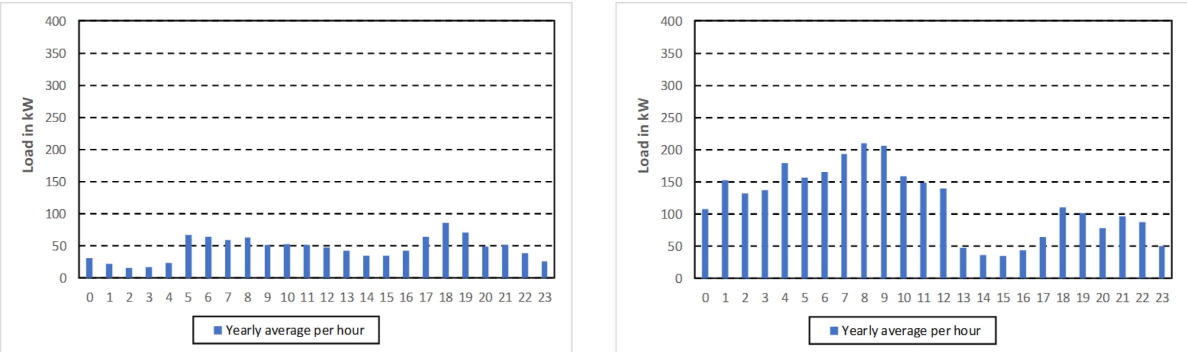


Figure 4-28: Change in the average load profile in the region Nöstl

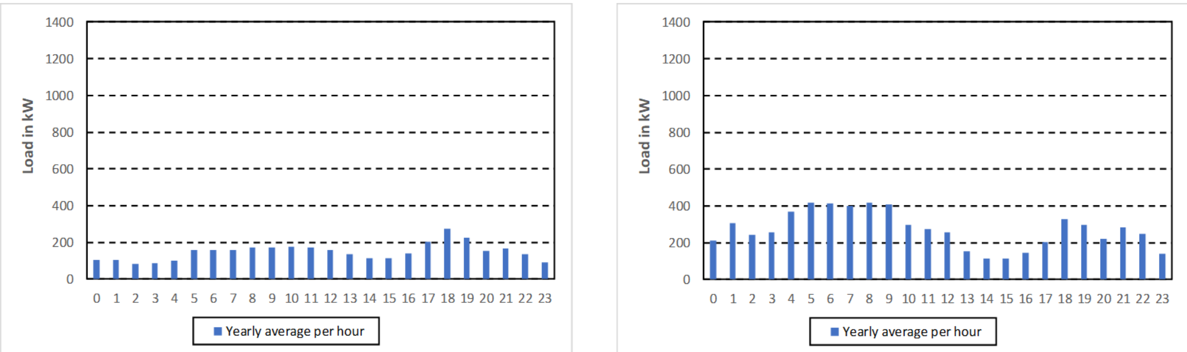


Figure 4-29: Change in the average load profile in the region Krottendorf West

These results show clearly, that while it might seem like a good idea to exchange elements of the system for seemingly preferable technical solutions there can be substantial drawbacks. These effects, or the magnitude of these effects could very likely surpass what would have been expected. These results clearly indicate the value of such a tool, as it relatively easy highlights such effects, which wouldn't have been visible beforehand.

4.2.3 Evaluation of the tool use

As stated above, the use of the tool is evaluated toward two criterions: usability and results.

Usability:
The usability of the tool is satisfactory, making the changes to the energy systems work self-explanatory. The results are stored in a way that they can easily be re-accessed throughout the procedure. Due to relatively long operation time, there is some optimisation potential in that, it is advisable to change make the changes at the lowest possible resolution.

Another limitation was observed: If the user wants to change multiple things within the energy system of the demonstration region, it is necessary to change one thing at a time, leading to multiple calculations being necessary. This process is rather time consuming, especially when chains of changes are required. The positive effect of calculating one change at a time is, that the changes can be reinvestigated and followed step by step. A possible update for the tool would be to let the user fabricate a chain of changes and simulate them simultaneously rather than iteratively.

Another critical point that was observed during demonstration operation is the evaluation of the load profiles. Generating the load profiles takes up quite some time and uses a lot of RAM as large amounts of data are being processed. As the load profile generation takes different devices in buildings into account, the product of "number of devices" x "amount of buildings" of load profiles is generated, each of them having single 35.040 entries. This bring the software Excel to its limits leading to several crashes during operation. This problem was assessed during the demonstration phase and the risks of crashes limited. Nevertheless, crashes still occurred from time to time.

Aside from these problems, which where partially solved, the tool works very well and smoothly for a region the size of Weiz. For bigger cities with more buildings it would be advisable to change the software and work with a software capable of handling the large amount of data.

Results:
To check the results of the tool a small set of data was used again and each step along the way of changing the technology in the energy system was controlled by hand. Starting from the overwriting of the data and checking whether the new data entries are correctly set to the results themselves.

As a conclusion the tool made the correct steps and the tests have proven that it is working properly.

4.3 Optimization of the own consumption

A more sophisticated part of the tool has the focus on the use of flexibilities. As described in the Deliverable D7.1 one approach to using these flexibilities is for own consumption increase. The issue with feeding surplus into the grid is, that you only get very limited compensation for this surplus feed in, ranging from 3.0 and 10.0 Cent/kWh[7]. In opposition, the costs for electricity

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[7] Selectra Österreich GmbH (2017): Der Strompreis in Österreich, https://stromliste.at/impressum, abgerufen am 04.09.2017

consumption currently range from 18.0 to 22.9 Cent/kWh[8], which clearly shows, that using one's own consumption is preferable to feeding it into the grid. To optimize the own consumption ratio, the operation cycles of flexible household devices as well as electrical heating and hot water production are shifted to time slots with a PV-generation surplus. Washing machines, dishwasher, fridges and freezers are considered as flexible household devices. All other household devices are considered as not flexible and can therefore not be shifted within the optimization process. Moreover, the tool can also take the charging of electrical vehicles into account. Due to the fact that no reliable information about electrical vehicles and their driving behaviour was available for the considered region, no electrical vehicles are considered in these calculations. The maximum shifting times, according to different studies, are explained in Deliverable 5.2. As the times are significantly varying between the studies, a few scenarios with different maximum shifting times are calculated.

The calculations are carried out with the data of the region of urban Weiz (excluding Krottendorf). For modelling the producer, the production profile of a photovoltaic plant is used. The peak production of the plant is varied between 0.5 and 1.5 times of the peak load demand of all consumers (flexible and not flexible). The not flexible demands are subtracted from the PV-production and only the remaining part (if existing) is used as production surplus for the optimization. A detailed description of the optimization procedure and the underlying assumptions is available in Deliverable 5.2.

4.3.1 Scenario 1a: Peak PV production = Peak load - short maximum shifting times

In Scenario 1 the peak PV production is chosen the same as the peak load of the sum of all consumers in the urban area of Weiz. For that region this would correspond to PV plants with a total peak production of about 13 300 kWp. The chosen maximum shifting times, shown in Table 1, are set within the lower values found in the literature.

Table 1: Maximum shifting times scenarios A

Demand type	maximum shifting time	
Dishwasher	6	h
Washing machine	8	h
Fridge	30	min
Freezer	30	min
electrical heating	120	min
electrical hot water preparation	100	min

[8] Selectra Österreich GmbH (2017): Der Strompreis in Österreich, https://stromliste.at/impressum, abgerufen am 04.09.2017

The maximum shifting time is the time, the operation cycle of a single device can maximally be shifted either to an earlier or to a later point of time. If the cycle time of a device is smaller than the maximum shifting time, the maximum shifting time is reduced accordingly, so no overlapping can occur.

In Figure 4-30 a characteristic winter day for the scenario 1a is shown. The PV production is much smaller than the non-flexible demands. Therefore, no optimization is possible for this day and in case of the scenario 1a for the most other days in winter too. The high peaks of electricity demand during the night time is due to direct electrical heating occurring in that window.

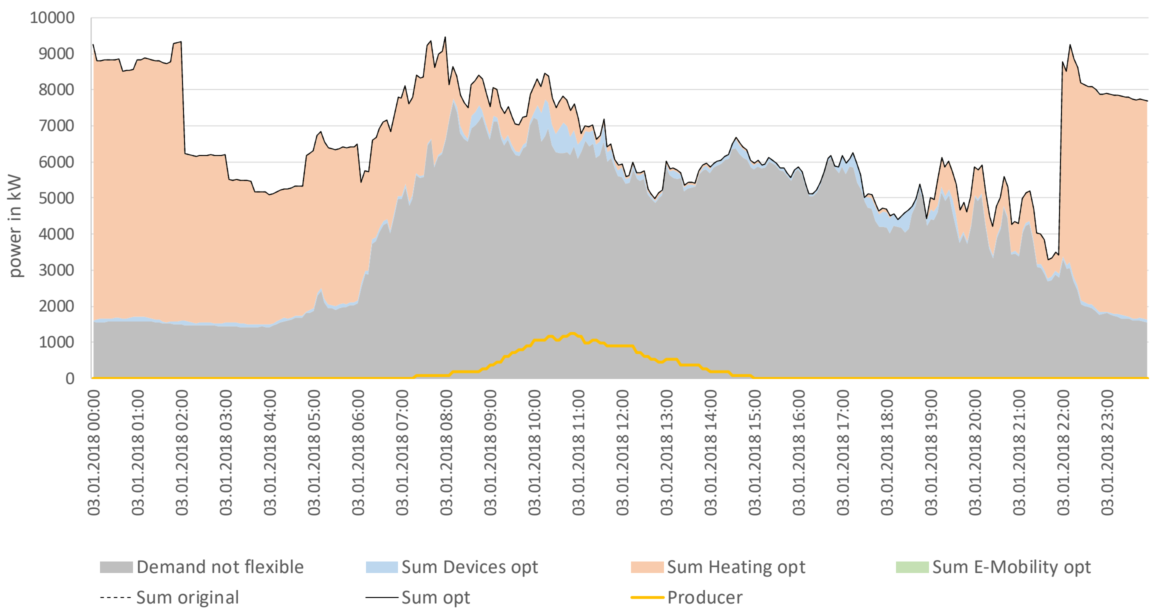

Figure 4-30: Example of a winter day in Scenario 1a

In contrast to Figure 4-30, in Figure 4-31 a characteristic summer day is shown. On this day a significant PV surplus is available for the optimization. However, the flexible demands are much smaller than during winter times. This difference mostly relates to the heating energy which makes up the largest part of the flexible demands in Weiz. Therefore, the availability of PV surplus and the amount of shiftable energy is contrary. Nevertheless, a significant increase of the coverage of the flexible demands can be achieved.

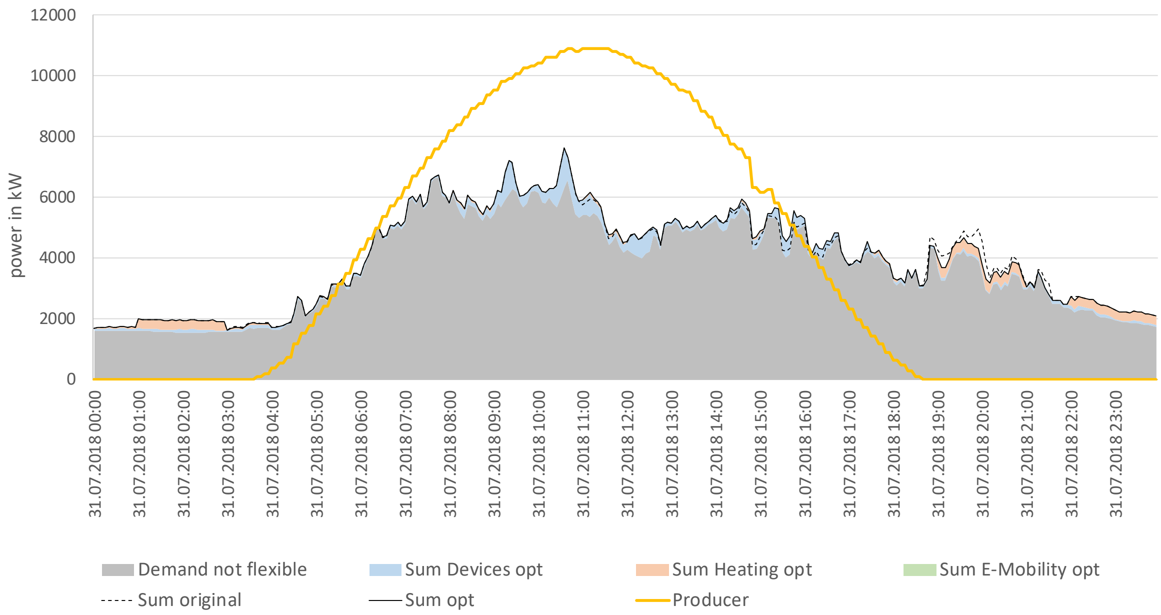

Figure 4-31: Example of a summer day in Scenario 1a

In Figure 4-32 the same day without non-flexible devices is shown. This makes it easier to see the difference caused by the shifting. The dotted line represents the total flexible demands before the shifting and the solid line the result after the shifting. In this example a lot of the flexible household demands (blue) have already been covered from the PV surplus before the shifting. But it is also seen that some devices are shifted from around 8 pm to an earlier point of time so that they are covered after the shifting.

In case of the hot water preparation (red) the maximum shifting times are with 100 min too short to shift them to times with a PV surplus. We will see the difference in scenario 1b, when a maximum shifting time of 18 h is used for heating and 11 h for hot water preparation.

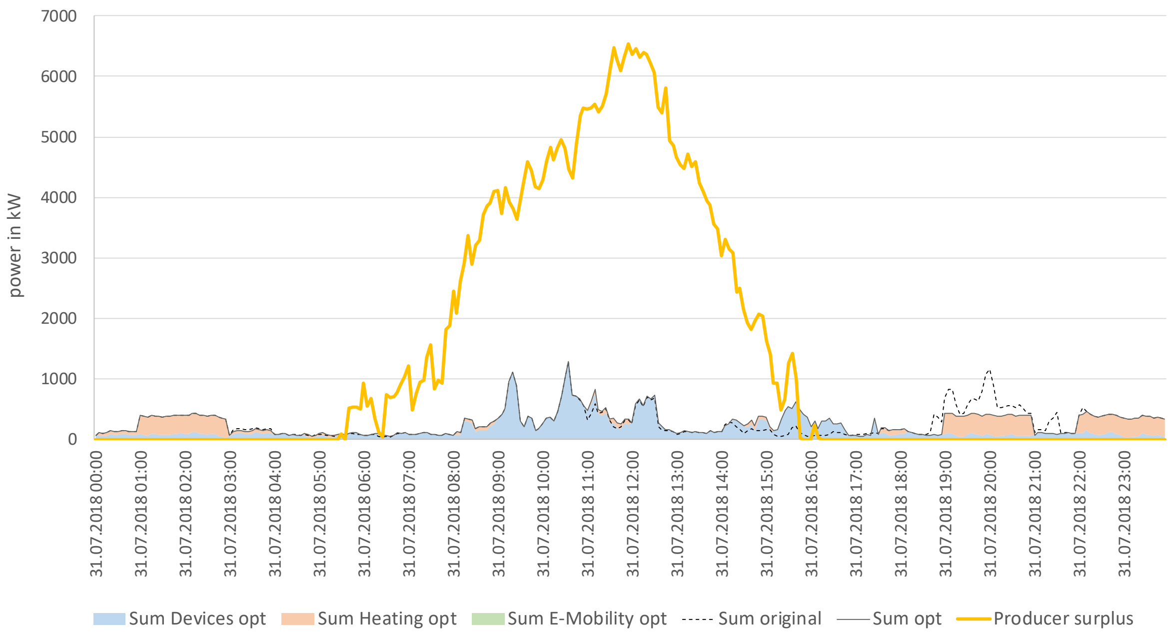

Figure 4-32: Example of a summer day without not flexible demands in Scenario 1a

The results of the optimization are shown in Table 8. The amount of covered flexible energy is increased from 444 MWh/a to 695 MWh/a what makes an increase of 56.6 %. Considering the total energy consumption and not only the flexible part of it, an increase of 2.2 % is reached. Regarding the self-coverage this means an increase from 27.8 % to 28.4 %. The own-consumption ratio can be increased from 76 % to 77.7 %. The equations (1)- (4) are used to calculate the effects of the optimization.

Table 2: Results of the scenario 1a

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	444	MWh/a
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	695	MWh/a
Increase flexible (1)	**56,6**	**%**
Coverage all demands original ($Q_{cov\_tot\_orig}$)	11322	MWh/a
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	11573	MWh/a
Increase total (2)	**2.2**	**%**
Self-coverage original (3)	**27.8**	**%**
Self-coverage optimized (3)	**28.4**	**%**
Own-consumption ratio original (4)	**76.0**	**%**
Own-consumption ratio optimized (4)	**77.7**	**%**

The variable *Increase flexible* calculates the percentage increase of the covered flexible energy amount related to the original coverage of the flexible energy amount

$$\textit{Increase flexible} = (Q_{cov\_flex\_opt} - Q_{cov\_flex\_orig}) / Q_{cov\_flex\_orig}$$ with: $Q_{cov\_flex\_opt}$: Amount of self-covered flexible energy with optimization in kWh $Q_{cov\_flex\_orig}$: Amount of self-covered flexible energy without optimization in kWh	**(1)**

The variable *Increase total* also calculates the percentage increase but related to the total (flexible + non-flexible) covered energy amount.

$$\textit{Increase total} = (Q_{cov\_tot\_opt} - Q_{cov\_tot\_orig}) / Q_{cov\_tot\_orig}$$ with: $Q_{cov\_tot\_opt}$: Amount of self-covered energy with optimization in kWh $Q_{cov\_tot\_orig}$: Amount of self-covered energy without optimization in kWh	**(2)**

The self-coverage is a common indicator to evaluate PV-systems. It is the ratio between the self-used PV energy and the total energy demand.

Self-coverage = $Q_{cov\_tot\_orig/opt} / Q_{demand\_tot}$ with: $Q_{cov\_tot\_orig/opt}$: Amount of self-covered energy with/without optimization in kWh Q_{demand_tot}: Total energy demand (flexible + non-flexible) in kWh	**(3)**

While the resulting numbers are rather limited, an increase of 2.2 % in self-coverage is not much. But that is mostly due to the fact, that the installed PV capacity is limited and during times where a lot of flexibility is available, little is used.

The own-consumption ratio is the ratio of the total covered energy to the total PV production and is therefore an indicator of the amount of directly used energy. The rest of the PV production has to be fed in to the public gird as no storage solutions are considered in the calculations.

Own consumption ratio = $Q_{cov\_tot\_orig/opt} / Q_{PV}$ with: $Q_{cov\_tot\_orig/opt}$: Amount of self-covered energy with/without optimization in kWh Q_{PV}: Total energy production of the PV plant in kWh	**(4)**

4.3.2 Scenario 1b: Peak PV production = Peak load - large maximum shifting times

The scenario 1b differs from the scenario 1a only in the chosen maximum shifting times. As can be seen from the results, the maximum shifting times have a big influence on the achievable improvement. In this scenario relatively large maximum shifting times are allowed, as shown in Table 3. For example, the hot water preparation can now be shifted for 11 h instead of 100 min and the shifting times for dishwashers and washing machines are increased to 24 h. These maximum shifting times are valid for all scenarios called "b" (1b, 2b and 3b).

Table 3: Maximum shifting times scenarios B

Demand type	maximum shifting time	
Dishwasher	24	h
Washing machine	24	h
Fridge	1	h
Freezer	1	h
electrical heating	18	h
electrical hot water preparation	11	h

For the winter time the same results than in scenario 1a occurs. There is no PV surplus available for the optimisation which is why the maximum shifting times does not matter.

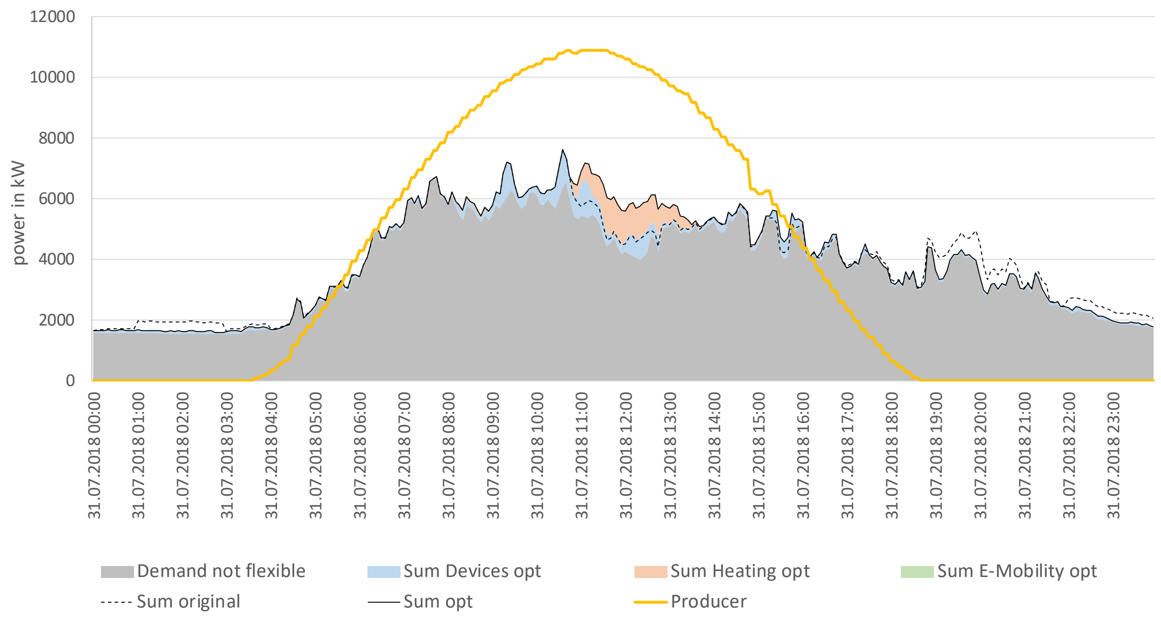

Figure 4-33: Example of a summer day in Scenario 1b

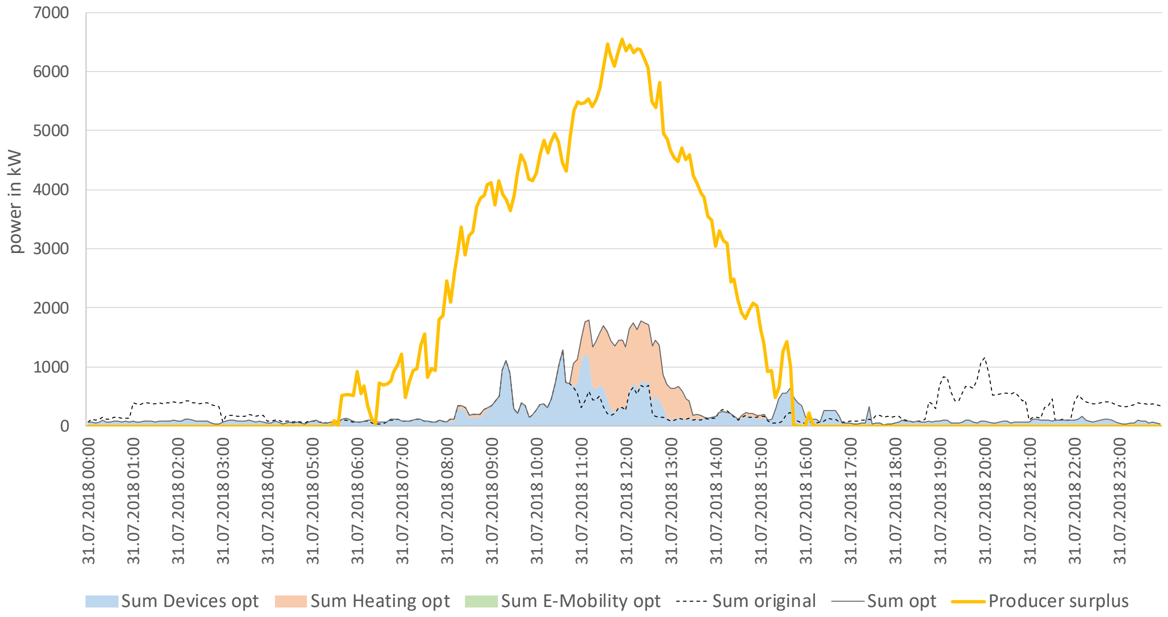

Figure 4-34: Example of a summer day without not flexible demands in Scenario 1b

In Figure 4-33 and Figure 4-34 the same characteristic summer day (31.07.2018) is shown as in scenario 1a. In this case the maximum shifting times have an influence on the results. In contrast to the scenario 1a now all hot water preparation cycles are shifted to times with a PV surplus. Moreover, the most household devices are shifted too. The remaining part of not shifted flexible household devices corresponds to fridges and freezers which are limited in their shifting times. Some of them with shorter times than the maximum shifting time because of operation cycles of only a few minutes.

The results for one year are shown in Table 4. The increase of the flexible demands is with 172.3 % much higher than in scenario 1a (56,6 %). The same applies for the total covered energy increase of about 6.8 % now. This is mainly the result of the lager shifting times for the heating demands. As shown in Figure 4-30, the most electricity for heating and hot water preparation is needed during the night hours, because the cheaper off-peak electricity is used. However, the off-peak electricity is not cheaper than the own consumption of PV-power. Therefore, the shifting of this demands makes sense but can only done if the maximum shifting times are chosen large enough. It can be assumed, that a shifting time of 11 h for hot water preparation should not be a problem for most of the systems, but as there are so many different heating system (with different storage sizes and so on), it is very difficult to name a universal maximum shifting time.

Table 4: Results of the scenario 1b

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	444	MWh
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	1209	MWh
Increase flexible (1)	**172.3**	**%**

Coverage all demands original ($Q_{cov\_tot\_orig}$)	11322	MWh
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	12087	MWh
Increase total (2)	**6.8**	%
Self-coverage original (3)	**27.8**	%
Self-coverage optimized (3)	**29.6**	%
Own-consumption ratio original (4)	**76.0**	%
Own-consumption ratio optimized (4)	**81.2**	%

*4.3.3 Scenario 2a: Peak PV production = 0.5 * Peak load - short maximum shifting times*

In scenario 2 half installed PV-capacity is used. The scenario is again calculated twice, once with short (2a) and once with long maximal shifting times (2b). In Figure 4-35 a winter day is shown. As expected, there is no PV surplus during this time in scenario 2.

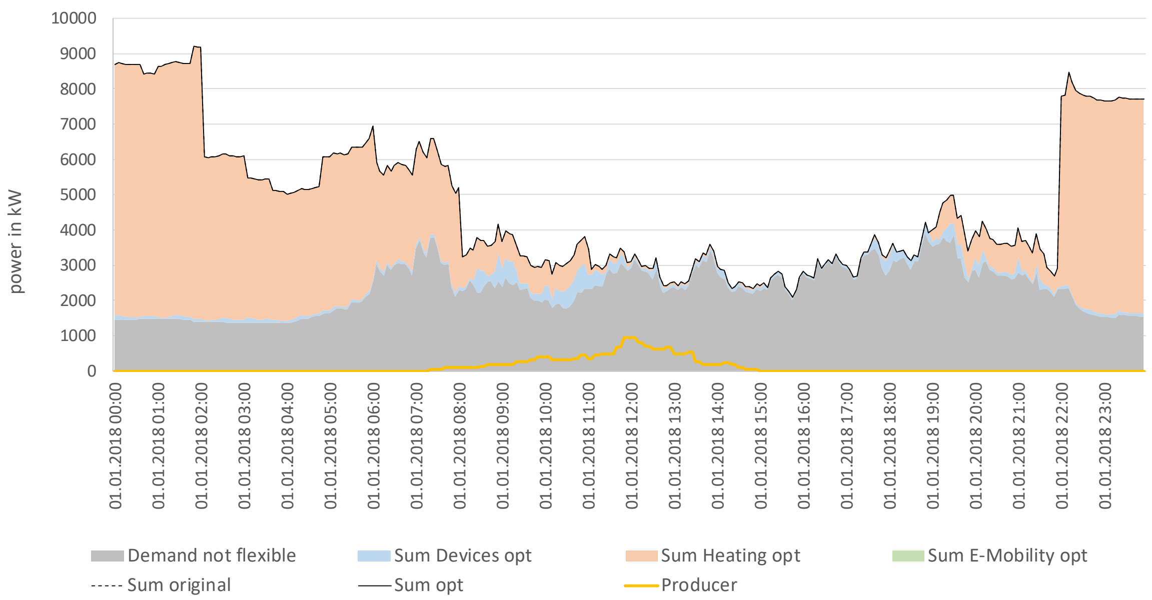

Figure 4-35: Example of a winter day in Scenario 2a

More interesting for the optimization is the summer time, shown in Figure 4-36. Even during this time there is only a small surplus available for the optimization. As the example represents a sunny day in July, there are only a few days with a PV surplus in scenario 2, this is due to the limited installed capacity. On the example day, this surplus can be covered completely with flexible demands.

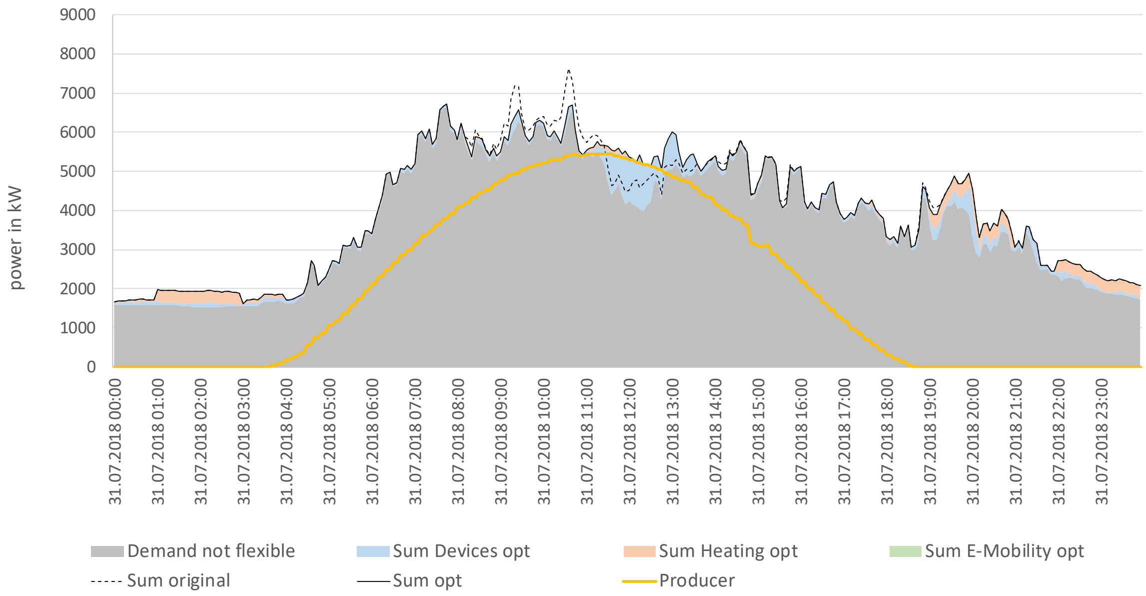

Figure 4-36: Example of a summer day in Scenario 2a

The details of the shifting are shown in Figure 4-37. It is obvious that in on this day, not all flexible devices could be shifted because of the small surplus. Nevertheless, the shifting of the loads has a positive effect on the own consumption rate.

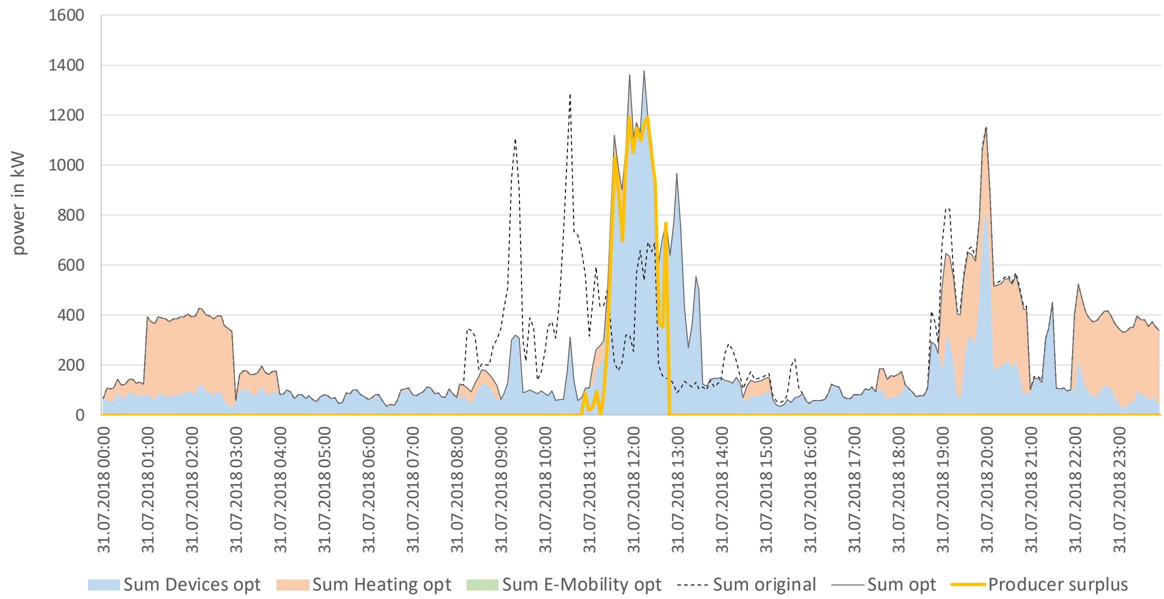

Figure 4-37: Example of a summer day without not flexible demands in Scenario 2a

The results are shown in Table 5. In comparison to scenario 1 the total increase of covered energy is about 1 % smaller (Total increase in scenario 1: 2.2 %). Therefore, half the installed

PV-capacity results in approximately half the potential increase of covered energy, with this basic data. The percentage increase of the covered flexible demands is even bigger in scenario 2, but this is the result of the originally already very small coverage of flexible demands.

The already high own-consumption of 97.1 % shows clearly, that there is not a lot surplus energy available in this scenario for shifting. However, an increase of 0.9 % to an own consumption ratio of 98 %can be achieved.

Table 5: Results of the scenario 2a

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	93	MWh
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	162	MWh
Increase flexible (1)	**74.9**	**%**
Coverage all demands original ($Q_{cov\_tot\_orig}$)	7229	MWh
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	7299	MWh
Increase total (2)	**1.0**	**%**
Self-coverage original (3)	**17.7**	**%**
Self-coverage optimized (3)	**17.9**	**%**
Own-consumption ratio original (4)	**97.1**	**%**
Own-consumption ratio optimized (4)	**98.0**	**%**

*4.3.4 <u>Scenario 2b:</u> Peak PV production = 0.5 * Peak load - large maximum shifting times*

Scenario 2b uses the large maximum shifting times, shown in Table 3. In contrast to scenario 1 the shifting times have a smaller influence on the results. Especially on the example day, shown in Figure 4-38 and Figure 4-39, this is true. On this day clearly the small PV surplus is the dominant limiting factor.

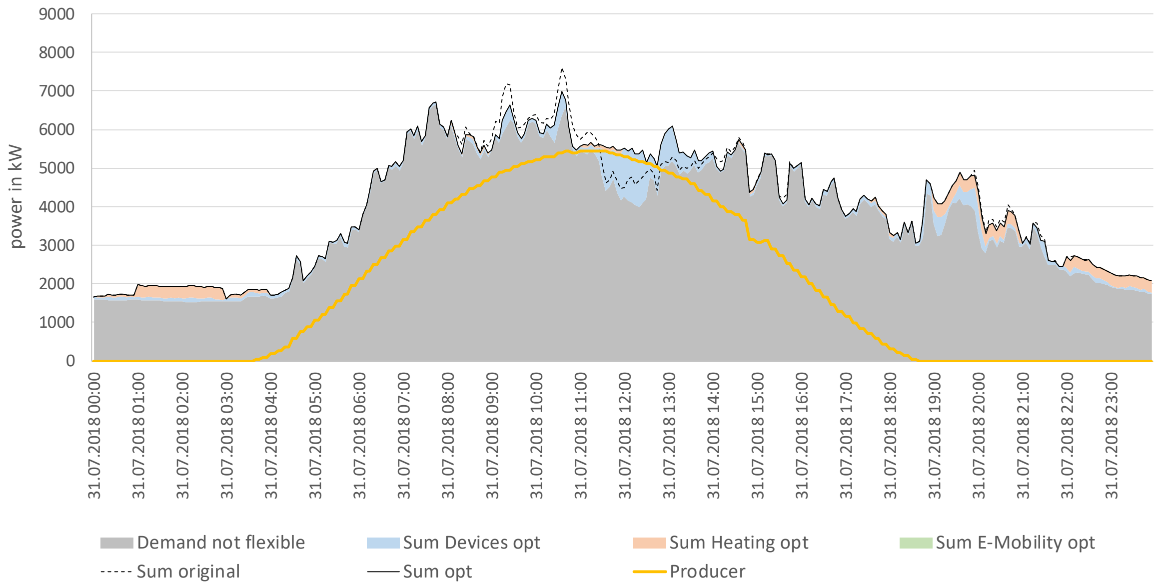

Figure 4-38: Example of a summer day in Scenario 2b

Figure 4-39 shows in detail, that it does not have a major impact if the heating demands can be shifted or not. The surplus can already be covered with the demand of the flexible household devices. The comparison of the detail of scenario 2a (Figure 4-37) and scenario 2b shows that the result (for this day) is quite similar.

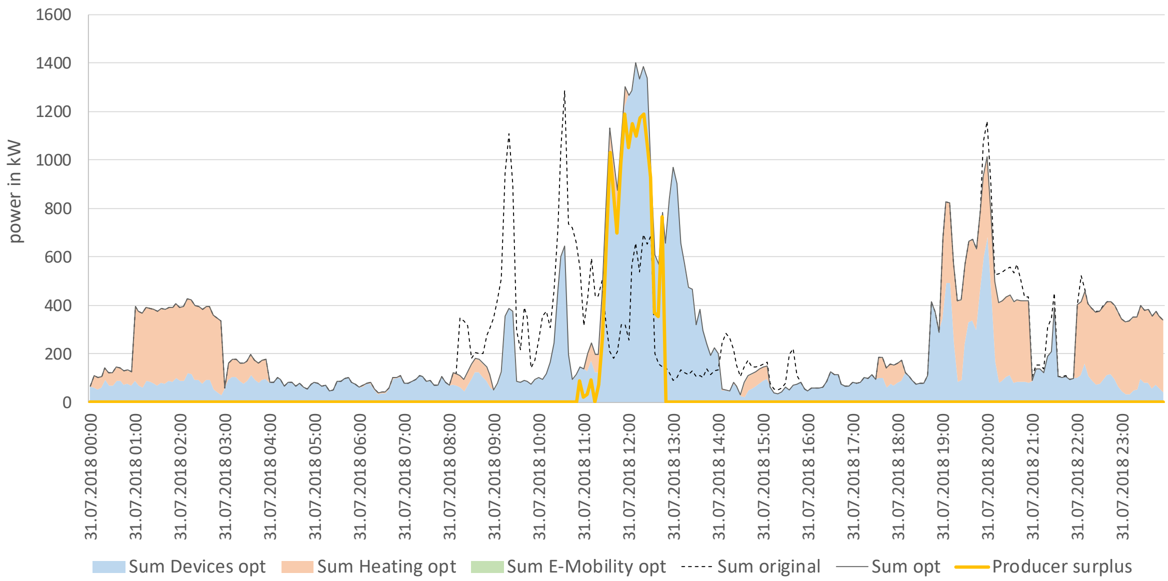

Figure 4-39: Example of a summer day without not flexible demands in Scenario 2b

Table 6 shows the results for scenario 2b for one year. Even if the increase in total numbers is smaller in scenario 2 than in scenario 1, a notable improvement can be reached with the optimization. Also, between scenario 2a and 2b there is a bigger difference than the example day would indicate. At the end, both, the PV surplus and the shifting times, have a major impact on the final result.

Table 6: Results of the scenario 2b

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	93	MWh
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	245	MWh
Increase flexible (1)	**164.8**	**%**
Coverage all demands original ($Q_{cov\_tot\_orig}$)	7229	MWh
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	7382	MWh
Increase total (2)	**2.1**	**%**
Self-coverage original (3)	**17.7**	**%**
Self-coverage optimized (3)	**18.1**	**%**
Own-consumption ratio original (4)	**97.1**	**%**
Own-consumption ratio optimized (4)	**99.1**	**%**

*4.3.5 Scenario 3a: Peak PV production = 1.5 * Peak load - short maximum shifting times*

Scenario 3 is calculated with the assumption of an increased installed PV capacity (1.5 * peak load of the devices). In Figure 4-40 it is shown that even the higher PV production is not high enough to enable a PV surplus on the example winter day. But it is also shown, that only a little more PV-energy (or a smaller demand) would be enough to gain a surplus. Therefore, it can be assumed, that there is a much higher number of days with a surplus than in the other scenarios.

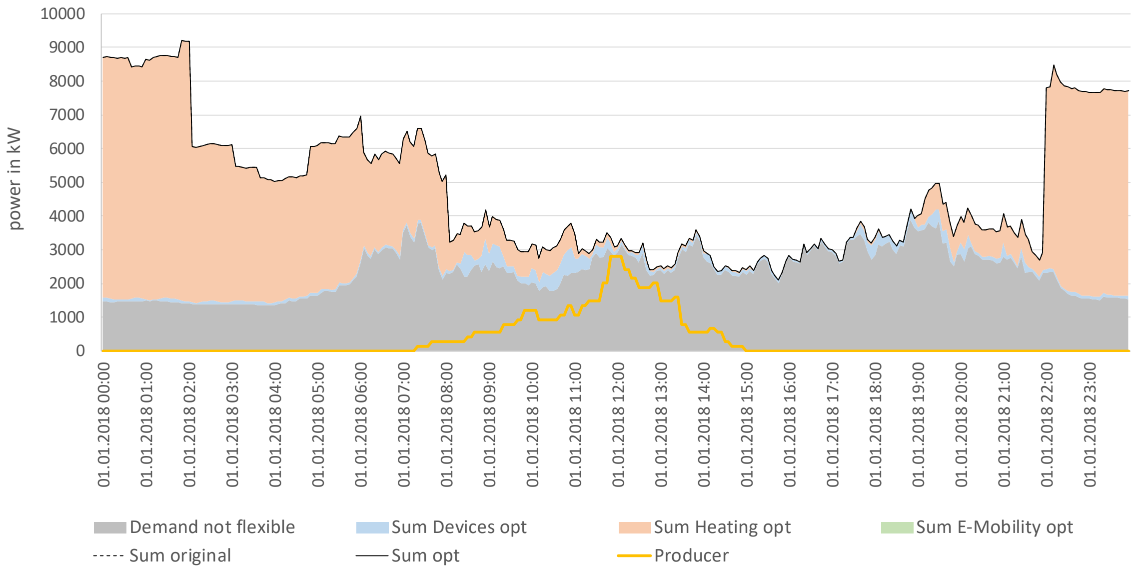

Figure 4-40: Example of a winter day in Scenario 3a

The example day for summer, illustrated in Figure 4-41. Figure 4-42, shows a very high PV-surplus for this time. In this time the only limiting factor for increasing the own consumption is the maximum shifting time.

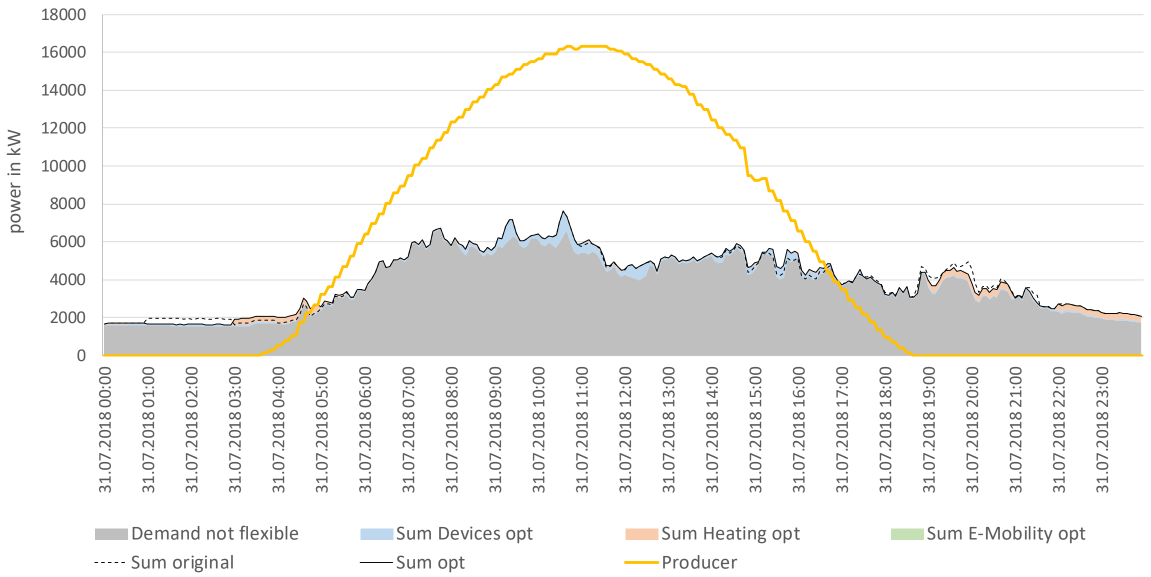

Figure 4-41: Example of a summer day in Scenario 3a

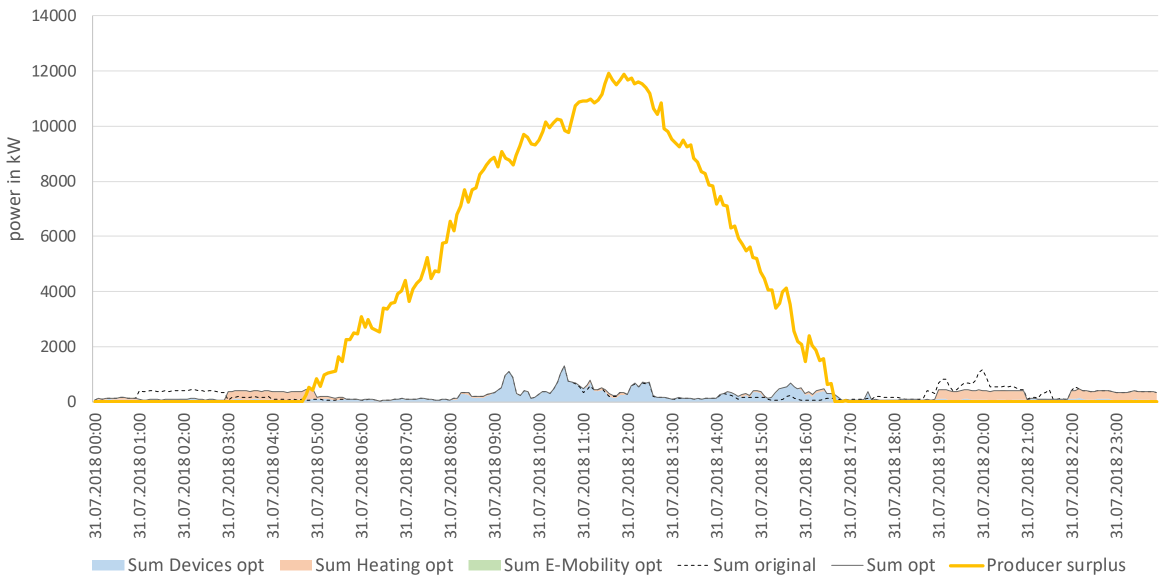

Figure 4-42: Example of a summer day without not flexible demands in Scenario 3a

The higher PV-production, which results in a higher PV-surplus, has a positive impact on the optimization potential of the shifting procedure. The total increase of covered energy makes 2.8 %, by already considering the high base coverage because of the larger times with surplus.

The self-consumption can be increased from 33 % to 33.9 %. The own-consumption ratio can be increased too (from 60.2 % to 61.8 %), but it is also shown that the own-consumption ration (not the increase!) is already much smaller than in scenario 1 & 2.

Table 7: Results of the scenario 3a

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	685	MWh
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	1058	MWh
Increase flexible (1)	**54.3**	**%**
Coverage all demands original ($Q_{cov\_tot\_orig}$)	13442	MWh
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	13814	MWh
Increase total (2)	**2.8**	**%**
Self-coverage original (3)	**33.0**	**%**
Self-coverage optimized (3)	**33.9**	**%**
Own-consumption ratio original (4)	**60.2**	**%**
Own-consumption ratio optimized (4)	**61.8**	**%**

*4.3.6 Scenario 3b: Peak PV production = 1.5 * Peak load - large maximum shifting times*

Scenario 3b is the one with a high PV production and with large maximum shifting times. In comparison with scenario 3a also the heating demands which occurs during night-time can be shifted to times with a PV-surplus. This is shown in Figure 4-43 with and in Figure 4-44 without non-flexible energies.

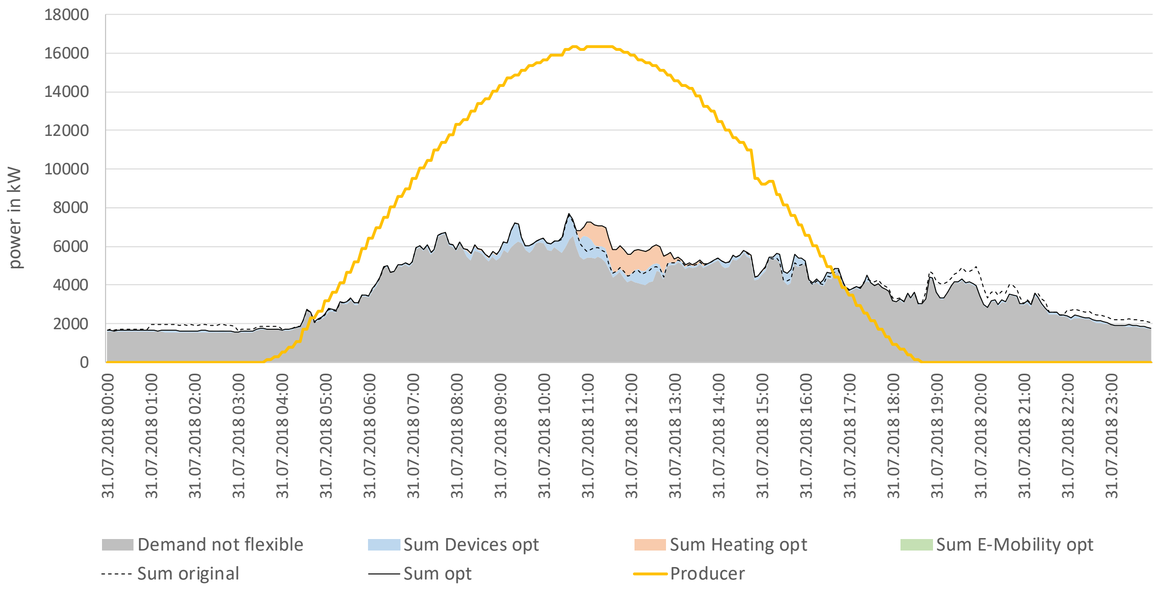

Figure 4-43: Example of a summer day in Scenario 3b

Figure 4-44 shows in detail, that on the example summer day nearly all flexible energy demands can be shifted to times with a PV-surplus, due to the relatively large shifting potentials. For this day a higher PV-production would have hardly any positive influence on the shifting result anymore. What does not mean that there is no positive influence on the yearly shifting result or on the total coverage.

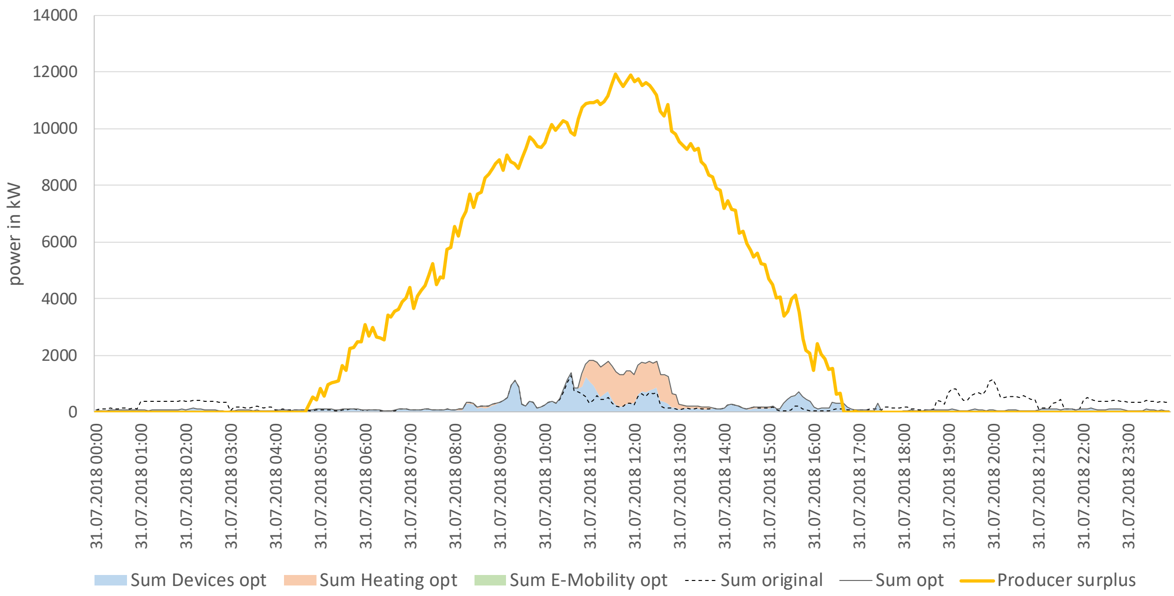

Figure 4-44: Example of a summer day without not flexible demands in Scenario 3b

The results of the scenario 3b are shown in Table 8. Because of the good framework conditions, the highest self-consumption of 36 % can be reached within this scenario. Moreover, the increase of the total coverage is with 9.1 % also quite high.

Table 8: Results of the scenario 3b

Coverage flexible demands original ($Q_{cov\_flex\_orig}$)	685	MWh
Coverage flexible demands optimized ($Q_{cov\_flex\_opt}$)	1913	MWh
Increase flexible (1)	**179.1**	**%**
Coverage all demands original ($Q_{cov\_tot\_orig}$)	13442	MWh
Coverage all demands optimized ($Q_{cov\_tot\_opt}$)	14670	MWh
Increase total (2)	**9.1**	**%**
Self-coverage original (3)	**33.0**	**%**
Self-coverage optimized (3)	**36.0**	**%**
Own-consumption ratio original (4)	**60.2**	**%**
Own-consumption ratio optimized (4)	**65.7**	**%**

Conclusion

In Figure 4-45 the results of the own consumption ratio optimization are summarized. On the horizontal axis the relation between the peak PV load and the peak demand is illustrated in the range between zero and four. A relation of zero means that there is no PV plant installed and a relation of four that the PV peak power is four times as high as the peak demand. On the left side the covered energy in MWh is shown and on the right sight the improvement in percent. The green line indicates the total covered energy (flexible + non-flexible), the blue line the self-consumption (3),the orange one the total increase of the coverage (2) and the red line the own-consumption (4). The bold lines stand for the original result without an optimization, the broken line for the optimization with small maximum shifting times and the dotted line for the optimization with large maximum shifting times.

Considering the improvement of covered energy in general (green line) compared to the PV-peak production, it is shown that the covered energy is of course rising with a higher PV-peak power. First for a peak PV load to peak demand ratio between 0 and 0.75 it is rising approximately linear. After that it starts to rise less steeply. That means that the increase of the PV size has the biggest impact on the self-coverage in the range between 0 and 0.75, what also means, that an investment in this range is the most economic.

The own consumption in contrast is decreasing with a higher PV load, what means that the energy surplus is increasing. A lower own consumption goes therefore hand in hand with a higher optimization potential.

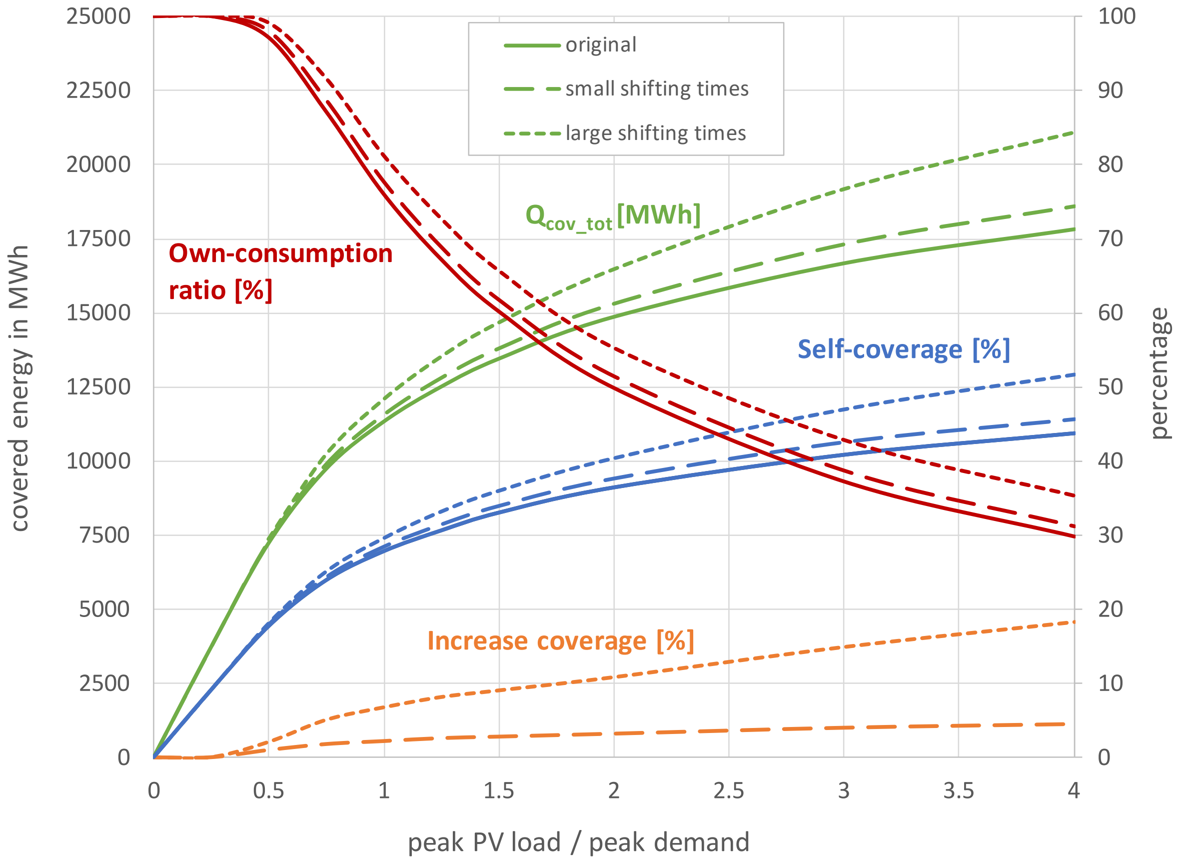

Figure 4-45: Summary of the results of the optimization process

The improvement of the optimization is therefore bigger at higher peak PV load to peak demand ratios. This is also shown in detail in Figure 4-46. The green area illustrates the possible range which is achievable with different maximum shifting times. The lower border marks the results with small (Table 1) and the upper border with large maximum shifting times (Table 3). For a ratio between 0 and 0.5 the optimization has hardly any impact, because the PV production is nearly completely used to cover the non-flexible demands and there is no PV-surplus for the optimization available. After this at a ratio of about 0.5 the additionally covered energy is growing approximately linear. As the gradient is higher for the large maximum shifting times, the maximum shifting times are getting more and more important at higher ratios.

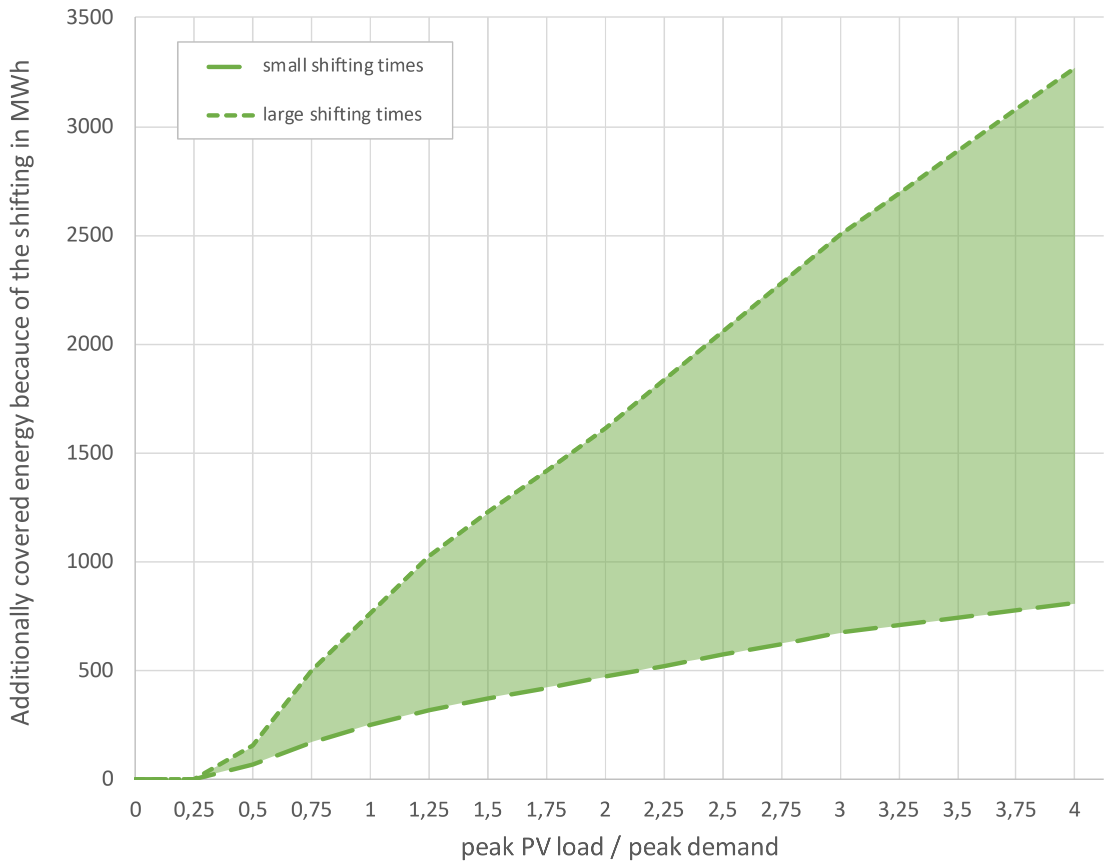

Figure 4-46: Increase of the used PV-generation because of the optimization (shifting) process

4.4 Compensation of forecast uncertainties

The second major application of the model is to simulate how flexibilities, as services provided to the energy system operator can reduce the uncertainty through forecasts. Vice-Versa, the results of the model-operation will indicate how improved predictions can lead to a reduction in uncertainty.

The basic principle is similar to the optimisation of the own consumption ratio but instead of the profile of a (renewable) energy source, a profile of forecast uncertainties or forecast errors is used. By shifting the flexible demands, the deviations caused by the uncertainties should be minimized. It has to be kept in mind, that only flexible demands which are located at a negative deviation can be shifted because all others would cause an unwanted positive deviation instead.

Since no measured values of the uncertainties are available the model implicates a Monte Carlo Approach. Two analysis are carried out. One for the photovoltaic and one for the demand forecast uncertainty compensation. The normal deviation for the PV-forecast uncertainty compensation was selected with 22 % and the for the demand uncertainty compensation with 9.23 %.

For the evaluation of the reached improvements, two indicators are chosen. One is the energy deviation, which means the sum of the absolute deviation, and one is the mean absolute power deviation, which is an indicator for the size of the power peaks. The difference between the original and the optimized situation is called EI (1) for the energy improvement and PI (2) for the improvement of the size of the power peaks.

$$EI = \sum \left(\frac{\left|\dot{Q}_{dev_{orig}}\right| - \left|\dot{Q}_{dev_{opt}}\right|}{\left|\dot{Q}_{dev_{opt}}\right|} \right) * 100 \qquad (3)$$

$\dot{Q}_{dev\_orig}$ energy deviation in kW before the optimization process

$\dot{Q}_{dev\_opt}$ energy deviation in kW after the optimization process

$$PI = \left(\frac{mean\left(\dot{Q}_{dev_{orig}} \neq 0\right) - mean\left(\dot{Q}_{dev_{opt}} \neq 0\right)}{mean\left(\dot{Q}_{dev_{orig}} \neq 0\right)} \right) * 100 \qquad (4)$$

A detailed explanation of the working procedure of the model as well as the chosen framework conditions is available in Deliverable 5.2.

4.4.1 Photovoltaic forecast uncertainty compensation

The photovoltaic forecast uncertainty compensation was carried out with the assumption of a peak PV production of 1.5 times the peak load. A higher PV peak production comes across with higher absolute deviations, but also with a higher optimization potential. The maximum shifting times, shown in Table 9, have been chosen approximately in the middle of the values found in different literature. In course of the Monte Carlo approach about 250 runs have been carried out, which is a rather limited number for a Monte Carlo approach. But due to the limited time for the demonstration, only a limited number of runs could be carried out. However, 250 runs should be enough to clearly see the tendency of the Monte Carlo Analysis and enables meaningful results.

Table 9: Maximum shifting times for the forecast uncertainty compensation

Demand type	maximum shifting time [min]	
Dishwasher	6	h
Washing machine	8	h
Fridge	30	min
Freezer	30	min
electrical heating	9	h
electrical hot water preparation	5	h

For a better understanding of the analysis and the meaning of the results, one example for a winter day and one for a summer day are shown in Figure 4-47 and Figure 4-48. During the winter the PV production and therefore the uncertainty deviations are comparatively small (in absolute numbers). On the example day the deviations can nearly be completely compensated by the shifting (comparison of the yellow line with the dotted orange one). For the shifting procedure mostly the flexible household devices (blue area) are used. This is because they mostly have shorter duration times and often needs smaller amounts of energy. Therefore, they are very suitable for the compensation of small deviations. In contrast to that, the electrical heating demands often have duration cycles of more than one hour. That means that they are often longer than the deviations in one direction (positive or negative) are. In that case a shifting would cause negative and positive effects at the same time. What does not mean that they are not shifted if the overall result is a positive one, but that the flexible household devices are mostly preferable.

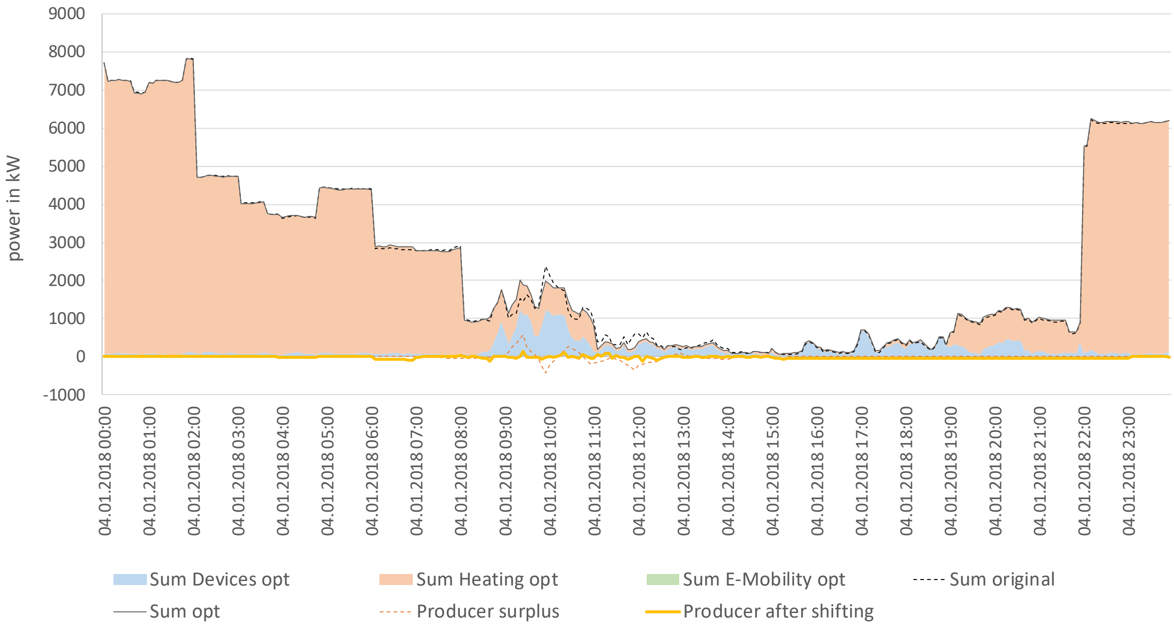

Figure 4-47: Example PV forecast uncertainty compensation winter day

During summer the situation looks different because the relation between the PV production and the flexible demands has changed. It is shown, that now not all deviations can be compensated anymore. There are simply not enough flexible demands available. But it is also shown, that many of the flexible devices which would be operated in times with a smaller PV production than estimated can be shifted to times with a lager production. This reduces the energy deviation (EI) as well as the absolute power deviation (PI).

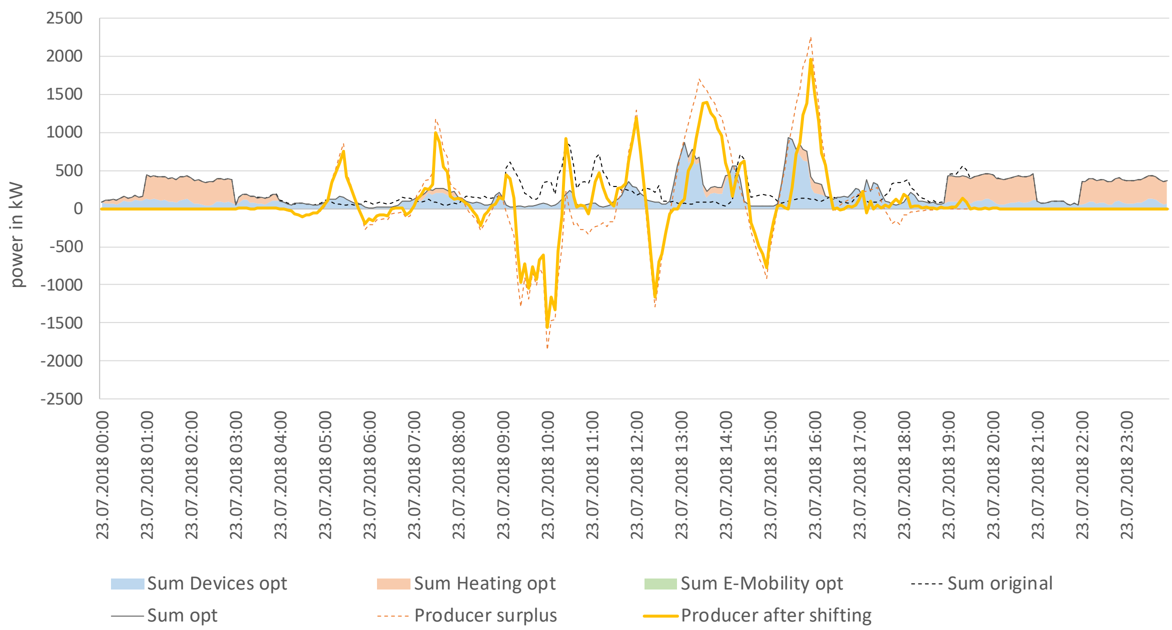

Figure 4-48: Example PV forecast uncertainty compensation summer day

Figure 4-49 shows the results of the Monte Carlo analysis. Improvements of 38.7 % to 42.5 % of the absolute power deviation (PI) and between 15.1 % and 17.1 % of the energy deviation (EI) can be reached. These are quite good results for both, but especially for the absolute power deviation. The optimization is therefore also a good option to reduce power peaks caused by forecast uncertainties.

Moreover, it is shown, that if the framework conditions of the system (PV peak power, kind of demands, shifting times, etc.) are known, the improvement of the optimization can be quantified relatively precise. All results lie in-between a few percentage (2 % EI, 3.8 % PI). Of course, larger deviations are possible, but they are not probable.

A correlation between the results for EI to the results for PI can not clearly be detected. But it is shown, that a high result for EI more often relates to a good PI too than the other way around. The edges with an inverse correlation are more or less empty, but the outlier with more than 17 % EI shows, that results like this are also possible.

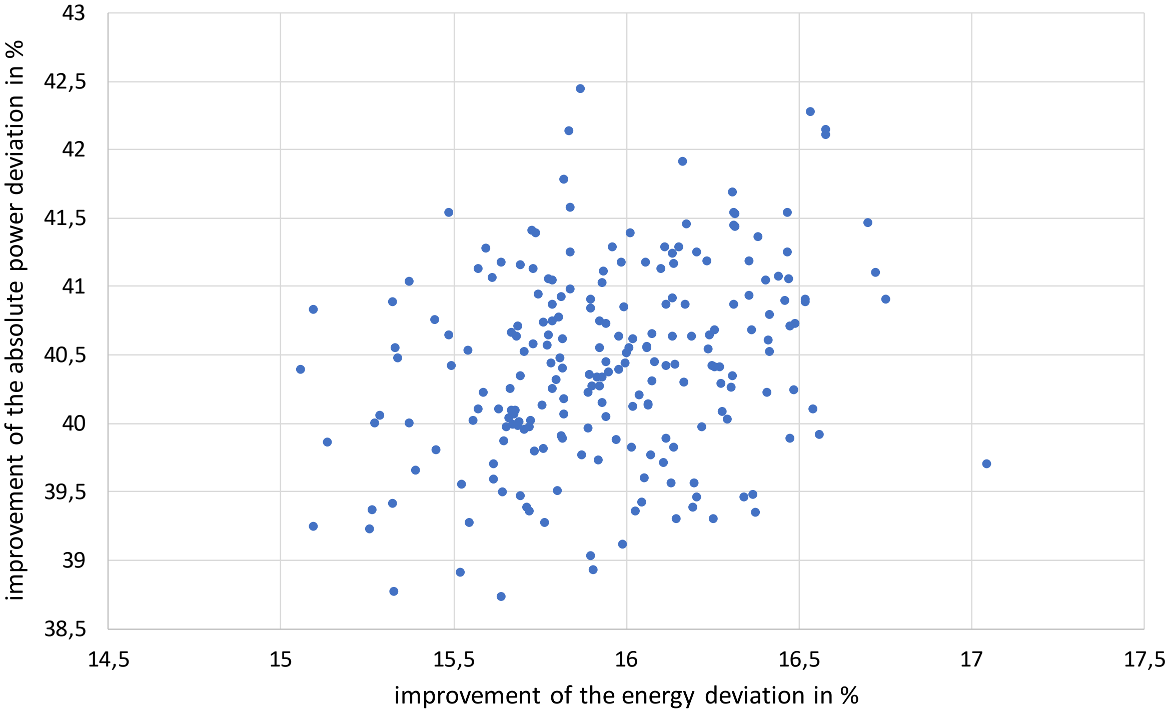

Figure 4-49: Monte Carlo Analysis of the PV forecast uncertainty compensation

The distribution of the results is shown in Figure 4-50 for EI and Figure 4-51 for PI in comparison with a normal distribution. The mean value is 15.95 and if the results would be a normal distribution, the standard deviation would be 0.35 for EI. For PI the mean value is 40.4 and the standard deviation would be 0.71. As the figures show, the real curve does not completely look like a normal distribution yet, but a tendency is seen. It is understood that more simulation results would lead to a closer match with the normal distribution.

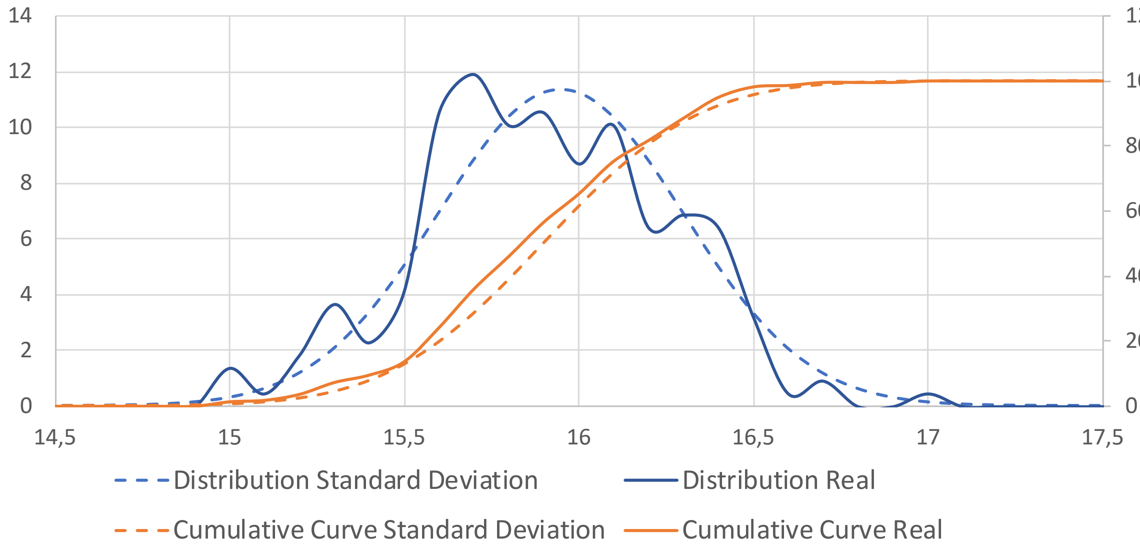

Figure 4-50: Improvement of the energy deviation in percent

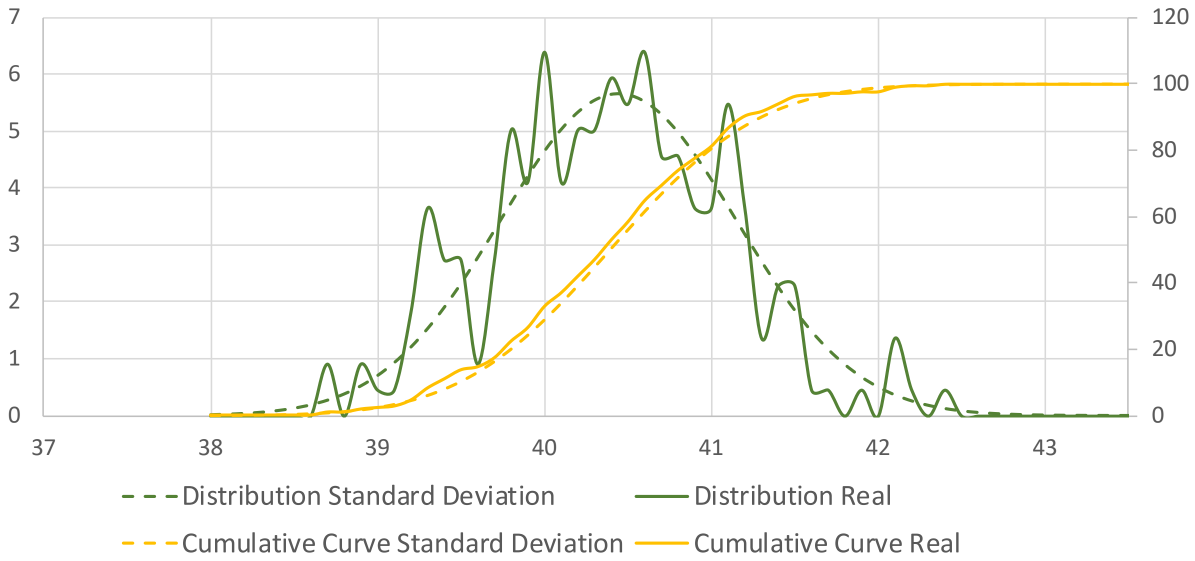

Figure 4-51: Improvement of the absolute power deviation in percent

4.4.2 Demand forecast uncertainty compensation

The same procedure as for the photovoltaic forecast uncertainty compensation was used for the demand forecast uncertainty compensation. The maximum shifting times are also chosen the same (see Table 9). The biggest difference is, that the demand deviations are not limited to the daytime, they are occurring day and night. However, as shown in Figure 4-52, the deviations are larger during daytime. The probability for a deviation stays the same for the whole day, but as a percentage deviation is assumed, the absolute deviations are dependent on the energy amount of the devices, which is smaller during night-time (see for example Figure 4-43).

Except of this, the result for the example winter day is similar to the PV forecast optimization. The flexible household devices are mostly shifted to reduce the deviations, while the heating demand is again not that suitable because of the long duration cycles and the higher energy amounts. Nevertheless a few shifts of the heating demands have been carried out anyway.

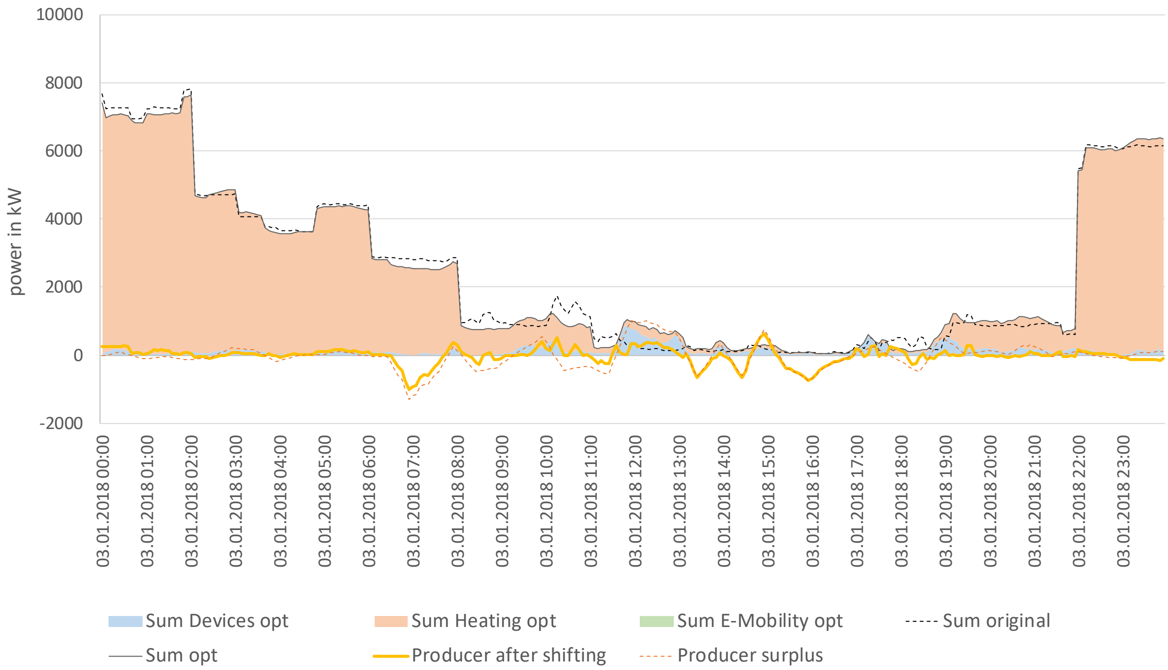

Figure 4-52: Example demand forecast uncertainty compensation winter day

During summer the flexible demands are smaller because no space heating is necessary anymore. The forecast deviations stay about the same because only the non-flexible demands are used for their calculation. It is shown that a lot of shifts are executed all over the day, to minimize the deviation. Though a complete compensation is again not possible, a significant improvement can be reached.

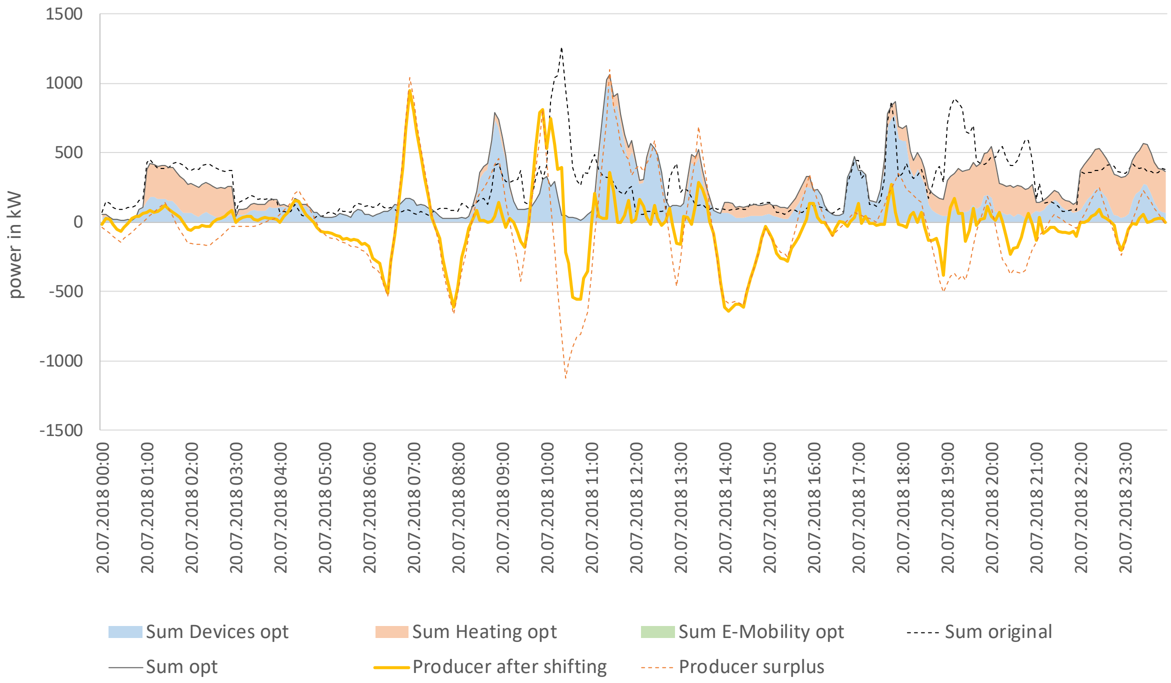

Figure 4-53: Example demand forecast uncertainty compensation summer day

The results of the Monte Carlo analysis are shown in Figure 4-54. This time a clear correlation between the EI and the PI is evident. Moreover, the EI is much higher than for the PV forecast uncertainty compensation while the PI lies in the same range. This seems to come from the characteristic of the deviation of the demand forecast uncertainties, which occurs all day around and not only a few hours per day. The difference of the results of the single runs lies this time in the range of 2 %.

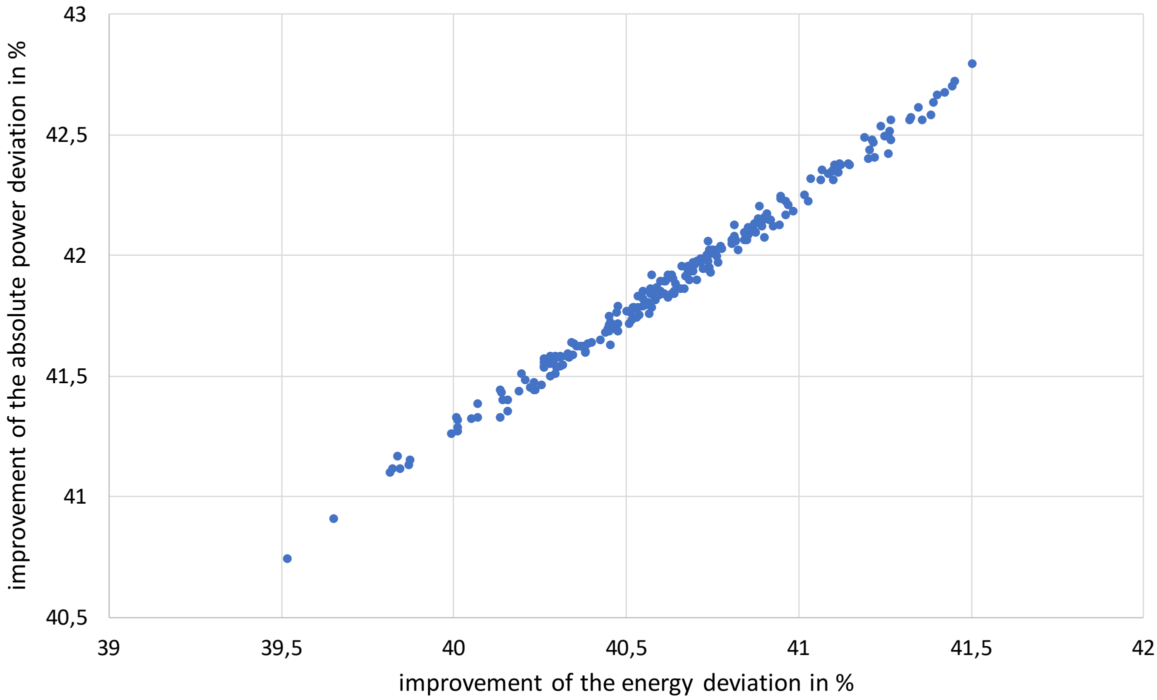

Figure 4-54: Monte Carlo Analysis of the absolute demand forecast uncertainty compensation

The statistical distributions are shown in Figure 4-55 and Figure 4-56. Again, the results of the Monte Carlo analysis are printed twice. Once with the assumption of a normal distribution and once as the real distribution rounded in per mil (0.1 %) steps. The mean value is 40.6 for EI and 41.9 for PI. In case of a normal distribution the standard deviation would be 0.38 for both.

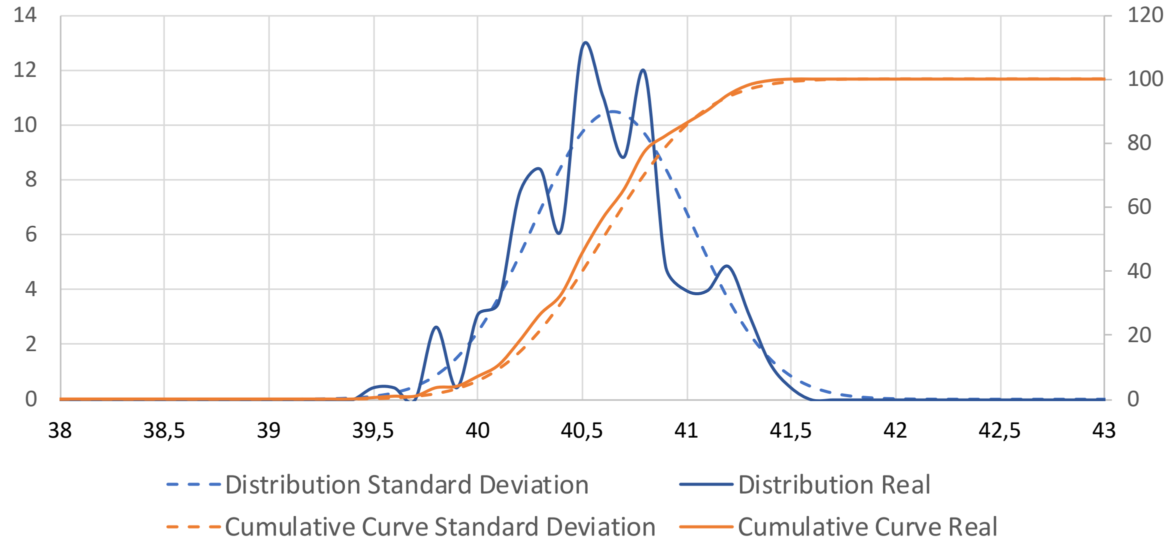

Figure 4-55: Improvement of the energy deviation in percent

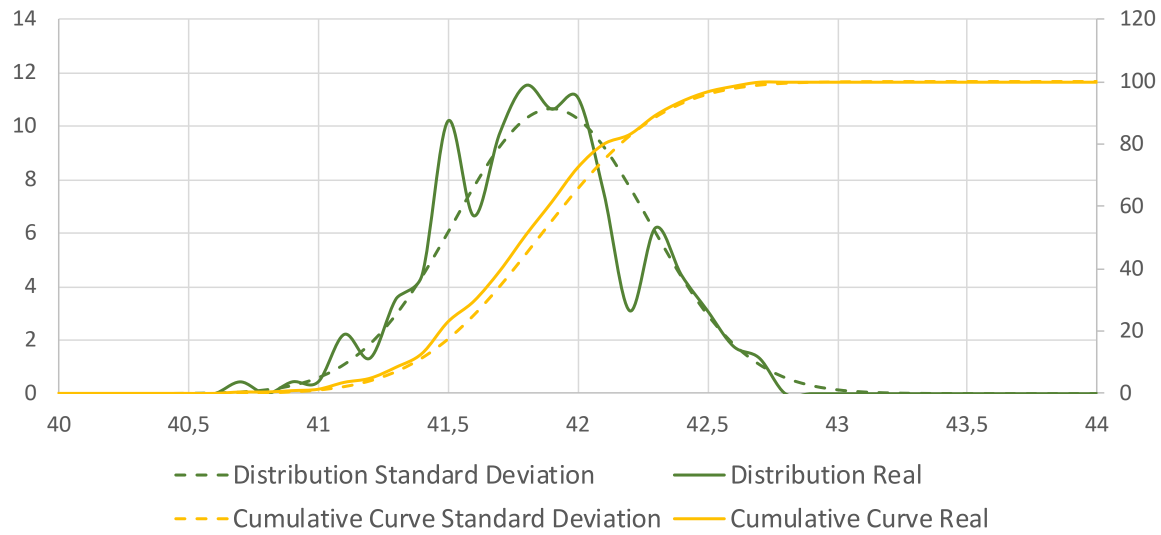

Figure 4-56: Improvement of the absolute power deviation in percent

5 Implementation of the mobility energy calculation

Overall, the mobility behaviour of 66 users was recorded in the Demonstrator Weiz in the period from 10/12/18 to 16/12/18. Due to the issues with the Energy App developed in the project and the delay in the data gathering, only a very limited time set was tested. Never the less this test has the purpose to see whether the energy calculation works satisfactory. Within this time, several parameters (see Table 10) were logged during the movements of the individuals.

Table 10: Parameter of the logged mobility data

Evaluation period 18/12/10-18/12/16	
Elevation	[m]
Speed	[km/h]
Time	[hh:mm:ss]
Date	[dd.mm.yy]
Longitude	[decimal degree]
Latitude	[decimal degree]

These parameters are necessary to calculate the energy demand of the vehicle. The timestep, the difference of the elevation from one to the other step as well as the difference of the speed are required to determine different resistances which result in the overall resistance to calculate the work respectively the energy demand.

Exemplarily for the logged users one user is evaluated in detail. In a first step the data was evaluated to identify the mobility behaviour of the user 1. 44% of the logged time represents standstill, closely followed by the rides with the bike was 35%. 13% show the use of the car by user 1 and only 8% of the logged time demonstrates the walk of the user.

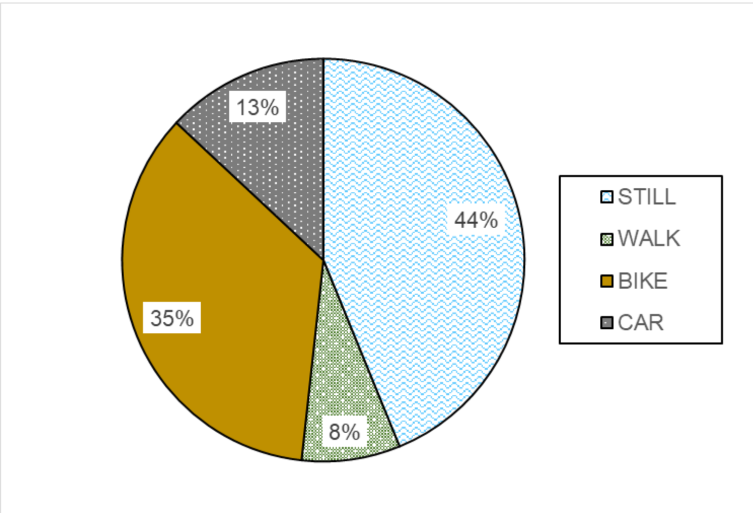

Figure 5-1: Weighting of the logged mobility types

Furthermore, the travelled distances of the different mobility types were evaluated.

The mobility type of user 1 with the longest distance travelled is the car. About 98.62% (187,1 km) of the total distance was covered by car. Only 1.13% (2.15 km) were covered by bike and only 0.25% (0,47 km) by walking. The expression of the different mobility types is shown in the next graphs, each depicting one day within the gathered data.

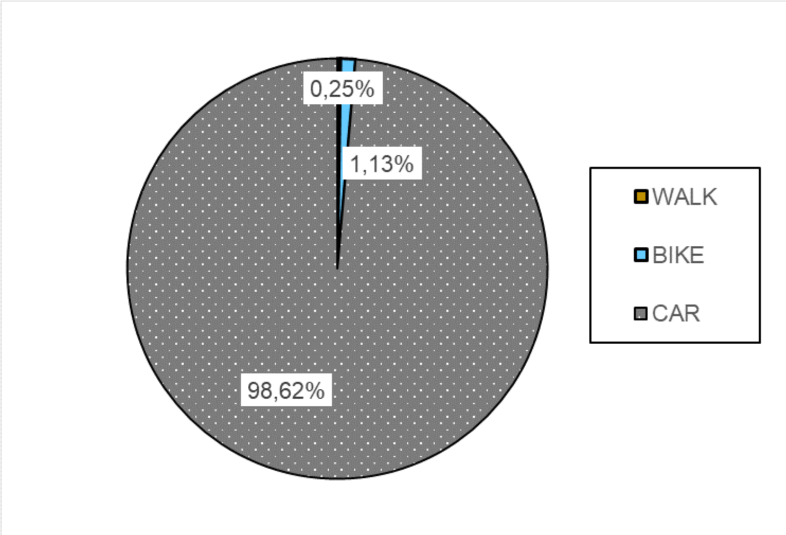

Figure 5-2: Covered distances by mobility type

Only the mobility types in motion are considered. The first figure (

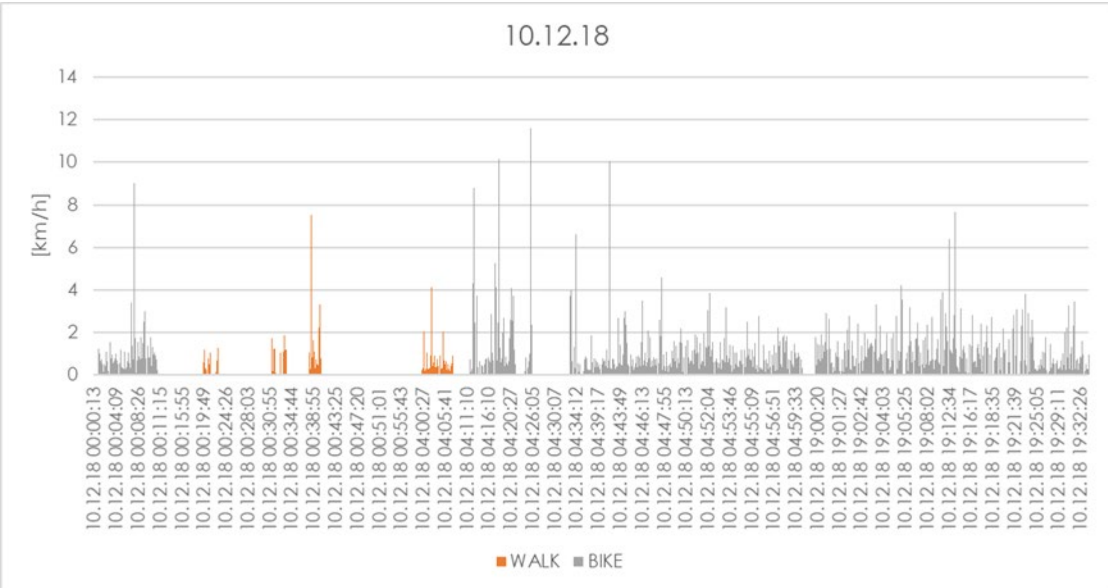

Figure 5-3) shows day 1 (10.12.18). As already mentioned, only the time blocks in which a movement was recorded are displayed. This representation was chosen because of the relatively short time intervals with a high temporal resolution. In the presentation of this interval in a graph, which represents the entire course of the day, the representation could only be done schematically, respectively the temporal courses are not as clear as in the selected representation.

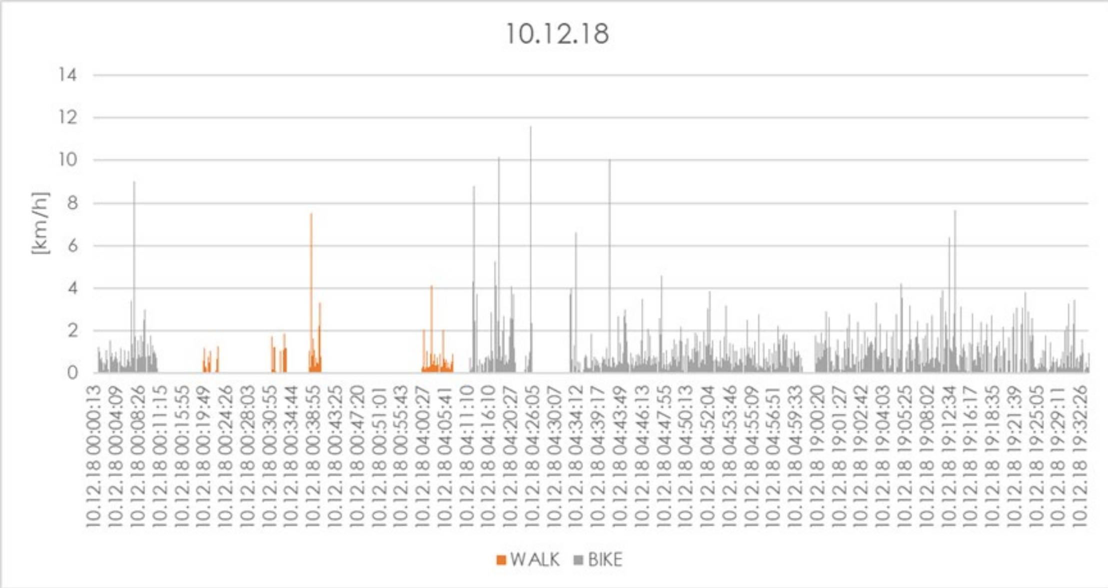

Figure 5-3: Presentation of the mobility of User 1 – 10.12.18

Only two of the three possible types of mobility in motion were used on the first day of the mobility data record. User 1 walked a distance of 0.21 km. Furthermore, User 1 cycled 1.48 km. The average speed was about 25 km/h. The following figure shows the second day. On the second day of the mobility data logging all three mobility options occurred. User 1 was walking for 3 minutes and covered a distance of 0.11 km. He covered a distance of 0.31 km by bike and about 2.5 km by car. The average speed of the car was about 59.8 km/h, while the average speed of the bike was about 10.3 km/h.

Due to the inaccuracy of the measurement no meaningful average speed can be determined for the walk. Therefore, these values are not taken into account in the following considerations.

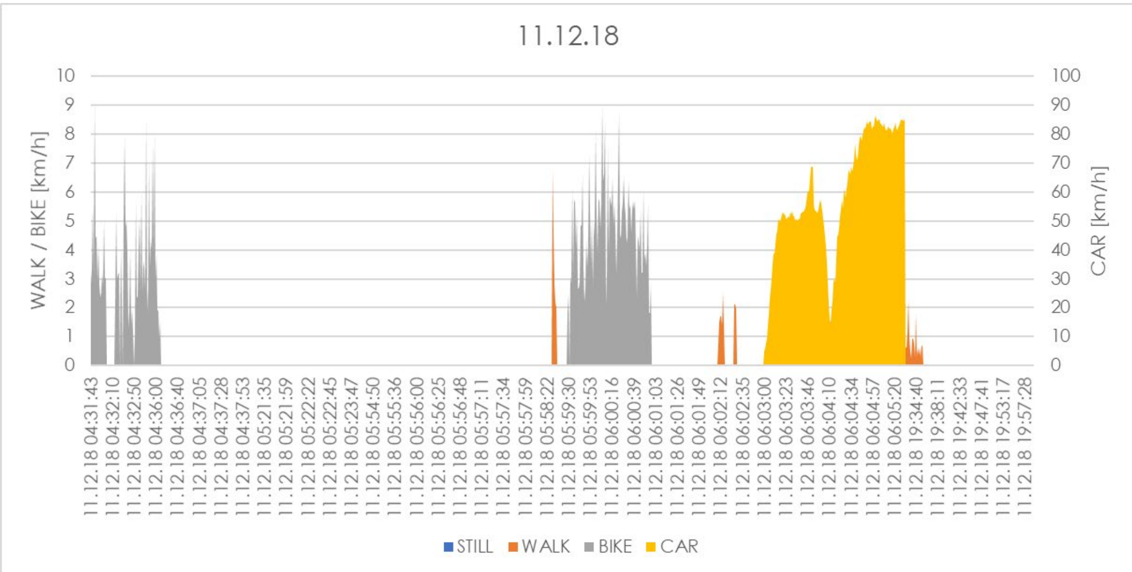

Figure 5-4: Presentation of the mobility of User 1 – 11.12.18

On the third day all three mobility types were used again. The car dominates clearly on this day. The short sequences (of the car mobility data) indicate gaps in the data transfer respectively the longer pauses could be caused on shorter standing positions (for example, because of a traffic light). All in all, a distance of 3.4 km was covered by car and 0.1 km on foot.

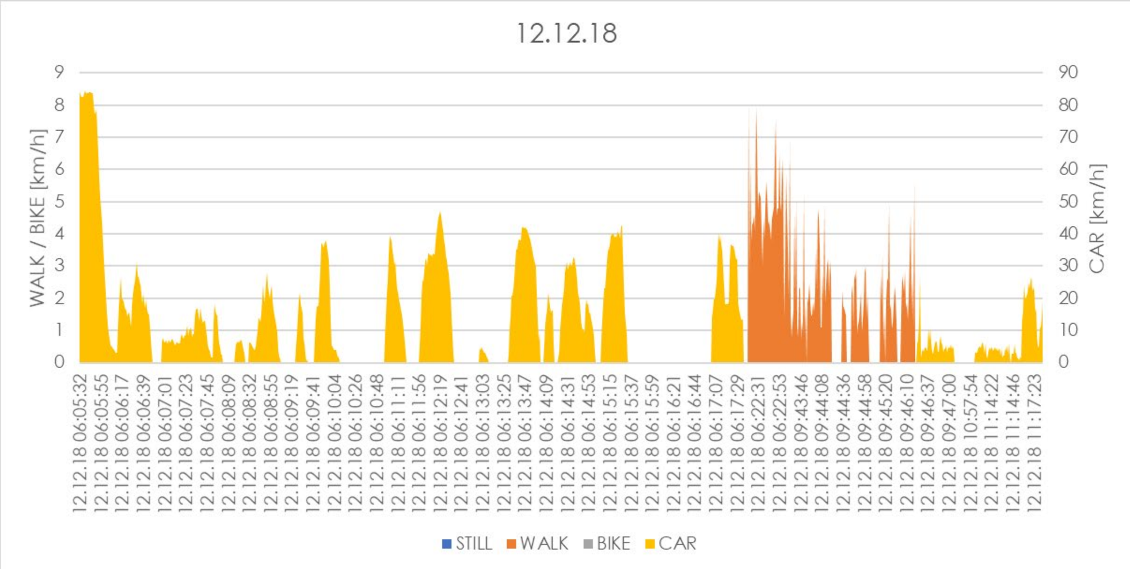

Figure 5-5: Presentation of the mobility of User 1 – 12.12.18

For the remaining 4 days the user used (with the exception of the last day) only the car and thus covers larger distances. On the fourth day one longer journey was recorded, with shorter downtimes at the beginning of the journey. This rest of the trip was then carried out without further time off. Overall, the trip took 23 minutes and it was covered a distance of 30.3 km. The average speed was about 81 km/h (including standstill times).

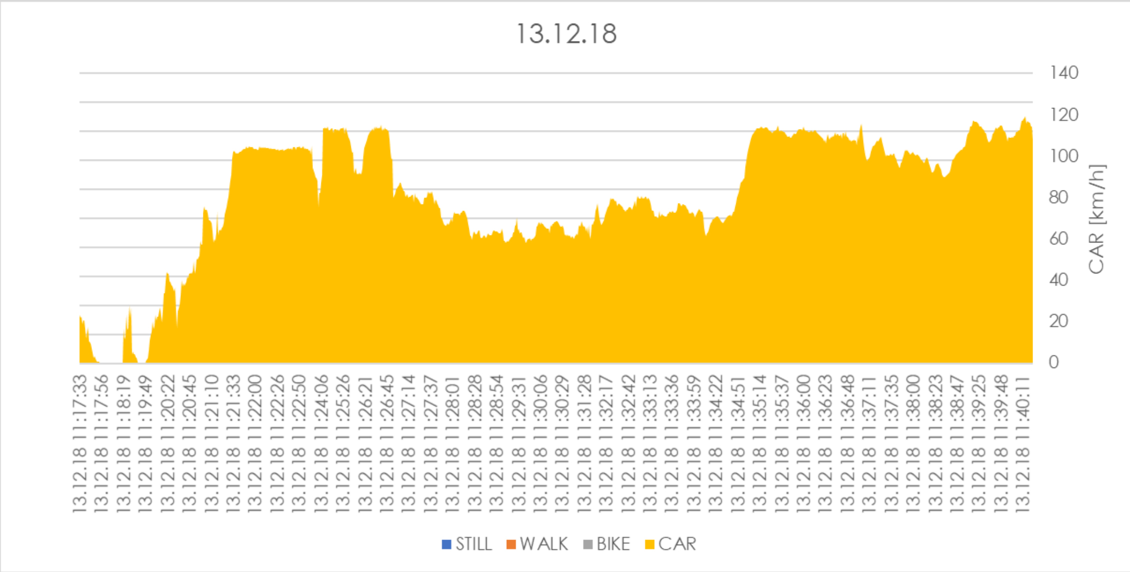

Figure 5-6: Presentation of the mobility of User 1 – 13.12.18

Day 5 represents another journey with the car. It took about 22 minutes. During this time a distance of approx. 44 km with an average speed of 121 km / h was covered. Since the recording has already started at very high speeds, we have to assume that not the entire journey was recorded correctly from the beginning respectively not to the end.

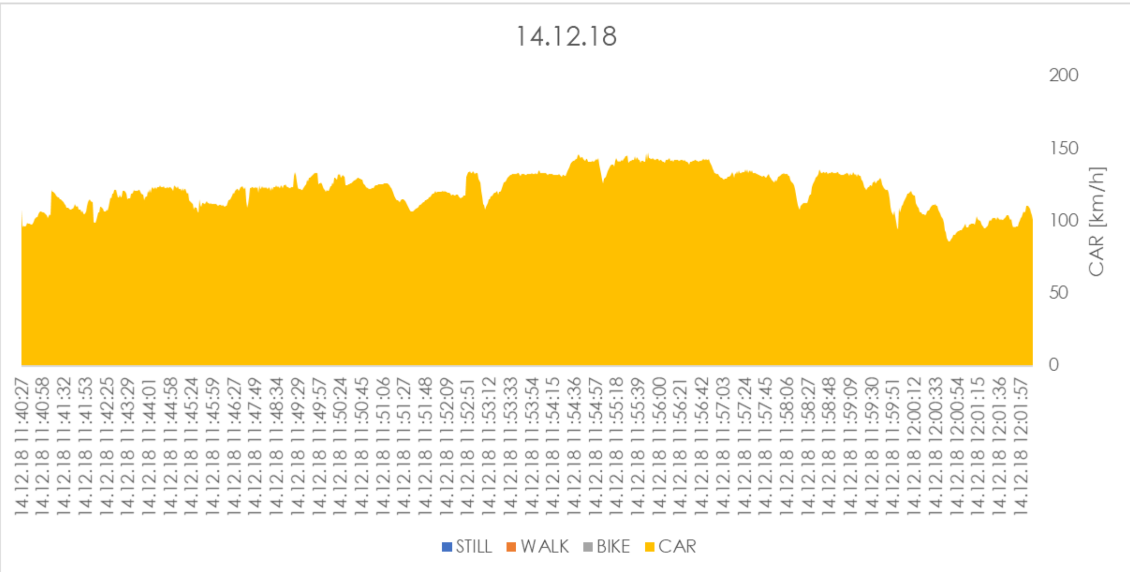

Figure 5-7: Presentation of the mobility of User 1 – 14.12.18

On the sixth day another longer journey with the car was recorded. In the 38-minute drive, a distance of 68 km was covered. The average speed of this trip was 107 km / h. Here too, we have to assume that not the entire journey was recorded correctly from the beginning (and not to the end), due to the high speeds at the beginning and at the end.

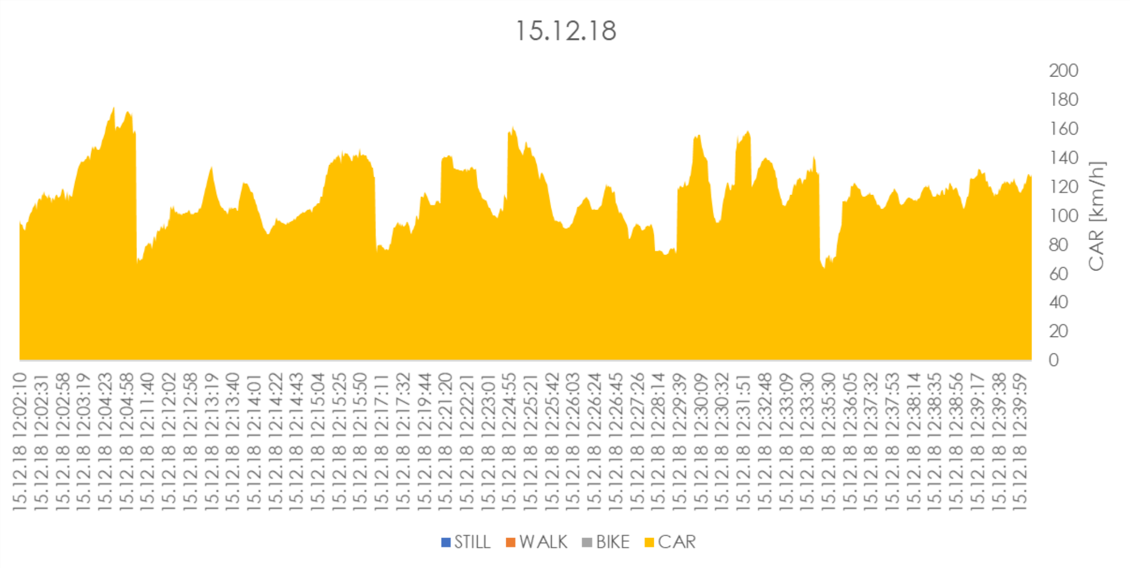

Figure 5-8: Presentation of the mobility of User 1 – 15.12.18

The evaluation of the last day showed again a strong dominance of the mobility type car. The drive by car took about 26 minutes. During this time a distance of 38.9 km was covered with an average speed of 78.3 km/h. Afterwards, the recording shows a short walk and a bike ride of about 6 minutes. A distance of 0.35 km was covered by bike.

For the observations on the energy demand, only the recorded data of the mobility type car were used. In Table 11 the distance travelled, the time required, and the average speed are listed on a daily basis.

Table 11: Overview of car usage on a daily basis

Car			
Date	[h]	[km/h]	[km]
10.12.2018	0,000	0,0	0,0
11.12.2018	0,042	59,8	2,5
12.12.2018	0,247	13,9	3,4
13.12.2018	0,372	81,2	30,3
14.12.2018	0,362	121,4	43,9
15.12.2018	0,634	107,3	68,0
16.12.2018	0,498	78,2	39,0
Total	**2,156**	**66,0**	**187,1**

The figure below shows the energy demand and CO_2-emissions for common vehicle types. The evaluation of energy demand shows that the VW (Golf) with 372.1 kWh has the lowest energy demand, closely followed by Ford (Fiesta) with 389.1 kWh. The biggest energy demand is required for the Mercedes (C180). It requires 482.74 kWh, which is about 30% more than the VW has needed.

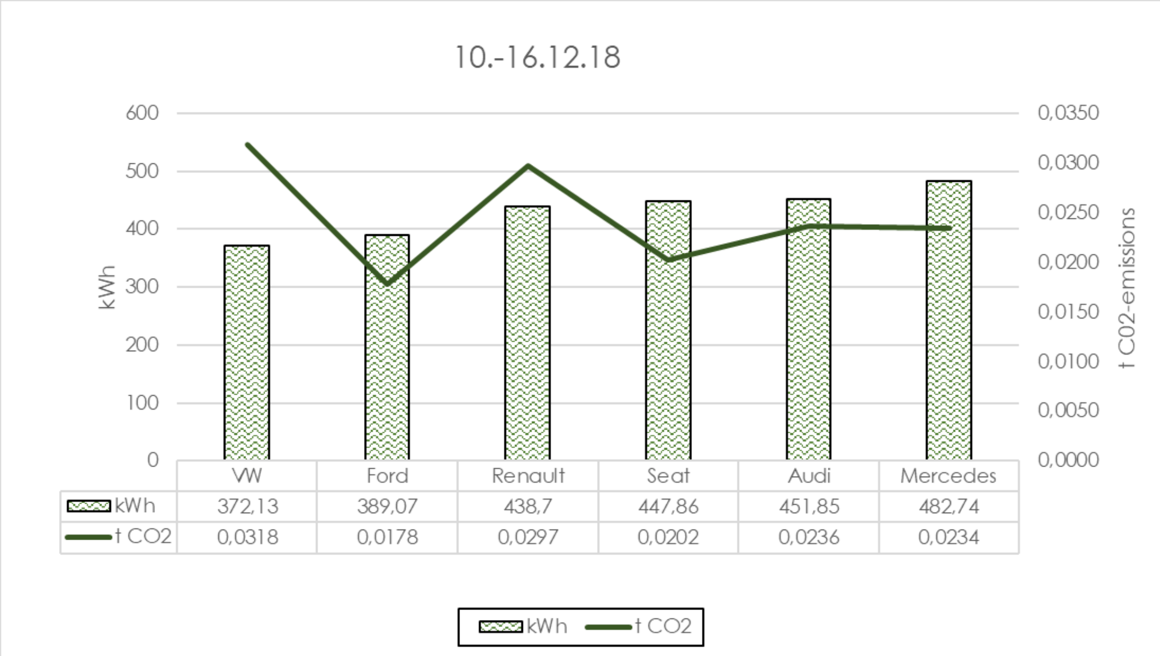

Figure 5-9: Energy demand and CO_2-emissions for different conventionally driven car types

Concerning the CO_2-emissions, the evaluation shows that VW is the largest emitter with 0.032 t CO_2, closely followed by Renault with 0.029 t CO_2. Overall, the Ford demonstrates the best performance. It has the second lowest consumption and with 0.018 t CO_2, it is also the smallest emitter of the examined vehicle types.

Once energy demand and CO_2-emissions have been calculated and presented for conventionally powered vehicles, the logged data will be used to calculate the energy demand and CO_2-emissions for electrically-powered cars. The graphical representation of the evaluation for three popular electrically-powered car brands is shown in the following figure.

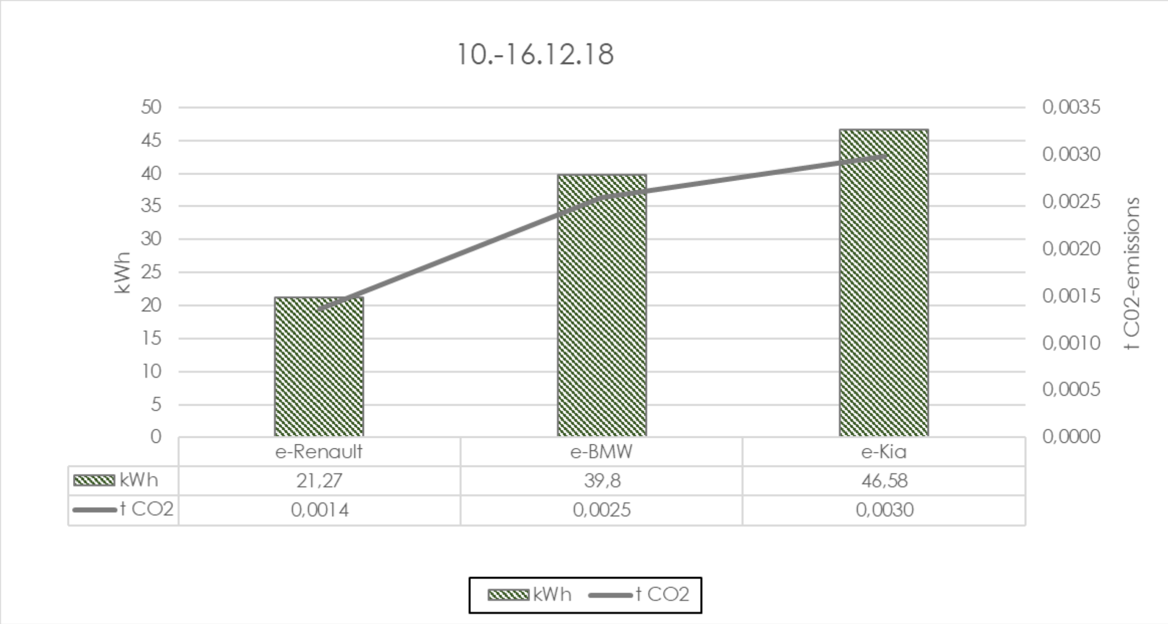

Figure 5-10: Energy demand and CO2-emissions for different electrically-powered car types

With 21,27 kWh, the Renault (Twizy) has by far the lowest energy demand and, with 0.0014 t CO_2, it is also the smallest emitter. The second largest need has the BMW (i3). It requires 39.80 kWh and emits 0.0025 t of CO_2. The largest consumer and emitter is the Kia (Soul). This vehicle requires 46.58 kWh and emits 0.0029 t of CO_2. The range of the calculated energy demands is in the field of practical tests.[9] The results of CO_2-emission calculations were also

[9] https://www.adac.de/rund-ums-fahrzeug/tests/stromverbrauch-elektroautos-adac-test/

checked for plausibility and compared with values in national publications. [10]

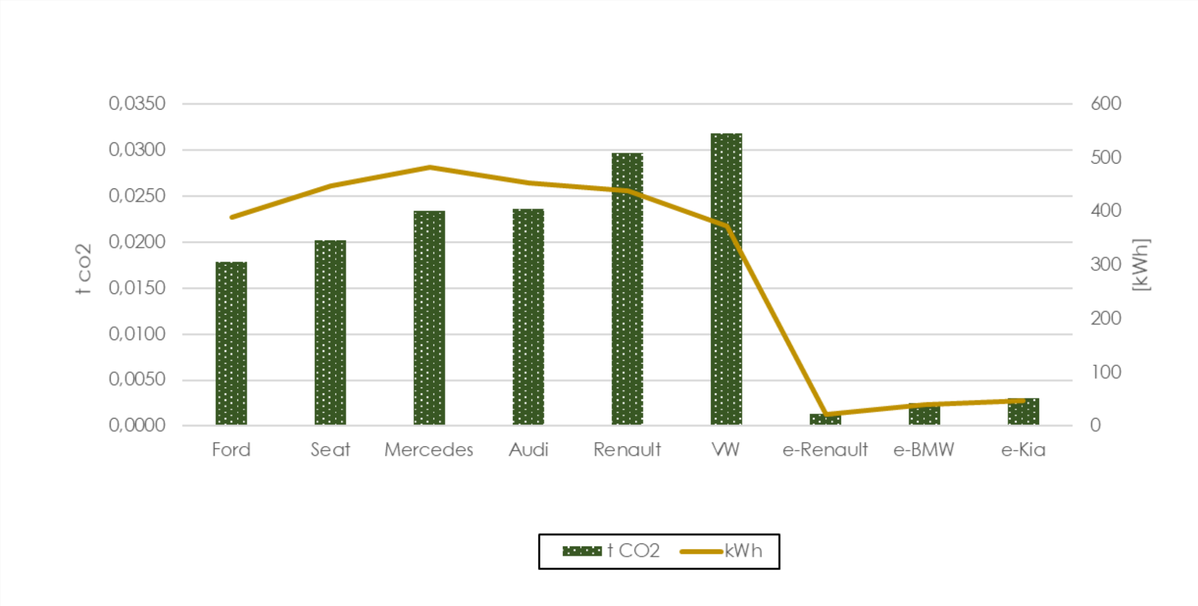

Figure 5-11: Overview CO2-emissions for different car types (conventional vs. electric)

The comparison of conventionally driven vehicles and electrically powered cars shows that the CO_2 emissions of electrically powered cars are significantly smaller. When using an average value of CO_2 emission for conventionally-driven vehicles compared to electrically-powered vehicles, these emit only about 5-10% of conventional emissions (taking into account the Austrian electricity mix in 2017, see Deliverable 3.1).

[10] http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0572.pdf

6 Conclusion and discussion

The target of WP 8 was the demonstration of the different tools and models created during the DESENT project. Which was done with great success, although there were some challenges along the way to implementation. In general, the tools and models developed can be, once the data is available in sufficiently high quality and quantity, easily applied, the results obtained from the implementation are presented in an understandable and visually appealing way.

Regardless of the quality of the tools and their corresponding output, one of the key challenges and most intensive challenges that arose while implementing the tools, resulting from obtaining the data. This is true for both energy related as well as activity related data. For mobility related data the key issue was with the obtaining both the travel diary as well as the GPS data. GPS tracking was more challenging than anticipated and several modes of tracking had to be tested to obtain feasible data – at least in the City of Weiz. This was not that much of a problem for the City of Helmond. The same goes obtaining the data from the travel diaries – while the Austrian consortium members did their best to acquire the required number of entries, participants were unwilling to share that information.

Similar challenges were met for the building and energy related data. For the City of Weiz a huge repository of data was already available, which made it easier to prepare the data for further work. Nevertheless, some effort had to be put into the preparation of the data in order to pass this knowledge on to the pilot cities. This was not the case for the City of Helmond that faced huge problems with gathering the data. The conclusion can be drawn that prior to using the tool, the user needs to check whether data is available at all. Additionally, this can be seen as a shout-out to cities to put effort into gathering building related data for energy analysis, otherwise no sensible mode of energy analysation can be implemented in those cities.

Besides the challenges with obtaining the data required for the tools, the application of both tools, ALBATROSS and the DESENT Energy Tool Box worked very well. The tools generated the required results and are ready to be used.

The ALBATROSS Tool generated the information of travel actions for the City of Helmond, creating a travel diagram for a four-digit postcode level. Also, on four-digit postcode level the type of energy (charging) behavior, regarding the type of activity is obtained. One of the final results, which will be crucial for the development of the charging infrastructure, is geopgraphical distribution of the charging behaviour.

The DESENT Energy Tool Box was applied to the City of Weiz obtaining valuable information on the Weiz Energy System. While the urban region of Weiz has the highest total energy consumption, the energy consumption per capita is significantly higher in certain rural regions. The same goes for CO_2 emissions. To analyse further developments in the energy system, a simplified use case was chosen which aimed at changing the heating systems and analysing the results. Using more energy efficient and eco-friendly solutions leads to reduced specific and total energy consumption and CO_2 emissions but to significantly higher electrical loads in the rural region (where a use of heatpumps was forced). While this scenario is not very likely, it functionality of the tool very clearly indicates the effects of such a system change.

Additionally, the tools provide the options to investigate the positive effects of flexibility use, which was investigated for the City of Weiz under different circumstances. The results indicate, that on a city-wide level a coordinated use of flexibilities can contribute largely to both an increase in RES consumption as well as to a reduction of uncertainties.

Finally, the tool for transport related energy consumption was tested on basis of one GPS-tracked set of for the City of Weiz. This worked sufficiently and generated realistic results.

Summing things up, the tools and models developed during the DESENT project can be implemented in the demonstration cities once the required data is available. Unfortunately, this is the great weak point of all tools and will need further consideration in future projects. Once that challenge is tackled, the tools can be used to generate substantial amounts of information for city planning be it in the mobility or the energy sector.