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D3.2 - 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.

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Abbreviations and Acronyms

Acronym	Description
CHP	Combined Heat and Power
CSV	Comma separated value
DHW	Domestic Hot Water
DWD	Deutscher Wetterdienst, German weather service
EEX	European Energy Exchange AG
EnEV	Energieeinsparverordnung, German federal direction for energy efficiency
GIS	Geographic Information System
IEC	International Electronical Commission
ISO	Internationale Organisation für Normung, engl.: International Organization for Standardization
LiDAR	Light Detection and Ranging
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
RES	Renewable Energy System
SLP	Standard Load Profiles
TLP	Temperature based Load Profiles

1. Executive Summary

The main objective of mySMARTLife project is the definition of an Innovative Urban Transformation Strategy in which the main lines of the project are depicted; highlighting that all interventions in the city must answer to real city challenges, identified following a city led approach and counting on with the active participation of the citizens through citizens' engagement strategies.

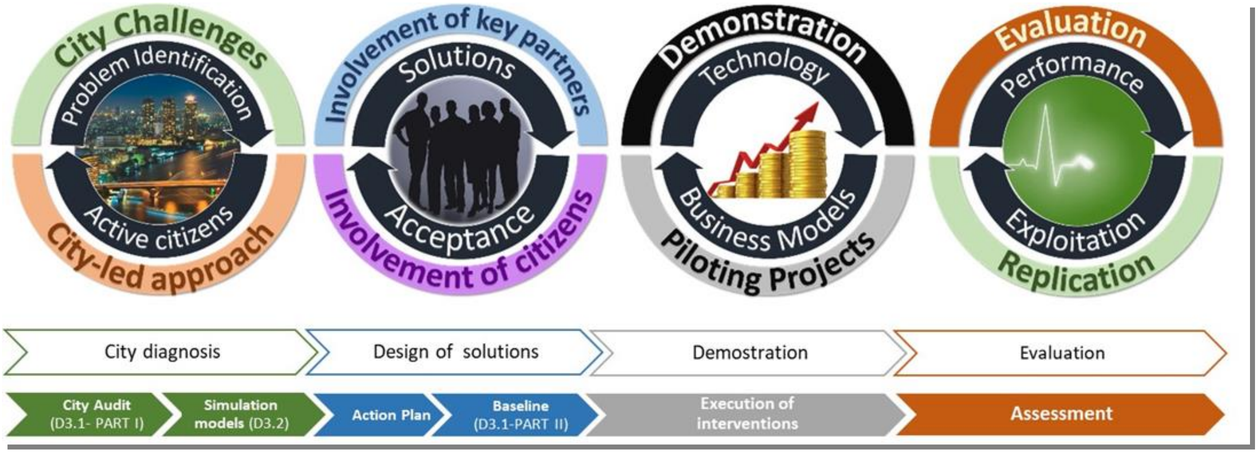

Figure 1: mySMARTLife Project concept

Within WP1 of mySMARTLife project, this Innovative Urban Transformation Strategy is being defined for three priority sectors (Energy, Mobility and ICT) and for the key frameworks of this process:

- A non-technological framework through the integration in Urban Plans of existing and innovative City Business Models overcoming the financial barriers, and the innovation frameworks.
- A Innovation framework, which aims to support technically the phases in the sense of existing methods and tools supporting these phases, the technology innovation and its integration in each of the priority sectors.

The Innovative Urban Transformation process started in Hamburg in Task 3.1 Baseline Assessment, with the City Diagnosis phase (PART I of Deliverable 3.1), whose aim is to identify the city challenges, needs and priorities, which will stablish the strategy that will led the political vision of the city, as a long-term vision of the city.

Afterwards, the Urban Transformation Process continues with the Simulation Models development, which will be delivered in this deliverable and in order to calculate a baseline, to establish the reference of the city, working in close collaboration to WP5 to summarise the current state in Hamburg in the beginning of the project.

This Urban Transformation Strategy, as well as its implementation, demonstration and replication stages, will be depicted and fully described within WP1, while this document aims at covering the second step of the first phase (City Diagnosis) within the Hamburg lighthouse city.

Due to the nature of the physical actions that are foreseen to be implemented in Hamburg, this deliverable is intended to include the simulation models that are necessary to be developed in order to simulate and model the building stock the transportation, the urban infrastructures and the energy supply in order to fully analyse the district in which the interventions will be implemented, with the information about the main architectural issues, energy facilities and energy consumption, mobility data that are necessary for the definition of the baseline.

Considering that an Amendment was requested in September (month 10) and that the process of negotiation and approval can still take several months, it was agreed with the project officer to submit an interim report at the original due date, month 12.

According to the actual schedule of implementation of the actions, foreseen to be completed in month 36 and for which the final details are still not ready, this deliverable is requested to be postponed to month 36 in order to include more accurate data from simulations of the interventions. This new requested due date is also in accordance to the original due date of the equivalent deliverable in WP2, “D2.2 Simulation models of the building stock, energy system, transportation, urban infrastructures”, related to Nantes demo site that is committed in the original version of the Description of the Action to be delivered in month 36.

2. Introduction

2.1 Purpose and target group

This report explain the simulation models that are being developed in Hamburg lighthouse city with the aim to diagnosis not only the demand in the different pillars of mySMARTLife project (mobility, energy and urban infrastructures) but also the energy supply potential of the City of Hamburg.

Special attention is being paid in Task 3.1 Baseline assessment in order to evaluate the 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.

Two different simulation models are expected to be done within Task 3.1. On the one hand, there will be simulation models to demand characterization, in particular:

- Simulation models of the building stock, in order to characterize the energy demand of Hamburg demonstration area.
- Simulation models of transportation, in order to characterize the mobility of Hamburg demonstration area.
- Simulation models of urban infrastructures, in order to characterize the urban infrastructures of Hamburg demonstration area such us, public lighting, smart grid, energy storage, etc.

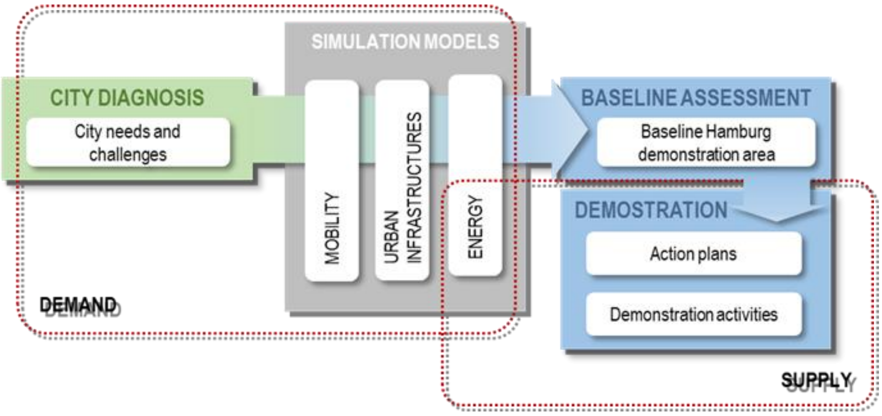

Figure 2: Simulation models approach

On the other hand, simulation models of the energy supply will be also defined in order to study the renewable energy potential of the demonstration area. Renewable energy plays an important role for the energy supply systems of the new and retrofitted buildings within the demonstrations areas. The audit

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report for available renewables shows the potential energy resources and will allow a comparison with the achieved use of RES for the supply with electricity and heat.

These useful simulation models will be used for baseline of Hamburg demonstration area, as an input of the huge analysis of the district in which the intervention will be implemented.

The present deliverable is structured as follows:

Chapter 3: shows the methodology scope to be implemented in the followings sections.

Chapter 4: shows the simulation model of the building stock. This model is being developed in close collaboration with task 1.4 “Advanced integrated urban planning”, so that in this section it is reported the work done and the methodology followed for the 3D models of the energy demand characterization of the Hamburg pilot.

Chapter 5: shows the simulation models for the characterization of the energy supply potential. The methodology defined in chapter 3 is being followed, starting with the data collection and analysis and continuing with the simulation models development, especially focused on the analysis of energy production potential in the fields of solar energy, the wind energy and ambient heat form surface water. This report is relevant for city and building planers seeking to increase the usage of local energy sources in order to build climate friendly and liveable cities.

Chapter 6: shows the simulation models of transportation. Two different simulation scenarios have been taken into consideration, so that both are presented and their approaches are defined.

Chapter 7: the simulation models of the urban infrastructures integrated with high-performance district will accomplished within this chapter. Nowadays, it will be focused on simulation models of the public lighting system stock.

Chapter 8: will show the conclusions of the deliverable. They will be provided in the final version of this deliverable.

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
CAR	Chapter 1,2
ENH	Chapter 5
HAM	Chapter 3.2, Chapter 7, Coordination and Translation

Participant short name	Contributions
HAW	Chapter 3.2, 4.2, 5.2, 6
KON	Chapter 3.2
TEC	Chapter 4.1

2.3 Relation to other activities in the project

The following table depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

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.
D3.4	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.
Task 1.4	The 3D model that is being developed in Task 1.4, will be analysis here in order to characterize the city demand.
Task 5.1	Evaluation framework. Project Level Indicators.

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3. Background and Context

As it was explained in the introduction section this deliverable is allocated in Task 3.1 Baseline Assessment, as it was stated many times, the main objective of this task is to develop the Baseline assessment of Hamburg, and the analysis to be done for the baseline is being developed in two different scales, at city level, and project level.

More specifically 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 located is being done in PART II of deliverable 3.1. The main objectives of the baseline 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.

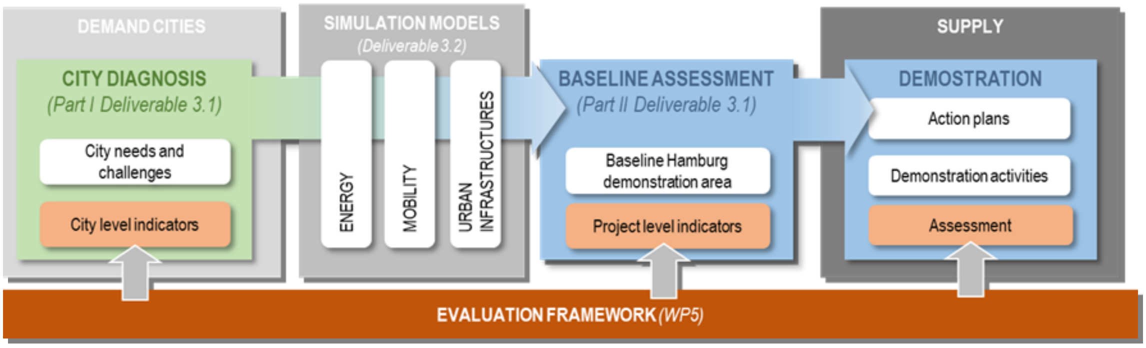


Figure 3: Simulation models background and context

The baseline is based on data collection from Hamburg demo site in order to have a reference for comparing the initial situation and the situation after the interventions. This data collection will cover the three main sectors where Urban Transformation Strategy is focused on: building, mobility, and urban infrastructures including ICT, and not only for the definition of this baseline but also for the calculation of the project level indicators, simulation models will be implemented in these three main sectors.

In this context a methodology for the simulation models development and implementation has been defined in order to ensure its goals achievement within mySMARTLife project.

4. Methodology for simulation models development

The methodologies will be applied to different areas. These are divided into the four areas: data generation, simulation, urban platform and presentation of results. The data generation is the base, used for the following simulations and the urban platform. The results from the simulation and the urban platform must be presented in a user-friendly way, which will then be implemented in the results presentation. The following figure 4 illustrates this schematically. The methodology is described in the next sections.


Data

Simulation

Urban Plattform

Results

Figure 4: graphic of the application of the methodologies

4.1 Data collection and Analysis

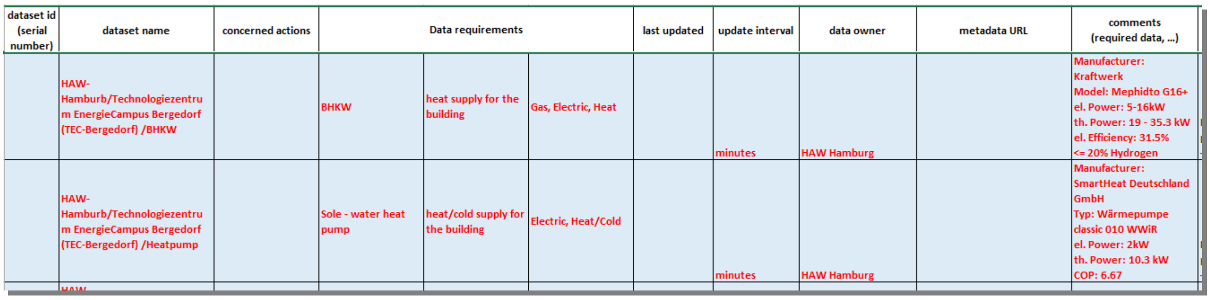
The project deals with different task in the project zone 1 the “high performance area” and the project zone 2 the “retrofitting area” (see Map in Annex 10.1). Here, the data will be recorded as follows:

- Public data sources: web services like solar cadastre, heat cadastre, existing studies, results from former projects or parallel running projects
- Talks with investors: During the project, new urban quarters will be built in the project areas and some existing buildings are planned to be retrofitted. In order to carry out these actions, it is necessary to activate the private investors to gain access to the energy data of these buildings.
- Inspection of objects: It is also possible to inspect existing buildings in the project areas in order to obtain further information.
- Building standards: Standardized building standards (such as the German energy efficiency standard “EnEV”) allow assuming defined values.
- Standard load profiles: Heat and electricity loads are rarely exist in a detailed level. Especially for buildings there is often just the annual consumption known. In this case it is possible to use the

standard load profiles, which are possible to generate by the consumption of the year of a household.

- Measurement data: Some project partners, like the Hamburg University of Applied Sciences (HAW) with its technology centre "E-Campus", already own energy facilities which are in operation. Actual energy production is measured and can be implemented in the simulation

A first data collection is done currently by the project partner T-Systems. In this course it was communicated from other partners what kind of energy facilities are already existing and operating in the project area and how these are configured (see figure 5):



dataset id (serial number)	dataset name	concerned actions	Data requirements			last updated	update interval	data owner	metadata URL	comments (required data, ...)
	HAW-Hamburb/Technologiezentrum EnergieCampus Bergedorf (TEC-Bergedorf) /BHKW		BHKW	heat supply for the building	Gas, Electric, Heat		minutes	HAW Hamburg		Manufacturer: Kraftwerk Model: Mephidto G16+ el. Power: 5-16kW th. Power: 19 - 35.3 kW el. Efficiency: 31.5% <= 20% Hydrogen
	HAW-Hamburb/Technologiezentrum EnergieCampus Bergedorf (TEC-Bergedorf) /Heatpump		Sole - water heat pump	heat/cold supply for the building	Electric, Heat/Cold		minutes	HAW Hamburg		Manufacturer: SmartHeat Deutschland GmbH Typ: Wärmepumpe classic 010 WWiR el. Power: 2kW th. Power: 10.3 kW COP: 6.67

Figure 5: A section of the actual data collection by T-System

The table contains the following attributes:

- Dataset id: the attribute contains a continuous numerating
- Dataset name: name of the dataset
- Concerned actions: in which action will the information of the dataset be used
- Data requirements: What kind of energy facility? What is the purpose? Which types of energy are used and generated?
- Last update: date of the last update
- Data owner: Who runs the facility and who is the owner of the facility?
- Metadata URL: URL to the metadata
- Comments: additional description
- Contact person: first contact person of the facility
- Service: the official name of the service
- Area: the bounding box with coordinates
- Topic: the topics delivered by the service

4.2 Simulation model development

The simulation box, showed in figure 4, does not contain a fixed simulation system. Depending on various research questions different simulation systems are possible.

The following methodology should be developed and applied within the framework of the project:

- Dimensioning of CHP and heat storage
- Investigation of potential of flexibility of buildings/ town quarters and/or e-mobility
- Building simulations with different heating generators
- Grid simulations (heating- and electricity grid)
- Business case analysis between heating based- and electricity based facilities
- CO2 valuation
- Analysis of energy balance

4.3 Urban platform development

One main part of the project mySMARTLife is the development of an urban platform for the city of Hamburg. It is planned to connect this urban platform with the real data of the energy facilities. Therefore it is possible to use the urban platform to evaluate the described simulation models. Depending on the users, it allows to offer different kind of reports. The methodology, which will be used in the simulation, will be also realized in the urban platform.

Due to data protection it is not possible to use the result of the reports 1:1, therefore it is necessary to define a classification system.

4.4 Simulation results

This section deals with the presentation of results from the simulations and the Urban Platform. Different user roles, such as the public, the authorities or the plant operator, are to be considered and the presentation of results adjusted in each case. Furthermore, it should be checked which (existing) platforms can be used for the project results, like the online platform “Wärmekataster Hamburg” (tr. heat cadastre of Hamburg).

5. Simulation models of the building stock

This chapter describes in detail what the project mySMARTLife will simulate in relation to the building stock and in relation to individual buildings. First the existing databases of the individual areas are considered and then the simulation model, expected results and finally a conclusion of the results.

5.1 Energy demands of the building stock

The analysis of the energy demands of the building stock of the selected districts is linked to Task 1.4: Advanced Integrated Urban Planning. In this task, a methodology developed in WP1 is used to analyse the current heating, cooling and DHW demand at district level.

More precisely, the methodology will serve to estimate the heating, cooling and DHW hourly demand of each of the buildings included in a district in a way that the results can be analysed both at the building and district level. The possibility of disaggregating evaluated energy demands into different categories (depending on the use of the building or on its construction period among others) will offer the opportunity to evaluate more in detail the baseline situation and to define in the future different improvement strategies for specific areas and buildings.

The simulation methodology is based on the analysis and use of basic cartography and available cadastral data and the environmental information (hourly temperature) that is combined with an internal database and an algorithm that allows obtaining automatically different energetic information.

The energy modelling distinguishes 3 main phases;

- Data collection and analysis: Input data
- Simulation model: Internal algorithm
- Results: Output data

5.1.1 Data collection and Analysis

The methodology considers different level of input data depending on the data available in the specific case of each city. It needs to be taken into account that most of the input data required by this methodology should be provided by the municipality.

This input data required is based on the cartography, city cadastre data and LiDAR information of the city. In the case that the municipality does not have available this information, there is a possibility to use Open Street Map directly to obtain the cartographic data.

In a following step, all the information obtained from the data sources provided by the municipality has to be processed and organized in order to get the relevant information that is required calculation of the main parameters used in the energy demand analysis of the district. The following figure 6 shows as an example the initial results of the data analysis and pre-processing for the zone of the city that was selected for the initial analysis.

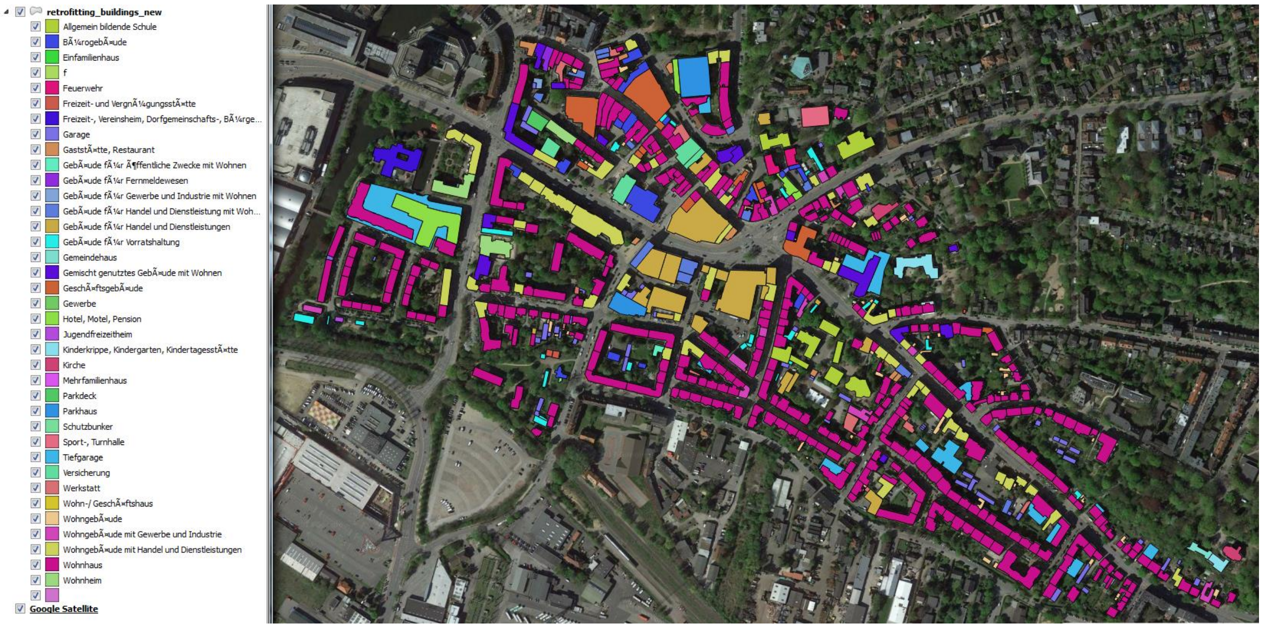


Figure 6: Example of a processed shape file for the retrofitting area in Hamburg, the different colours showing different types of use of the buildings (own design)

The table below shows the main input data that are necessary for the calculation process of the energy demand of buildings distinguishing between the mandatory and optional data. In the case that the data sets identified as optional are not available in the city, the calculation algorithm will estimate their values internally.

Regarding the information related to the geometry of the building, it needs to be considered that it will be used directly in the calculation process. However, the information regarding the age and the use of buildings must be processed before using them. In the case of the age of the buildings, 7 construction periods have been considered in order to make easier the assignation of this characteristic for each building: Pre-1945, 1945-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2010, post-2010.

On the other hand, in the case of use of the building, the methodology considers 9 uses: Residential, offices, commerce, health care, public administration, education, hotel, restaurant and sports. Therefore, the specific uses defined in the cadastre of each city need to be adapted or at least assigned to one of them.

Table 3: Input data contained in the shape file

Parameter	Mandatory / Optional	Source
Building ID	Mandatory	SHP of the District
Building Geometry	Mandatory	SHP of the District
Footprint area	Mandatory	SHP of the District
Height	Mandatory	SHP of the District or LiDAR
Year of construction	Mandatory	SHP of the District
Building Use	Mandatory	SHP of the District
Gross floor area	Optional	SHP of the District
Number of floors	Optional	SHP of the District
Roof area	Optional	SHP of the District

5.1.2 Simulation model

The simulation methodology uses an internal algorithm that aims to achieve a balance between the accuracy of the results and the computational effort necessary for the analysis. The main reason is that the methodology proposed aims to serve in the future to extent the boundaries of the evaluated area or district of the city in a way that larger areas of the city can be semi-automatically evaluated with a similar procedure. However, taking into account the scope of the project, in task 1.4 the evaluated area covered by the analysis will be limited to the specific area of the city that will be intervened.

For the calculation of the building thermal energy demand, the proposed methodology uses an internal energy assessment algorithm composed by the following 3 equations, based on the “Degree Day Method” that has been adapted for the analysis in order to provide an hourly energy demand analysis instead a yearly analysis:

$$HD = \sum_{n=1}^{8760} (HDH_n \cdot A \cdot U + Gains + H.ventilation\ losses) \cdot Heating\ schedule$$

$$CD = \sum_{n=1}^{8760} (CDH_n \cdot A \cdot U + Gains + C.ventilation\ losses) \cdot Cooling\ schedule$$

$$DHWD = (DHW\ demand \cdot gross\ floor\ area \cdot DHW\ schedule)$$

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Besides, as it can be seen above, extra parameters are considered in addition to those usually considered in the "Degree Day Method". Those parameters are focused on the analysis of the internal gains, solar gains, ventilation losses, as well as operating schedules for heating and cooling.

It can be seen in the equations above that the area of the elements of the building envelope is an input for the algorithm, while the rest of the parameters considered in the equations are part of the internal database of the method.

In this last case, in order to select and access these information sets, some inference rules have been previously defined in the algorithm. These inference rules link some of the inputs of the methodology with the information of database, which depends, in some cases, on one or more parameters, as it is summarized in the table 4 below.

Table 4: Inference rules of the internal energy assessment algorithm

	Construction period	Schedules	Internal gains	WWR	U-value	Ventilation losses	Solar gains	DHW demand
Country					X	X	X	
Age	X				X	X		
Use		X	X	X	X		X	X

5.1.3 Results

The main output information of the analysis is obtained once that the calculation process finishes and 2 CSV files and a shape file are generated. The first CSV file provides the energetic information for each building as well as the rest of the information related to it. Most relevant output parameters provided by the analysis are summarized in the table below.

Table 5: Main output data obtained with the analysis

Parameter	Unit	Parameter	Unit
Country	-	Total annual heating demand	kWh/year
ID	-	Total annual cooling demand	kWh/year
Use	-	Total annual DHW demand	kWh/year
Construction year	-	Maximum cooling demand	kW
Gross Floor Area	m2	Maximum heating demand	kW
Volume	m3	Maximum cooling demand	kW
Footprint	m2	Maximum DHW Water demand	kW

Parameter	Unit	Parameter	Unit
Facade Area	m2	Specific annual heating demand	kWh/(m2·year)
Window area	m2	Specific annual cooling demand	kWh/(m2·year)
Height	m	Specific annual DHW demand	kWh/(m2·year)

This information can also be provided in a shape file, so that the results can be visualized in an open GIS tool. A second CSV could also be provided which includes the output information grouped per different categories such as the type of use or the construction period among others. This will help to understand better the potential linked to specific building groups that can be refurbished or in which different energy efficiency measures can be implemented.

The contrast and the validation of the results obtained by the modelling will depend on the availability of actual energy consumption data at building and district scale. Both, actual energy consumption data and information obtained by monitoring activities in buildings will serve to calibrate the methodology.

5.1.4 Conclusions of the simulation study

In contrast to the traditional analysis that is based on the energy demand analysis of individual buildings, results obtained with this analysis will allow evaluating the city district in a different way, providing a general and visual baseline situation of the energy demands of the building stock. This information will potentially serve to identify improvement options no only at building scale but also at district scale.

5.2 Energy and Building simulation

The chapter energy and buildings is about the energy flows from electricity and heat of a building or a town quarter within the project area of Hamburg. Owing to the actual low gas price, most combined heat and power (CHP) facilities are constructed for the heat-controlled operation. On the one hand, the simulation will examine the relationship of different heat generators on the overall heat supply in the project area, while on the other hand, concepts for an increasing on-site usage of electricity is analysed, combining PV and batteries and furthermore, integrating e-mobility.

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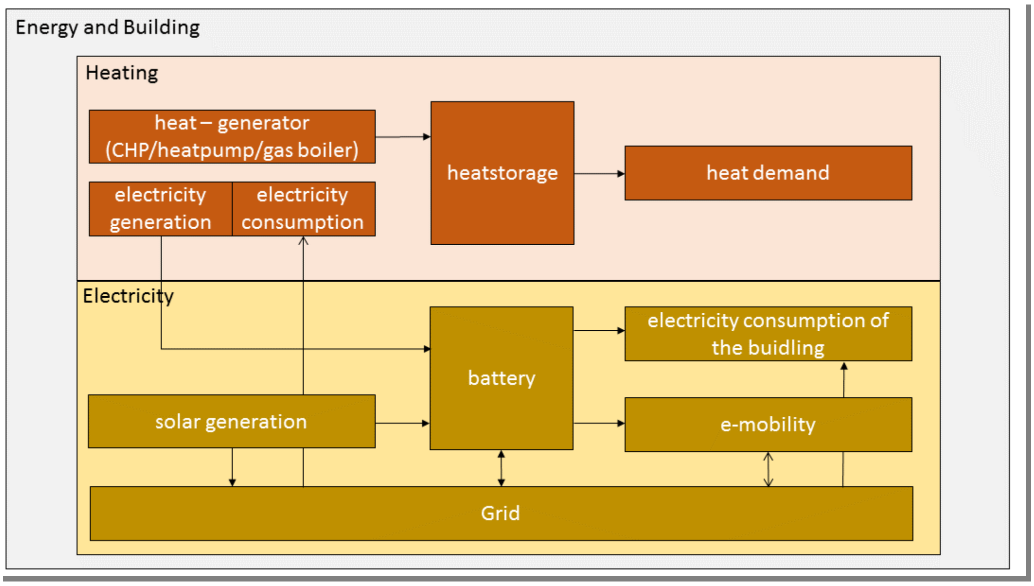

Figure 7: Overview of the model components for the Task Energy and Building

5.2.1 Data collection and Analysis

The simulation requires different data, which are not yet available at all and must be produced and recorded during the project. The necessary data sources are described below.

5.2.1.1 Standard load profile

Standard Load Profiles (SLPs) provide reasonably accurate forecasts for fifteen-minute power and heat consumption. SLPs are characteristic load profiles, which are used for different groups of consumer (e.g. households, industry) with similar electricity purchasing behaviour. Temperature-dependent consumers are mapped using daily parameter-dependent load profiles (TLP).

5.2.1.2 Heat-generator

The data of a possible generator should be used, but it is not yet known at the present time of the project.

5.2.1.3 e-Mobility

The data of a possible e-mobility service (e.g. the e-busses) should be used, but it is not yet known at the present time of the project.

5.2.2 Simulation model

The Energy and Building task deals with heat and power side of the building sector. Figure 7 shows the individual components necessary for consideration in this task. The complexity of the components can be chosen individually. Depending on the question, not all components of the simulation model have to be used necessarily.

In order to optimize the dimensioning CHP and heat storage, it is necessary to know how great the heat demand is and which conditions for the building should be met (interior temperature etc.).

If, on the other hand, the building / quarters as a whole should be considered in detail, it is necessary to represent all the components. But even here, the individual components can be displayed in any level of complexity. Thus, each component could be built up as a simulation model or mapped over a time series.

5.2.3 Results

Result should be the analysis of the influence of different heat productions of the heat supply in combination with the integration of e-mobility.

6. Simulation models for energy supply potential

This chapter provides detailed information on how the amount of locally available energy in zone 1 of the demonstration site in Hamburg (Schleusengraben area) was calculated. It is focused on renewable energy sources in the widest sense, supplemented by industrial waste heat.

6.1 Data collection and Analysis

6.1.1 Solar energy from building roofs

The estimation of potential energy gains from solar irradiation nowadays is based on advanced modelling and simulations tools. The worldwide success of photovoltaic triggered the development of these tools which are used for the planning of solar energy generators and plants.

For the city of Hamburg there exists an area-wide „Solaratlas“ (Solaratlas, 2017), which shows the solar irradiation on every roof surface. The creation of this online service was sponsored by the electric utility company „Hamburg Energie“ and was implemented by Hamburg’s State Agency for Geoinformation and Surveying (LGV, linked third party of HAM in mySMARTLife).

The Solar-Atlas was used for a detailed analysis of solar irradiation in the Schleusengraben area, which represents zone 1 the high performance area of Hamburg’s demonstration site within mySMARTLife.

6.1.2 Wind energy from small turbines

The area of the city of Hamburg is categorized as “wind zone 2” out of 4 possible classifications where “wind zone 1” represents the lowest average wind force. In wind zone 2 the average wind speed is 25.0 m/s measured according DIN 1055-4:2005-03. This type of standardized wind speed measurement assumes a flat open landscape at an altitude of 10 m over ground. These conditions are not met in urban areas.

According to wind measurements from the DWD (german weather service) the yearly average wind speed in the southern periphery of Hamburg-Bergedorf is about 3.6 m/s to 3.8 m/s in 10 m altitude.

The strong dependency on the local topographic conditions and the specific physical characteristics of wind turbines make it impossible to calculate a potential energy gain from wind turbines out of models and wind zone categorization. It would be necessary to carry out a long term wind measurement at the location and in the altitude of a planned wind turbine location.

6.1.3 Ambient heat from surface water

The usage of surface water for heating or cooling purposes is still unusual. There is a small number of implemented projects in Switzerland and Germany which did not trigger follow up projects besides being successful and in operation since many year (Doelling, 2011)

Based on hydrological and temperature data an estimate for the potential amount of heat energy in the water body of the Schleusengraben canal is given in the following section. These data for the river Bille and it is extension the Schleusengraben canal were derived from official environmental reports. Flow data were taken from the last hydrological measuring point of the river Bille before completely flowing into the Schleusengraben canal (FHH, 2014). Average temperature values for the lower part of the river Bille including the canal were taken from the publication "Umsetzung der EG-Wasserrahmenrichtlinie (WRRL) (FHH, 2004).

6.2 Simulation model development

6.2.1 Solar energy from building roofs - Simulation

A high resolution area-wide 3D scan of Hamburg provided the data basis for the simulation. The scan was done in 2010 with an air born laser mounted on a helicopter. The cruising altitude was 250m, the density of measuring points on ground was 30 to 40 points/m2 with a resolution of 7 cm in height for solid underground. All measured data points form a 3D-Model of the city of Hamburg with an accuracy of at least LoD2 (Level of Detail) (FHH, 2016). A 3D model with LoD2 represents the building envelopes, the roof styles and simple surface textures.

Simulations of solar irradiation were conducted with „simuSOLAR“, a computer based numerical simulation tool development and owned by „simuplan Engineering Office“, Dorsten, Germany.

simuSOLAR assigns standardized roof shapes (flat, shed, saddle, hipped) to detected building objects. Each roof surface element gets converted to a calculation mesh with an edge size of 20 cm. The irradiation analysis is done for each cell of this mesh. Solar irradiation is calculated with representative time series data using a time scale of 5 minutes. Shadowing effects of adjacent buildings, topography and vegetation are accounted for in detail by using horizon lines. Overlapping roof elements are accounted for by cutting roof geometries after roof style detection (geometric cutting is a graphical computer computation technic). Direct and diffuse irradiations are calculated separately.

6.2.1.1 Photovoltaic

Based on the calculated solar irradiation and roof geometries a placement of standard PV modules on the roof surfaces is simulated. The usable area for a PV installation given by the „Solar Atlas“ is the sum of the PV module sizes placed on the roof according to this simulation.

The energy gain per simulated roof is calculated according to this symbolic formula:

*Simulated irradiation per area and year * PV area * PV module efficiency * system performance ratio=*

PV energy per year

The Results which are given in the Solar-Atlas use values of 15% for PV module efficiency and 80% for the performance ratio of the whole PV system, which were common values in 2010. For the analysis given

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in this report value of 18% for PV module efficiency and 82% for system performance ratio were used. The value for module efficiency is based on real data for PV generators installed by ENH since 2015. A performance ratio greater 80% is a realistic value for new installed PV systems according to the photovoltaic report of Fraunhofer ISE from 2017 (Fraunhofer, 2017).

6.2.1.2 Solar Thermal Energy

Potential thermal energy gains were calculated with a rate of 35% of the modelled solar energy irradiation.

6.2.1.3 Comprehensive survey Schleusengraben area

A comprehensive survey has been conducted collecting data for all objects shown in Figure 8 and Figure 9, Table 16 (Annex 10.2) lists these objects. Table 10 summarizes the results.

For the list of the complete result of all investigated buildings see table 16 in Annex 10.2.

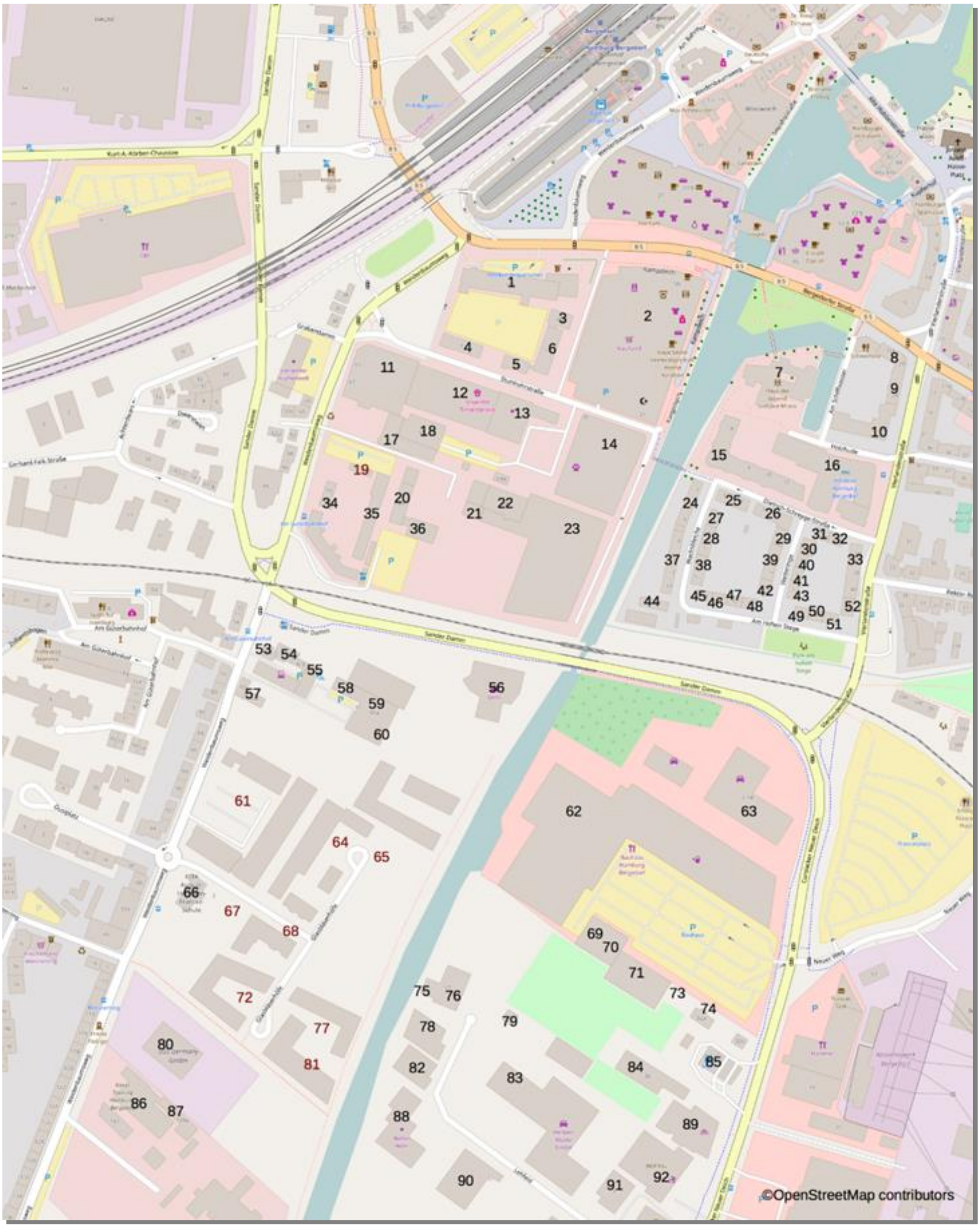

Figure 8: Investigated buildings for solar energy analysis zone 1, north

Figure 9: Investigated buildings for solar energy analysis zone 1, south

6.2.2 Wind energy from small turbines - hypothetical scenario

The following section describes a hypothetical scenario for small/mid-sized wind turbines besides commercial buildings in the Schleusengraben area.

Since there is no way for a model based approach to calculate a potential energy gain from wind turbines, this is an attempt for a typical case scenario based on measured standard data for a distinct type of turbine.

Assumptions per wind turbine:

- Choice of the biggest small/mid-size wind turbine which is allowed to be built under the simplified approval procedure in Hamburg: 15m max height from ground to wing tip in commercial areas.
- Small/mid-sized turbine from a certified manufacturer with a complete set of measured data from a wind test field.
- Installation on a pylon as far away from the building as possible for optimal performance.

These assumptions have been made according to the planning guide for small and midsized wind turbines from the publication „Kleinwindkraftanlagen, Ratgeber für Privat & Gewerbe” (Jüttemann, 2015), which is one of the most complete and comprehensive publications for this topic. The estimated energy production for the given types of wind turbines were calculated with a tool from the same author.

Table 6: Calculated energy production per wind turbine

Parameter	Value	Description
Position of wind turbine	+54.45 ; +10.20	Am Schleusengraben, Hamburg (Bergedorf)
Average wind speed in 10 m altitude	3.80 m/s	Measurement from DWD
Weibull form factor	1.84	Frequency distribution of wind speeds (DWD)
Roughness profile value of ground	0.500	Typical value for city periphery and parks
Scenario EasyWind 6		
Pylon height [m]	12.00 m	Above ground
Calculated wind speed [m/s]	**4.03 m/s**	Calculated with the wind values above
Rotor diameter [m]	6.00 m	➔ Pylon height + rotor radius = 15 m
Rated power of wind turbine	6 kW	at a wind speed of 10.6 m/s (Model: EasyWind 6)
Calculated energy production per year	**5.8 MWh/a**	with 90% overall system efficiency
Scenario Osiris 10		
Pylon height [m]	10.15 m	
Calculated wind speed [m/s]	**3.82 m/s**	Calculated with the wind values above
Rotor diameter [m]	9.70 m	➔ Pylon height + rotor radius = 15 m
Rated power of wind turbine	10 kW	at a wind speed of 9.0 m/s (Model: Osiris 10)
Calculated energy production per year	**11.6 MWh/a**	with 90% overall system efficiency

Real values for energy production can be up to 30% lower than the calculated ones!

Assumptions and rationales for wind turbines scenario locations:

- Industrial area at the south-eastern periphery of the Schleusengraben area. In Hamburg the installation of small wind turbines under a simplified approval process is only allowed in industrial areas. This also makes sense with respect to achievable energy production gains, since in industrial areas it is much more likely that a wind turbine can be installed on a stand-alone pylon. Tools like the one used here (s.a.) to calculate estimated energy production gains from wind turbines assume a pylon based installation. (Up to now there is very low evidence, that roof top installations are energy efficient and noise compliant for the residents or employees.)
- The main wind direction in northern Germany is westerly to north-westerly. The chosen area for the scenario has open space towards this direction due to the Schleusengraben canal. All other areas in the Schleusengraben area have a (planned) high building density which makes them less suitable.
- 5 industrial real estates are located in the chosen area. It seems feasible to install up to 2 wind turbines with 6 kW rated power per site, leading to a total of 10 wind turbines of this type for the scenario. For larger turbines this number is respectively lower.

Table 7: Small wind turbine site scenario

Parameter	Value	Description
Scenario area	Schleusengraben area, Hamburg (Bergedorf), see figure 10	
Scenario EasyWind 6		
Number of turbines	10	
Calculated energy production per year	**58.4 MWh/a**	
Worst case energy production per year	**40.9 MWh/a**	Estimated 30% below calculated energy production
Scenario Osiris 10		
Number of turbines	6	Less than 10 due to larger rotor
Calculated energy production per year	**69.4 MWh/a**	
Worst case energy production per year	**48.6 MWh/a**	Estimated 30% below calculated energy production

The potential suitable area for small wind turbines in zone 1 is shown in the following figure:

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

Figure 10: Potential area for small wind turbines in zone 1

6.2.3 Ambient heat from surface water - Simulation

This study follows a similar approach as described in a master thesis which examined the potential heating/cooling capabilities of rivers in Baden-Würtemberg, Germany (Schwinghammer, 2012). Additional hints were taken from a planning guide for surface water usage published by Bavarian Water Authorities (Deggendorf, 2011).

The main assumptions according to these documents are:

- The temperature of the whole water body should only be changed by a maximum of 1 K.
- The minimal water temperature should always stay above 2°C.
- Different seasonal flow scenarios should be considered:
    - Long term minimal average flow during winter and summer conditions (Standard German hydrological notation: MNQ; average over 39 years for Schleusengraben canal). These are worst case scenarios.

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- Long term average flow during summer and winter (Notation: MQ; average over 39 years).

These maximum permissible temperature values were mandated by the authorities in Switzerland and Germany who were in charge of the approval process for the reference projects (Schwinghammer, 2012).

Symbolic formula for an average potential energy gain per season:

*Energy = Flow rate * Water density * Effective heat capacity of water * Temperature difference * Half year*

Only heat out take is considered for the Schleusengraben area which should be in accordance with potentially required environmental allowances. The river Bille and its extension Schleusengraben Canal are one of the few remaining cold tributary waters of the river Elbe and as such have a positive environmental impact.

6.2.3.1 Hydrological and environmental data basis

Hydrological data are not directly available for the Schleusengraben canal but for the river Bille which completely flows into this canal at the former inner harbour of Hamburg-Bergedorf (called „Serrahn“). The nearest flow measuring post is at the city of Reinbek (Pegel Nr. 114094, Reinbek) approximately 6 km upstream. (FHH, 2014)

Temperature data were taken from the publication “Umsetzung der Wasserrahmenrichtlinie (WRRL) (FHH, 2004), page 144. The measuring post called „Be 61“ is at the end of the river Bille before flowing into the Serrahn.

Table 8 Hydrological and temperature data Schleusengraben Canal

Parameter	Value	Remark
MNQ, 39 years, winter	1.25 m^3/s	Average long term minimal flow rate in winter
MNQ, 39 years, summer	0.795 m^3/s	Average long term minimal flow rate in summer
MQ, 39 years, winter	3.47 m^3/s	Average long term flow rate in winter
MQ, 39 years, summer	1.60 m^3/s	Average long term flow rate in summer
Average Temperature	9.14 °C	
Temperature 10% perc.	3.4 °C	10% percentile of lowest temperatures

6.2.3.2 Potential heat energy extraction

The following table provides an overview of the heat energy contained in the water body of the Schleusengraben canal under average flow conditions. The given values don’t represent an achievable amount of energy which could be extracted by a specific technical process.

Table 9: Ambient heat energy Schleusengraben Canal

Flow conditions	Power	Energy per season	Energy per year
Average minimal flow MNQ, winter	5.25 MW	**22995 MWh**	**37574 MWh**
Average minimal flow MNQ, summer	3.33 MW	**14579 MWh**	
Average flow MQ, winter	14.57 MW	**63834 MWh**	**93175 MWh**
Average flow MQ, summer	6.70 MW	**29341 MWh**	

Physical parameters of water (Wiki Books, 2017):

- Density at 5°C: 1000.00 kg/m3, at 10 °C: 999.70 kg/m3
- Specific heat capacity at 5°C: 4.200 kJ/(kg·K), at 10°C: 4.188 kJ/(kg·K)
- Constraints: Temperature of water body lowered by 1 K, minimal water temperature 2 °C

Since the 10% percentile of the lowest temperature values for the Schleusengraben canal amounts to 3.4 °C even in winter the shown potential energy gains are not limited due to the constraint of the 2 °C minimum for most of the time.

6.3 Results of Potential local energy resources

6.3.1 Solar energy from building roofs in zone 1

For the city of Hamburg there exists an area-wide „Solar-Atlas“ showing the solar irradiation on every roof surface. The amount of irradiation was simulated by an advanced simulation program which uses high resolution 3D city models as geometrical input data (for details see chapter 5.2.1).

Table 10: Summary solar energy from buildings, zone 1, Hamburg

Parameter	Value
Number of buildings investigated	154
Total potential solar energy gain **Photovoltaic**	**9615 MWh/a**
Total potential solar energy gain **Solar Thermal** Collectors	**22072 MWh/a**

6.3.2 Wind energy from small turbines in zone 1

Energy gains from wind turbines cannot be calculated from average wind data, since the influence of local conditions and technical parameters of the turbines is too high. Instead a scenario based approach with two distinct types of small/mid-sized turbines with 6 kW and 10 kW nominal power was chosen (see chapter 5.2.2 for details).

Table 11: Small wind turbine potential energy gain overview

Parameter	Value	Comment
Worst case energy production per year	**40.9 MWh/a**	Estimated 30% below calculated energy production for 6 kW turbines; this is the most realistic scenario
Best case energy production per year	**69.4 MWh/a**	Best case scenario for 10 kW turbine

6.3.3 Ambient heat from surface water in zone 1

The following table provides an overview of the heat energy contained in the water body of the Schleusengraben canal under average flow conditions. These values were derived from hydrological data (for details see chapter 5.2.3). Schleusengraben canal is the extension of the river Bille, this canal forms the waterfront of all new buildings in zone 1 of Hamburg’s demonstration site.

Table 12: Ambient heat energy Schleusengraben Canal - overview

Flow conditions	Energy per year
Average minimal flow	**37574 MWh/a**
Average flow	**93175 MWh/a**

The given values don’t represent an achievable amount of energy which could be extracted by a specific technical process.

6.3.4 Waste water heat in zone 1

The main communal sewage pipe of the district of Hamburg-Bergedorf runs through zone 1. Hamburg’s water utility company „Hamburg Wasser“ calculated a theoretical average heat power of **0.9 MW** contained in the waste water flow, assuming an average waste water temperature between 12°C and 15°C and a temperature change of 1 K by heat extraction. This would lead to a yearly average potential heat energy of **7884 MWh**.

The technically possible heat extraction rate would be significantly lower.

Table 13: Power and energy from waste water heat in zone 1

Parameter	Value
Average potential power	**0.9MW**
Average potential energy per year	**7884 MWh/a**

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

6.3.5 Industrial waste heat in zone 1

At the time of the creation of this report there was one planned commercial facility in zone 1 which will have a large continuous cooling demand. This cooling demand will produce a **1MW** heat stream at **25°C** water flow temperature for **255 days** per year.

Since the downtimes with a total of about 110 days per year will not be evenly distributed over the year this would make complementary heat sources necessary. The relatively low flow temperature of 25°C would make this heat source an ideal component of a low exergy heat network.

A rough estimate for the average thermal energy dissipated per year is **6120 MWh.**

Table 14: Power and energy from industrial waste heat in zone 1

Parameter	Value	Remark
Max. constant power	1 MW	Power output for ~255 days per year
Average energy per year	**6120 MWh/a**	Delivered during 255 days per year

6.4 Conclusions of the energy supply potential analysis

The amount of local renewable energy sources within the new construction area in Hamburg’s demonstration area zone 1 “Schleusengraben” has been investigated in order to produce a ballpark estimate for usable electric and heat energy for new buildings. For solar energy this could be done by advanced modelling and simulation technics. Potential heat energy gains from other sources like ambient heat or industrial waste heat can only be estimated from environmental and geophysical data, since there is no standardized technology to extract energy from these sources. For electric energy gains from small wind turbines a scenario based approach was chosen.

The results show that the most promising renewable energy sources are solar, ambient heat and heat from waste water. Industrial waste heat should also be considered if complemented by other heat sources.

All investigated RES sources, except small wind turbines, could deliver a significant share of the local energy demand in zone 1 and should be considered in future planning.

Table 15: Overview potential RES sources in zone 1

RES Type	Energy per year	Remark
Solar Photovoltaic on Building Roofs	9615 MWh/a electricity	Based on advanced modelling
Solar Thermal on Building Roofs	22072 MWh/a heat	Based on advanced modelling, occupied roof areas are competing with photovoltaic

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RES Type	Energy per year	Remark
Ambient Heat from Surface Water	37574 MWh/A heat	Theoretical energy potential in water flow under average minimal winter flow conditions
Heat from Waste Water	7884 MWh/a heat	Theoretical energy potential in waste water flow
Industrial Waste Heat	6120 MWh/A heat	Planning data for new facility, reliable value, but not continuous
Small/mid-sized Wind Turbines	49 MWh/A electricity	Based on worst case scenario, which is to be expected in urban areas

7. Simulation models of transportation

In this chapter two scenarios are presented. The first one considers the conversion of local public transport (VHH) to e-buses and the second one considers the impact of e-mobility on the urban infrastructure.

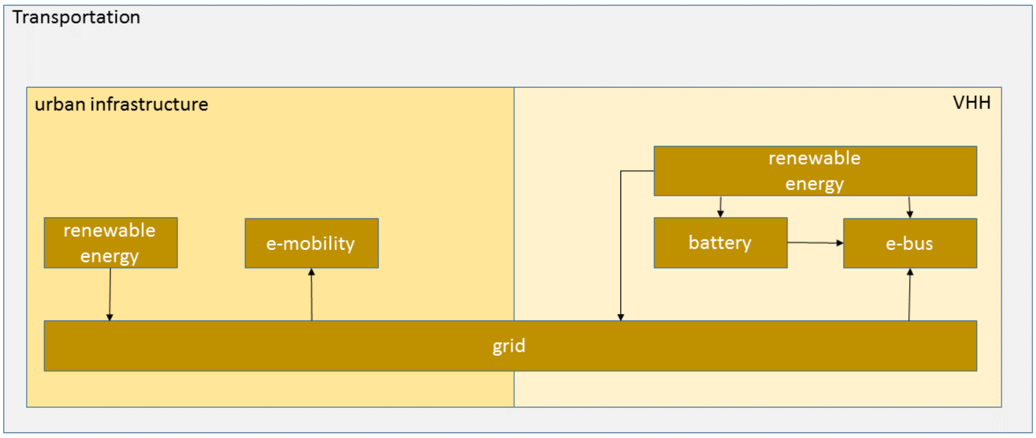

Figure 11: Overview of the simulation components for the task transportation

The scenario on the left side depicts the system components for the urban infrastructure and the one on the right side the required components for the electrification of the bus depot of the VHH. These are presented in more detail in the following subchapters.

7.1 Analysis of the charging infrastructure of the e-bus fleet

Basically the simulation model consists of the components of renewable energy and the charging infrastructure for batteries and e-buses (see Figure 11Figure 11Figure 11Figure 11, right). The simulations should show a possible way, how an optimal loading strategy can be realized in combination with renewable energies. Furthermore, the load potential of the e-buses will be determined and the economic potential will be considered. Finally, the influence of the charging process on the distribution network will be reflected.

7.1.1 Data collection and analysis

Required data for the simulation:

- Information about the planned e-bus fleet of the VHH
- Baseline scenario
- Data about the local grid
- Data from the EEX market

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7.1.2 Simulation model

The first approach for the simulation model is to analyse the Metastudy “Anforderungen an das Stromnetz durch Elektromobilität insbesondere Elektrobusse in Hamburg” (engl.: "Electricity requirements for electric vehicles, especially electric buses in Hamburg") from the Helmut Schmidt University. This paper described the requirements for the electric grid and the impact by using electric vehicles, especially electric buses in Hamburg. With the help of the document, the simulation requirements and the conception should be specified.

The second step is to use the planning from the project partner VHH. The planning data described the specification of the electric bus, the stationary battery and the installed power of the renewable energy and will be used to parametrize the simulation model.

The data from the local network operator described the electric grid.

The simulation model will be developed iteratively, depending on the data quality.

7.1.3 Results

Results should be a loading strategy for the e-busses, load potential, the impact of the charging process of the grid.

7.2 E-mobility in the urban infrastructure

This part deals with the increase of the use of e-mobility in the project area in Hamburg-Bergedorf. In particular, the impact of the charging infrastructure in the project zones should be considered in detailed level. Therefore should be analysed, which load potentials can be activated, in order to increase the consumption of renewable energies in the area of Hamburg-Bergedorf. The influence of e-mobility on the distribution network will also be considered in more detail. Another aspect to be analysed is the impact of the increasing standardization in the field of e-mobility. It will be considered, what is currently possible with the IEC 61851 and what will be possible in the future with the ISO 15118.

7.2.1 Data collection and analysis

Standards in e-mobility: IEC 61851 describes the general requirements for charging systems for electric vehicles.

The ISO/IEC 15118 is an extension of the IEC 61851 standard and introduces extensive authentication and billing features, as well as the exchange of energy and performance data. This will allow the implementation of loading schedules in order to operate an extended load management. The ISO/IEC 15118 consists of 8 parts, of which only 3 are actually completed. Existing e-cars do not yet support this standard.

7.2.2 Simulation model

An overview of the system components for the simulation can be seen in Figure 11 on the right side. The complexity of the system components depends on the data collection.

A first simple simulation model can be created by using profiles of wind energy generation and charging electric cars. With the help of this simple simulation model, the proportion of wind energy in the loading of electric vehicles can be determined. The idea is that the simulation model grows iteratively, depending on the data quality.

7.2.3 Results

Results could be which load potential could be activated in the area of Hamburg-Bergedorf.

8. Simulation models of Urban Infrastructures

The main urban infrastructures modified by the project are the bicycle way with the new smart street lights. The smart street lights will offer a range of new sensor systems and services for the citizens like adaptive lighting, w-lan or bicycle traffic counting systems. Through the connection to the urban platform is it possible to analyse the use of the urban infrastructure by the citizens.

8.1 Data collection and analysis

It is planned, that the smart street lights are connected to the urban platform and reports could be delivered to the responsible authorities.

8.2 Simulation model

The simulation model will relate to the question how often the offered services from the smart streets lights, such as the use of the adaptive lighting or the w-lan connection is used, related to specific locations and daytime. By this information it should be possible to get an approach for future deployment of smart street lights and the specific sensors.

8.3 Results

Results should be information about future placement and equipment of sensors for smart street lights.

9. Conclusions

During the first 12 months of the project, a thorough analysis of the different possibilities for developing simulation models for the different sectors concerned in mySMARTLife was carried out. Several possibilities were outlined, starting with an outline of the methodology for developing simulation models, continuing with an outline of possibilities for solar energy, wind power and ambient heat possibilities. Transportation was also studied, focusing on charging infrastructures and sustainable mobility, mainly e-mobility. Finally, possible methods for development of Urban Infrastructures simulation models were analysed.

This section will be further developed for the final submission according with the date proposed in the amendment that was requested in September (month 10).

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11. Annex

11.1 Map of the Project area

In the following Figure 12, the map of the affected areas by mySMARTLife project actions in Hamburg is represented.

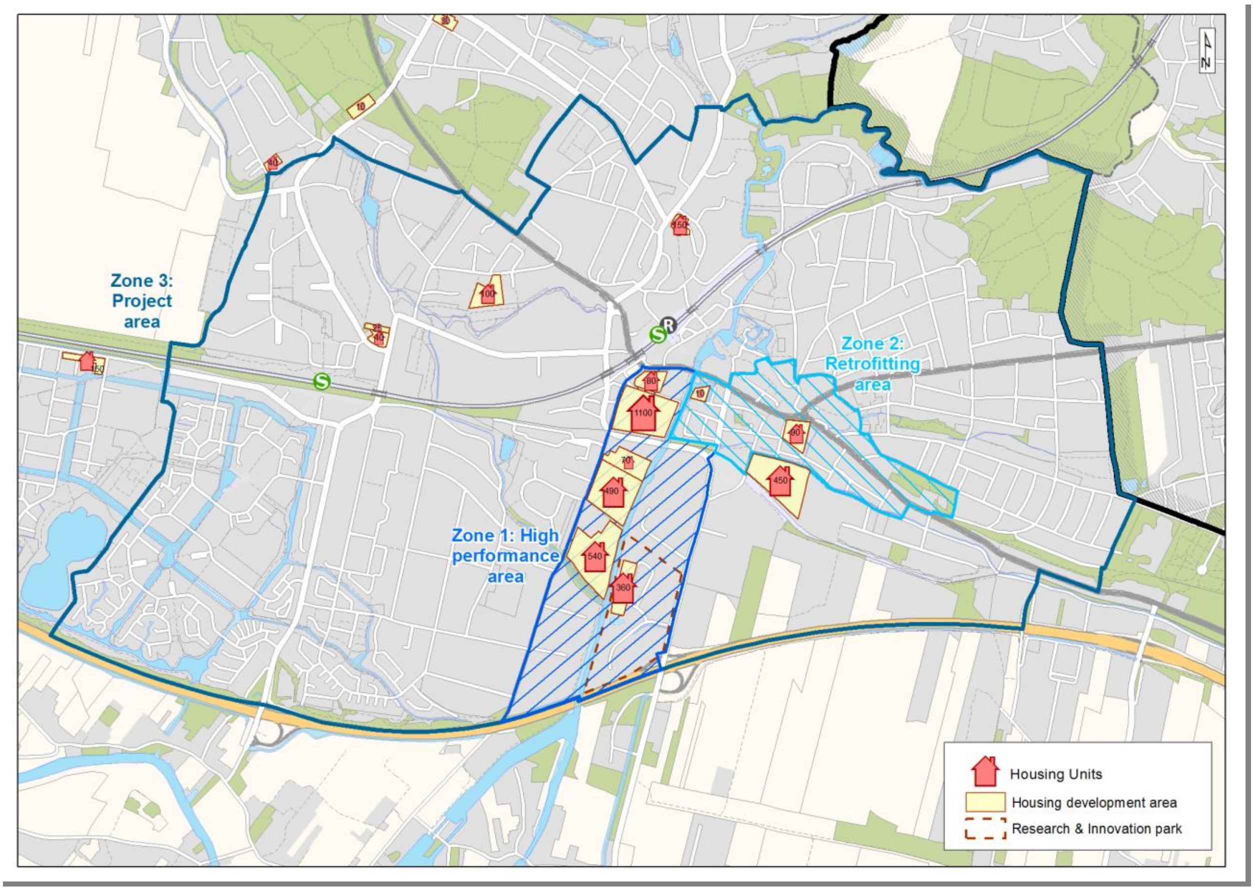

Figure 12: The location of the different parts of the project area and the location of new planned housing development areas with their planned amount of housing units (own design)

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

The complete results of the Solar irradiation data of all buildings in the High Performance Area (project zone 1).

Table 16: Solar irradiation data Hamburg Demonstration Site, all buildings in Zone1 High Performance Area

No. in map	radiation density [kWh/m²·a]	pot. –PV Area [m²]	pot. PV peak power [kWp]	pot. PV yield [MWh/a]	CO2 reduction [Mg/a]	pot. thermal collector area [m²]	pot. solar thermal yield [MWh/a]
1	1063.60	505.20	75.70	79.31	33.10	527.20	184.50
2	1049.30	1994.40	299.00	308.89	128.80	2440.60	900.60
3	1029.20	58.40	8.70	8.87	3.70	77.10	27.00
4	1061.10	125.00	18.70	19.58	8.10	126.30	44.20
5	954.10	179.50	26.90	25.28	10.50	116.60	40.80
6	1062.90	202.10	30.30	31.71	13.20	202.10	70.70
7	1041.40	179.90	26.90	27.65	11.40	413.70	144.60
8	1008.00	85.00	12.60	12.65	5.10	104.40	36.40
9	889.70	516.30	77.30	67.80	28.20	319.20	111.60
10	980.70	440.20	65.90	63.72	26.30	449.60	157.10
11	1063.00	978.50	146.70	153.53	64.10	1003.30	351.10
12	1012.90	1540.60	230.90	230.33	96.00	1850.90	647.70
13	979.30	662.80	98.90	95.80	39.40	751.30	262.40
14	946.00	3539.90	530.40	494.27	206.00	2819.80	986.40
15	1062.10	333.10	49.70	52.22	21.50	347.60	121.30
16	1057.90	629.60	94.20	98.31	40.90	746.30	260.80
17	1065.60	217.40	32.60	34.19	14.20	281.40	98.40
18	935.50	493.20	73.90	68.10	28.40	548.70	192.00
19	1050.80	44.70	6.70	6.93	2.90	44.70	15.60
20	1064.20	140.50	21.00	22.07	9.20	144.40	50.50
21	0.00	0.00	0.00	0.00	0.00	6.40	2.20
22	1061.60	213.10	31.90	33.39	13.90	222.00	77.70
23	1055.60	2135.80	320.20	332.77	139.00	2257.70	790.10
24	858.00	280.60	42.00	35.54	14.70	155.90	54.40
25	959.60	126.90	18.90	17.97	7.30	119.20	41.70
26	995.20	136.40	20.40	20.04	8.30	168.10	58.70
27	867.00	111.40	16.60	14.26	5.90	58.30	20.40
28	857.40	131.30	19.60	16.62	6.90	66.60	23.30
29	869.50	170.60	25.50	21.89	9.10	101.80	35.60
30	850.40	111.70	16.70	14.02	5.70	60.40	21.10
31	999.90	57.00	8.50	8.41	3.50	64.20	22.40
32	1002.90	59.10	8.80	8.75	3.60	66.80	23.40
33	881.70	385.20	57.60	50.13	20.70	261.90	91.50
34	918.40	122.70	18.40	16.63	6.90	128.50	44.90

No. in map	radiation density [kWh/m^2·a]	pot. –PV Area [m^2]	pot. PV peak power [kWp]	pot. PV yield [MWh/a]	CO2 reduction [Mg/a]	pot. thermal collector area [m^2]	pot. solar thermal yield [MWh/a]
35	906.50	531.30	79.50	71.09	29.60	606.30	211.90
36	1054.90	170.00	25.40	26.47	11.00	175.60	61.30
37	860.90	430.50	64.50	54.70	22.70	216.70	75.70
38	868.00	217.00	32.50	27.80	11.50	132.60	46.30
39	864.60	310.50	46.40	39.62	16.40	164.80	57.70
40	851.90	106.80	15.90	13.43	5.50	59.80	20.90
41	859.20	116.60	17.40	14.79	6.10	66.10	23.10
42	857.20	127.00	18.90	16.07	6.60	68.10	23.70
43	862.50	120.60	18.00	15.35	6.20	78.50	27.40
44	804.60	71.00	10.60	8.43	3.50	104.80	36.70
45	1022.40	47.00	7.00	7.09	2.90	50.20	17.50
46	1026.20	50.90	7.60	7.71	3.20	58.00	20.30
47	1030.20	37.50	5.60	5.70	2.30	43.70	15.30
48	1030.50	33.10	4.90	5.03	2.10	34.80	12.80
49	1026.90	46.20	6.90	7.00	2.90	49.70	17.40
50	1029.80	56.10	8.40	8.53	3.50	58.90	20.60
51	1022.10	56.70	8.50	8.55	3.50	60.20	21.10
52	864.00	124.00	18.60	15.81	6.60	102.20	35.70
53	959.00	23.80	3.50	3.37	1.40	66.80	23.40
54	1038.40	61.80	9.20	9.47	3.90	63.00	21.90
55	1018.80	18.90	2.80	2.84	1.10	32.70	11.40
56	1045.80	381.40	57.10	58.87	24.50	540.50	189.00
57	1055.60	78.60	11.70	12.25	5.00	85.30	29.80
58	1051.40	133.60	20.00	20.73	8.60	159.60	55.80
59	1053.20	371.00	55.50	57.67	23.90	542.40	189.50
60	1046.20	814.00	122.00	125.70	52.40	984.00	356.00
61	1058.20	2316.60	347.30	361.83	151.10	2339.10	816.60
62	1059.90	4193.50	628.80	656.04	273.90	4609.60	1612.90
63	1052.70	869.40	130.00	135.09	56.20	993.90	347.70
64	985.40	2345.80	351.10	341.18	141.50	2268.10	793.10
65	933.80	721.90	108.00	99.50	41.30	846.50	296.00
66	1058.90	126.20	18.90	19.72	8.20	128.00	44.80
67	1064.00	1297.30	194.60	203.74	85.10	1330.20	465.50
68	1059.80	543.50	81.40	85.02	35.40	547.50	191.60
69	1051.40	167.00	24.90	25.92	10.70	186.80	65.40
70	998.80	393.70	59.00	58.04	24.10	399.60	139.70
71	931.00	1266.90	189.80	174.09	72.50	1264.90	442.70

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No. in map	radiation density [kWh/m^2·a]	pot. –PV Area [m^2]	pot. PV peak power [kWp]	pot. PV yield [MWh/a]	CO2 reduction [Mg/a]	pot. thermal collector area [m^2]	pot. solar thermal yield [MWh/a]
72	1058.70	800.90	120.00	125.15	52.10	836.60	292.60
73	850.80	106.30	15.90	13.35	5.50	115.90	40.50
74	929.80	115.60	17.00	15.86	6.30	65.50	22.80
75	1024.60	30.90	4.60	4.67	1.90	53.40	18.60
76	1061.30	99.30	14.80	15.56	6.50	100.70	35.20
77	896.70	510.20	76.40	67.53	28.10	295.60	103.40
78	1047.50	296.70	44.50	45.87	19.10	343.00	120.00
79	1064.60	38.00	5.60	5.97	2.40	38.00	13.30
80	1061.40	234.60	35.00	36.75	15.10	361.50	126.30
81	982.30	1132.00	169.70	164.13	68.40	888.90	310.80
82	966.20	75.30	11.20	10.74	4.40	145.10	50.60
83	1049.90	1494.40	223.70	231.58	96.40	1535.50	539.20
84	945.00	836.10	125.20	116.62	48.60	850.70	297.60
85	1040.30	126.80	18.90	19.47	7.90	208.60	72.70
86	922.40	900.20	134.80	122.56	51.10	509.80	178.40
87	1028.20	69.20	10.30	10.50	4.20	115.40	40.20
88	1064.40	592.70	88.80	93.12	38.70	604.40	211.40
89	1049.60	432.80	64.80	67.05	28.00	554.50	194.00
90	1064.30	453.00	67.90	71.16	29.70	458.40	160.40
91	1055.20	223.10	33.40	34.75	14.50	225.10	78.70
92	1060.30	627.70	94.00	98.24	41.00	690.50	241.60
93	931.50	1958.70	293.30	269.30	112.00	1200.30	419.50
94	948.50	1544.80	231.60	216.27	90.20	1543.40	540.10
95	974.20	334.10	50.00	48.04	19.90	394.90	138.10
96	957.90	638.40	95.60	90.26	37.50	645.40	225.70
97	979.10	364.10	54.40	52.62	21.70	386.70	135.10
98	1066.00	115.00	17.20	18.09	7.50	115.00	40.20
99	976.90	372.50	55.70	53.71	22.30	464.00	162.30
100	1062.20	161.00	24.10	25.24	10.50	179.00	62.60
101	1057.00	61.10	9.10	9.53	3.90	65.00	22.70
102	863.20	44.60	6.60	5.68	2.30	29.80	10.40
103	896.40	56.20	8.40	7.44	3.10	58.60	20.40
104	1061.30	264.00	39.50	41.36	17.20	277.10	96.90
105	896.40	54.80	8.20	7.25	3.00	72.40	25.30
106	914.30	227.70	34.10	30.73	12.70	226.50	79.30
107	932.70	894.80	134.20	123.18	51.40	443.30	155.10
108	898.80	34.20	5.10	4.54	1.80	38.00	13.20

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No. in map	radiation density [$kWh/m^2 \cdot a$]	pot. –PV Area [m^2]	pot. PV peak power [kWp]	pot. PV yield [MWh/a]	CO2 reduction [Mg/a]	pot. thermal collector area [m^2]	pot. solar thermal yield [MWh/a]
109	1043.70	444.90	66.60	68.54	28.50	515.50	180.30
110	1063.00	191.30	28.60	30.01	12.40	198.20	69.30
111	941.10	586.70	87.90	81.50	33.90	584.80	204.50
112	1058.20	16.70	2.50	2.61	1.00	64.80	22.30
113	863.60	378.30	56.60	48.22	19.90	202.80	70.80
114	970.80	71.30	10.60	10.22	4.10	56.50	19.70
115	1054.00	77.00	11.50	11.98	5.00	79.40	27.80
116	933.20	221.00	33.00	30.44	12.40	155.50	54.20
117	914.00	320.90	48.10	43.29	18.00	134.50	47.00
118	874.30	181.30	27.10	23.40	9.70	95.20	33.30
119	1043.70	144.00	21.60	22.18	9.20	150.40	52.60
120	1042.80	51.50	7.70	7.93	3.30	51.50	18.00
121	925.00	191.10	28.60	26.09	10.80	196.60	68.60
122	903.80	190.80	28.50	25.45	10.50	172.50	60.30
123	1053.60	871.00	130.50	135.45	56.30	916.80	320.60
124	956.90	62.50	9.20	8.83	3.60	60.20	21.00
125	930.40	323.20	48.40	44.38	18.50	260.70	91.10
126	1044.90	46.80	7.00	7.22	3.00	82.40	28.70
127	997.30	222.00	33.10	32.68	13.40	264.80	92.50
128	919.40	218.10	32.60	29.60	12.10	223.70	78.20
129	1023.40	50.80	7.50	7.67	3.10	87.10	30.40
130	936.10	249.30	37.30	34.45	14.30	248.30	86.80
131	1059.10	121.50	18.00	18.99	7.70	122.30	42.80
132	945.90	259.70	38.90	36.26	14.90	267.90	93.60
133	953.50	697.40	104.50	98.15	40.90	714.50	250.00
134	1001.70	757.30	113.30	111.97	46.40	883.20	308.80
135	1065.50	115.20	17.20	18.12	7.50	118.20	41.30
136	1047.00	80.00	12.00	12.36	5.10	165.90	57.90
137	1061.50	59.60	8.90	9.34	3.90	62.20	21.70
138	879.10	170.20	25.30	22.08	9.10	127.20	44.40
139	1014.70	532.40	79.70	79.74	33.10	638.40	223.10
140	1057.00	59.90	8.90	9.35	3.80	68.50	23.80
141	1052.90	93.10	13.90	14.47	5.90	99.40	34.70
142	1066.40	158.60	23.80	24.96	10.40	158.80	55.50
143	916.80	170.00	25.50	23.00	9.50	186.30	65.10
144	1049.50	167.60	25.00	25.96	10.60	208.50	72.70
145	1058.70	313.00	46.80	48.91	20.30	343.00	120.00

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No. in map	radiation density [kWh/m^2·a]	pot. –PV Area [m^2]	pot. PV peak power [kWp]	pot. PV yield [MWh/a]	CO2 reduction [Mg/a]	pot. thermal collector area [m^2]	pot. solar thermal yield [MWh/a]
146	1066.70	96.90	14.50	15.26	6.30	96.90	33.90
147	1027.70	18.00	2.70	2.73	1.10	154.30	54.00
148	1061.30	170.50	25.50	26.71	11.10	173.70	60.80
149	1066.50	232.10	34.80	36.54	15.20	232.10	81.20
150	941.60	601.60	90.10	83.61	34.80	590.10	206.50
151	1065.30	139.40	20.80	21.92	9.00	146.50	51.10
152	1064.10	217.80	32.60	34.21	14.20	234.10	81.90
153	921.80	543.20	81.40	73.91	30.70	478.30	167.40
154	1055.30	160.40	24.00	24.98	10.30	163.60	57.20
Sum	**n.a.**	**63052.50**	**9440.50**	**9275.40**	**3855.10**	**62945.10**	**22071.90**