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D3.13 - Simulation models of the building stock, energy system, transportation, urban infrastructures WP3, Task 3.1

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**
Project Duration	1st December 2016 – 30th November 2021 (60 Months)
Deliverable	D3.13 Simulation models of the building stock, energy system, transportation, urban infrastructures
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Lead beneficiary	HAM
Contributing beneficiary(ies)	CAR, ENER, KON, VHH
Task description	According to the Grant Agreement this deliverable aims at modelling, simulation, and systems engineering of the building stock, energy system, mobility and urban infrastructures.

Date	Version	Author	Comment
28/11/2017	Interim version	Petrit Vuthi (HAW), Jutta Wolff (HAM-BGD)	Preparation, finalization and submission of interim version
31/03/2019	0.1	Petrit Vuthi (HAW), Julian Sahr (HAM-BGD)	Update of table of contents
15/06/2019	0.2a	Julian Sahr (HAM-BGD) + all others	Drafting the contents in consultation with the partners involved + HAW
12/07/2019	0.2b	Fredy Vélez (CAR), Julian Sahr (HAM-BGD)	Consultation regarding the scope and contents of the deliverable
01/08/2019	0.3	Julian Sahr (HAM-BGD) + partners involved	Readjustment of table of contents and drafts of interventions to be included
20/09/2019	0.4	Fredy Vélez (CAR), Julian Sahr (HAM-BGD)	Finalization of table of contents,
30/09/2019	0.5	Julian Sahr (HAM-BGD)	Revision of chapters 2. and 3. which were part of the interim version.
21/10/2019	0.6a	Maya Kayser (HAM-LSBG)	Submission of chapter 4.2
25/10/2019	0.6b	Nina Zeun (VHH)	Submission of chapter 4.3.1
06/11/2019	0.6c	Klaas Wulff (KON)	Submission of chapter 4.1.1
14/11/2019	0.6d	Julian Sahr (HAM-BGD)	Finalization of chapter 4.3.2

14/11/2019	0.7a	Ana Quijano (CAR), Julian Sahr (HAM-BGD)	Last consultation with Cartif, removal of additional contents
15/11/2019	0.7b	David Janknecht (ENER)	Submission of chapter 4.1.2
18/11/2019	0.8	Julian Sahr (HAM-BGD) + partners involved	Adding submissions together, last coordination with partners regarding calculations
19/11/2019	0.9a	Julian Sahr (HAM-BGD)	Finalization of chapter 4., proofreading
20/11/2019	0.9b	Julian Sahr (HAM-BGD)	Layout editing, internal review submission for review
28/11/2019	0.9b	Natacha Javalet (ENG)	Review
28/11/2019	1.0	Julian Sahr (HAM-BGD)	Inclusion of comments from review
28/11/2019	1.0	Julian Sahr (HAM-BGD)	Final submission

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Abbreviations and Acronyms

Acronym	Description
CHP	Combined Heat and Power
CO_2	Carbon dioxide
EEWärmeG	Erneuerbare-Energien-Wärmegesetz, German Renewable Energies Heat Act
EnEV	Energieeinsparverordnung, German federal Energy Saving Ordinance
H_2	Hydrogen
LED	Light-emitting diode
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
RES	Renewable Energy System

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1. Executive Summary

This deliverable is intended to include simulation models or descriptions of the initial situation in order to model previous energy demands in different areas, including the building stock, transportation and urban infrastructures. Information about energy consumption in the mobility and building-related actions in the project mySMARTLife in Hamburg-Bergedorf, are another integral element to fully analyse the district in which the interventions are implemented and eventually to define baselines of these.

A comprehensive interim version to this deliverable has been created, the deliverable 3.2. Yet, due to difficulties in the preparation of the implementation of some of the actions major adjustment in previously described the actions had to be made. Moreover, because of the early due date of the interim version, M12, the scope of that version differs in large parts from the scope of this final version.

Previous situations from which energy demands of the situation before the mySMARTLife measures have been implemented in Hamburg are described here for following interventions: The utilization of hydrogen in a local district heating grid, retrofitting and smart heating islands in Hamburg-Bergedorf, the replacement of street lights by smart LED lights and the electrification of bus lines in Hamburg-Bergedorf and of the public vehicle fleet. Further descriptions of the actions covered here can be found in additional deliverables.

To present a baseline for the utilization of hydrogen, energy data and emission values previously to the injection of hydrogen are presented. The heating central at the new development is already in operation, but the usage of hydrogen has not started yet. For the retrofitting area in Hamburg-Bergedorf it is possible to present heat and electricity demand for the project area. The initial situation of the smart heating island is described with technical data of the previous heating system that is replaced in the course of the project. Energy consumption values for the replaced street lamps can be presented, whereas this data has been recorded before. It is already possible to indicate possible energy savings when the old consumption is compared to expected consumption data from the LED lamps. For some LED lamps that are newly installed, however, comparable conventional lamps are considered. For the actions were fleets are electrified, both the busses and the public vehicle fleet, driving performance values and consumption data are used to indicate the fuel consumption and CO_2-emissions that are saved, once the fossil fuelled vehicles are replaced by electric vehicles.

These results are the basis for a later monitoring and evaluation of the implementations in the Hamburg project area within the mySMARTLife project.

2. Introduction

2.1 Purpose and target group

This deliverable shall describe the approach to model the baseline for the mySMARTLife measures in the lighthouse city Hamburg. The aim is to determine the energy demand previously to the implementation of mySMARTLife in the different pillars of the project: mobility, energy and urban infrastructures.

Special attention is being paid in Task 3.1 Baseline assessment to the evaluation of existing city plans, as an input for the diagnosis characterization, so that, in D3.1 Baseline report of Hamburg demonstration area a deep review of the existing city plans was made.

Moreover, within Task 3.1 different approaches are applied in order to develop simulation models or modelled scenarios to outline the situation in the different project areas before the mySMARTLife measures or interventions were implemented. These baselines will be used for a later evaluation of the results. There will be descriptions for demand characterizations:

- For new and retrofitted buildings, in order to characterize the energy demand of the Hamburg demonstration area.
- For urban infrastructures, in order to characterize possible energy saving potentials the urban infrastructures in the Hamburg demonstration area.
- For mobility, in order to characterize emission saving potentials in the mobility sector in the Hamburg demonstration area.

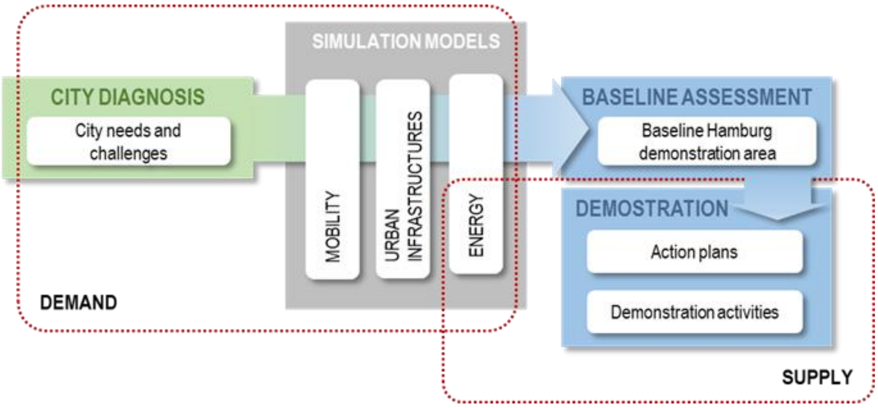

Figure 1 Classification of the simulations within the context of the baseline assessment (Cartif, own source).

As explained in the introduction section, this deliverable is allocated in Task 3.1 Baseline Assessment. The main objective of this task is to develop the baseline assessment of Hamburg. The analysis that needs to be conducted for this is being developed in two different scales, at city level, and project level.

Previously to this deliverable, a deep city diagnosis has been done in PART I of deliverable 3.1, which collects information from the Hamburg lighthouse city and carries out an accurate diagnosis of its current status within the framework of the Urban Transformation Strategy. Thus, it covers the diagnosis for seven fields: buildings and district, energy supply, city transportation, suitable urban infrastructures for integration, existing urban plans for promoting low energy districts and sustainable mobility, public procurement procedures, regulations and normative; and existing actions for citizens' engagement.

At project level, a district baseline of the area in which the interventions will be presented in PART II of deliverable 3.1 (D3.12). The main objectives of the baseline assessment are:

- Definition of the baseline for the project evaluation and areas of intervention.
- Definition of the baseline scenario to evaluate the savings of energy consumption, costs and greenhouse gas emissions of the building and districts and urban mobility interventions.
- Definition of the reference baseline based on existing normative and/or current practices for the demo sites.

The assessment shall pick up results from this deliverable (Figure 2). Hence, it will refer to data from the Hamburg demo site in order to have a reference for comparing the initial situation and the situation after the interventions. This data collection shall cover the three main sectors of the Urban Transformation Strategy: building, mobility, and urban infrastructures. This will not only help for a final display and assessment of the baseline, but also to calculate the project level indicators.

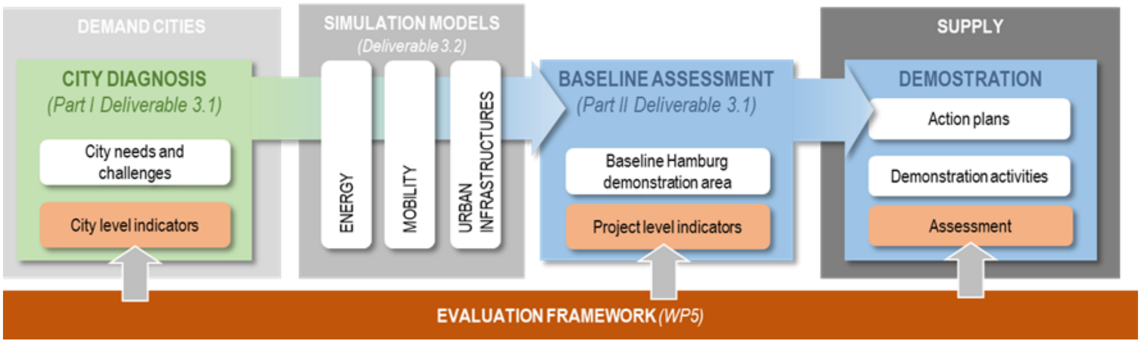

Figure 2 Simulation models background and context (Cartif, own source).

This deliverable addresses especially stakeholders and decision makers, but also the interested public, who want to follow the implementation of the different measures within the mySMARTLife project in Hamburg and who are interested in the output of the project. With the description of the situation previously to the project, for most measures where energy savings and emissions reductions are expected, this deliverable will serve as starting point for a technical description of the monitoring. For readers outside of the project, it is also recommended to read following deliverables that deal with the monitoring of the project.

2.2 Structure and contributions of partners

For a better understanding of the structure of this deliverable, it needs to be taken into consideration that a comprehensive interim version of the deliverable 3.2 had to be prepared already in month 12. Because this was still an early phase of the project and the implementation of the project's measures was not yet well-developed. Hence, the scope of the interim version was broader than it has to be for the final version. The interim version did not focus on the baseline of individual interventions or actions, instead the focus was on a higher macro level. It was also tried to simulate approaches of certain actions regarding RES or to generate models for these implementations. These were conducted because renewable energies are considered as important parts for the energy supply of the new and retrofitted buildings within the demonstration areas. After large parts of the intervention where this investigation was conducted had to be changed in an amendment, this approach was no longer pursued. Nevertheless, the findings and conclusions from this investigation can still be of interest for planners, whereas potentials for innovative renewable energies have been examined. Therefore, it is recommended to take note of the deliverable 3.2.

In this final version, however, detailed descriptions of the initial situations, the baselines, of the most relevant actions in Hamburg are compiled. These baselines indicate energy and fuel consumptions which will be improved or replaced by renewable energies in the course of the project mySMARTLife. Moreover, the baseline values and descriptions will serve as reference for the monitoring and the final evaluation of the specific action.

2.2.1 The present deliverable is structured as follows:

With the contextual integration of this deliverable in the overall context of the project mySMARTLife, but also within the activities in Hamburg, and the description of the content, **chapter 2** provides the overview of this deliverable. The following **chapter 3** shows the methodology that is used in the followings sections. The simulations or comprehensive descriptions of the initial situation for the applicable measures, are presented in **chapter 4**. In this chapter, which has to be considered as main chapter, also calculations for previous energy demands or emissions are shown. **Chapter 6** shows mentioned simulations from the interim version, which are also in this context suitable to be presented to indicate what findings were made in an earlier stage of this project, which can also be also compared to findings from chapter 4. Conclusions are presented in form of brief descriptions of the calculation results for the different interventions in chapter 4.

2.2.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1 Contribution of partners.

Participant short name	Contributions final version – D3.13
HAM-BGD	Chapters 1, 2, 3, 4.3.2, calculations for the fleets, general coordination and editing of all chapters
HAM-LSBG	Chapter 4.2
KON	Chapter 4.1.1
ENER	Chapter 4.1.2
VHH	Chapter 4.3.1, 4.3.2.2

2.3 Relation to other activities in the project

The following table depicts the main relations of this deliverable to other activities (or deliverables) within the project mySMARTLife, which need to be considered for a better understanding of the scope of this document.

Table 2 Relation to other activities in the project.

Deliverable Number	Contributions
D3.1	Existing city plans reviewed done within this deliverable will be as an input for the demand characterization.
D3.3	Comprehensive descriptions of building related measures covered by the present deliverable.
D3.4	Depending on the feasibility and the economic decisions of the investors RES will be used within the energy supply systems for the buildings in the demonstration areas.
D3.8	Comprehensive descriptions of mobility related measures covered by the present deliverable.
D3.10, D3.11	Comprehensive descriptions of infrastructure related measures covered by the present deliverable.
D3.12	As the second part of D3.1, D3.12 shall pick up results from this present deliverable
D5.1	Calculations and methodologies used in the present deliverable are further explained and described in the overall context of the project.
Task 5.1	Evaluation framework. Project Level Indicators.

3. Methodology for the baseline presentation

The simulation models generated and presented in this deliverable are closely connected to the information that is required for the final assessment of the baseline. Before this baseline can be presented, however, it is necessary to survey the initial situation and to analyse the approach that needs to be taken. Simulation models are here understood as calculated or simulated models of the situation previously to the implementation of the mySMARTLife project measures. The description of the baseline follows the procedure presented in Figure 3.

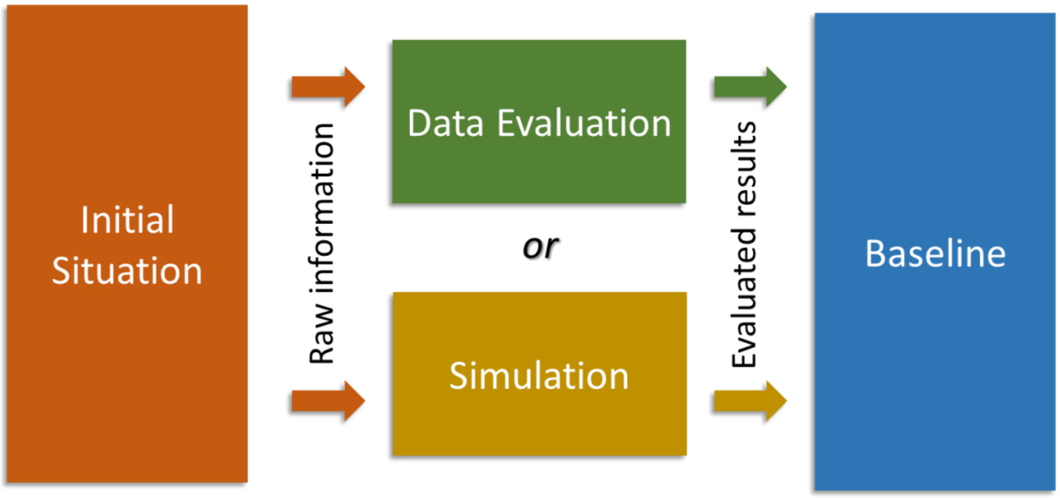

Figure 3 Scheme of the generation of the baseline description (HAW, HAM, own source).

The methodologies comprises different steps. First, the initial situation needs to be analysed. This analysis shows what data or information is available to generate the baseline. This can be either measured data or only points of reference and other vague information. In any case, most likely the information is not prepared to such an extent that it can be presented directly as baseline. Hence, this information or date needs to be prepared accordingly. In this step, depending on the quality of the available data, it needs to be decided whether a simulation will be conducted or if it sufficient to evaluate the available data. Latter is possible when the available data from the initial situation is already real measured data. If, however, no such data is available, ongoing from the vague information of the initial situation further assumptions need to be made and the initial situation needs to be simulated in a model. In any case, either if available data is further evaluated or a simulation is performed, the evaluated results can be used as baseline. Whereas the actions for which baselines can be presented differ largely, the specific method applied to come to the baseline is described individually for each case.

The baseline values that are presented in this deliverable, will be used for the calculation of energy or emissions savings achieved through the implementation of the mySMARTLife measures. For this, different calculations will be performed during the later monitoring and evaluation of the project.

4. Initial situations and baseline values in Hamburg

With the wide range of topics, the project mySMARTLife comprises, a broad spectrum of different measures that are implemented during the project duration in Hamburg. It is not surprising, that these measures, or actions also vary largely in the type of implementation, scope, goal and result. Due to this, it is reasonable to consider that the presentation of a baseline is not suitable for all actions that are implemented. In this deliverable, primarily energy-related actions from the focus areas, buildings, infrastructure and mobility are presented. As stated before, the main focus of the investigation of the baselines is on energy demands. This not only takes technical actions into account where reductions of the energy demand are expected by the increase of efficiency, once the mySMARTLife action is implemented, but in some cases also the shift to other energy sources or the use of different technologies. For those actions that are described here, it is possible to present a description of the initial situation. The used data for the generation of the baseline and baseline values will be of further interest for the implementation and monitoring of the individual actions. Against this background, it should be noted here, that actions shall not be taken into account, where the focus is set solely on the generation of renewable energies or the integration of these energies into the energy supply system. In these cases, the baseline differs from the implemented or post-project situation only in the share of generated renewable energy. For a later assessment or for a monitoring of the impact of these actions, a comprehensive description of the initial situation and a provision of baseline values is not necessary.

In general, it should be taken into account, that the description of the initial situations or the baseline values cannot all be depicted with the same level of detail. This can have different reasons including the availability of data or information, or the complexity of the initial situation and of the action to be implemented. The availability of data can also be restricted due to privacy issues. Especially with respect to energy consumption data, this can be a major impediment, whereas this information is seen as highly confidential in Germany and can only be used when it is authorised by the end user.

Following interventions are covered:

Building-related energy demands

- Utilization of hydrogen in a local heating network “Am Schilfpark”
  - Expected energy generation data of the heating central without the usage of hydrogen.
- Bergedorf-Süd Retrofitting project and Smart heating islands in Retrofitted area of Bergedorf-Süd.
  - Estimated thermal and electrical energy demands of the retrofitting area and energy generation data of the smart heating island.

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<u>Energy demands in urban infrastructre</u>

  - Consumption values of comparable conventional street lamps and expected energy savings.

<u>Mobility-related emissions and fuel consumption</u>

- Electrification of bus lines in Hamburg-Bergedorf
  - Calculation of fuel consumption and CO_2-emissions of diesel busses
- Electrification of the public vehicle fleet
  - Calculation of fuel consumption and CO_2-emissions of petrol and diesel cars

After a brief description of the action that is implemented in the project mySMARTLife and of the initial situation, the derivation of the baseline is presented, followed by the baseline values and if applicable, a brief analysis of the results.

4.1 Building-related energy demands

Energy demands that occur at buildings can be found in the high-performance area along the Schleusengraben channel, as well as in Bergedorf-Süd, the retrofitting area of the mySMARTLife project area in Hamburg. In the high-performance area the focus in on the in the new development area “Am Schilfpark”. The following chapter includes two actions that focus on the use of hydrogen as a new energy source in district heating grids and two further actions that deal with the reduction of energy demands and a rise of energy efficiency in the production and distribution in the retrofitting area.

4.1.1 Utilization of hydrogen in a local heating network „Am Schilfpark“

The following section combines Action 13 *District heating with a high share of renewable hydrogen* and Action 18 *Local District Heating supplied with H2* whereas both actions closely linked to each other. The general idea is that Action 13 deals with the installation of the required equipment for the utilization of hydrogen, whereas Action 18 follows with the injection and actual utilization of the hydrogen in local district heating network and heating central.

4.1.1.1 Energy supply concept „Am Schilfpark“

enercity Contracting Nord GmbH develops and implements an energy concept for the new residential quarter "Am Schilfpark". The energy concept is predestined to test the suitability of the energy supply system for adding hydrogen to the natural gas grid as part of the mySMARTLife project.

Nine buildings with a total heated area of 24,832 m² were built in the “Schleusengraben” area. A total of 273 apartments are supplied with heat in the quarter. The buildings comply with the legal requirements of the Renewable Energies Heat Act (EEWärmeG) and the Energy Saving Ordinance (EnEV) for the heat supply of new buildings.

The heat supply concept is based on a central heat production with a local district heating network. The heat is distributed via an approx. 460 meters long local heating network, most of which was installed in the underground car park and basement. This system offers a modern and efficient energy infrastructure with attractive primary energy factors. For heat generation, enercity Contracting uses several generation plants which, in combination, take into account the aspects of energy efficiency, cost-effectiveness and supply security.

4.1.1.2 Heat generation:

The heat demand of the residential complex is essentially covered by a combination of a highly efficient CHP plants (Combined Heat and Power) and a condensing boiler system. The energy concept makes it possible to integrate hydrogen as a renewable energy carrier into the district's energy supply concept.

For the year-round heat supply, two CHP plants were erected, which are operated heat-led with an output of approx. 2 x 50 kW_{el} and 2 x 100 kW_{th} and supply the base load and medium load of the local heat supply. During the heating-free period, the system covers the heat demand for domestic hot water preparation, compensates for heat network losses and is designed in such a way that the condensing boiler system only has to be used during heat load peaks. The CHP plant operates under the funding regime of the German Combined Heat and Power Act (Kraft-Wärme-Kopplungsgesetz). The electricity generated in the CHP unit is fed into the public power grid at low-voltage level, minus the electricity required by the power plant itself.

The high utilisation of the CHP plant is ensured by the use of three hot water buffer storage tanks with a total volume of approx. 12,000 litres.

For the dimensioning of the heating system, the maximum heat demand needs to be considered. For this, the so called standard outside temperature is taken into account. This temperature describes the lowest-possible average temperature over 48 hours during winter. In Hamburg it is at – 12°C. In order to cover the peak heat load at this temperature in Hamburg and to secure the output of the aforementioned heat generator, a natural gas-fired double condensing boiler with a thermal output of approx. 2 x 500 kW was additionally installed. For the best possible utilisation of the energy contained in the flue gas, the condensing boilers were equipped with condensing heat exchangers. The condensing boiler is only used at very low outside temperatures and during a planned or unplanned shutdown of the CHP plant during maintenance work.

In summary, the use of the following heat generators is planned for the district supply:

Table 3 Energy output of the heating system “Am Schilfpark” (enercity AG, own source).

	Heat output	Electricity output
CHP	200 kW$_{th}$	100 kW$_{el}$
boiler	2 x 500 kW$_{th}$	
total	**1,200 kW$_{th}$**	**100 kW$_{el}$**

The permanent availability of the reserve and peak load boiler means that even in the event of a failure of the CHP plant, full security of supply for the district heating system can be guaranteed at all times.

4.1.1.3 Heat balance

The contribution of the two planned heat generation plants to the district's heat supply over a calendar year is illustrated in the following diagram in Figure 4. The annual load curve shows the heat demand of the residential quarter over 8,760 hours in an orderly manner.

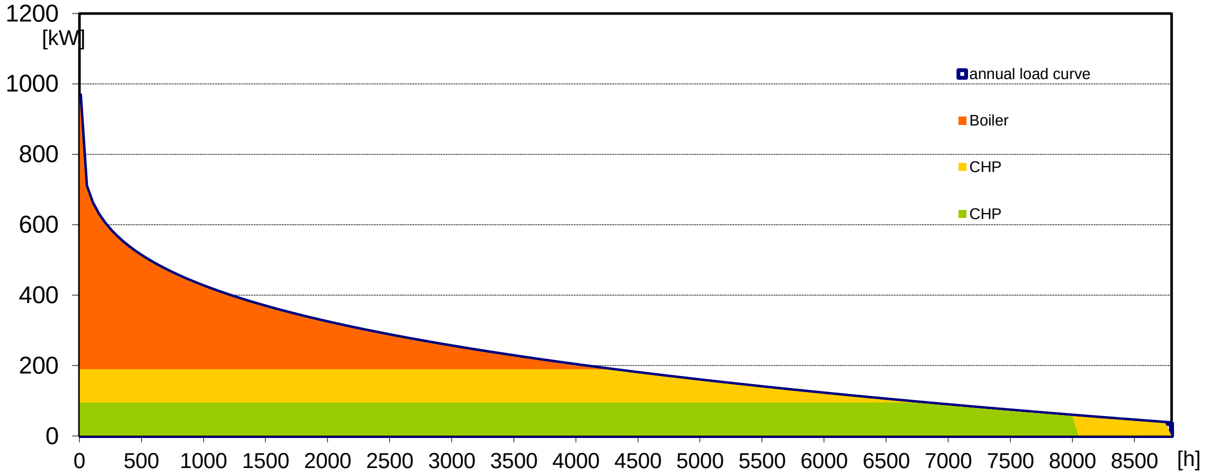

Figure 4 Load duration curve of the heating system “Am Schilfpark” (enercity AG, own source).

The CHP plants are in operation over 88% of the year and cover the majority of the district's heating requirements. The condensing boilers are only put into operation during peak heat loads and during scheduled and unscheduled shutdowns of the CHP plants.

Based on the total annual heat requirement of the residential complex of approx. 1,968 MWh, as shown in Table 54, the heat balance is as follows:

Table 4 Heat balance of the heating system "Am Schilfpark" (enercity AG, own source).

	Total heat production	CHP	CHP	boiler
heat supply [MWh]	1.968	749	587	632
Percentage [%]	100%	38%	30%	32%

The proportion of the heat demand that is covered on the supply concept which based on CHP is 68%. The requirements of the EEWärmeG for the heat supply of the building are thus exceeded by CHP alone by 35%.

4.1.1.4 Energy demands for the CHP plans “Am Schilfpark”

The obligation of using renewable energy according to § 3 I EEWärmeG is fulfilled if at least 50% of the heat demand of new buildings is covered by a CHP plant (§ 7 Ib EEWärmeG). The share of the heat demand, which is covered by the CHP on the basis of the supply concept is over 60%.

The energy requirements for buildings are laid down in the EnEV. The EnEV applies to buildings that are heated or air-conditioned. In addition to heating and air-conditioning technology, its requirements relate primarily to the thermal insulation standard of the building. The EnEV aims to reduce the primary energy requirement for heating buildings and hot water. The annual primary energy demand of a new building for heating, hot water, ventilation and cooling must not exceed a permitted maximum value. This maximum value is determined on the basis of a "reference house". The reference residential building has the same geometry, dimensions, usable building area and orientation as the planned residential building. The data for the construction and technical equipment of the reference house is provided by the EnEV in a table. This includes the following information:

- The heat transfer coefficients (U-values) of the building components surrounding the heated or cooled building volume: External wall, roof, floor slab, windows and external doors,
- the thermal bridge surcharge for these exterior components,
- the design value for the airtightness of the building envelope,
- the rules for taking sun protection into account,
- technical equipment for heating, hot water preparation and ventilation.

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The energy supply concept was based on the total heat demand of the planned residential development from the data in the EnEV certificate in the amount specified below:

Table 5 Heat demand of the new development "Am Schilfpark" (enercity AG, own source).

Name	Value
Total heated area approx.:	24.832 m²
Number of housing units	273 HU
Connected load heat approx	972 kW
Specific heat requirement:	79,27 kWh/m²/a
Total heat demand approx.:	1.968.453 kWh/a

Whereas CHP plants are used, means that not only heat is generated, but at the same time also electricity and certain losses have to be expected throughout the entire operation of the plants, it is not possible to directly calculate the emissions from the heat demand alone. Moreover, it is necessary to know how much gas is needed to produce the required amount of heat. For this it is necessary to consider the electricity generation and additionally, the type of gas that is used. The gas demand can be indicated with around 3,050 MWh_{Hs}/a when calculating the CO_2-emissions, an emission factor of 244 $kgCO_2/MWh_{Hi}$ needs to be applied. Whereas values for two different kinds of gasses are applied and losses at the CHP need to be considered, only an approximate result can be given.

$$CO_2 - emissions\ [kg/a] = gas\ demand\ [MWh/a] * emission\ factor\ [kgCO_2/MWh] * gas\ conversion\ factor * loss\ factor$$

Eventually, a value of approximately 671 tCO_2/a would be emitted, when the CHP plants in the development area "Am Schilfpark" are only powered by natural gas. When, as planned in the mySMARTLife action, up to 30% of hydrogen in the gas mixture are supplemented, tit is expected that CO_2-emissions will decrease.

Further outlooks on the emission reductions and a general description of the setting is presented in the deliverable 3.3 *Report on retrofitted actions and implemented actions new buildings including RES and storages in HH*.

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4.1.2 Retrofitting area Bergedorf-Süd and Smart Heating Islands

The retrofitting area “Bergedorf-Süd” (Figure 5) was chosen for the mySMARTLife project because of the complexity of a wide mixture of old buildings (approximately 500 buildings with ca. 5,000 apartments with 330,000 m²) and a highly diversified house owner structure. In this area two actions are performed. The first one includes an approach for the energetic refurbishment of existing buildings (*Bergedorf-Süd retrofitting project*, Action 2). Here an activation approach is followed in order to motivate and advise house owners on energetic retrofitting. The second one comprises a concept for the implementation of micro-heating networks, so called heating islands. This concept is tested in Action 14 *Smart heating islands in retrofitted area of Bergedorf-Süd*. Because both actions are performed within the same area and partially overlapping, they are described here together. Moreover, with its heterogeneous development, user and ownership structure, the area can serve as a sample location in order to transfer approaches developed there to other quarters.

A more comprehensive description of the urban status-quo, the local structures and the implementation approaches applied for the retrofitting and the heating islands, can be found in the deliverable 3.3 *Report on retrofitted actions and implemented actions new buildings including RES and storages in HH*.

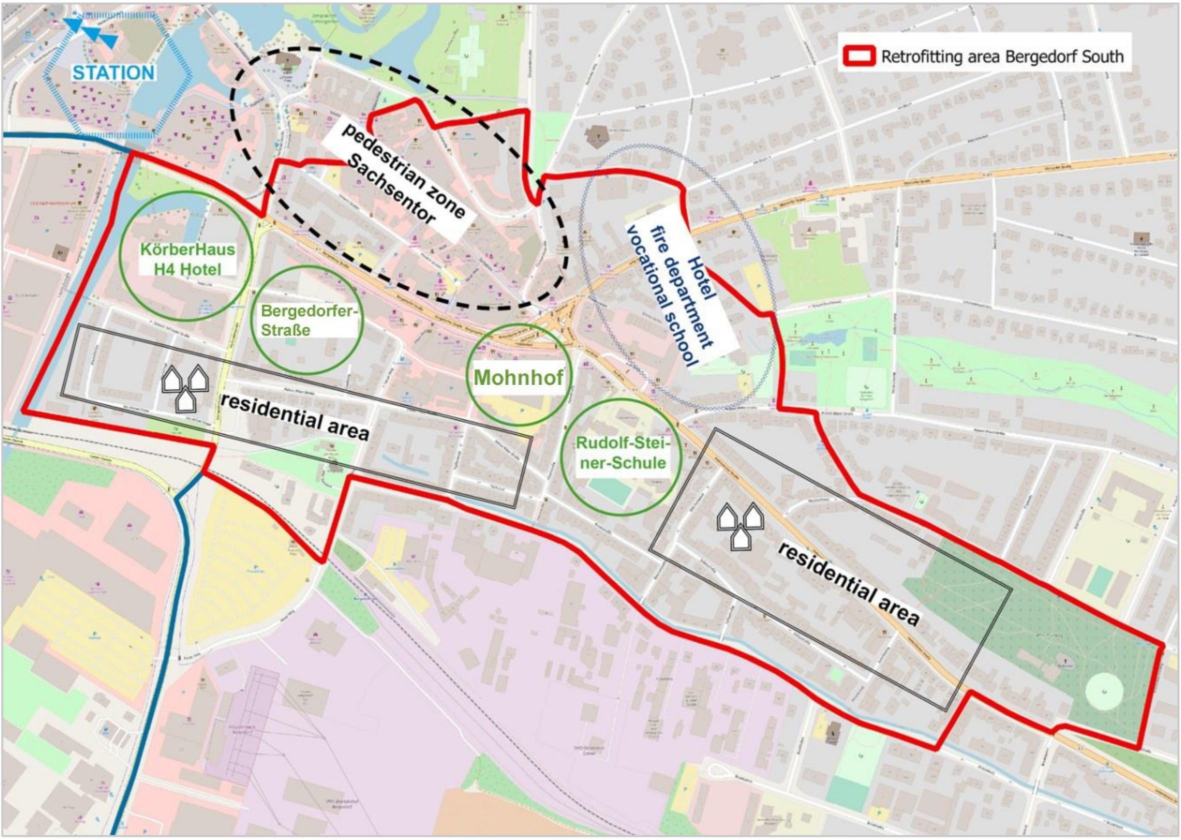

Figure 5 Project area Bergedorf-Süd (data: konsalt; map: www.openstreetmap.org)

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4.1.2.1 Smart Heating Islands

An evaluation of major public and commercial buildings was conducted in order to establish a possible district heating network. Overall, the proposal consists of four active co-generators to feed the district heating network (see green circles in Figure 5).

The potential heating island around the H4 Hotel and a new cultural centre, the so-called “Körber Haus”, the development area at “Bergedorfer-Straße” in the west, as well as the Rudolf-Steiner School in the east are eligible for solar thermic generation. Whereas the development at “Mohnhof” near the centre of the project area is considered eligible for a geothermal heat pump fuelled with bio-Methane.

4.1.2.2 Heating island H4-Hotel

The existing heating system of the H4 Hotel was considered as anchor point for one of the heating islands. Primarily because a modernization of the heat supply was required, whereas the existing heat supply system was outdated. With the heating central of the H4 Hotel as starting point, in this heating island the H4 Hotel, as well as approximately 50 surrounding apartment buildings are together supplied with heat.

In coordination with the responsible technical manager of the property, an energy plan has been set up for the optimization of the existing heating plant. Already in the first talks, potentials for an energetic optimization have been identified. The replacement of the heating central could provide a sustainable solution, e.g. based on combined heat and power plant with a district heating network, in which surrounding buildings and residential areas could be included. During an on-site inspection of the entire building, various structural measures were identified at the building envelope, which could reduce the energy requirements of the building.

Figure 6 New heating central at heating island H4 Hotel (konsalt GmbH).

The director of the H4 Hotel showed a keen interest in a district heating solution and the implementation of energetic refurbishment measures, so that further consulting sessions were held with him and the technical manager of the property. In early 2019 a new CHP (Figure 6) for the supply of the H4 Hotel and the surrounding housing block with 50 apartments was put into operation. Overall, dialogues are currently being held with various partners to obtain more up-to-date data for the whole area and more data for the heating island H4-Hotel.

Table 6 Data of the old twin boiler at the heating Island at the H4 Hotel (konsalt GmbH, H4-Hotel Hamurg-Bergedorf).

Type 1	Paromat-Duplex
Nominal heat output	760 - 875 kW
Fuel	Natural gas
Typ 2	Paromat-Duplex
Nominal heat output	475 – 545 kW
Fuel	Natural gas

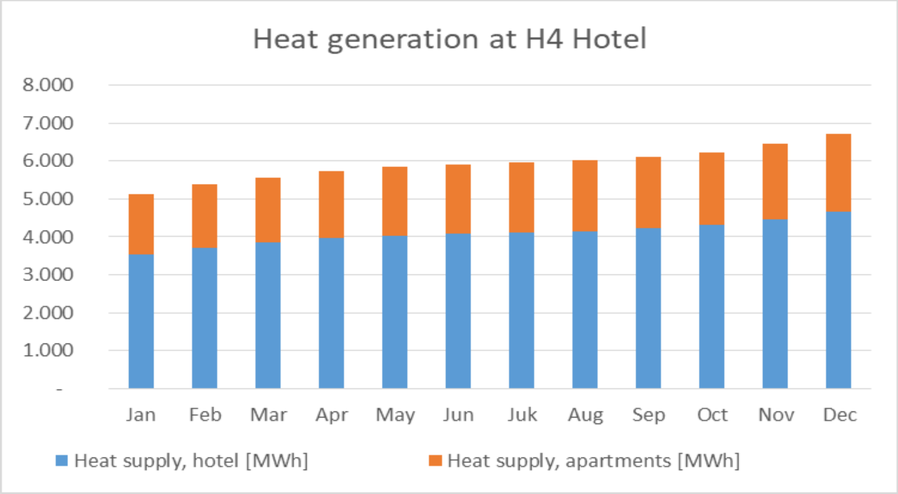

Figure 7 Distribution of generated heat at the H4 Hotel heating island in 2017 (konsalt GmbH, H4-Hotel Hamurg-Bergedorf).

With the old twin boiler system (Table 6) that has been replaced in 2019 by a CHP heating central, the total amount of generated heat summed up to 71.078 MWh in 2017 (Figure 7). 31%, 21.968 MWh were distributed to the apartments that are connected to the heating island, the remaining 69% of the generated heat, 49.110 MWh, remained at the hotel. The monitoring and future measurements will show to what extent the replacement of the boiler and the optimization of the heat distribution system can lower the amount of heat that is generated in the heating central of the H4 hotel heating island.

4.1.2.3 Energy demand in “Bergedorf-Süd“

The heat supply in the area is mainly based on natural gas and to a small fraction on night storage heaters (NSH). No data is available on other energy sources for heat supply. In consultation with the district chimneysweeper, the estimated share of other energy sources is approx. 3%.

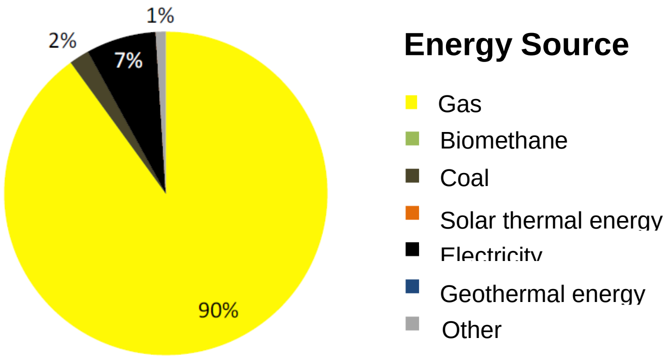

Figure 8 eat supply 2010 in Bergedorf-Süd (Arbeitsgemeinschaft konsalt GmbH, MegaWATT GmbH und Metropol Grund GmbH, 2017)

According to the information provided by Hamburg Netz, natural gas consumption in the total area amounted to 34.28 GWh/yr in 2011. Only in a single block is the proportion of electricity greater than 50%. In all other blocks, natural gas has a share of at least two-thirds; in some even over 90% (Figure 9). The connection density to the gas grid is rated as high with 81% of all buildings.

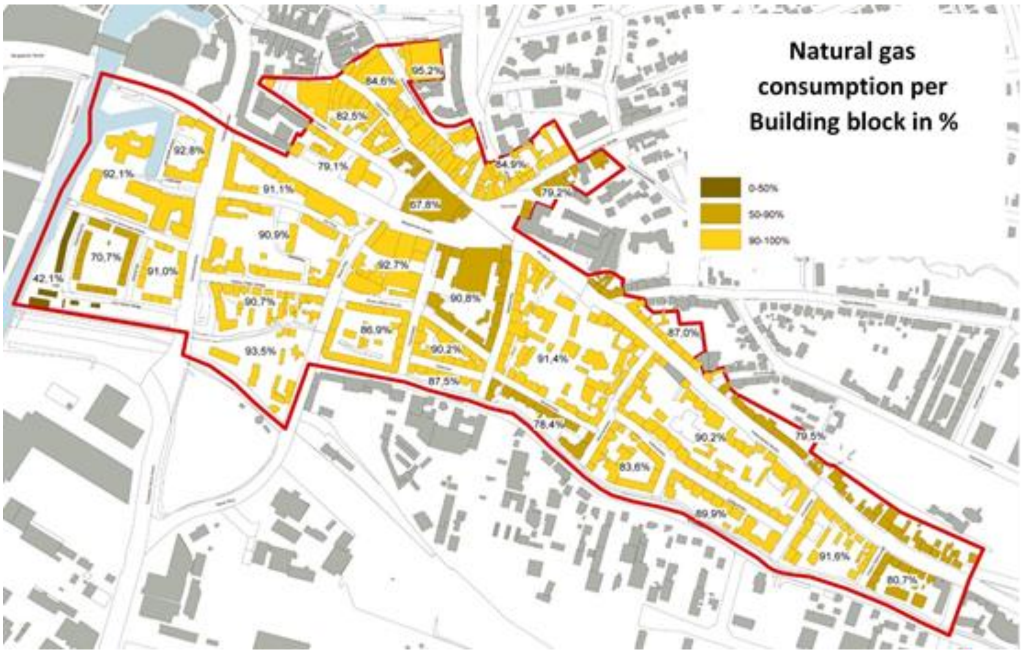

Figure 9 Natural gas consumption per Building block in % (data: konsalt GmbH; map: Borough of Bergedorf).

Including the type of heat generator, the primary energy requirement was 56.57 GWh/y. This corresponded to a specific primary energy requirement of approx. 175 kWh/m²y (Figure 10).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

A high electricity consumption (Figure 11) occurs particularly in the blocks at Bergedorfer Straße, Bergedorfer Schloßstraße, Sachsentor and Holzhude in the center of the map. There are houses with a huge proportion of commercial Space. In blocks with predominantly residential use, the electricity consumption is significantly lower.

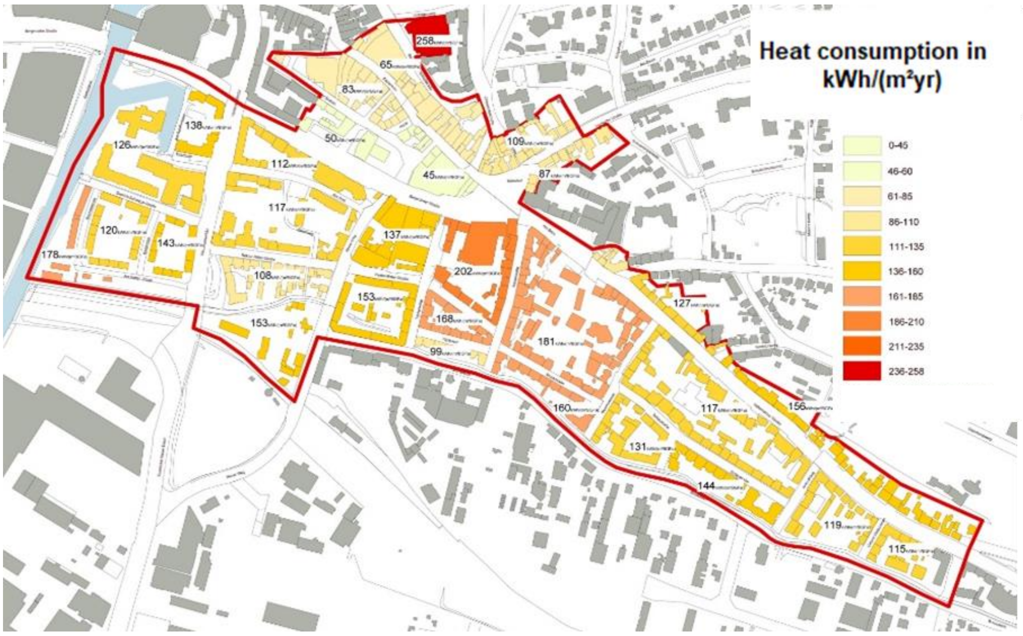

Figure 10 Heat consumption in kWh/(m²yr) (data: konsalt GmbH; map: Borough of Bergedorf).

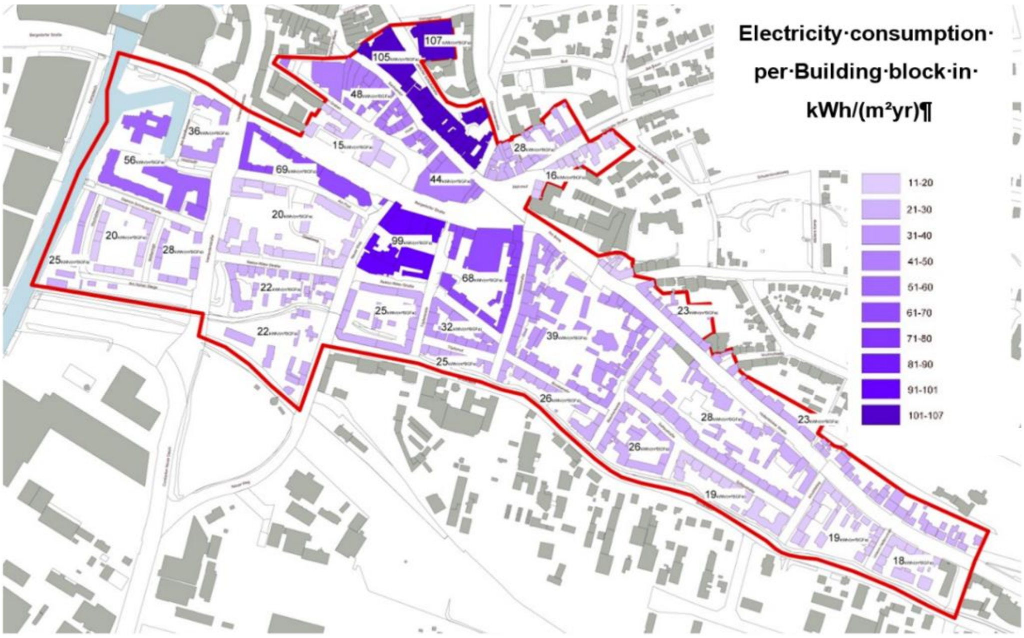

Figure 11 Electricity consumption per Building block in kWh/(m²yr) (data: konsalt GmbH; map: Borough of Bergedorf).

The analysis of the energy consumption of the Bergedorf-Süd region showed the following energy consumption for heat and electricity:

- According to the information provided by Hamburg Netz, natural gas consumption in the total area amounted to 34.28 GWh/yr in 2011.
- Electricity consumption for replenishment heaters (NSH) was 2.20 GWh/yr in the total area.
- The sum of the weather-adjusted gas and NSH electricity consumptions including boiler losses and auxiliary power for generating plants as well as the current in instantaneous water heaters amounted to 43.40 GWh/yr, including boiler losses and auxiliary power.
- Electricity consumption for households and commercial uses less electricity consumption for instantaneous water heaters for domestic hot water production was 12.63 GWh/yr.

Heat consumption in 2013 was on average 120 kWh/(m²yr), about 20% below the statistical average for residential buildings in Germany. Household electricity consumption, at 41 kWh/(m²yr), was about 30% above the German average. For the entire area of Bergedorf-Süd, the values stated above can be considered baseline values, whereas they indicate the different energy demands that occur in that area.

4.1.2.4 Further potentials in Bergedorf-Süd

The studies of the area have shown that further potentials can be exploited. Retrofitting, the replacement of old buildings and the successive conversion of energy supply to RES and the implementation of heating island can lead to energy savings and CO_2-emissions reductions.

Through various analyses and assumptions on the development of the building stock in Bergedorf-Süd (increase of retrofitting rates and depths) annual savings potentials were simulated and extrapolated. This results in a theoretically possible reduction in CO_2-emissions from building retrofitting by almost 45% by 2050.

In the beginning of the mySMARTLife project it was already clear that some of the old buildings would not be retrofitted. Instead it would be cheaper and more energy efficient to build new replacement buildings. For some buildings, not only energy savings but also modern floor plans could be implemented. In addition to energy-efficient retrofitting and energy-efficient new buildings, one of the most important levers is the gradual conversion of the energy supply to a high share of RES and low CO_2-intensity. With regard to heat generation, theoretically about one third of the heat demand could be covered on the basis of solar thermal collectors if all suitable areas could be used. By increasing the technical potential in the field of electricity generation by using all the appropriate PV areas in the area, electricity consumption could be covered by up to 20 per cent. In order to implement more RES or more efficient energy sources in neighbourhoods, so-called "Heating Island" concepts were deepened.

4.2 Energy demands in urban infrastructure

In the two actions Number 15 *Smart Street Lighting* and 16 *Humble Lamppost*, it will be tested how far the street lighting can be considered as a possible platform for additional sensors. In addition, it is expected that energy savings can be achieved with the LED technology. The deliverables D3.10 *Adaptive lighting concept* and D3.11 *Humble lamppost concept* have already been produced and submitted for both actions in month 24 (November 2018).

For several decades, the city of Hamburg has repeatedly taken measures to continuously reduce the energy consumption of public lighting and to keep it as low as possible. As described in the two deliverables D3.10 and D3.11 respectively in chapter 3.2 “Types of lighting in Hamburg”, the city has continuously improved its energy consumption by using new technologies and replacing individual components (e.g. electronic ballasts).

The texts explain the concepts of the two actions. In addition to the description of public lighting in Hamburg and its history, the lighting technology is also discussed with the advantages and disadvantages of LED technology. These deliverables deal with the operation of and the energy supply for the lighting. The following is an explanation of the electricity costs.

The electricity cost of the public lighting are calculated by a flat rate to the city of Hamburg. This means that the power consumption is not counted by every light or every street. In some cases, so-called reference meters are installed, which serve as a monitoring of the calculation of power consumption. The abandonment of electricity meters results in lower maintenance costs.

For the calculation, the specified energy consumption of a lamp is multiplied by the average burning time for a specific switching command. Most street lamps have a burning time of about 4,100 hours / year. Other switching commands are e.g. lights on pedestrian crossings that are turned on at an earlier time. The switching times are logged, so that it is reproducible at which time the lighting was switched on or off.

$$Specified\ energy\ consumption * Burning\ time = Annual\ energy\ consumption$$

The energy savings are calculated the same way for all lamps considered here. Yet, the used base data differs. Whereas it was possible to use old energy data for those lamps that were replaced, for the newly placed LED lamps at Schleusengraben and “Am Schilfpark”, it had to be assumed what conventional lamps would be placed there if not LED lamps would be used. In these cases, energy data from that assumed lamp type is used as reference for the situation prior to the installation of LED lamps within mySMARTLife. To calculate the energy savings, the annual power consumption of the

$$energy\ saving\ [kWh/a] = \text{power consuption, total } [\text{kWh/a}]_{conventional} - \text{power consuption, total } [\text{kWh/a}]_{LED}$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.2.1 Baseline – Smart Street Lighting

Within the context of this action, a footpath and cycle path will be built in the high performance area at “Schleusengraben”. This path will connect the new development area with the inner city center of Bergedorf. An adaptive lighting system with LED technology will be implemented in the environment of a near-natural space. Bicycle counting sensors on the light poles will document the traffic flow. The data will be evaluated at a later point in order to optimize the bicycle traffic. In order to increase the amenity values, a Wi-Fi service is also installed along the path.

LED lights are already installed in the neighboring development area "Am Schilfpark". A Wi-Fi service is also being implemented here.

The already implemented lighting system in the area “Am Schilfpark” was built according to actual standards. Table 7 shows the power consumption of a conventional lighting system and the new LED system. Each of the 3 lines in "conventionally" and "LED" represent the different types of lamp that were installed in this area.

Table 7 “Am Schilfpark”: Comparison of conventional and new lighting (HAM-LSBG, own source).

Action 15: “Am Schilfpark”							
Lamp type	**Number of lamps**	**Power consumption [kW/lamp]**	**Total electricity con-sumption [kW]**	**Burning duration [h/a]**	**Power consumption [kWh/lamp/a]**	**Power consumption, per type [kWh/a]**	**Power consumption, total [kWh/a]**
conventional	11	0.036	0.396	4,100	147.6	1,623.6	**3,632.6**
	11	0.036	0.396	4,100	147.6	1,623.6	
	2	0.047	0.094	4,100	192.7	385.4	
LED	11	0.024	0.264	4,100	98.4	1,082.4	**2,681.4**
	11	0.03	0.33	4,100	123.0	1,353.0	
	2	0.03	0.06	4,100	123.0	246.0	
						Expected total energy savings [kWh/a]	**951.2**

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The table shows that the power consumption has remained about the same. At the same time, however, the lighting yield has increased, the uniformity of luminance and the sense of security have been improved.

At “Schleusengraben”, an adaptive lighting system is implemented that illuminates the path at a reduced lighting level during the night. Presence detectors integrated in the luminaires detect pedestrians and/or cyclists and increase the brightness to a maximum. After a follow-up time of a few minutes without detection, the brightness level is reduced to a minimum again. It is assumed that savings can be generated by reduced lighting during the night. The extent to which this is offset against the consumption of the additional control components remains to be evaluated. The following Table 8 compares the power consumption of a conventionally planned footpath and cycle path with the newly planned one.

Table 8 “Schleusengraben”: Comparison of conventional and new lighting (HAM-LSBG, own source).

Action 15: “Schleusengraben”						
Lamp type	**Number of lamps**	**Power consumption [kW/lamp]**	**Total electricity con-sumption**	**Burning duration [h/a]**	**Power consumption [kWh/lamp/a]**	**Power consumption, total [kWh/a]**
conventional	17	0.025	0.425	4,100	102.5	**1,742.5**
led	27	0.0083	0.2241	4,100	34.03	**1,118.1**
sensor technology	27	0.0018	0.0486	4,100	7.38	
Expected total energy savings [kWh/a]						**624.4**

It can be seen that there is a reduction in power consumption although the number of poles has been increased. Because of the low pole height (approx. 4-5m), the LED technology can produce a much more effective light output than conventional lamps. The measure of the efficiency of light sources is the so-called luminous efficacy. It indicates how much energy must be used for a specific luminous flux; unit [lumen/watt]. This value is higher for LEDs than for conventional light sources.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.2.2 Baseline humble lamppopst

Action16 focuses on the replacement of conventional lighting with LED technology without additional sensors (see D3.11 Chapter 3.4 and 4) after a demand and feasibility analysis. With the basic overhaul of the complete lighting system on the section of the street “Reinbeker Redder”, both the lamps and the lighting poles were replaced. The goal was to make the lighting of the road more homogeneous in order to increase road safety by better illumination. For this reason, the pole distances were reduced and 10 additional lighting poles were placed along the complete distance.

Table 9 shows the consumption of conventional and newly installed light sources.

Table 9 “Reinbeker Redder”: Retrofitted public lighting (HAM-LSBG, own source).

Action 16: “Reinbeker Redder”								
Lamp type	**pole height [m]**	**Number of lamps**	**Power consumption [kW/lamp]**	**Total electricity consumption [kW]**	**Burning duration per year [h/a]**	**Power consumption [kWh/lamp/a]**	**Power consumption, per type [kWh/a]**	**Power consumption, total [kWh/a]**
conventional	7.5	17	0.041	0.697	4,100	168.1	2,857.7	**4,989.7**
	9.5	8	0.065	0.52	4,100	266.5	2,132.0	
LED	7.5	27	0.03	0.81	4,100	123.0	3,321.0	**4,436.2**
	9.5	8	0.034	0.272	4,100	139.4	1,115.2	
Expected total energy savings [kWh/a]								**553.5**

This table is divided into two pole heights. At conflict zones, e.g. crossroads and junctions, higher masts are placed for a brighter illumination. Here the poles are already placed more closely so that the distance did not have to be changed.

The table shows that the overall energy consumption has nevertheless been reduced there at a simultaneous increase of the number of lamps.

What has not been considered in this calculation is the operational lifespan of the lamps.

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In contrast to conventional light sources, regarding to LED light sources the complete lamp has to be replaced at the end of its service life. A standard requiring the replacement of individual components is not yet feasible from an economic point of view.

In Bergedorf, two additional streets were equipped with LED technology. Both roads pass through nature reserves. As the LED produces more directed light with little diffused light it is a reasonable decision to use this technology in a near-natural area. Although due to the beam characteristics, the pole distances have to be adjusted and reduced. The following two tables Table 10 and Table 11show the conversions with the corresponding energy consumption.

Table 10 "Kirchwerder Landweg": Retrofitted public lighting (HAM-LSBG, own source).

	Number of lamps (pieces)	Power consumption [kW/lamp]	Total electricity con-sumption [kW]	Burning duration [h/a]	Power consumption [kWh/lamp]	Power consumption, total [kWh/a]
conventional	103	0.041	4,223	4,100	168.1	**17,314.3**
LED	197	0.025	4,925	4,100	102.5	**20,192.5**
			Expected total energy savings [kWh/a]			-2,878.2

Table 11 "Weidemoor": Retrofitted public lighting (HAM-LSBG, own source).

	Number of lamps (pieces)	Power consumption [kW/lamp]	Total electricity con-sumption [kW]	Burning duration [h/a]	Power consumption [kWh/lamp/a]	Power consumption, total [kWh/a]
conventional	10	0.071	0.71	4,100	291.1	**2,911.0**
LED	17	0.016	0.272	4,100	65.6	**1,115.2**
			Expected total energy savings [kWh/a]			1,795.8

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4.2.3 Conclusion

In some places it can be seen that the renewal does not lead to any savings in energy consumption in terms of figures. On the one hand, this can be explained by the fact that Hamburg is continuously keeping the electricity consumption of public lighting as low as possible. In the past, the savings had the effect that streets in residential areas could not be uniformly illuminated. In order to create a greater feeling of safety and also to reduce the risk potential, newly planned lighting poles are being placed more closely together. As a result, the LED lamps consume less energy per unit. As the number of lamp poles, however, increases, total energy savings cannot be produced in every case. Yet, it needs to be underlined that in the streets where the two actions were implemented 179 conventional lamps would be needed, whereas it is now 300 LED lamps with a better illumination of the streets. Even though the number of new LED lamps is with 121 additional lamp posts well above the number of conventional lamps, still a yearly energy reduction of 1,046.7 kWh is expected (Table 12).

Table 12 Summary of total energy consumption and expected energy savings (HAM-LSBG, own source).

Location	Lamp type	Power consuption per year totaly [kWh/a]	Energy savings per year [kWh]
Am Schilfpark	Conventional	3,632.6	951.2
	LED	2,681.4	
Schleusengraben	Conventional	1,742.5	624.4
	LED + sensor technology	1,118.1	
Reinbeker Redder	Conventional	4,989.7	553.5
	LED	4,436.2	
Kichwerder Landweg	Conventional	17,314.3	-2,878.2
	LED	20,192.5	
Weidemoor	Conventional	2,911.0	1795.8
	LED	1,115.2	
Total energy consumption [kWh/a]	Conventional	**30,590.1**	
	LED	**29,543.4**	
Expected total energy savings [kWh/a]			**1,046.7**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.3 Mobility-related emissions and fuel consumption

For both actions described in the following, the methodology to come to baseline values is principally the same, whereas both actions deal with the electrification of vehicles. Whereas the first action deals with diesel fuelled busses that are replaced by e-busses, it is in the second action about fossil fuelled cars that are replaced by e-cars. For both fleets the previous fuel-consumption and CO_2-emissions shall serve as baseline values for a later assessment and evaluation of implementations. The basic approach is also in detail described in the last version of the deliverable 5.1 *Integrated evaluation procedure*.

Based on the findings from this present deliverable, the emission reductions will later be calculated as follows:

$$CO_2\ emissions\ saved = CO_2\ emissions\ due\ to\ combustion\ of\ fuel\ -\ CO_2\ emissions\ from\ new\ E-cars$$

The individual calculations of the fuel consumption and the CO_2-emissions are of the busses and cars are presented in the following subchapters.

4.3.1 *Electrification of bus lines in Hamburg-Bergedorf*

For action 21 *Electrification of Bus lines* with new E-Busses the VHH will procure 10 electric vehicles for regular public transport services within the project area, a complete description of the action can be found in the deliverable 3.8 *Development of new Mobility services and intermodality strategies.*

Currently the VHH fleet consists of a range of diesel vehicles ranging from Euro IV to Euro VI, with the older busses being replaced first through newer technologies.

4.3.1.1 Necessary considerations for the electrification of the bus fleet

All diesel vehicles can currently be deployed on the various lines within the project area. For better efficiency the VHH does not simply allocate one bus to a certain line but uses a software tool to generate routes with a mix of lines that minimise the empty km and fit best with driver times and pauses. The busses rotate in their service across all routes to achieve the best distribution of km across the fleet to ensure an even depreciation of material across all busses. This is an optimised system and the VHH will aim to deploy the e-busses in the same way.

Unfortunately, not all routes will be possible to service by e-bus due to range restrictions of the battery technology. Therefore, the e-busses need to be deployed on shorter routes. Eventually, this leads to a shorter yearly performance of the e-buses compared to diesel buses. While the VHH diesel busses average 70,000 km per year, the expected yearly performance of the e-busses will be around 45,000 km.

Hence, for the calculation of the baseline, it is not possible to use the total mileage of ten diesel busses. Instead, the expected annual performance of an e-bus needs to be taken into consideration. Because the main reason for the electrification of the bus fleet is the reduction of carbon emissions. Thus, CO_2-emission are the key indicator for the baseline of this action. The baseline the amount of CO_2-emissions that can be saved per year when diesel busses are replaced by e-buses, taking the above stated explanations regarding the routing into consideration.

4.3.1.2 Description of the baseline

For the baseline, which can also be understood as a forecast of possible CO_2-emissions reductions, following auxiliary calculations are needed:

Diesel consumption adjusted to the yearly performance of an e-bus:

$$Yearly\ diesel\ consumption\ [l/a] = Yearly\ average\ mileage\ [km/a] * specific\ diesel\ consumption[l/a]$$

With a specific diesel consumption on 40 l per 100 km, the yearly diesel consumption sums up to 18,000 l, when a yearly average mileage of 45,000 km is considered.

CO_2-emissions according to the calculated diesel consumption:

$$Yearly\ CO_2\ emissions\ [kgCO_2/a] = yearly\ diesel\ consumption\ [l/a] * \text{ diesel emission factor } [\text{kg}CO_2/l]$$

For diesel an emission factor of 2.64 $kgCO_2/l$ is applied. With the above calculated yearly diesel consumption, the CO_2-emissions per diesel fuelled bus with an yearly average mileage of an e-bus amounts to 47.25 tCO_2/a. Since ten busses are to be implemented within mySMARTLife, this number needs to be multiplied by ten.

For the baseline, it needs to be assumed that 10 diesel busses would have the same annual performance as 10 e-busses. The usage of these busses in the regular bus schedule would lead to a total of 475.20 tons of CO_2-emissions per year, which will be reduced to zero emissions by the use of e-busses in the following years.

As an outlook it can be summarized that some routes within the project area are very suitable to the shorter distance runs as they service the central Bergedorf district. Leaving the centre of Bergedorf, however, the routes lead through some rather rural areas and become much longer. So scaling up the number of busses presents a new challenge to the deployment of the e-busses. An adaptation to the optimisation software has been requested from the manufacturer/programmers and VHH has committed to 16 e-busses overall. Further tenders for e-busses have been fielded and digitalisation needs have been identified to better equip the VHH as transport service company to deal with these new challenges. Further, with the constant progress that is made in the battery technology, it is expected that in the future e-buses will have the same yearly mileage as the diesel busses

4.3.2 Electrification of public vehicle fleet

Within this action the largest parts of the vehicle fleet of the borough of Bergedorf, as well as further service vehicles of the VHH, one of the two public bus operators, are being electrified. At the borough of Bergedorf, 12 battery electric Renault Zoe and one hydrogen fuel cell car Toyota Mirai have been purchased. The 12 Renault

Zoes replaced nine VW Polos, of which six were petrol-fuelled and three diesel-fuelled. The VW Polos were used at the borough's department that is, besides others, responsible for the maintenance of the public space and greenery. At the VHH, 10 battery electric Volkswagen e-up! have been purchased, which replaced a variety of similar sized compact cars. Extensive descriptions of the replacement of the cars, as well as of the corresponding charging infrastructure and load management can be found in the deliverable 3.8.

4.3.2.1 Baseline for the Borough of Bergedorf

Because the Renault Zoes and the VW e-ups are used in the same departments from the same personnel, as the conventional cars they replaced, it is possible to use the usage data of these cars as baseline for this action. Whereas this action comprises the electrification of cars that are used on a daily bases, the most relevant aspect with regards to the goals of the project mySMARTLife is the reduction of fossil fuels, or of CO_2-emissions. From the VWs at the Borough, the existing records only provide information regarding the leasing period, the total mileage and the consumption and emission values as given by the manufacturer.

With the available technical specifications of the replaced petrol- or diesel-fuelled cars on the one hand and the total driving performance during the leasing period on the other hand the CO_2-emissions per kilometre can be calculated. It is of course necessary to note that these results can only be approximations to the real CO_2-emissions, whereas the individual fuel consumption and eventual CO_2-emissions can differ largely from between what is given by the manufacturer and what is consumed and emitted in real conditions. Additionally, the individual driving behaviour can also lead to values higher or lower the values provided by the manufacturer.

Following Table 13 provides an overview of the annual driving performance of those nine VW Polos that were in use at the department of public space replaced by electric vehicles.

Table 13 Annual driving performance of the replaced cars in the Borough's fleet (HAM-BGD, own source).

No	Model	Fuel	Registration date	Deregistration date	Mileage, total [km/year]	Mileage, average [km/year]
P1	VW Polo 6R	Petrol[1]	15.12.2014	22.03.2017	11,213	4,943
P2	VW Polo 6R	Petrol[1]	15.12.2014	22.03.2017	26,372	11,625
P3	VW Polo 6R	Petrol[1]	15.12.2014	22.03.2017	18,121	7,988
P4	VW Polo 6R	Petrol[1]	01.12.2014	22.03.2017	17,138	7,429
P5	VW Polo 6R	Petrol[1]	01.12.2014	22.03.2017	19,008	8,240
P6	VW Polo 6R	Petrol[1]	15.12.2014	22.03.2017	12,860	5,669
D1	VW Polo 6R	Diesel[2]	26.01.2015	22.03.2017	37,441	17,387
D2	VW Polo 6R	Diesel[2]	15.12.2014	22.03.2017	40,196	17,719
D3	VW Polo 6R	Diesel[2]	15.12.2014	22.03.2017	33,588	14,806

Following steps are taken to calculate the annual driving performance:

To calculate the annual average mileage, it is necessary to know how many days the vehicle was in use:

$$\mathit{Usage\ days} = \mathit{Registration\ date} - \mathit{Deregistration\ date}$$

Then the total driving performance, or mileage, is divided by the total usage days and multiplied by 365 days to receive the average mileage per average year.

$$Average\ mileage\ [km/year] = (Total\ mileage\ [km]/\ Usage\ days) * 365\ days$$

Ongoing from the information presented in Table 13, it is possible to calculate the fuel consumption and the CO$_2$-emissions. The manufacturer provides three different values for these two categories. These are urban, extra-urban and a combination of both. Whereas the Borough of Bergedorf has both urban and rural areas, which both need to be checked by the department for management of public space, the values for the combined use are applied. These are for the petrol-fuelled vehicles 4.7 l/100 km for the fuel consumption and 106 gCO$_2$/km for the CO$_2$-emissions, for the diesel-fuelled vehicles it is accordingly 3.4 l/100 km and 88 gCO$_2$/km.

For fuel consumption the applied formula looks as follows:

$$Fuel\ consumption\ [l/year] = (fuel\ consumption\ value\ [l/100km] *\ Mileage\ [km/year] *)/100$$

For the CO$_2$-emissions, it is:

$$CO_2\ \text{emissions}\ [kgCO_2/year] = (CO_2\ emissions\ value\ [CO_2/km] * Mileage\ [km/year])/1{,}000$$

Table 14 Fuel consumption and CO$_2$-emissions of the replaced vehicles of the Borough (HAM-BGD, own source).

No	Model	Fuel	Mileage [km/year]	Fuel consumption combined [l/year]	CO$_2$-emissions combined [kg/year]
BGD-P1	VW Polo 6R	Petrol[1]	4,943	242	524
BGD-P2	VW Polo 6R	Petrol[1]	11,625	546	1,232
BGD-P3	VW Polo 6R	Petrol[1]	7,988	375	874
BGD-P4	VW Polo 6R	Petrol[1]	7,429	349	787
BGD-P5	VW Polo 6R	Petrol[1]	8,240	387	873
BGD-P6	VW Polo 6R	Petrol[1]	5,669	266	601
	Total, petrol-fuelled vehicles		**45,894**	**2,157**	**4,865**
BGD-D1	VW Polo 6R	Diesel[2]	17,387	591	1,530
BGD-D2	VW Polo 6R	Diesel[2]	17,719	602	1,559
BGD-D3	VW Polo 6R	Diesel[2]	14,806	503	1,303
	Total, petrol-fuelled vehicles		**49,912**	**1,697**	**4,392**
	Total, all vehicles		**95,807**	**3,854**	**9,257**

[1] Fuel consumption* [l/100 km]: urban: 5.7, extra-urban: 4.1, combined: 4.7
CO$_2$-emissions* [g/km]: urban: 129, extra-urban: 93, combined: 106

[2] Fuel consumption* [l/100 km]: urban: 4.0, extra-urban: 3.1, combined: 3.4
CO$_2$-emissions* [g/km]: urban: 102, extra-urban: 81, combined: 88

* according to manufacturer's specifications

Whereas the CO_2-emissions of the replaced fossil-fuelled vehicles is the parameter that should be changed through implementation of the mySMARTLife measure, the electrification of the vehicle at the department for management of open space at the Borough of Bergedorf, the baseline value is 9,257 $kgCO_2$/year, as shown in Table 14.

4.3.2.2 Baseline for the VHH cars

At the municipal bus operator VHH the electrification of the vehicle fleet is taking place differently as compared to the Borough of Bergedorf. Whereas at the Borough of Bergedorf all vehicles of the fleet at the specific department have been replaced by electrical vehicles, the VHH replaces conventional cars individually by. The methodology that is used for the calculation of the fuel consumption and CO_2-emission values that should serve as values to be taken into consideration when the emission savings are calculated after the implementation and monitoring is similar to the one used above. As mentioned before and further described in the deliverable 3.8, the conventional vehicles at VHH that are being replaced by electric vehicles are used for the same purpose. At shift changes, bus drivers are taken from or brought to busses at terminal stations with these vehicles. In total 38 vehicles are used for this purpose. The vehicles that were in use in 2017 range from compact cars with two seats and minivans with five to seven seats to mini busses with nine seats. Whereas only compact cars with two to five seats are replaced by electrical cars so far, only these should be considered for the calculation of the baseline values. This would leave it to 16 cars of which four cannot be taken into account because the data from the records is not plausible. Because for the VHH fleet data for the annual performance for the year 2017 is available, it is not necessary to calculate the annual performance from accumulated figures of the total period of use. As for the calculations for the Bergedorf fleet, combined data for fuel consumption and CO_2-emissions is used here. In this context, the same calculations are made for the consumption and emissions as for the other public fleet.

For fuel consumption the applied formula looks as follows:

$$Fuel\ consumption\ [l/year] = (fuel\ consumption\ value\ [l/100km] *\ Mileage\ [km/year] *)/100$$

For the CO_2-emissions, it is:

$$CO_2\ \text{emissions}\ [kgCO_2/year] = (CO_2\ emissions\ value\ [CO_2/km] * Mileage\ [km/year])/1{,}000$$

The results from thes calculations for the previous VHH fleet are presented in Table 15.

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Table 15 Fuel consumption and CO_2-emissions of the VHH car fleet in 2017 (VHH, own source).

No	Model	Fuel	Mileage [km/year]	Fuel consumption combined [l/year]	CO_2-emissions combined [kg/year]
VHH-D1	Smart Fortwo[1]	Diesel	11,278	383	992
VHH-D2	Smart Fortwo[1]	Diesel	11,519	392	1,014
VHH-D3	Smart Fortwo[2]	Diesel	12,556	414	1,080
VHH-D4	Smart Fortwo[2]	Diesel	13,623	450	1,172
VHH-D5	Smart Fortwo[2]	Diesel	14,426	476	1,241
VHH-D6	Smart Fortwo[2]	Diesel	15,824	522	1,361
VHH-D7	VW Polo V[3]	Diesel	7,744	294	767
VHH-D8	VW Golf IV[4]	Diesel	5,822	297	803
VHH-D9	VW Golf IV[4]	Diesel	3,819	195	527
VHH-D10	VW Golf IV[4]	Diesel	7,819	399	1,079
VHH-D11	VW Golf VI[5]	Diesel	15,222	685	1,811
VHH-D12	VW Golf Plus[6]	Diesel	10,663	565	1,471
Total, all vehicles			**130,315**	**5,072**	**13,318**
Average			**10,860**	**423**	**1,110**

[1] Fuel consumption* [l/100 km]: combined: 3.4; CO_2-emissions* [g/km]: combined: 88
[2] Fuel consumption* [l/100 km]: combined: 3.3; CO_2-emissions* [g/km]: combined: 86
[3] Fuel consumption* [l/100 km]: combined: 3.8; CO_2-emissions* [g/km]: combined: 99
[4] Fuel consumption* [l/100 km]: combined: 5.1; CO_2-emissions* [g/km]: combined: 138
[5] Fuel consumption* [l/100 km]: combined: 4.5; CO_2-emissions* [g/km]: combined: 119
[6] Fuel consumption* [l/100 km]: combined: 5.3; CO_2-emissions* [g/km]: combined: 138

* according to manufacturer's specifications

Because not the entire fleet is electrified at once, but car by car, and also because it cannot be said what car is next to be electrified, it is useful to use the average values as baseline for individual cars. Depending on the number of cars that will be electrified at VHH during mySMARTLife, the average values for one car need to be multiplied by the number of cars replaced by e-cars. When renewable electricity is used to charge these cars, the CO_2-emissions caused by the operation of the vehicle, can then be reduced on average by 1,110 kgCO_2/a to zero per e-car.

5. References

Arbeitsgemeinschaft konsalt GmbH, MegaWATT GmbH und Metropol Grund GmbH (2017). Energetisches Sanierungsmanagement Bergedorf-Süd. Available at: http://suche.transparenz.hamburg.de/dataset/endbericht-zum-energetischen-sanierungsmanagement-bergedorf-sued [21.11.2019]

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