D6.3 Heating and cooling strategies for pilot areas – Milton Keynes

Prepared by:

Jeremy Draper & Christine Ballard, Milton Keynes

Magdalena Kowalska & Anders M. Odgaard, PlanEnergi

Reviewed by:

Marcus Hummel, e-think

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Project Information

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Project coordinator	Lukas Kranzl Technische Universität Wien (TU Wien), Institute of Energy Systems and Electrical Drives, Energy Economics Group (EEG) Gusshausstrasse 25-29/370-3 A-1040 Wien / Vienna, Austria Phone: +43 1 58801 370351 E-Mail: kranzl@eeg.tuwien.ac.at **info@hotmaps-project.eu** www.eeg.tuwien.ac.at www.hotmaps-project.eu
Lead author of this report	Anders M. Odgaard & Magdalena Kowalska PlanEnergi +45 9682 0400 amo@planenergi.dk

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The Hotmaps project

The EU-funded project **Hotmaps** aims at designing a toolbox to support public authorities, energy agencies and urban planners in strategic heating and cooling planning on local, regional and national levels, and in line with EU policies.

In addition to guidelines and handbooks on how to carry out strategic heating and cooling (H&C) planning, **Hotmaps** will provide the first H&C planning software that is

User-driven: developed in close collaboration with 7 European pilot areas

Open source: the developed tool and all related modules will run without requiring any other commercial tool or software. Use of and access to Source Code is subject to Open Source License.

EU-28 compatible: the tool will be applicable for cities in all 28 EU Member States

The consortium behind

Scientific partners

Pilot areas for developing and testing the tool

Bistrita Municipality

Abbreviations

CIBSE – Chartered Institution of Building Services Engineers

CMK - Central Milton Keynes

CSE – Centre for Sustainable Energy

DECC – Department of Energy and Climate Change

DH – District Heating

DHN – District Heating Network

GIA – Gross Internal Area

HD – hard dig

PW – electricity supply connection via private wire

RHI – Renewable Heat Incentive

SD – soft dig

UK – United Kingdom

USEA - United Sustainable Energy Agency

Executive Summary

This heating strategy for Milton Keynes was developed in the course of the EU project **Hotmaps**. In order to reach the political targets of greenhouse gas emission reduction and energy efficiency at local as well as national and EU level heating and cooling systems have to be changed. In order to find technically, economically and resource-efficient solutions to fulfil these targets strategic analyses are needed. In the course of the project **Hotmaps,** a strategy development process for decarbonising the heating system in Milton Keynes has been performed.

In January 2019, the Milton Keynes Sustainability Strategy[1] was approved by the full council, with the headline target to reduce carbon emissions in the borough to net-zero by 2030. At the same time, the council declared a climate emergency. Low or zero-carbon heat sources have been identified as a major contribution to meeting this goal. Using heat networks to distribute heat sourced from industrial waste heat or generated by low carbon heat sources is key to this process.

Also in 2019, the Council formally adopted its new local planning document – Plan:MK[2] which also identifies heat networks as an important step to achieving zero carbon requirements for new developments.

The results of the Hotmaps scenarios show that the ambitious district heating expansion in Milton Keynes with up to 78.2 % share in 2050 and ambitious district heating supply with regards to large scale heat pumps utilising low-temperature excess heat and other sources supplemented with solar district heating and backup biomass boilers are both, the most economically and environmentally feasible. This allows for up to 39.1 % cost reduction in comparison with the decentral heating supply, and simultaneously, it helps to achieve the 2050-targets and results in the lowest CO2-emission from the heating sector as a whole – by the CO_2 abatement up to 63.0 % compared with the decentral heating supply.

[1] https://www.milton-keynes.gov.uk/environmental-health-and-trading-standards/mk-low-carbon-living/the-2019-2050-sustainability-strategy
[2] https://www.milton-keynes.gov.uk/planning-and-building/plan-mk

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1 Introduction to Milton Keynes

Location: Northwest Europe Size: 89 km^2	Population (inhabitants): 265,000 (+2-3 % pa)

Milton Keynes is located in Buckinghamshire in the South East part of England and is both a borough and a unitary authority (see also Figure 1). Milton Keynes turned 50 years back in 2017[3]. The young city was conceived by an Act of Parliament in 1967 which approved the building of a new community of 250,000 people covering 8,850 hectares (21,869 acres) of Buckinghamshire farmland and villages with the purpose of reducing the housing pressure in London 85 km to the South East.[4]

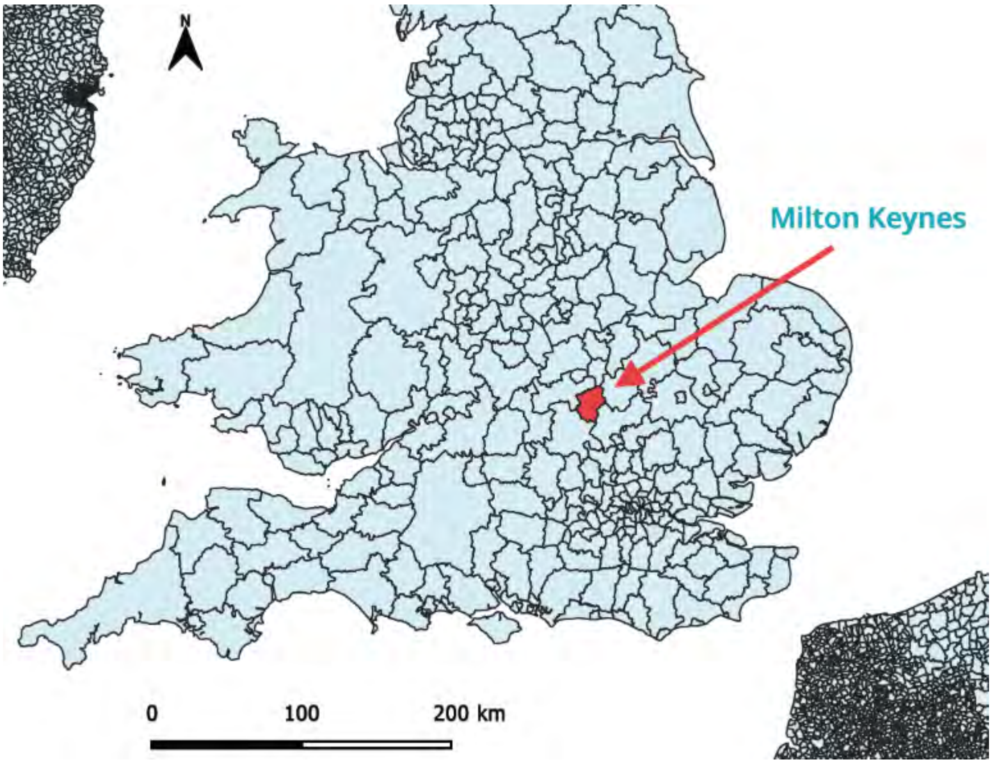

Figure 1: The Local Administrative Unit (LAU) of Milton Keynes in South East part of England (Copyright: European Commission, Eurostat (ESTAT), GISCO).

Milton Keynes has grown together with Bletchley to the south and together with Newport Pagnell to the northeast but separated by the M1 motorway (see Figure 2 below). There are no other larger cities in the surrounding area.

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[3] Milton Keynes Council, 2016, “50 Facts for MK at 50”, https://www.milton-keynes.gov.uk/pressreleases/2016/mar/50-facts-for-mk-at-50

[4] BBC, 2017, “Milton Keynes: The middle-aged new town”, https://www.bbc.co.uk/news/uk-england-beds-bucks-herts-38594140

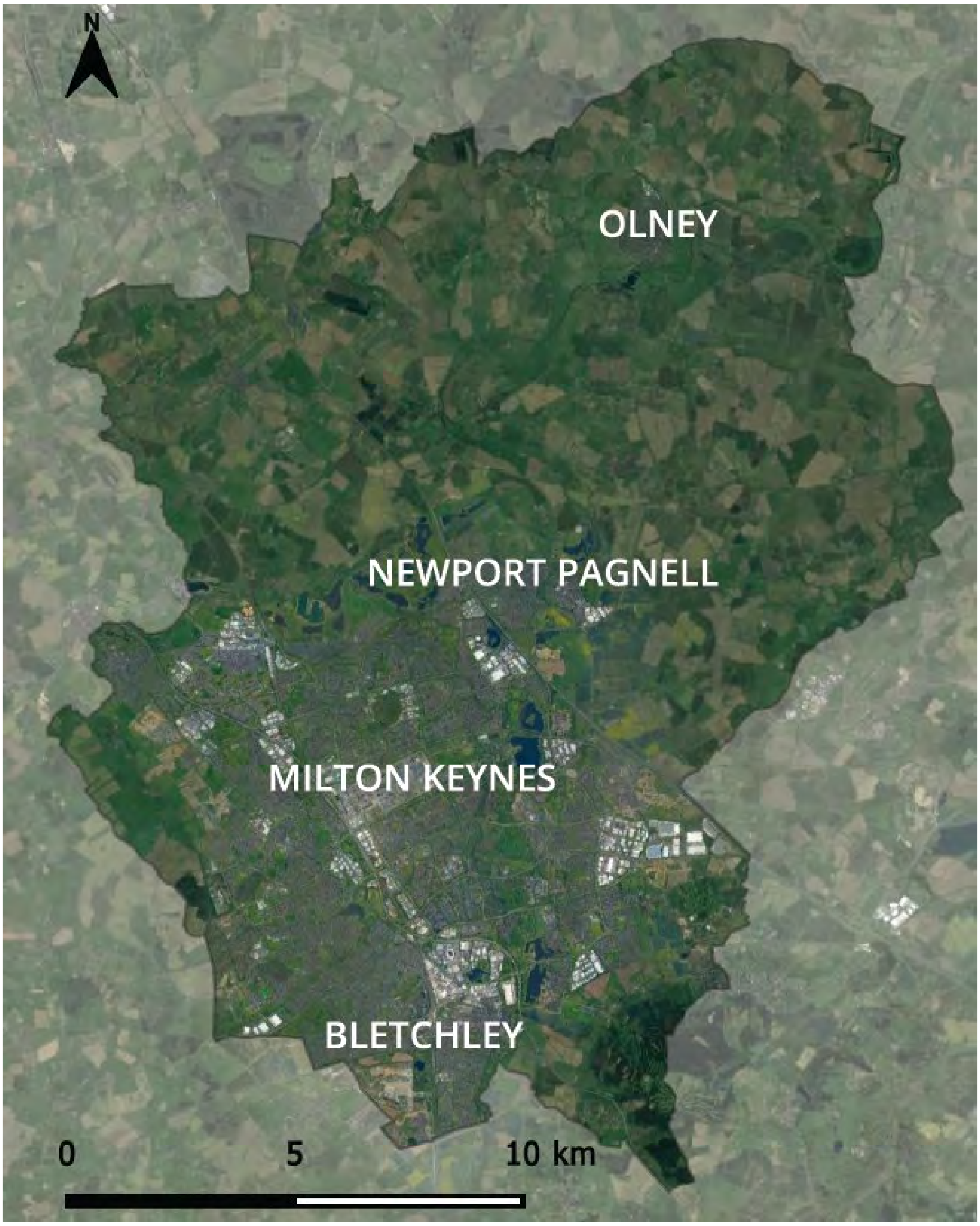

Figure 2: Milton Keynes (Copyright: Contains OS data © Crown copyright and database right (2017). Cointains Images ©2019 Google.)

The characteristics of the city of Milton Keynes are wide roads and separated traffic system connecting communities on a 1km grid pattern. The grid squares were planned as "garden cities" with single family houses, intensive tree planting, lakes and parklands. In the middle of these grid squares Central Milton Keynes ("CMK") was planned. It was not planned with the intention to be a traditional town centre as in old towns, but as a dedicated central business and shopping district.

As seen in Figure 2 above Milton Keynes consists of both the dense CMK with commercial buildings, surrounding urban areas with residential buildings and schools and leisure centres spread out in the grid squares. Spread out in clusters are industrial buildings (incl. data centres). The educational buildings for the universities University Campus Milton Keynes, which is a campus of the University of Bedfordshire as well as the Open University is also located in clusters south and southeast of CMK, respectively. The Milton Keynes University Hospital is located in a cluster between the university clusters.

The population in Milton Keynes was 248,800 in the 2011 Census[5], and is growing by 2-3 % per year and is today approximately 265,000. The average population density in Milton Keynes is 26.5 inhabitants/ha, which is slightly higher than that of the county as a whole with a population density of 23.0 inhabitants/ha. The relatively low population density is due to the large rural area surrounding the urban centre of Milton Keynes – in the urban centre, the population density is approx. 30.2 inhabitants/ha.

Milton Keynes has a younger age profile than England as a whole. A growing proportion of dwellings in Milton Keynes is flats. In 2001 just 11.9% of dwellings in Milton Keynes were flats, by 2011 this had increased to 16.2% in 2011. However, this is still below the proportion for England as a whole (22.1%). There has been a growth in the proportion of people living in private rented accommodation in Milton Keynes. It grew from 9.2% in 2001 to 18.2% in 2011.

[5] Milton Keynes Council, 2017, "*Census*", https://www.milton-keynes.gov.uk/your-council-and-elections/statistics/census

2 Objectives and approach

2.1 Objectives for Heating Strategy for Milton Keynes

The objective for the **Hotmaps** Heating Strategy for Milton Keynes is to be used in the following strategic work in Milton Keynes helping with achieving the goal of carbon neutrality by 2030 and carbon negativity by 2050. To help achieve this the **Hotmaps** toolbox becomes very useful in both the short-term, medium-term, and long-term planning process for Milton Keynes.

The **Hotmaps** Handbooks for Strategic Heat Planning[6] emphasise that strategic heat planning in Europe should address a radical change focusing on minimising fuel consumption for the purpose of heating. This necessitates a technical analysis, which is not limited by policies and institutional structures inherited from fossil fuel-based energy supply. Therefore, this strategy also accesses **Hotmaps** scenarios. The heat demand and heat supply options have been mapped and quantified without looking at policy or institutional limitations.

Strategic heat planning requires changes at both technical, organisational and institutional level. The 3-phase model outlined in the **Hotmaps** Handbook for strategic heat planning is a possible procedure, which can be followed to support and facilitate the strategic heat planning process. In the technical analysis, it is important to maintain an energy system perspective to heat planning to avoid sub-optimisation. Likewise, the identification of energy supply solutions should have a long-term, socio-economic perspective. The establishment of district heating systems as an infrastructure for utilising sustainable heat sources requires policies addressing the organisation of the systems. This includes aspects such as ownership models for monopoly structures and price regulation. These two regulatory elements should ensure consumer acceptance, access to capital, and the organisational capability to maintain a long-term focus in heat planning. The strategy identifies some of these organisational and institutional limitations, so that the council, policymakers, and other stakeholders can act on them.

The themes that Milton Keynes is looking to address is:

- Establish heat network opportunities
- **Citywide heat network** (refer to chapter 6.1)
- Where are interesting, cost-effective areas for district heating?
- **Heat networks for new greenfield developments** (refer to chapter 6.2.5)
- **Expansion of existing CHP heat network** (refer to chapter 6.2.5)
- Heat resources
- **Waste to energy plant** (refer to chapter 6.2.4):

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[6] Hotmaps, Djørup et al., 2019, "*Summary of the Hotmaps Handbooks for strategic heat planning*", https://www.hotmaps-project.eu/wp-content/uploads/2019/04/Summary-Hotmaps-Handbook.pdf

- Link to low-temperature district heating (60-70 °C supply temperature)
- **Heat sources for large scale heat pumps** (refer to chapter 6.2.4):
- Possible sources are the lakes at Willen, Furzton and Caldecotte.
- **Place an economic value on these resources** (refer to chapter 6.2.7):
- How much money is flowing out of the area and which could be avoided by use of regional resources (circular economy)

2.2 Approach in the Hotmaps process

To reach the political targets of greenhouse gas emission reduction and energy efficiency at local as well as national and EU level, the heating and cooling systems have to be changed. The technically, economically and resource-efficient solutions which enable to fulfill these targets require strategic planning. In the course of the project **Hotmaps** a strategy development analysis for decarbonising the heating system in Milton Keynes has been performed. This process was conducted according to the following methodological steps:

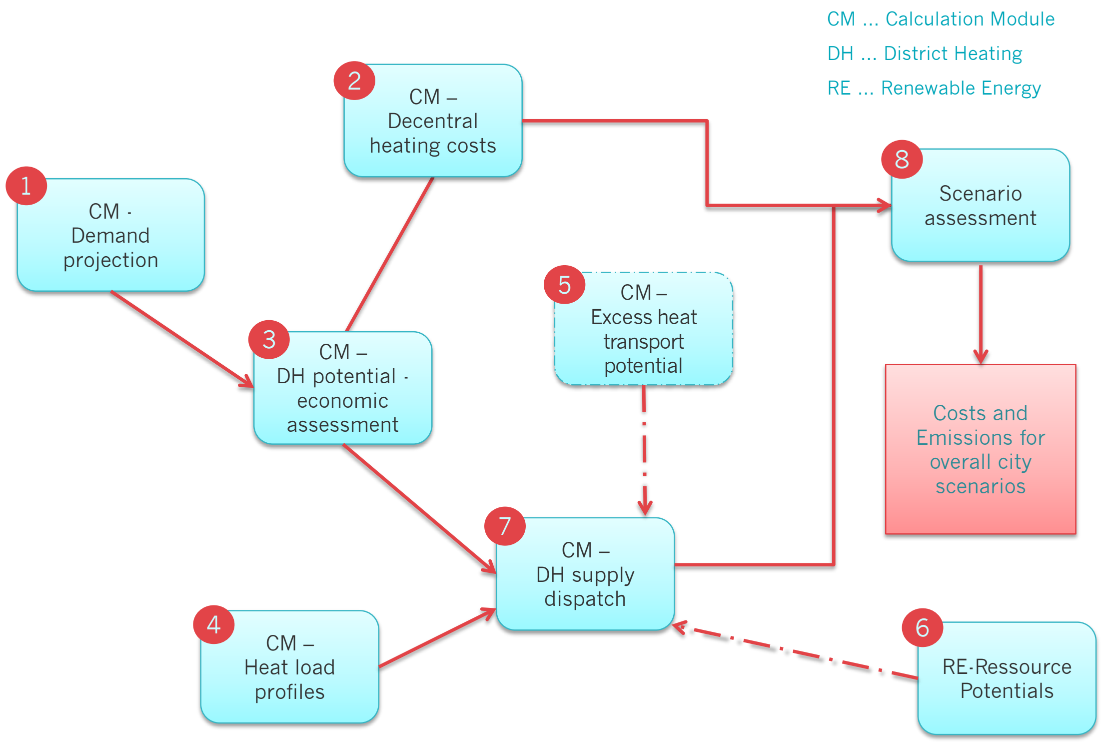
- **Description of the city and stakeholder analysis:**
    - Definition of local, regional and national targets for GHG emission reduction and energy (see chapter 3.1)
    - Analysis of stakeholders relevant to address when seeking sustainable decisions in heating and cooling transition (see chapter 3.2)
    - Description of the existing heating and cooling system in the city (see chapter 4.2)
    - Analysis of barriers against and drivers towards a transition of the heating and cooling systems in Milton Keynes (see chapter 5)
- **Mapping of demand, resource potentials and existing plants:**
    - Analysis and mapping of resource potentials of renewable and excess heat sources in Milton Keynes potentially usable in the mid to long term (see chapter 4.1)
    - Mapping of the status quo of the heating and cooling system in the city including demand and supply points (see chapter 4.2)
- **Stakeholder meeting**
    - Participants from MK Council Housing regeneration team and the sustainability team attended a meeting on 7th October 2019
    - Topics discussed at the meeting: the mapping of heat demand, resource potentials and existing plans in Milton Keynes, the **Hotmaps** database and toolbox and its data sources and available calculation modules, method for scenario calculation in the strategy process, potential scenarios and sensitivities to be calculated
- **Setting up scenarios:**
    - Compilation of economic input data for the economic assessment of future heating scenariosbased on the **Hotmaps** toolbox and stand-alone tools (see chapter 6.1 & 6.2 respectively)

    - Calculation of various potential scenarios for heating supply from renewable and excess heat sources in the **Hotmaps** toolbox and stand-alone tools (see chapter 6.1 & 6.2 respectively)
    - Assessment of the calculated scenarios regarding costs and CO_2 emissions in the **Hotmaps** toolbox and stand-alone tools (see chapter 6.1 & 6.2 respectively)
- **Second stakeholder meeting**
    - Participants from MK University Development team[7] and all council planning and sustainability sections attended a meeting on 27th January 2020
    - Topics discussed: preliminary results of assessments and derived recommendations
- **Strategy formulation:**
    - Prioritisation of alternatives and development of a roadmap for changes in the heating systems of the city in the next years (see chapter 6.4)

2.3 The Applied Hotmaps Toolchain

The **Hotmaps** toolbox is used in this strategy for calculating scenarios of potential future low carbon heating demand and supply in Milton Keynes and all the related costs and emissions. The overall approach for the calculations in this strategy is to limit the applied data to the use of (modified) data and tools within the open-source, publicly available, browser-based version of the **Hotmaps** toolbox[8]. The diagram below illustrates the applied toolchain for these calculations and serves thus as a how-to for the use of the **Hotmaps** toolbox and its integrated calculation modules (CMs) in a heating strategy development. Please note that some of the calculation steps yield intermediate results, only to be used as input parameters in subsequent calculation modules. The order (number 1 to 8) of the calculation steps in the toolchain are structured in order of succession. For more information on the CMs check the **Hotmaps** Wiki[9].

[7] MK University is a new project to build a new university campus in Central MK
[8] https://www.hotmaps.eu/map
[9] https://wiki.hotmaps.eu/



For more information on how to use the calculation modules in a toolchain please also refer to the training material and exercises from the **Hotmaps** training workshops[10].

2.3.1 CM – Demand Projection

This calculation module generates both a heat demand density and a gross floor area density map in the form of raster files. The input to the module is different development scenarios of the heat demand and gross floor areas at national levels and broken down to each raster element as well as user-defined parameters to describe the relative deviation to the developments in the scenarios. Please refer to the **Hotmaps** Wiki for more information on this CM[11].

The default data set in the **Hotmaps** database in the 2020-version only covers the current heat demand estimate, based on building stock data from 2014. The CM Demand Projection can be used to create future projections of heat demand and gross floor area density maps, by applying scenarios of the development of the national building stocks under different boundary conditions calculated with the Invert/EE-Lab model to the selected region. The projection based on the precalculated scenarios can be adjusted by the user regarding the development of basic parameters like the floor area and the specific energy needs (kWh/m^2).

10 https://wiki.hotmaps.eu/en/training-material

11 https://wiki.hotmaps.eu/en/CM-Demand-projection

The module has been used in course of this strategy calculation process in order to develop heat demand density and gross floor area density maps for the year 2050 for different assumptions of renovation ambition. For specific information on how it has been used for the assessment of **Hotmaps** scenarios for Milton Keynes and the results from the calculation module please refer to chapter 6.1.

2.3.2 CM – Decentral Heating Supply

This module calculates the costs of heat supply in buildings via decentral heat supply technologies. Inputs to the module are investment costs, O&M costs, energy prices, the hourly load profile of heat demand as well as depreciation time and interest rate. Furthermore, the composition of buildings and renovation states of the buildings in the analysed area are required. The outputs are heat supply costs of various decentral heat supply technologies for the defined buildings and price assumptions as well as reference decentral supply costs for the analysed area and related CO2 emissions. Please refer to the **Hotmaps** Wiki for more information on this CM[12].

The reference prices for the individual heating supply in Milton Keynes are identified in the CM Decentral Heating Supply. These costs are used to assess the economically competitive heating price the possible district heating system would have to compete against. Prices for individual heating can be found for a large array of building types, energy efficiency standards/heat demands etc., and the local specific needs can thus be addressed in the presentation of individual heating supply costs.

For specific information on how it has been used for the assessment of **Hotmaps** scenarios for Milton Keynes and the results from the calculation module please refer to chapter 6.1.

2.3.3 CM – District Heating Potential – Economic Assessment

This calculation module determines potential district heating areas based on a simplified assessment of the heat distribution and transmission costs. The costs for the heat distribution mainly consist of the investment costs for the network infrastructure. Inputs to the module are heat demand and gross floor area density maps, costs of network expansion, development of heat demand and connection rates, depreciation time, interest rate and a threshold for the accepted heat distribution costs. Furthermore, it calculates the costs of transmission lines between identified district heating areas. The calculation module CM – District Heating Potential – Economic Assessment builds on a concept developed by Persson & Werner (2011 as well as Persson et al 2019. The concept is based on the following relations:

1. A relation of the effective width with the plot ratio,
2. A relation between the effective width, the distributed heat demand, and the average pipe diameter

[12] https://wiki.hotmaps.eu/en/CM-Decentral-heating-supply

3. A relation between the average pipe diameter and the overall investment costs in the network construction.

These relations have been derived based on the analysis of several existing district heating projects around Europe. Please refer to Fallahnejad et al. 2018 for a detailed description of the CM or refer to the **Hotmaps** Wiki for more information[13].

In the **Hotmaps** scenario calculations for Milton Keynes the future scenarios for heat demand and gross floor area density maps for 2050 with different renovation ambitions is calculated with the CM Demand projects (1). With CM Decentral heating costs (2) the reference heating prices is calculated. With these demands and reference heating prices at hand, i.e. which heat density to expect and which costs for decentral heating supply to compete with, this CM District Heating Potential – Economic Assessment (3) can be used to analyse the economic potential for district heating, taking into account the input parameters and thresholds, defined in previous calculation steps. The results of this CM are used to evaluate the span of potential district shares, depending on the given choice of parameters. Hence, results from this CM are used in the development of scenarios, cf. section 2.3.8 below.

For specific information on how it has been used for the assessment of **Hotmaps** scenarios for Milton Keynes and the results from the calculation module please refer to chapter 6.1.

2.3.4 CM – Heat Load Profiles

This module generates load profiles of demand for space heating and hot water generation for a selected region. It uses default load profiles for the residential and tertiary sector on NUTS2 level and scales it to a given demand in those sectors and provides the load profiles separated for space heating and hot water generation. Please refer to the **Hotmaps** Wiki for more information on this CM[14].

Different consumer types influence the heat load profiles of a heating grid, which affects the need for installed heat generation capacity. Hence detailed heat load profiles are necessary to make precise calculations for the energy system modelling possible, i.e. to assess needs for installed base and peak load capacity as well as to ensure enough redundant heat generation capacity. The CM Heat Load Profiles develops such heat load profiles, taking into consideration predefined annual load profiles (resolution: hourly) for several consumer groups. The user can affect the developed heat load profile by adapting the weighting of the heating and hot water for residential and tertiary consumers respectively.

In the **Hotmaps** scenarios for Milton Keynes the default heat load profiles where assessed as found representative for the area.

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[13] https://wiki.hotmaps.eu/en/CM-District-heating-potential-economic-assessment

[14] https://wiki.hotmaps.eu/en/CM-Heat-load-profiles

2.3.5 CM – Excess heat transport potential

This module calculates the flow and the costs of heat transmission from potential excess heat sources located outside of potential district heating areas to the district heating area. The inputs are hourly load profiles of the excess heat flow and the district heating demand, the location of the excess heat source and the potential district heating system, investment costs in heat exchangers and transmission lines and threshold values for distance and transmission costs. Please refer to the **Hotmaps** Wiki for more information on this CM[15].

The default dataset for the primary sources on excess heat in the **Hotmaps** Toolbox do not include potential sources in the areas of investigation, as there is no heavy industry within 40 km of Milton Keynes this CM has not been used for the assessment of Hotmaps scenarios for Milton Keynes. Hence, possible excess heat sources need to be identified based on knowledge to possible projects in the area. Almost all available excess heat sources in the area of Milton Keynes is low temperature (below 85 °C) and therefore needs to be utilised with a heat pump - this is done the CM District Heating Supply dispatch (7), cf. section 2.3.72.3.8 below.

2.3.6 RE-Resource Potentials

The Renewable Resource Potentials consist of five calculation modules where only two are used indirectly in the **Hotmaps** scenarios for Milton Keynes:

- CM - Heat source potential

This module aims to highlight the heat source that can be classify as: suitable, conditionally suitable, and not suitable for an energy exploitation at urban level regarding mapping the thermal energy resource potentials from Wastewater Treatment Plants (WWTP). Please refer to the **Hotmaps** Wiki for more information on this CM[16].

- CM - Biomass potential

This module assesses the potential biomass energy that can be generated from a biomass source. The aims of this CM are to assess the electric and thermal energy that can be used from the biomass potential of NUTS3 regions. The module considers different typology of biomass that can be exploited to produce energy. The CM uses the default data set for the whole EU that are at NUTS3 level. Please refer to the **Hotmaps** Wiki for more information on this CM[17].

Before creating and calculating scenarios for possible future district heating systems, the available resources, apart from the above-mentioned industrial excess heat, need to be mapped. The **Hotmaps** Toolbox can be used for this, by evaluating the different potentials in the *Layers* tab and creating selections for the area under investigation or by using the calculation modules, e.g. CM - heat source potential and CM - Biomass potential. The selection area for these potentials may very well cover the hinterland of an upcoming district heating supply area. In the **Hotmaps** scenarios for Milton Keynes the resources is identified and assess separately but has been verified by the **Hotmaps** potentials. The identified potentials is used

[15] https://wiki.hotmaps.eu/en/CM-Excess-heat-transport-potential

[16] https://wiki.hotmaps.eu/en/CM-Heatsource-potential

[17] https://wiki.hotmaps.eu/en/CM-Biomass-potential

to develop scenarios on the CM District Heating Supply dispatch (7), cf. section 2.3.72.3.8 below.

2.3.7 CM – DH supply dispatch

This calculation module can be run in two modes: 1) dispatch, 2) invest. In the dispatch mode, it calculates the cost-minimal operation of a portfolio of heat supply technologies in a defined district heating system for each hour of the year. The inputs to the module are hourly profiles for the heat demand in the network, for the potential heat supply from different sources and for energy carrier prices. Furthermore, cost and efficiency parameters for each technology are required. The module yields the costs of heat supply, the share of energy carriers used and the implied CO2 emissions. In the invest mode, the module optimizes the capacities of installed heat supply technologies to cover heat demand. Please refer to the **Hotmaps** Wiki for more information on this CM[18].

In the Hotmaps scenarios for Milton Keynes the dispatch mode is used. The necessary information regarding the two sections of a heating system (supply and demand) are gathered and scenarios for the heating supply can be defined. These scenarios are investigated in an iteration in the CM District Heating Supply Dispatch, creating supply scenarios based on defined capacities of supply units and related costs. As stated above almost all available excess heat sources in the area of Milton Keynes is low temperature (below 85 °C) and therefore needs to be utilised with a heat pump, these potentials as therefore been taken into account in the CM when defining heat pump capacities and efficiencies. Equivalent the biomass potentials as well as sustainability and alternative uses is defining for the biomass boiler capacities investigated.

For specific information on how it has been used for the assessment of **Hotmaps** scenarios for Milton Keynes and the results from the calculation module please refer to chapter 6.1.

2.3.8 CM - Scenario Assessment

This calculation module allows comparing different heating scenarios. The module is not integrated into the **Hotmaps** Toolbox, but it is provided as a separate Excel workbook that combines the results of other calculation modules to be previously run. The template as it is allows comparing up to 9 different scenarios, but if properly adapted, it can work for any number of scenarios. Separate worksheets are set up to collate the key indicators from each calculation module, while key indicators are automatically collated in the final table and represented in graphs. Please refer to the **Hotmaps** Wiki for more information on this CM[19].

Finally collecting all the above calculations on competing district heating supply scenarios, the results need to be analysed, interpreted, and discussed to formulate the techno-economic input to a heating strategy roadmap. The scenario assessment is performed as abovementioned in a spreadsheet file – this gives the user more flexibility and overview of the inputs and outputs and makes it easier to analysis the results. The scenario assessment is used

[18] https://wiki.hotmaps.eu/en/CM-District-heating-supply-dispatch

[19] https://wiki.hotmaps.eu/en/CM-Scenario-assessment

to evaluate the competing scenarios by different parameters, such as the total heat supply costs, levelized cost of heating (LCOH), total CO_2-emission, share of local renewable energy resources, share of fuel/combustion free heating and thus, different scenarios may perform good on some indicators and less optimal on others.

For a description of the chosen scenarios and how they were derived, based on the input described in the previous steps please refer to chapter 6.1 on the assessment of the **Hotmaps** scenarios.

3 Target and policy instruments

3.1 Local, regional, and national targets and policy instruments

National targets

In May 2007 the UK Labour government published the 'Meeting the Energy Challenge: A White Paper on Energy' known as the Energy White Paper. Here the government addressed the issues regarding energy security and climate change. To deliver energy security and accelerate the transition to a low carbon economy the government set up the following actions: save energy, develop cleaner energy supplies, and secure reliable energy supplies at prices set in competitive markets. (Department of Trade and Industry, 2007)

In 2008 the UK parliament approved The Climate Change Act, which committed the UK government by law to reduce carbon emissions by 80 % of 1990 levels by the year 2050. The Act aims to enable the UK to become a low-carbon economy and introduces powers to the ministers necessary to achieve the targets. A Committee on Climate Change was also introduced to provide advice to the UK Government on these targets and related policies. (Climate Change Act 2008).

In 2019 new targets were introduced which commits the UK government by law to reduce carbon emissions by 100 % of 1990 levels (net zero) by the year 2050. (GOV.UK, 2019)

The national targets for the green energy transition in the heating sector were disseminated in the strategy and guideline documents such as: Clean Growth Strategy, The UK National Energy and Climate Plan (NECP), The Low Carbon Transition Plan, and The Future of Heating. These are discussed in detail in chapter 5.1.2.

Local target

In 2019 Milton Keynes Council approved the Sustainability Strategy for 2019-2050. The council have far exceeded its target of 40% CO_2-emission reduction by 2020 compared to 2005 for the whole population of Milton Keynes. The region has currently achieved a 43.59% reduction (as of Report released June 2019 using 2017 data).

Work is now in progress on the action plan to support the Strategy. The actions for implementing low carbon and renewable energy schemes, passive design measures and Community Energy Networks are elaborated in chapter 5.1.3.

The Milton Keynes Council demonstrated its engagement in the climate change emergency actions since 1996, when the council became a member of Energy Cities. Over the years, the partnership has worked together on many projects and succeeded with establishing the Milton Keynes Energy Agency and launching the project pioneering Energy Performance Certification. Currently, the council's leader Pete Marland is the Vice President of the organisation. In 2009, the Milton Keynes Council signed up to the Covenant of Mayors which is the international coalition of cities and local governments with a shared long-term vision.

3.2 Stakeholder analysis

In this chapter, the stakeholders are identified, which is the required prerequisite for defining and addressing the potential barriers and drivers to the energy planning (see chapter 5). The stakeholders' identification should be completed in the preparation phase cf. the **Hotmaps** Handbooks for Strategic Heat Planning (Djørup, 2019). A part of this process is to map central stakeholders and analyse what role they are likely to play in a transition process, and what role they may have in a future heat supply system.

The stakeholders are organised in Table 2 by a category of an institution or a party, starting with the regulators and policymakers and finishing with the energy producers and the final energy consumers. They are presented with their expectations (needs) from the energy strategy and their role in the energy planning phase (contributions). These are then assessed in the three-score scale and summarised in the visual map (Table 1). Additionally, the potential risks associated with the planning stage are identified specifically for each stakeholder. The stakeholder overview is concluded with the status for engagement which varies from the purely informative to the active involvement.

Table 1 Visual map of stakeholders

	• Low Interest / Impact	• Medium Interest / Impact	• High Interest / Impact
High Power / Influence	•	• Local government (Milton Keynes Council)	• Building and landowners (Public sector)
Medium Power / Influence	•	•	• Conventional energy supply companies (Eon, Western Power, Transco) • Utilities (National - gas and electricity) • Utilities (Local - independent Heat and Power network operator Thamesway)
Low Power / Influence	•	• Industrial energy • Energy agencies (national and local)	• Citizens • Building and landowners / Property developers / Investors (Private sector) • Alternative energy sources (Waste to energy plant)

Table 2: Overview of stakeholders

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
Local government (Milton Keynes Council)	Authorities	Medium	High	Introducing and implementing energy policy framework.	Establishing heat network opportunities for the existing customers and for the greenfield developments. Evaluating the economics of multiple small vs. single larger heating network. The council has a politically approved policy statement with a core statement of intent to make the city carbon neutral by 2050, however, without a detailed action plan. The document – Imagine MK2050 – does make reference to wider use of Community Heating and Power networks.	Elected members are not experts in CH(P) and rely on council planning officers for advice and guidance, but they are responsible for making planning decisions.	Inform Local planners must implement local and national priorities for new developments. They need to understand what is practical to demand of developers for new areas.

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
					The political influence can affect the direction that planners take, within a politically approved policy framework – subject to national regulations. Planners understand the law and their powers to request heat network connections.		
Citizens	Final energy consumers	High	Low	Cheap and reliable heat and power. Any project must address their needs with a priority. Little interest in the underlying environmental benefits of the technology.	Engagement in future policy, especially in planning policy formulation via public fora and consultations.	Diversified (often limited) awareness and understanding of the subject among the engaged citizens.	Inform, Keep satisfied Residents need to understand the benefit of heat networks from the economic, living comfort and environmental benefit viewpoint.
Building and landown	Final energy	High	Low	Minimising capital cost.	Little input into the planning phase.	Reluctance to invest into CH(P) connection.	Inform Housebuilders need to understand the benefit

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
ers / Property developers / Investors (Private sector)	consumers			Limited influence of the CH(P) connection on the rental cost.	Establishing heat network opportunities for the existing customers and for the greenfield developments. Evaluating the economics of multiple small vs. single larger heating network.		of heat networks from the financial and marketing viewpoint. Financial backing for any heat network is crucial to a successful project.
Building and landowners (Public sector)	Final energy consumers	High	High	Implementing policy and planning decisions that were officially approved by public consultations and authorities.	As the Gatekeepers for the planning process – they can determine the type of information that will be delivered to other stakeholders and as a consequence, they can influence the decision-making process strongly. Establishing heat network opportunities for the existing customers and for the greenfield developments. Evaluating the economics of multiple small vs. single larger heating network.	Limited knowledge of CH(P) schemes and a strong reliance on expert analysis of proposals for connection.	Inform, Monitor A national company owing the majority of buildings for rent in the MK has a classical landlord-tenant dilemma. It has to be involved in the planning process and convinced of reasons for increasing rents.

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
Conventional energy supply companies (Eon, Western Power, Transco)	Energy suppliers	High	Medium	Maximizing company profit. High performance of the plant and heat and electricity network.	Providing heat and electrical energy. Responsible for meeting demand, contingency planning and supplying reliable energy network.	Limited involvement in the planning/strategy making phase.	Inform, Get involved Energy suppliers should become active partners in energy planning to cope with network demands for both gas and electricity (Smart networks).
Alternative energy sources (Waste to energy plant)	Energy suppliers	High	Low	Maximizing company profit. High performance of the plant and heat and electricity network.	A resource of know-how, information, knowledge, data, technical expertise. Could provide this waste-derived energy.	Limited involvement in the planning/strategy making phase.	Get involved Energy suppliers should become active partners in energy planning to increase the proportion of low-carbon energy in the DH supply.
Industrial energy	Energy suppliers	Medium	Low	Dispose of excess energy. Making additional profit at the limited effort.	Offering a cheap alternative excess energy.	Limited knowledge of CH(P) technologies and little input into planning.	Inform, Keep satisfied Industrial energy suppliers should be informed and involved in energy planning to increase the proportion of excess

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
				Increasing interest in Corporate Social Responsibility (CSR) (larger companies). Compliance with various carbon emissions reporting and tax processes (larger companies).			energy in the DH supply.
Utilities (National - gas and electricity)	Energy suppliers	High	Medium	Maintaining competitiveness and profitability of the national grid.	Enabling incorporation of new heat sources, district heating and power network.	Little role in the planning process, other than regional utility planning. Limited knowledge of CH(P) technologies. May consider local CH(P) networks competition to their business.	Keep satisfied, Monitor

Name	Category	Interest / Impact	Power / Influence	Needs	Contributions	Blocking risk	Engagement strategy
Utilities (Local - independent Heat and Power network operator Thameswey)	Energy suppliers	High	Medium	Maximizing company profit. High performance of the local heat and electricity network.	Providing advice to developers in the area to meet planning requirements for connection to heat networks. They have local experience and knowledge and would be crucial to expansion of the network.	Their advice is perceived by developers as a 'tick box' exercise, with no real intention, to connect but having to comply with the regulation.	Get involved Local utility company should get engaged in the planning to gain more respect among developers.
Energy agencies (national and local)	Other	Medium	Low	Primarily environmental and social interest (alleviating fuel poverty – defined as spending more than 10% of disposable income on heat and power).	May help guide National policy direction on CH(P).	No real input into planning process unless called upon to do environmental analysis for a developer. Knowledge is patchy, relying heavily on specialist companies.	Inform, Get involved Energy agencies should get engaged in the planning process to help guide National policy direction on CH(P).

4 Description of energy demand and supply

4.1 Mapping of demand, resource potentials and existing plants

The examination of the energy needs and supply potential started from reviewing the historical studies performed specifically for the Milton Keynes Borough. The following chapter compares the findings from the Summary report dated to 2012 (CSE, 2012) with the results of using the **Hotmaps** tool.

The heat demand density maps presented in the Summary report were produced by the CSE in partnership with the USEA for DECC enabling users to locate and investigate areas of high heat demand that may be suitable for district heating. (CSE, 2012). The map was built from a bottom-up address level model of heat demand in England. The model estimates the total heat demand of every address in England but based on published sub-national energy consumption statistics and without making use of metered energy readings [20]. (The purpose of the map is to support planning and deployment of local low-carbon energy projects in England, by providing publicly accessible high-resolution web-based maps of heat demand by area. The spatial heat density values are expressed in kWh of thermal energy per square meter, while the coloured-code indicates the low-density areas (blue) and high density areas (red).

The heat demand density map in the Hotmaps default database has been developed via a top-down approach. Energy demand for space heating and hot water generation in residential and non-residential buildings at national level has been broken down to the hectare level. For this statistical data at NUTS3 level as well as data on the more detailed regional level was used: e.g. soil sealing data from the Corine land use database, a building footprint database, building height distributions derived from the OSM database and also heating degree days on hectare level. More details can be found in chapter 2.3 and on the project homepage (Pezzutto et. al. 2018).

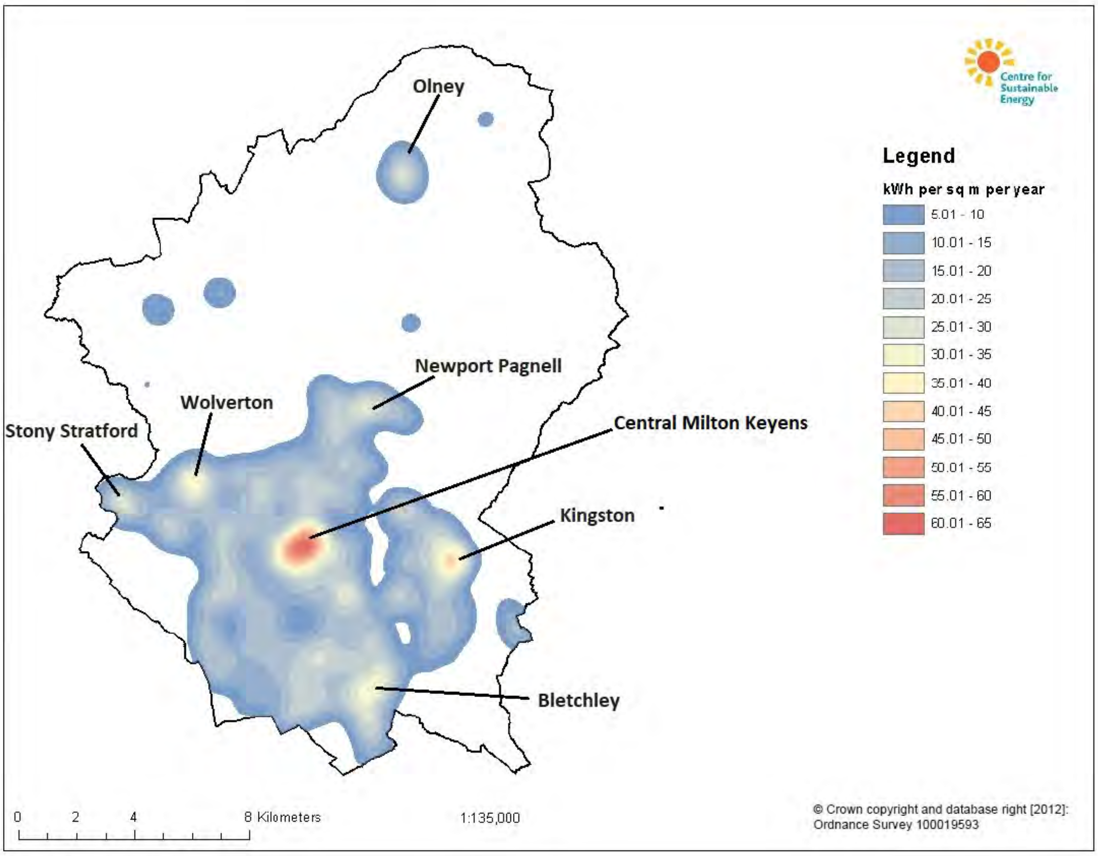
Heat mapping

Overall, as can be seen on Figure 3, the heat demand is concentrated in Central Milton Keynes, as would be expected. There are also areas of high heat demand in Wolverton and Stony Stratford to the West, Newport Pagnell and Olney to the North, Kingston to the East and Bletchley to the South.

The heat mapping performed using **Hotmaps** (Figure 4and Figure 6) confirmed the concentrations of largest demand which only expanded and heating demand density increased

20 https://www.cse.org.uk/projects/view/1183

since the study was issued (Figure 3 and Figure 5). The two corresponding maps, one for the entire borough and another for the Central Milton Keynes can be compared by noticing the high and low dense heating areas. Please notice that orange marking in the **Hotmaps** layout already indicates the high consumption ~500-1000 MWh/ha which is highlighted in red in the heat map from the historical study.



Centre for Sustainable Energy

Figure 3 Heat density map for Milton Keynes Borough (Centre for Sustainable Energy, 2012).

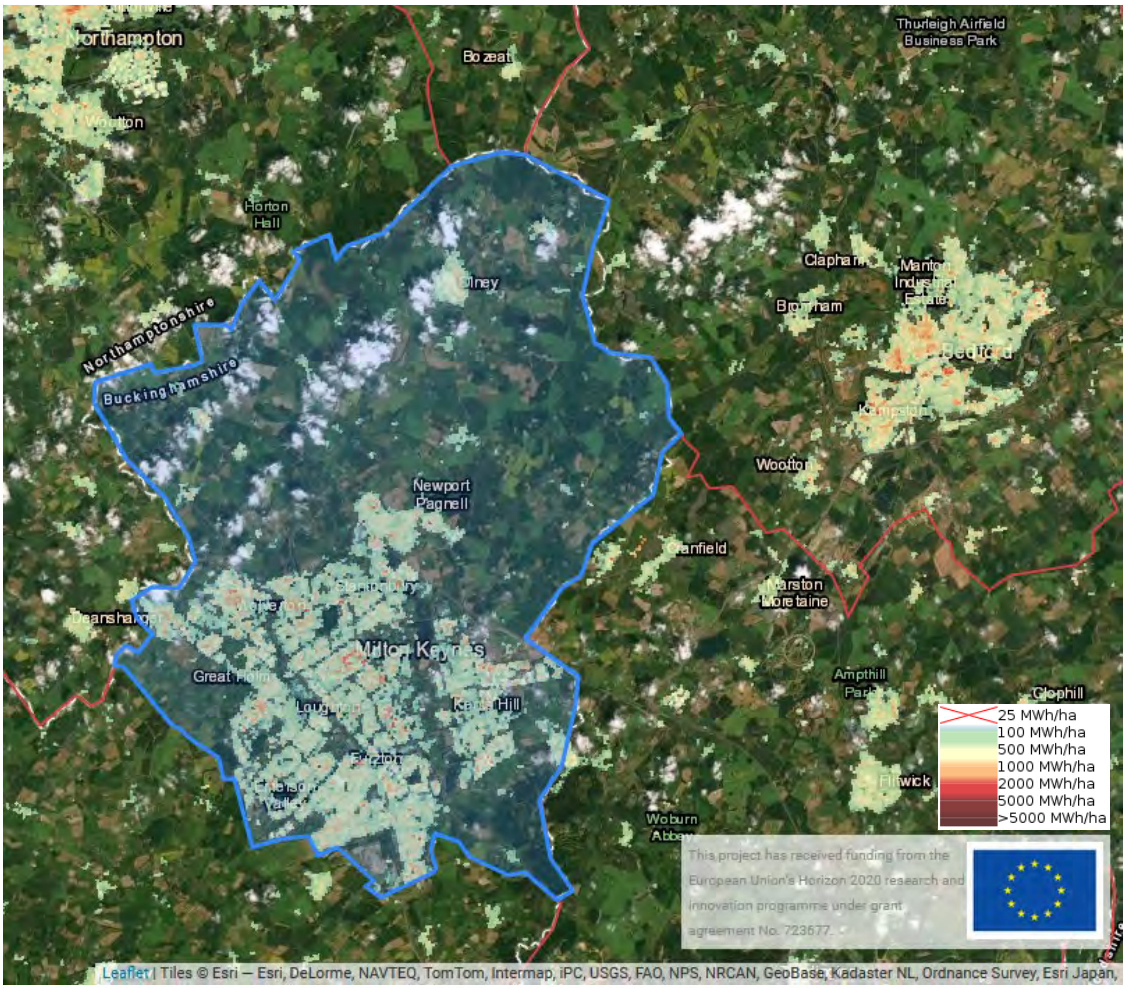


Figure 4 Heat density map for Milton Keynes Borough using Hotmaps default data (Pezzutto et. al. 2018).

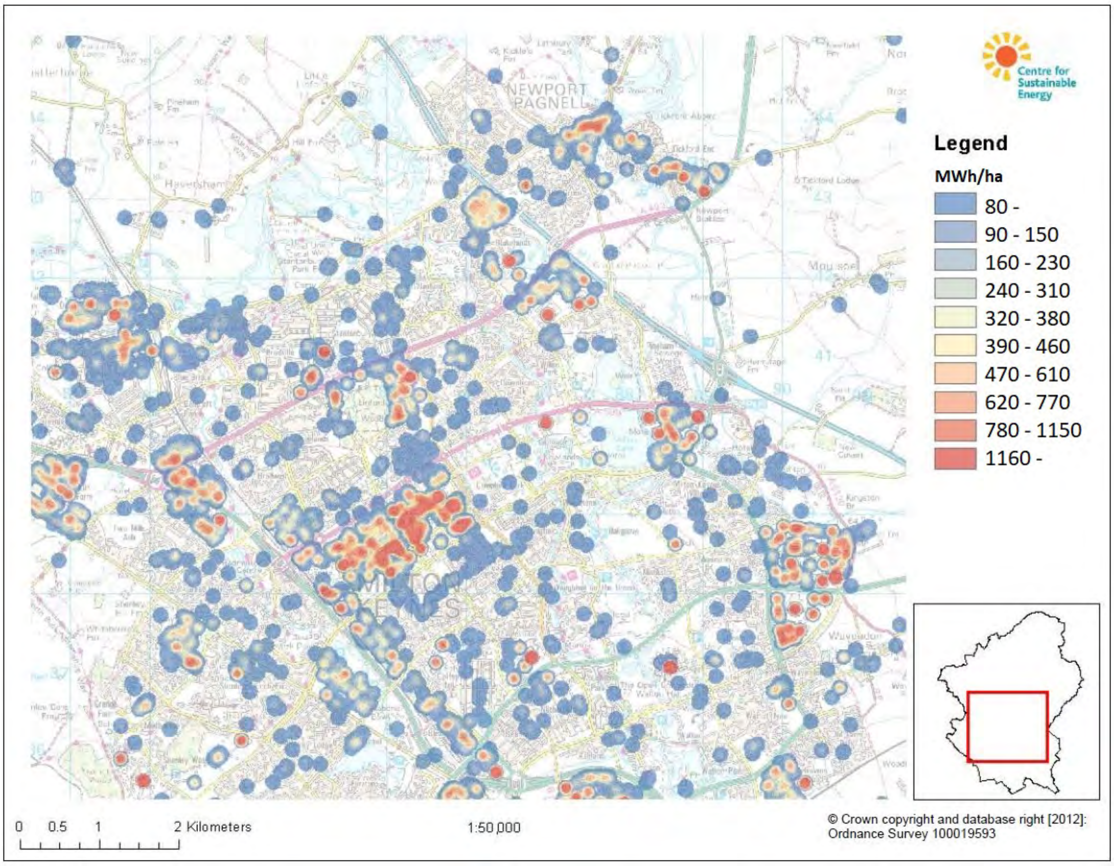


Figure 5 Heat density map for Central Milton Keynes (Centre for Sustainable Energy, 2012).

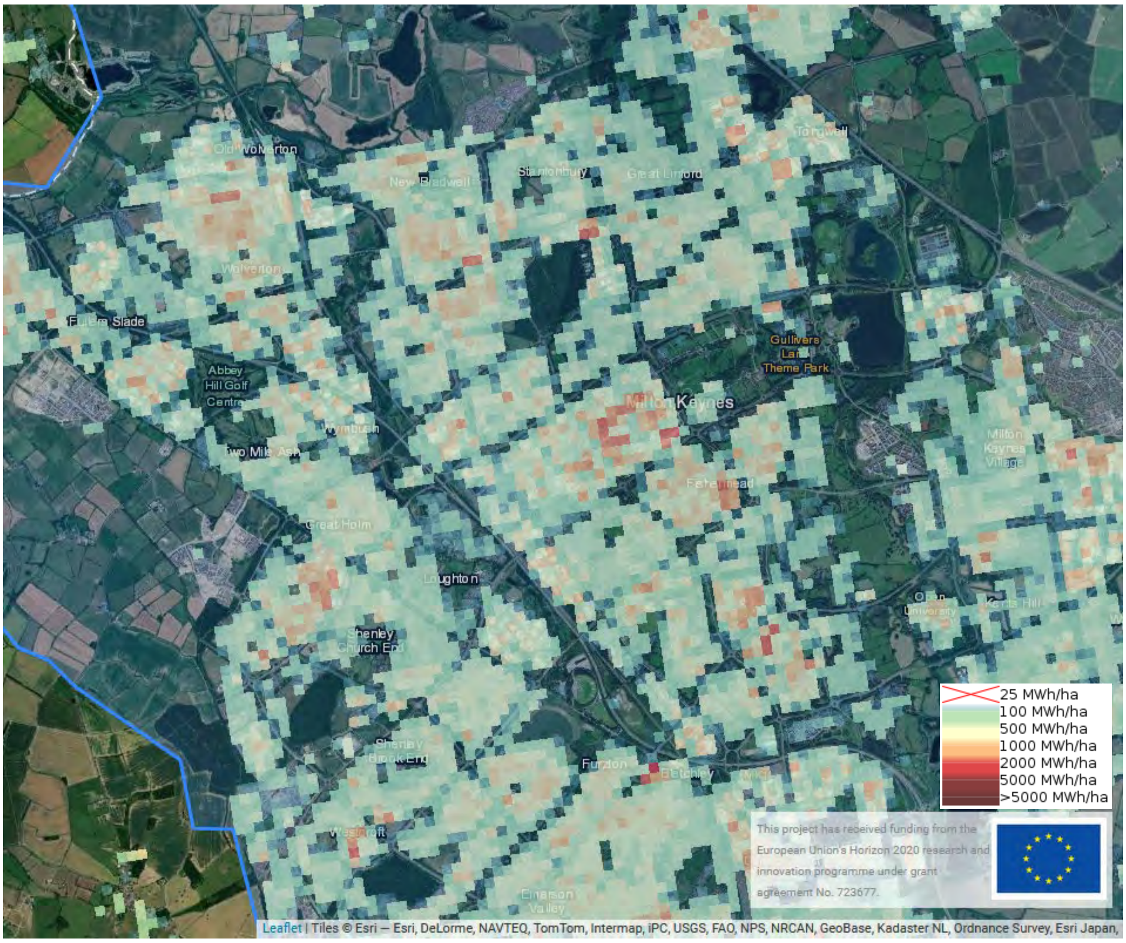


Figure 6 Heat density map for Central Milton Keynes using Hotmaps default data (Pezzutto et. al. 2018).

The approach in identifying district heating (DH) opportunities within Milton Keynes according to the Summary report dated to 2012 (Centre for Sustainable Energy, 2012) included specific criteria for the locations. The targeted consumers were the so-called anchor loads or areas within the radius of 200 m from the anchor loads which are characterised by high and stable demand for heat. These included blocks of flats, social housing, hospitals, hotels, shopping centres and premises from the public sector with heating needs exceeding 100 MWh/yr. These requirements have been met by the areas highlighted as ‘Identified areas’ in Figure 7.

Among them, a more scrutinous assessment was made to distinguish the feasible DH application, given the buildings concentration level and required length of DHN. The dispersed consumers and smallest demand concentrations were excluded. Starting from the top of the map this includes the following suburbs:

- Newport Pagnell - a number of potential anchor loads including schools, Middleton swimming pool, police station, fire station, community centres and health centres.
- Wolverton - anchor loads include schools, Milton Keynes Museum, Town Hall, Health Centre.
- Central Milton Keynes (CMK) - the largest cumulation of shops, offices and premises with the existing district heating system. There are a number of large loads located

here, including John Lewis and XScape, and so the existing district heating system could be extended to include them.

- Kingston / Brinklow - an industrial area with several premises with high heat demand. There are few anchor loads and no domestic premises.
- Eaglestone / Netherfield - the location of Milton Keynes University Hospital as well as the Redway School and Buckland Lodge Sheltered Housing. Langland Combined School is nearby.
- Bletchley - two patches in the south in the Bletchley area contain some large housing blocks and a large number of anchor loads.

All the identified potential DH areas are shown in Figure 7. The Central Milton Keynes and Old Wolverton were given a particular attention by the Milton Keynes Council. Additionally, the Council requested to include a newly planned housing area in the Fullers Slade in the scope of the analysis.

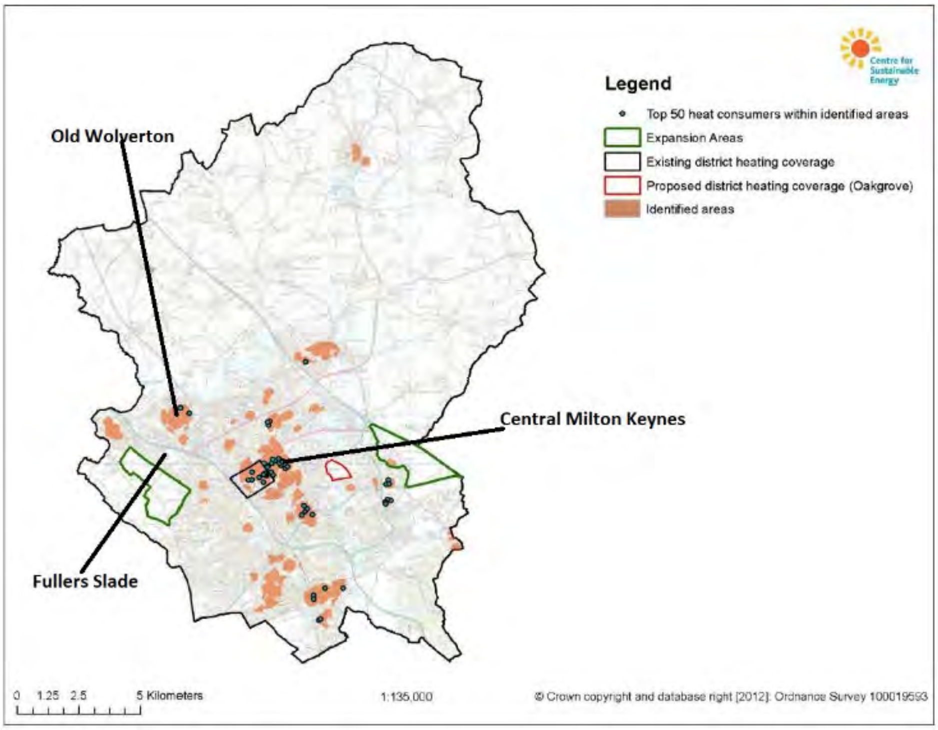


Figure 7 Potential district heating areas identified in the previous study (Centre for Sustainable Energy, 2012).

The **Hotmaps** toolbox is also able to estimating potential DH areas and the share of the heat demand covered by DH. To compare the findings from the CSE study, where the anchor demands were identified with the minimum consumption criterion of 100 MWh/yr, the corresponding input parameter were determined in order to run a corresponding analysis in **Hotmaps**. Given, that the heat demand parameter in the **Hotmaps** is set at the fixed resolution of a hectare (100 m x 100 m), it was assumed that each hectare by average is approx. 50 % (5000 m^2) occupied by buildings with a GIA (gross internal area) of 1000 m^2. This equals five buildings (5 x 1000 m^2) and based on the minimum heat demand of 100 MWh/yr per building (CSE study), the equivalent input parameter for the DH calculation module in **Hotmaps** is given at 500 MWh/yr.

The relevance of DH coverage (instead of limiting the DH area with the fixed 200 m radius) in **Hotmaps** was identified using the minimum requirement for the network thermal capacity. For the minimum 30 GWh size of DH, the most feasible DH locations have been indicated as shown in the following Figure 8.

The heat mapping based on the **Hotmaps** toolbox confirmed the DH potential areas in determined areas of the Old Wolverton and Central Milton Keynes. It also indicated other locations as Fullers Slade to be feasible for DH connection, which is among new housing developments to be even further expanded in the nearest future.

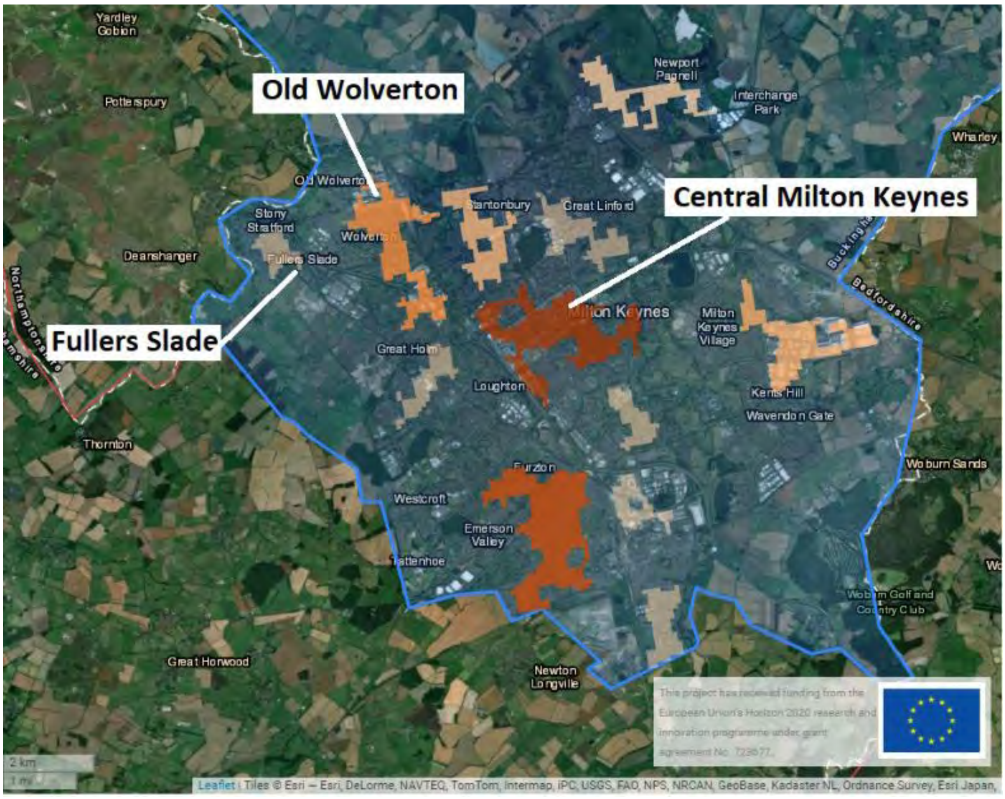


Figure 8: Potential district heating areas identified using Hotmaps toolbox and database (Pezzutto et. al. 2018)

The most interesting locations selected for further analysis of the economic feasibility of District Heating are the following:

- Central Milton Keynes,
- Old Wolverton including the Radcliffe School and Leisure Centre, and
- Fullers Slade.

These have been examined in detail in chapter 6.2, in terms of heating needs and low-carbon energy supply strategy using DH networks. This is not an exhaustive list as the city continues to grow and new opportunities are presented.

4.2 Description of existing heating and cooling

The local energy supply is dominated by natural gas and electricity from the national grid. However, the proportion of locally produced biogas is rising (a biowaste to gas plant was completed in 2019), together with increasing renewable electricity supplies from photovoltaics, 9 MW wind and a small scale combined heat and power plant (CHP) based on natural gas. Most of the energy plants belong to private investors/companies.

In addition, a large-scale waste to energy plant (refer to 6.2.4 for details) is located in the northern part of the city (neighbouring with the Old Wolverton site). This plant is optimised to generate electricity, the excess heat is currently wasted. The waste throughput of the treatment plant is around 94,000 tonnes per year with an electric capacity of 5.8 MWe. (Amey, Milton Keynes, Advanced Thermal treatment, n.d.).

At present, there appear to be no customers to justify the installation of a heat supply network to make use of the heat from the waste to energy plant, but the area has the potential for growth in both industry and housing.

Central Milton Keynes (CMK) has a small existing heat and power network in the city centre, operated by a third party – Thameswey MK Ltd. The Thameswey power plant operates a 10 MW gas-fired boiler and two gas CHP units rated at 3 $MW_{installed}$ each (the plant is marked with a green icon in Figure 9). The plant is substantially oversized (40-50%) for the connected loads due to the slowdown in expected growth in heat demand from 2008.

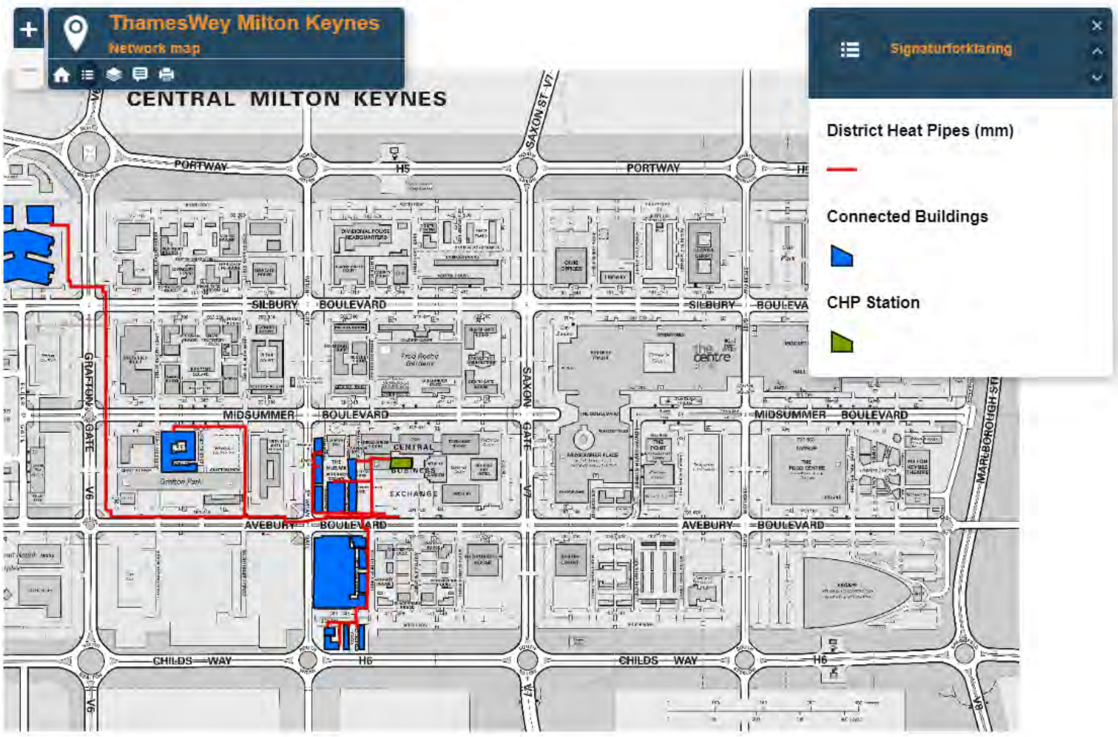


Figure 9 ThamesWey energy centre and DHN in the Central Milton Keynes (ThamesWey, web map).

The system supplies 1,100 business and domestic customers within a 1.5 km radius generating 14 GWh of electricity and 12 GWh of heat per year (ThamesWey). Electricity is distributed to the customers via a ‘Private Wire’ arrangement, avoiding many charges levied by the conventional electricity supply network.

No cooling is generated centrally in the Thameswey plant. However, at least one customer has an absorption chiller connected to the network.

5 Barriers and drivers

In this chapter the drivers that promote and the barriers that hinder strategic heat planning are analysed. In chapter 3.2 the stakeholders were mapped in order to better identify, analyse, and evaluate the economic and political barriers and drivers. Based on this, the ownership and business models that align with the strategic objectives for Milton Keynes can be developed. However, this step is out of the scope of the strategy process performed in course of the Hotmaps project and described in this document.

5.1 Drivers

Strategic heat planning is driven by a number of factors including:

- International policy
- National legislations
- Local legislations
- Industry sector standards
- Subsidies to investment cost
- Subsidies to operation costs
- Business sector and economic factors

5.1.1 International policy

The Kyoto Protocol (1997) is an international treaty with the goal of achieving the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

The Paris Agreement (2016) is an international agreement relating to national level commitments to reducing greenhouse gas emissions. Each country that has signed up to the agreement set nationally determined contributions which specify how much they will reduce their emissions by.

EU Energy Performance of Buildings Directive (EPBD, 2002) is European legislation which requires all EU countries to improve their Building Regulations and introduce energy certification schemes. The 2010 recast EPBD requires countries to move towards new and retrofitted 'nearly zero energy buildings' standards by 2020 (2018 for public buildings). The directive was updated in 2016 to cover additional efficiency and technology in buildings.

EU 2030 Energy Strategy (2014) sets out a framework for the development of climate and energy policies across EU member states. The UK is committed to meeting targets agreed between the European Commission and the Member States to reduce CO_2 emissions by 40% on 1990 levels by 2020.

Milton Keynes Energy Mapping Report, Milton Keynes Council, AECOM, Project number: 60549497, January 2018

5.1.2 National level legislations

As of December 2018, there is no regulator for heating networks, as there is for electric and gas networks (Ofgem), meaning consumers on DHNs have less security than traditional gas and electric consumers. This means there is no ombudsman to receive complaints, which can discourage consumers from connecting to the heating network, making it even harder for network owners to make the necessary connections for an ESP to begin talks. The only current legislation specific to DHNs is the Heat Network (Metering and Billing) Regulations 2014. The others include DHN development as part of the decarbonisation strategy measures. All relevant documents are demonstrated below.

Clean Growth Strategy published by the UK government in 2017 - this sets out the measures for implementing the ambitious carbon abatement target, in the context of the UK's legal requirements under the Climate Change Act (UK carbon account should decrease at least 80% compared to the 1990 baseline by 2050). This also indicates the immediate actions in regard to the heat sector which comprises approximately 40% of the UK's greenhouse gas emissions and these include:

- Support of approximately £3.6 billion to upgrade around a million homes through the Energy Company Obligation (ECO) and for energy efficiency improvements in homes and buildings until 2028 - an extension from previous commitments which ended in 2021-22;
- A commitment to invest £100 million in carbon capture usage and storage (CCUS) for industrial purposes focusing on the use of waste heat from industry, rather than carbon capture from power plants;
- The implementation of boiler efficiency measures which should ensure 1.2 million new boilers reach an ErP efficiency of at least 92% up from the current 88% threshold;
- To ensure homes classified as 'fuel poor' and as many other homes as possible reach an Energy Performance Certificate Band C by 2035, provided it is practicable, cost-effective and affordable to do so. On average, an EPC C rating saves a household £270 per annum over an EPC D rated home;
- A commitment to undertake an independent review on building regulations, to understand whether changes would promote low carbon and higher energy efficiency heating, ventilation and air conditioning systems in new commercial buildings in cost-effective and affordable ways;
- A call for evidence on the potential reform of the structure of the Green Deal scheme.

KPMG, Government recommits to clean growth, Super Thursday, October 2017, Available online: https://home.kpmg/content/dam/kpmg/uk/pdf/2017/10/clean-growth-strategy.pdf.

The UK National Energy and Climate Plan (NECP) published in January 2019 summarises the progress for the proposed action plan laid out in the Clean Growth Strategy. The UK government indicates spending £4.5 billion between 2016 and 2021 (through the Renewable Heat Incentive, RHI) to support innovative low carbon heat technologies in homes and businesses, such as heat pumps, biomass boilers and solar water heaters.

Department for Business, Energy and Industrial Strategy (BEIS), **The UK National Energy and Climate Plan (NECP)**, January 2019, Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774235/national_energy_and_climate_plan.pdf

The Low Carbon Transmission Plan sets out a vision of a changed Britain, powered by cleaner energy used more efficiently in the homes and businesses, with more secure energy supplies and more stable energy prices, and benefiting from the jobs and growth that a low carbon economy will bring. For the heating actions, it focuses on

- Increasing house efficiency (through Green Deal, Energy Company Obligation),
- Moving away from high carbon-intensive fuels towards e.g. heat pumps (through Renewable Heat Incentive),
- Building new houses with high environmental standards (by improving building standards Part L of the Buildings Regulations 2010),
- Changing customer behaviour (by installing 50 million smart gas and electricity meters).

HM Government, Carbon Plan, Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47621/1358-the-carbon-plan.pdf

The Future of Heating addresses the range of barriers that were identified for the UK in areas including efficient low carbon heat in industry, heat networks, heat and cooling in buildings, grids and infrastructure. Specifically, in relation to the community heating and cooling and district heat network, the document emphasises the importance of improving the efficiency of the energy demand side and expanding the DH infrastructure on the energy supply side.

Department for Business, Energy and Industrial Strategy (BEIS), The Future of Heating, March 2013, Available online: https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge

Under the **Committee on Climate Change's core Net Zero** scenario, around 5 million homes across the UK need to be connected to heat networks by 2050. Building on the pathway set out by HM Government's Clean Growth Strategy which suggested that around one in five buildings will have the potential to access a largely low carbon district heat network by 2050.

Net Zero The UK's contribution to stopping global warming, Committee on Climate Change, May 2019, Available online: https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

Heat Network (Metering and Billing) Regulations sets out the requirements for the correct and accurate heat metering and heat bills transparency. In essence, the regulations place certain responsibilities on anyone supplying and charging for heat, cooling or hot water.

The Heat Network (Metering and Billing) Regulations 2018. Available online: https://assets.

publishing.service.gov.uk/media/5b55965740f0b6338218d6a4/heat_networks_final_report.pdf

5.1.3 Local level legislations

The Milton Keynes Council Plan:MK 2016 -2031 is Milton Keynes Council's emerging development policy, which sets out the Council's approach to planning up to the year 2031. The plan:MK formulates the need for promoting community energy networks and strategic renewable energy developments.

Policy SC3 indicates that low carbon and renewable energy schemes will be attributed with a significant weight in their favour and will be supported where it can be demonstrated that there are not any significant negative social, economic, or environmental impacts associated with them. Large developments (over 100 homes or non-resident developments of over 1000 m^2) and those in proximity to existing CHP or local energy networks will be expected to connect to these. The policy, however, makes it subject to that connection being economically competitive in comparison with alternative means.

Policy SD1 put an emphasis on adaptation of passive design measures in the new developments to reduce the energy demand for heating, lighting and cooling, create comfortable and healthy environments, and be responsive to predicted changes in climate. Additionally, it suggests considering the use of community energy networks in line with Policy CS14 'Community Energy Networks and Large-Scale Renewable Energy Schemes'.

Policy SC2 has specific aims for Community Energy Networks and large-scale renewable energy schemes. This concludes with the following targets:

> A. Low carbon and renewable energy schemes will be attributed significant weight in their favour, and will be supported where it can be demonstrated that there will not be any significant negative social, economic, or environmental impacts associated with them.
>
> B. Proposals for over 100 homes and non-residential developments of over 1,000 m2 will be expected to consider the integration of community energy networks in the development. This consideration should form part of development proposals and take into account the site's characteristics and the existing cooling, heat and power demands on adjacent sites.
>
> C. All new developments in proximity of an existing or proposed combined heat and power (CHP), combined cooling, heat and power (CCHP) station or local energy network will be expected to connect to the network unless it can be demonstrated that:
>
> > 1. a better alternative for reducing carbon emissions from the development can be achieved; or
> >
> > 2. heating and/or cooling loads of the scheme do not justify a CHP connection;
> >
> > or
> >
> > 3. the cost of achieving this would make the proposed development unviable.

Despite central and local government policies to encourage heat networks, there are no 'teeth' to enforce planning requirements in the UK.

5.1.4 Industry sector standards

The Heat Trust is a voluntary standard launched by industry participants, while the Association for Decentralised Energy (ADE) and Chartered Institution of Building Services Engineers (CIBSE) have produced a heat network code of practice. Both of these are voluntary, and it is unclear how many DHNs in the United Kingdom meet these standards and practices. Therefore, it is clear that the UK must push legislation and regulation around heating networks in order to provide safe, secure and competitive heating network markets in order to facilitate the 17% predicted domestic heat supply by DHNs by 2050.

M.A. Millar, N.M. Burnside, Z. Yu, District Heating Challenges for the UK, College of Science and Engineering, University of Glasgow, MDPI Energies journal, January 2019.

5.1.5 Subsidies – Investment costs

In May 2018, the UK Government launched the **Buildings Mission**, the first mission under the Clean Growth Grand Challenge, which aims to at least halve the energy use of new buildings by 2030, reduce the cost of retrofitting efficiency measures in existing buildings, and to ensure homes and businesses are heated by clean energy sources. The Mission was backed by £170 million of public money through the Transforming Construction Industrial Strategy Challenge Fund. It is expected this will be matched by £250 million of private sector investment, meaning over £400 million will be invested in new construction products, technologies and techniques.

The **Heat Networks Investment Project (HNIP)** is delivering £320 million of capital investment support to foster the creation of a self-sustaining heat networks market, which currently only constitutes just 2% of total heat consumption. All Heat Network schemes funded by HNIP today must be lower carbon than the counterfactual heating solution and have the capability to further decarbonise in the future.

Green Deal enables to invest, at no upfront cost, home energy efficiency improvements that are expected to pay for themselves through energy bill savings.

Energy Company Obligation is to support delivery at scale of cost-effective measures that require additional assistance to be taken up through the Green Deal, such as solid wall insulation. Additionally, the Energy Company Obligation will provide extra support for low-income vulnerable households. This will enable people who might face more challenges to take advantage of the Green Deal.

5.1.6 Subsidies – Operation costs

The **Renewable Heat Incentive (RHI)** is to provide support to homes and businesses choosing to install renewable heat technologies. This scheme acts to drive down the emissions that result from heating our homes and will also play an important part in meeting the UK's EU target to source 15% of its energy from renewable sources by 2020. RHI is calculated based on the volume of heat produced and the eligible technology and is used to support operational costs.

5.1.7 Business sector and Economic factors

DHNs in the United Kingdom are typically led by the local authority or by the property developer (however, some community-owned schemes are also present). This means that the key decision-making factors are the profitability of the investment and potentially marketing. Since the active regeneration process is financially driven, the opportunities to implement heat networks may be lost if a sound financial case cannot be made. This is especially given very competitive low gas fuel prices.

A significant hurdle to financial viability in domestic schemes is the consumer uptake. Energy Services Providers (ESPs) will have a minimum dwelling uptake to be able to consider a DHN, some will require as many as 500 dwellings to consider a CHP scheme economically viable. However, an active regeneration process is underway, with several areas of the city due for large scale demolition and rebuild at higher density (1000 dwellings per area). This is according to a studie on "*Research into Barriers to Deployment of District Heating Networks*" by Department of Energy and Climate Change[21].

5.2 Barriers

The primary barriers breaking the strategy/heating and cooling planning include cf. University of Edinburgh and the Centre for Sustainable Energy [22]:

- Difficulties with meeting development and capital costs
- Uncertainty regarding longevity and reliability of customer demand
- Uncertainty regarding reliable heat sources
- Lack of regulation and inconsistent pricing of heat
- Lack of generally accepted contract mechanisms
- Lack of a generally accepted and established role for local authorities
- Customer expectations
- Skills gaps

5.2.1 Difficulties with meeting development and capital costs

There are several financial barriers to heat network development: obtaining capital funding is a challenge because projects' payback periods are long in commercial terms, high upfront costs and the uncertainty of return on the investment.

The key financial barrier is the large upfront cost for the heat network infrastructure and incorporating the existing and new buildings into the centralised system. The investors would always have to expect a long payback period. The better business case is anticipated for new

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[21] Department of Energy and Climate Change London, UK, 2013. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191542/Barriers_to_deployment_of_district_heating_networks_2204.pdf

[22] BRE, University of Edinburgh and the Centre for Sustainable Energy, 2013, Research into barriers to deployment of district heating networks.

development where a heat network can replace the need for a gas network and coincide with the installation of other utilities such as water, electricity and waste network.

Although not major, yet still a significant cost element is the project preparation phase including master planning, heat mapping and feasibility studies.

5.2.2 Uncertainty regarding longevity and reliability of customer demand

This barrier refers to the uncertainty related to the energy consumption of the customers. This results from difficulty of combining heat reduction due to applying heat reduction measures and future community expansion. The quality of the historical heating and cooling consumptions also can significantly vary and while it was relatively straightforward to obtain heat consumption data for council-owned buildings, accessing this information from organisations over which the council had little influence was much more difficult.

5.2.3 Uncertainty regarding reliable heat sources

The combined heat and power (CHP) technologies are the primary source of the DH networks. Although, currently it is the most efficient source of energy, in comparison to gas boilers and grid electricity, carbon savings from gas CHPs are expected to decrease along with the electricity grid decarbonisation (more RES and low-carbon technologies in the electricity generation in the UK).

The alternative heat sources are sought which include biomass, heat from waste, large heat pumps all coupled with the thermal storage. Both, the biomass and energy from waste plants require significant spatial areas and specific and regular fuel supply which is not suitable for a dense urban environment. Heat pumps, on the other hand, do not operate efficiently with the high heat supply temperatures that currently are the typical design requirements. For example, Milton Keynes has a new, large waste to energy plant, but its location is in some distance from potential customers.

5.2.4 Lack of regulation and inconsistent pricing of heat

A consistent methodology for setting heat tariffs for DH is needed to ensure consumers that they would be treated reasonably and charged a fair price. Lack of coherent regulations addressing this fact is a common problem across the whole country, which discourages potential customers from connecting to district heating.

5.2.5 Lack of generally accepted contract mechanisms

There is a lack of standardisation of the commercial arrangements that are needed to deliver the construction and operation of heat networks. These include models that would indicate how development and operational risks can best be reduced or shared. Developers and local authorities are therefore required to start from scratch on new projects rather than implementing standard solutions. This is caused by the novelty of projects and increases transaction costs around the commercial aspects of heat network schemes. Local authorities, unfamiliar with new and complex models, have to procure costly specialist advice to guide them through the process

5.2.6 Lack of a generally accepted and established role for local authorities

The activity of local authorities in relation to heat networks is present in different areas and is not particularly standardised at higher level. Often, the political support is highly needed for the progress of the project. However, lack of sufficient understanding of the scheme among the authorities creates a barrier.

Typically, the local council is politically supportive of heat networks. They identify a group of buildings under their (or public) ownership that is in close proximity with significant demand for heat and committed to long-term heat supply contracts. However, it is usually difficult to set a collaboration with the public institutions which are reluctant to invest into DH infrastructure before having the buildings ready to connect. Irrespective of the approach made, the commitment and dedication of an individual person within the local authority was essential in achieving the scheme mobilisation.

5.2.7 Customer expectations

Significant costs associated with connecting existing buildings to the DH is discouraging homeowners to join a heat network, but that there may be less resistance to heat networks in new buildings. Some concerns raised in relation to potential networks attached to existing properties include the level of disruption needed to build the heat network infrastructure and to install in individual properties, and the potential need for heat generators close to homes. It is highly important to reassure homeowners that they would still be able to control the temperature in their properties.

5.2.8 Skills gaps

The transition to low carbon heat will require specialised, highly skilled and experienced heat focused engineers. These skills are not readily available in Milton Keynes.

6 Local heating and cooling strategy

The local heating strategy for Milton Keynes consists of three parts:

1. Assessment of Hotmaps scenarios for all of Milton Keynes as well as for two areas investigated and calculated in the **Hotmaps** toolbox.
2. Assessment of stand-alone scenarios for two areas investigated and calculated in stand-alone calculation tools (Termis and EnergyPRO)
3. Development of a Heating Strategy Roadmap for Milton Keynes based on recommendations derived from both analyses.

The potential areas for DH supply selected for the analysis have been identified based on the heat mapping assessment described in chapter 4.1. These locations are spread across the city with the largest concentration in the city centre (Central Milton Keynes) and the western suburb (Old Wolverton and Fullers Slade).

Central Milton Keynes is one of the key locations for developing the DH system, not only because it has the highest heating needs per square meter. This significant heat demand also relates to a low number of consumers (commercial buildings, offices, warehouses), which reduces the number of connections to the network. Furthermore, there is already an existing DHN that could be further expanded.

Old Wolverton is an industrial cluster with a mixture of warehouses, shops and the run-down Geminin Rail Services, which is planned to be entirely demolished. The area is envisaged to serve as a commercial zone with the space for new offices, warehouses and small businesses. Old Wolverton is the only part of the greater Wolverton suburb, which consists of private housing, a school and a leisure centre. The last two are also considered as feasible DH consumers and included in the energy strategy.

Fullers Slade is not identified as a potential district heating area based on the heat mapping described in chapter 4.1., as this currently includes mainly older council homes and other affordable housing. This, however, underwent the planning process with the aim of regeneration, and in 2017 an options appraisal was launched with the engagement of local communities and stakeholder group. As part of regeneration, the homes could be either fully refurbished or demolished and re-built.

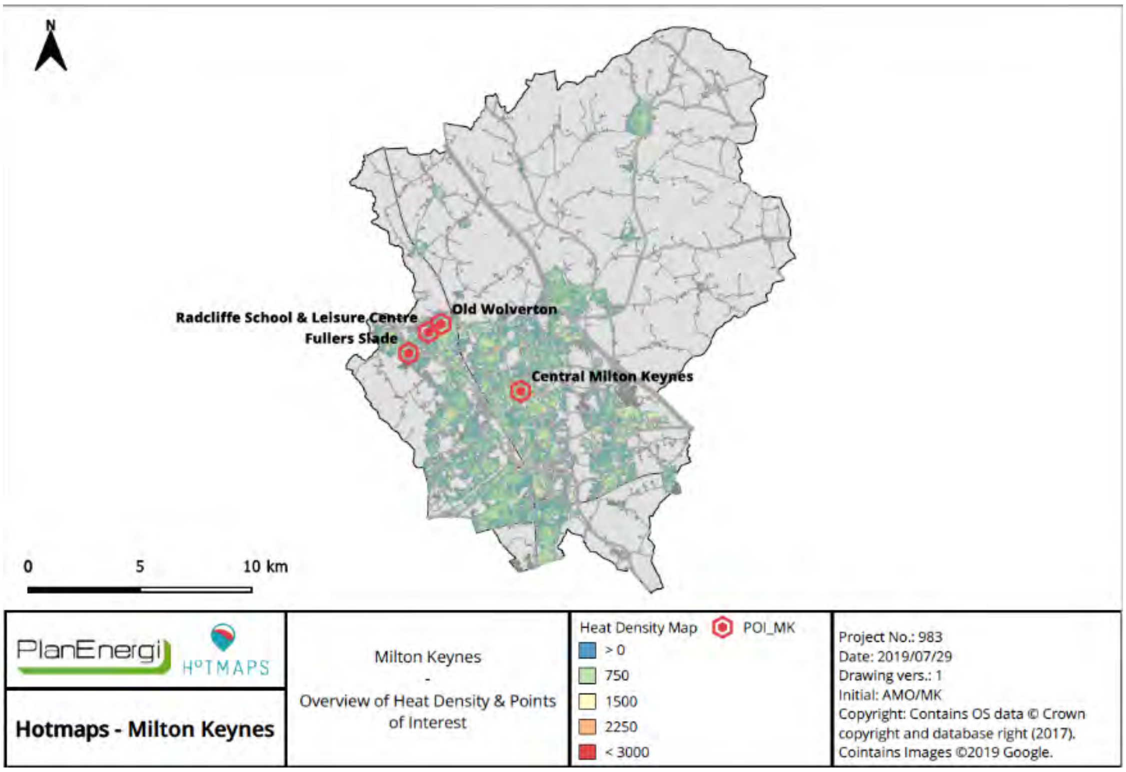

Figure 10 Potential heating areas in Milton Keynes.

6.1 Assessment of Hotmaps scenarios

The overall approach for the calculations and the use of the **Hotmaps** toolbox in this strategy is illustrated by the toolchain and the descriptions of its integrated calculation modules (CMs) in section 2.3. For more information on the CMs check the **Hotmaps** Wiki[23]. The specific information on how the **Hotmaps** toolbox has been used for the assessment of **Hotmaps** scenarios for Milton Keynes and the results from the calculation modules are described in the subsections below.

6.1.1 Demand projections

The calculation module CM – Demand projection has been used in course of this strategy calculation process to develop heat demand density and gross floor area density maps for the year 2050 for different assumptions of renovation ambition. It also considers the high population growth in Milton Keynes (2-3 % p.a.). In the table below the results from the calculation of demand projections are shown:

[23] https://wiki.hotmaps.eu/

Table 3: Demand projections of heat density and heated area in Milton Keynes for different levels of ambition in the renovation of buildings.

Name	Description	2020 Heat demand [GWh/yr]	2020 Heated gross floor area [m²]	2050 Heat demand [GWh/yr]	2050 Heated gross floor area [m²]
1.1 A MK 2050	Moderate refurbishment	2438	21.7	2657.7	27.7
1.1 B MK 2050	Semi-Ambitious refurbishment	2438	21.7	2581.4	27.7
1.1 C MK 2050	Ambitious refurbishment	2438	21.7	2571.3	27.7

In Milton Keynes, a large increase in population until 2050 is foreseen. Thus, also in case of ambitious refurbishment, a slight increase in heat demand as seen in 1.1 C MK 2050 (Table 3) might be projected. The ambitious refurbishment is more likely to be economically feasible for buildings with decentral heating.

The total heat demand is increasing from 2020 to 2050, but this is due to a high population growth until 2050. The heat demand per heated area is decreasing from 112.3 kWh/m2/yr in 2020 to 93.0 kWh/m2/yr in 2050 in the ambitious refurbishment calculations.

The outputs are saved as e.g. “1_1A_MK2050_hdm.tif” and “1_1A_MK2050_gfa.tif”.

Please refer to 8.1 Appendix A1 for details on assumptions, inputs, and outputs.

6.1.2 Decentral heating supply

Possible reference prices for the individual heat supply in Milton Keynes in 2050 are identified with the CM Decentral Heating Supply. These costs are used to assess the economically competitive heat price, the possible district heating system would have to compete against. Prices for individual heating are calculated for a large array of building types, construction periods, energy renovations etc., and the local specific emission factor for electricity. The calculations for the **Hotmaps** scenarios are divided into two parts: 1) Single family houses and 2) Apartment blocks, Other non-residential buildings, and Offices.

The scenarios are simplified to only model two construction periods. The TABULA WebTool[24] is used to find the characteristics of buildings originated from those periods. The toolbox provides a database with buildings main characteristic in different European countries, including the UK and England. There was a slight discrepancy between the age category of buildings in TABULA and Hotmaps, therefore the periods 1965 - 1980 and 2004 – 2009 available

[24] http://webtool.building-typology.eu/

in TABULA have been used to match the construction periods 1970 - 1979 and 2000 – 2010 respectively in Hotmaps.

The shares of final energy consumption per building type in Milton Keynes has been estimated, based on aerial photos and site visit.

Table 4: Assumptions for the decentral heating supply in Milton Keynes.

Name	Construction period	Building type	Heated gross floor area [m^2]	Savings for space heating in 2050	Final energy consumption share per building type [%]
1.3 A MK 2050	1970 - 1979	SFH Single family houses	123	40	20
1.3 B MK 2050	2000 - 2010	SFH Single family houses	149	10	7.5
1.3 C MK 2050	1970 - 1979	TH Terraced houses	85	40	20
1.3 D MK 2050	2000 - 2010	TH Terraced houses	98	10	7.5
1.3 E MK 2050	1970 - 1979	Apartment blocks	4357	40	7.5
1.3 F MK 2050	2000 - 2010	Apartment blocks	4045	10	2.5
1.3 G MK 2050	1970 - 1979	Other non-residential buildings	2179	40	12.5
1.3 H MK 2050	2000 - 2010	Other non-residential buildings	2023	10	7.5
1.3 I MK 2050	1970 - 1979	Offices	545	40	10
1.3 J MK 2050	2000 - 2010	Offices	506	10	5

The projected CO_2 emission intensity for electricity in 2035 for the UK at 0.041 kg/kWh cf. Department for Business, Energy & Industrial Strategy[25] has been used for the 2050 scenarios

[25] Department for Business, Energy & Industrial Strategy - '*Updated Energy and Emissions Projections 2018*': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794590/updated-energy-and-emissions-projections-2018.pdf

– since it is the best available estimate for the emission intensity for electricity in 2050. This has also been done to make pessimistic calculations on the use of electricity for e.g. heat pumps regarding CO_2-emissions. A CO_2-price of 200 EUR is used in calculations cf. Department of Energy & Climate Change[26].

Below is shown the share of CO_2-emissions, final energy, and useful energy consumption for different technologies of decentral heating supply in Milton Keynes in 2050.

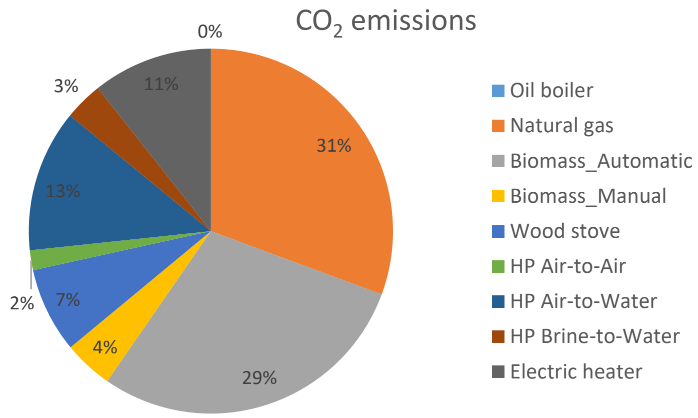

Figure 11: Share of CO_2-emissions from different decentral technologies in Milton Keynes.

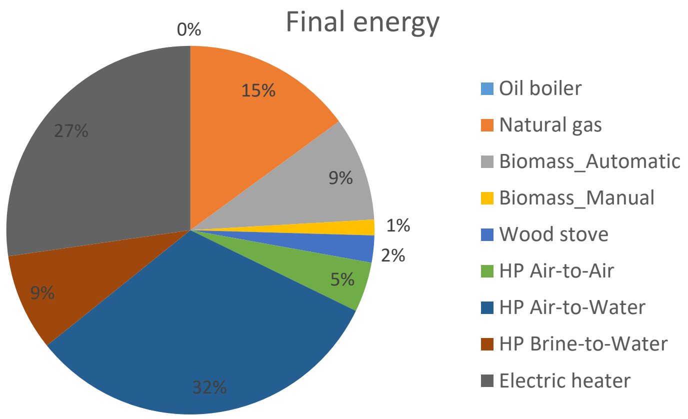

Figure 12: Share of final energy consumption from different decentral technologies in Milton Keynes.

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[26] Department of Energy & Climate Change - '*Guidedance on estimating carbon calues beyond 2050: An Interim Approach*': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48108/1_20100120165619_e____carbonvaluesbeyond2050.pdf

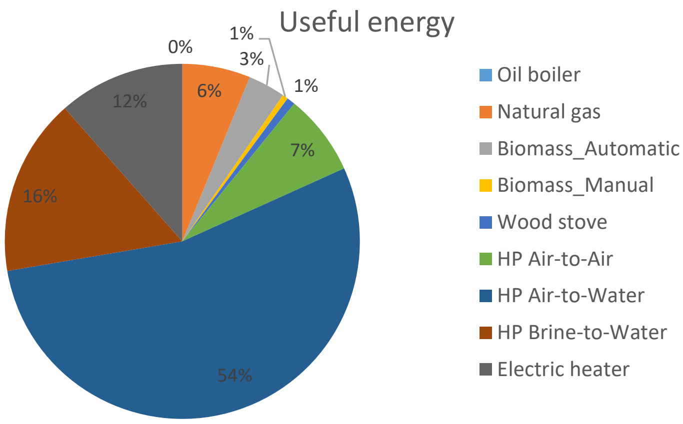

Figure 13: Share of useful energy consumption from different decentral technologies in Milton Keynes.

The high efficiencies and therefore high share of heat demand covered by heat pumps with a relatively small amount of electricity can be seen in Figure 12 and Figure 13.

Please refer to 8.2 Appendix A2 for details on assumptions, inputs, and outputs.

6.1.3 District heating economic assessment

The **Hotmaps** calculation module CM District Heating Potential – Economic Assessment is used to analyse the economic potential for district heating in Milton Keynes, considering different input parameters and thresholds. The results are used to evaluate the span of potential shares of district heating, depending on the given choice of parameters on e.g. depreciation time, market share of district heating in areas with district heating in 2050, maximum allowed grid costs and refurbishment ambitions.

Nine calculations have been performed with the module. Hereby, three different scenarios of refurbishment cf. 6.1.1 have been considered:

- Moderate refurbishment
- Semi-ambitious refurbishment
- Ambitious refurbishment

and three different scenarios of district heating expansion have been considered:

- Moderate district heating expansion
- Semi-ambitious district heating expansion
- Ambitious district heating expansion

In these three scenarios of district heating expansions, the depreciation time is set between 30 and 40 years, the market share of district heating in 2050 is set to between 80 % and 90 % within potential district heating areas. The grid costs consist of a district heating grid cost ceiling that is set between 30 and 35 EUR/MWh, a construction cost constant set between 212 and 200 EUR/m and a construction cost coefficient varied between 4464 and 3500 EUR/m^2.

These input parameters yield between 1 and 51 economic coherent district heating areas and a district heating share in 2050 between 0 % and approx. 80 %.

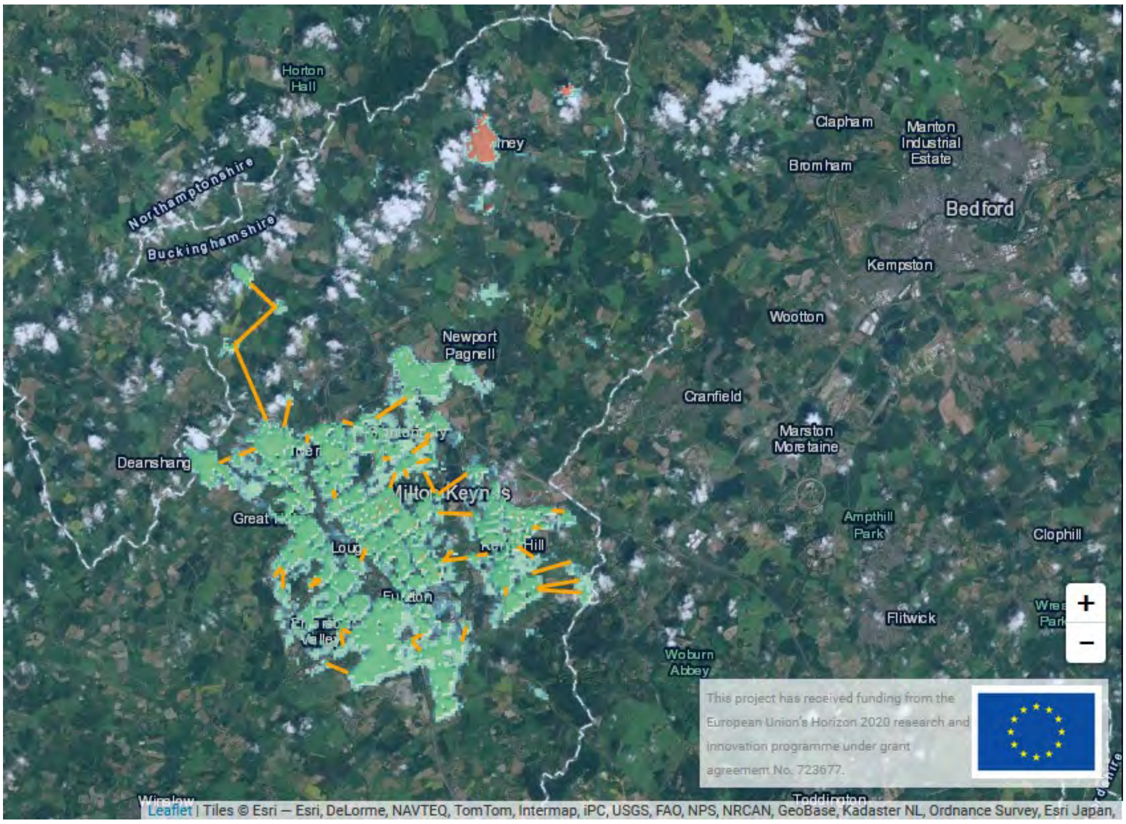

Figure 14: Areas identified as potential district heating areas with the CM – District Heating Potential: Economic Assessment for the scenario with semi-ambitious district heating expansion and ambitious refurbishment.

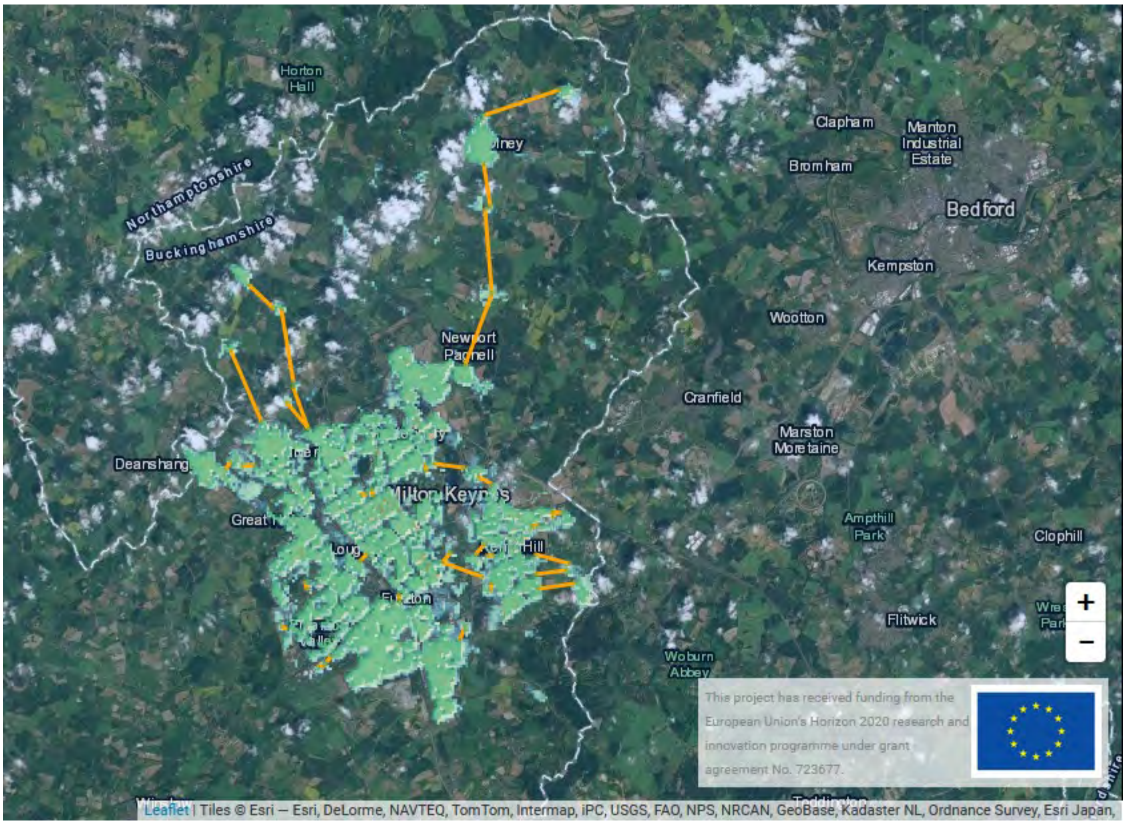

Figure 15: Areas identified as potential district heating areas with the CM – District Heating Potential: Economic Assessment for the scenario with ambitious district heating expansion and ambitious refurbishment.

Please refer to 8.3 Appendix A3 for details on assumptions, inputs, and outputs.

6.1.4 District heating supply dispatch

The supply of heat to potential district heating systems has been calculated with the CM – District heating supply dispatch. In Milton Keynes, several different technologies could be used to supply district heat. According to the estimation of potentially available resources, the following technologies have been taken into account in the compilation of district heating supply portfolios: biomass boilers; large-scale heat pumps utilizing excess heat from the wastewater treatment plant (WWTP) and other sources (e.g. groundwater, lake or air); solar district heating; and the existing waste-to-energy CHP plant. These technologies have been combined with different capacities to create different portfolios:

- Moderate district heating supply
- Semi-ambitious district heating supply
- Ambitious district heating supply

In the Hotmaps scenarios for Milton Keynes, the dispatch mode is used in the calculation module. Thus, the capacities of the different technologies have been defined and only the utilisation of the different technologies is optimized by the calculation module. The CM is used for calculating the supply of 100 % of the heat demand in Milton Keynes. Afterwards, in the scenario assessment, the calculated values are scaled to fit the actual heat demand in the district heating system according to the scenarios calculated with the CM – District heating Potential – economic assessment. The portfolios are investigated in an iteration in the CM District heating supply dispatch, creating supply scenarios based on defined capacities of supply units and related costs. This has resulted in following district heating supply portfolios that are used in the following scenario assessment to supply the different sizes of district heating systems identified in the district heating economic assessment:

Table 5: District heating supply portfolios in 2050 for Milton Keynes.

Name	Description	Waste-to-Energy CHP plant [MW_{total}]	Biomass boilers [MW_{total}]	Heat pumps [MW_{total}]	Solar district heating [MW_{total}]
1.3 A MK 2050	Moderate DH supply	100	445	100	25
1.3 B MK 2050	Semi-Ambitious DH supply	25	295	325	100
1.3 C MK 2050	Ambitious DH supply	25	120	500	200

Peak heat capacity:

The peak heat demand for supplying 100 % of the heat demand in Milton Keynes in 2050 is 645 MW, but as it can be seen in Table 5, the portfolios need to have 100 % redundancy for the solar district heating (SDH) due to the very low solar radiation in the winter months.

Waste-to-Energy plant:

In the moderate portfolio, the existing Waste-to-Energy CHP plant is expanded to 100 MW_{total} as it is seen as a continuation of the existing policy. This is limited to 25 MW in the other portfolios which is only a minor expansion compared to the existing plant – which today only focuses on producing electricity. The existing waste-to-energy CHP plant which treats any waste remaining which is not recyclable or compostable in an advanced thermal treatment (ATT) plant. The ATT process does not combust the residual waste but instead transforms it into a gas (synthesis gas or syngas), which in turn is combusted to generate high-temperature steam which creates renewable electricity in a turbine. The heat produced as a by-product is partly used for the ATT plant and partly rejected to the environment. This excess heat could be utilised to feed a DH system (Amey, Milton Keynes, Advanced Thermal treatment). The emission factor for the waste is set to 0.114 tCO_2/MWh (fuel) for the Waste-to-Energy plant in the CM – District heating supply dispatch which almost correspond to mixed municipal waste cf. Department for Environment Food & Rural Affairs[27] and Department for Business Energy & Industrial Strategy [28] – so a mix of biodegradable and non-biodegradable municipal solid waste.

Biomass boilers:

The biomass boilers are used as the primary capacity in the moderate portfolio with a biomass consumption of up to 239 GWh/yr. Whereas the biomass boilers are mostly used for backup capacity in the ambitious portfolio. The CM Biomass potential shows a potential for thermal energy production in Milton Keynes at 83.33 GWh/yr from agricultural residues and 1.41 GWh/yr from forest residues. The latter is perhaps a bit underestimated due to large green areas in the city, including gardens, parks and green roadsides, which also yields a lot of biomass residues, andsome of it can be used as feedstock for biomass boilers. The reason for limiting the use of biomass in the ambitious portfolio is the deficit in biomass potentials as well as sustainability concerns and alternative uses of biomass. The biomass is entered as wood pellet in the CM but is regarded as wood chips. The thermal efficiency of a wood chips boiler is approx. 115 %, but the CM can only handle up to 100 %.

Heat pumps:

The efficiency in terms of coefficient of performance (COP) for large-scale heat pumps is set to an average of 3.8 based on a COP of air source heat pumps of between 3.6 up to 3.9 (also taking the seasonality of the ambient temperature into account) and a COP of 5 for excess heat. This average is used due to the assumed large portion of air source heat pumps, due to the possible low amount of utilised excess heat. As stated above almost all available excess heat sources in the area of Milton Keynes is the low temperature (below 85 °C) and therefore needs to be utilised with a heat pump. Milton Keynes has had a dialogue with commercial data centres, with little success. The reason being is that they tend to have relatively short contracts with clients (~5 years) so the availability of heat cannot be guaranteed in the long term (~20 years) required for a cost-effective investment for a heat pump by a heat network. Therefore, new regulations or incentives need to be put in place to secure utilisation of these excess heat sources. Moreover, the heat sources for heat pumps from wastewater treatment plants (WWTP) is located east of Central Milton Keynes and the CM heat source potential identifies 20.62 MW as 'heat sources classified as Suitable' and an additional 0.5 MW as 'heat sources classified as Conditionally'. In the ambitious portfolio, the heat sources for heat pumps from excess heat and WWTP is up to 75 MW and the remaining 425 MW is from the air source, lake source or groundwater with an emphasis on the first – which can have a surprisingly high COP of 2.6 up to 3.0 even in the winter months.

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[27] Department for Environment Food & Rural Affairs, 2020 – '*UK Statisticson Waste*': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918270/UK_Statistics_on_Waste_statistical_notice_March_2020_accessible_FINAL_updated_size_12.pdf

[28] Department for Business Energy & Industrial Strategy, 2019 – '*2019 Government greenhouse gas conversion factors for company reporting: Methodology paper*': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904215/2019-ghg-conversion-factors-methodology-v01-02.pdf

Solar district heating:

The defined portfolios consist of up to 200 MW solar district heating (SDH), which seems ambitious since the available plots (green fields) in Milton Keynes is limited due to the high population growth and fast urban development – the 200 MW equals almost 28.5 hectares.

Other assumptions:

No high temperature excess heat sources have been identified within 40 km (25 miles) distance of Milton Keynes and are therefore disregarded.

The same CO_2-price of 200 EUR/ton of CO_2 cf. Department of Energy & Climate Change[29] as used for decentral heating supply is used in the district heating supply.

Technical data on efficiency, lifetime, investment costs, variable and fixed O & M is verified by the Danish Technology Data catalogue[30] and adapted to the UK – e.g. multiplying the investment for SDH with 20 % in order to take into consideration a higher price of land in Milton Keynes and a possibly higher cost for SDH in the UK.

Please refer to 8.4 Appendix A4 for details on assumptions, inputs, and outputs. Sensivity calculations are made on the basis of a heat demand of 65 % of the total for Milton Keynes in 2050 instead of 100 %. The effect and result of the sensivity calculations are descriped in the scenario assessment in section 6.1.5. Please refer to 8.6 Appendix A6 for details on the sensitivity calculations.

6.1.5 Scenario Assessment - Hotmaps results

The final stage of the energy assessment is collecting all the above calculations on competing district heating supply scenarios. The results need to be analysed, interpreted, and discussed to formulate the techno-economic input to a heating strategy roadmap.

Eight scenarios (Scenario 1 to 8) have been developed for district heating in Milton Keynes in year 2050 using the **Hotmaps** toolbox. Besides, a reference scenario 0 has been developed to compare the district heating scenarios with the reference with individual heating in the entire building stock of Milton Keynes. The nine scenarios that have been assessed are shown in Table 6 below:

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[29] Department of Energy & Climate Change, n.d. - '*Guidedance on estimating carbon calues beyond 2050: An Interim Approach*': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48108/1_20100120165619_e____carbonvaluesbeyond2050.pdf

[30] Danish Energy Agency, 2020: '*Danish Technology Data catalogue - The Technology Data for Generation of Electricity and District Heating*': https://ens.dk/sites/ens.dk/files/Statistik/technology_data_catalogue_for_el_and_dh_-_0009.pdf or see all at: https://ens.dk/en/our-services/projections-and-models/technology-data

Table 6: 2050-scenarios for Milton Keynes.

Name	Refurbishment	District heating expansion	District heating supply
Scenario 0	Moderate refurbishment	No DH expansion	Only decentral supply
Scenario 1	Moderate refurbishment	Semi-Ambitious DH expansion	Moderate DH supply
Scenario 2	Ambitious refurbishment	Semi-Ambitious DH expansion	Moderate DH supply
Scenario 3	Moderate refurbishment	Ambitious DH expansion	Moderate DH supply
Scenario 4	Ambitious refurbishment	Ambitious DH expansion	Moderate DH supply
Scenario 5	Moderate refurbishment	Semi-Ambitious DH expansion	Ambitious DH supply
Scenario 6	Ambitious refurbishment	Semi-Ambitious DH expansion	Ambitious DH supply
Scenario 7	Moderate refurbishment	Ambitious DH expansion	Ambitious DH supply
Scenario 8	Ambitious refurbishment	Ambitious DH expansion	Ambitious DH supply

In the eight scenarios, four different district heating shares are assessed:

- 58.0 % in scenario 2 and 6.
- 64.4 % in scenario 1 and 5.
- 76.7 % in scenario 4 and 8.
- 78.2 % in scenario 3 and 7.

For each of these four district heating shares, two different supply portfolios have been evaluated, all consisting of biomass boilers; heat pumps utilizing excess heat and waste water treatment plant (WWTP) and other sources (e.g. ground water, lake or air); solar district heating; and the existing waste-to-energy CHP plant. The shares of the different technologies vary in the two scenarios as described in the subsection district heating supply dispatch above.

The scenario assessment is used to evaluate the competing scenarios according to the following indicators:

- Total heat supply costs,
- Levelized cost of heat supply (LCOH),

- Total CO_2-emission,
- Share of local renewable energy resources.

Please refer to 8.5 Appendix A5 for details on the outputs.

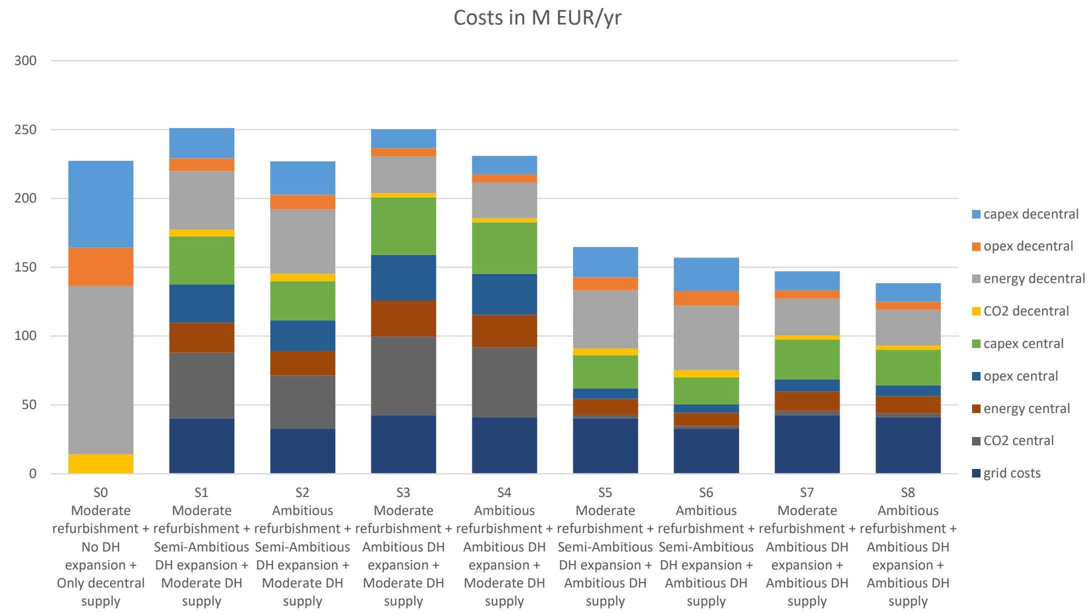


Figure 16: Costs of scenarios in Milton Keynes.

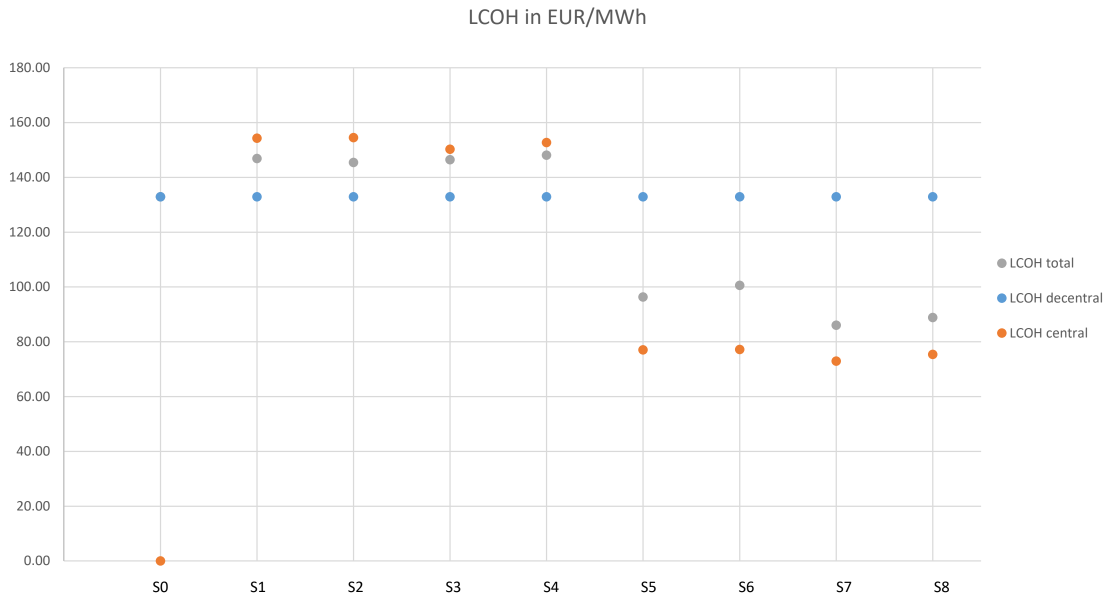


Figure 17: Levelized Costs of Heating (LCOH) of scenarios in Milton Keynes.

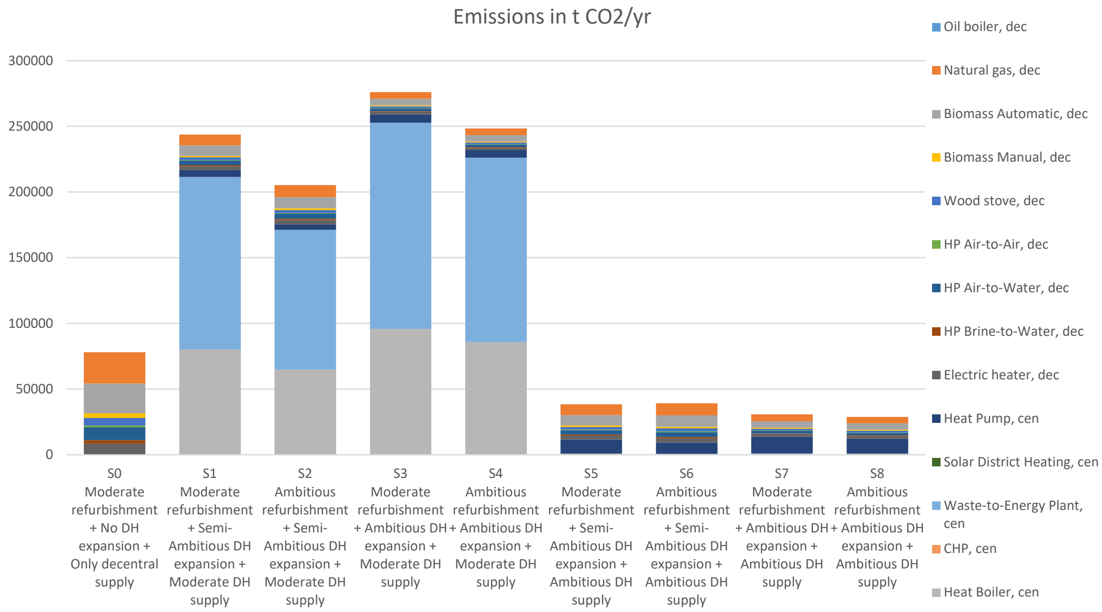


Figure 18: CO_2-emissions of scenarios in Milton Keynes.

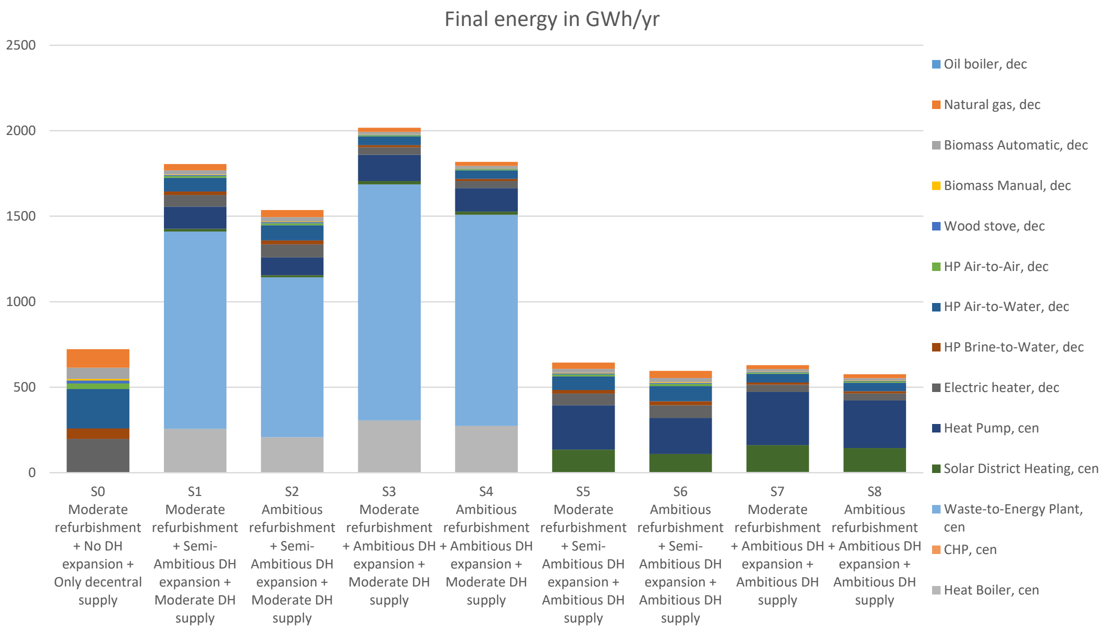


Figure 19: Final energy consumption of scenarios in Milton Keynes.

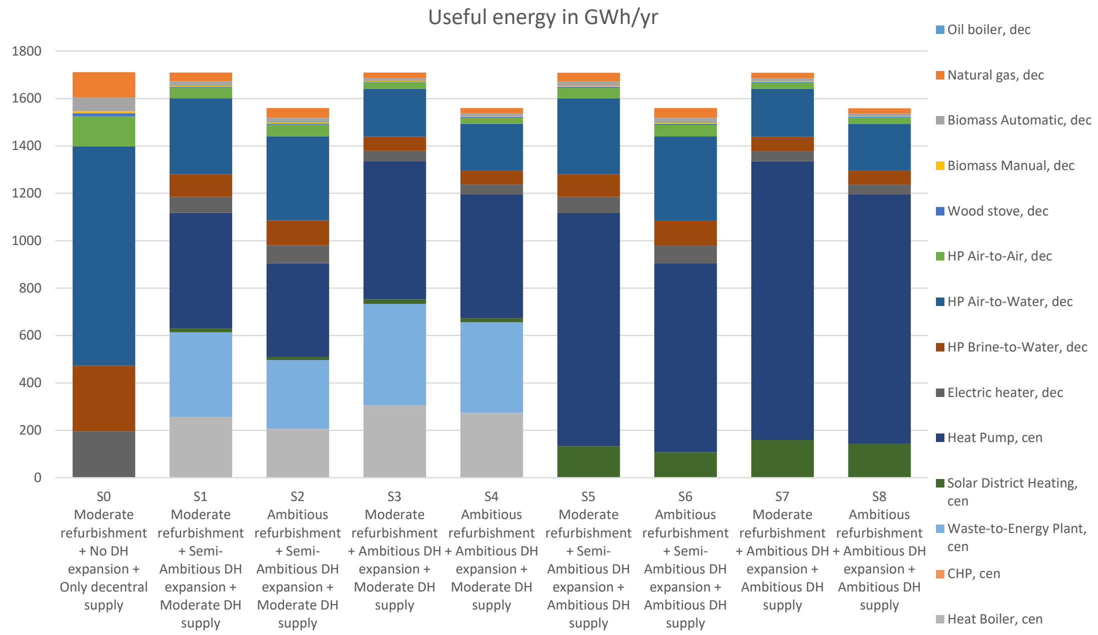


Figure 20: Useful energy consumption of scenarios in Milton Keynes.

As seen in Figure 16, scenarios 1 to 4 with semi-ambitious or ambitious district heating expansions and only moderate district heating supply is more expensive or equal in annual cost compared to the reference scenario 0 with only decentral heating supply. Whereas scenarios 5 to 8 with ambitious district heating supply result in an annual cost that is 27.6 % to 39.1 % lower than the cost of the decentral heating supply. The overall annual cost is lowest in Scenario 8 with ambitious refurbishment, ambitious district heating expansion, and ambitious district heating supply. However, the levelized cost of heating (LCOH) is lower for scenario 7 with only moderate refurbishment – due to the lower heat demand in scenario 8. The small difference between scenario 7 and 8 could indicate that the high costs associated with ambitious refurbishment might not feasibly for the overall system compared to a cheap ambitious district heating supply – but where the optimum lies needs to be analysed in more detail.

The approach with using the *CM – District heating supply dispatch* for calculating district heating supply for 100 % of the heat demand in Milton Keynes and afterwards, in the scenario assessment, use the calculated values but scaled to fit the actual heat demand in the district heating system according to the scenarios calculated with the *CM – District heating Potential – economic assessment* can lead to false conclusions. This may be the case if the heat demand and therefore the peak heat capacity in the district heating system is somewhat lower than the assumed 100 %. In this case the system could settle for the lower cost resources or capacities and not need to use more expensive resources or capacities, which would be needed in course of higher demands. This can lead to reduced LCOH for smaller systems, which is not reflected in the assumed 100 % calculation. Therefore, sensivity calculations are made on the basis of a heat demand of 65 % of the total for Milton Keynes in 2050 instead of 100 %. This is done for the scenarios with ambitious district heating supply (scenario 5 to 8). The details on the sensitivity calculations are shown in 8.6 Appendix A6. Based on sensitivity calculations, it can be seen that the total LCOH (levelized cost of heat supply (EUR/yr)) is between 24 % and 30 % lower than the above for the scenarios 5 to 8 and the LCOH for central (district heating) heat supply (EUR/MWh) is about halved. Wheras the total annual is the same for scenarios 5 to 8 in both cases (100 % and 65 %). This means that scenario 7 and 8 is still the most feasible, but the cost of suppling additional district heating (EUR/MWh) will be lower than the default calculations indicate – but maybe not half.

The annual CO_2-emissions are also lowest in scenario 8 followed by scenario 7, 5, 6 and 0 in the mentioned order as seen in Figure 18. So, without an ambitious district heating supply Milton Keynes will not be able to fulfil its targets and should instead try to minimise the heat demand in buildings with the refurbishment and low carbon heat supplies like heat pumps – even though this solution is shown to be up to 39.1 % more costly and emitting 63.0 % more CO_2.

When comparing the final energy consumption in Figure 19 with the useful energy consumption in Figure 20 the high efficiency of heat pumps (COP) can clearly be seen – especially in Scenario 5, 6, 7, and 8 with high large-scale heat pump capacities but also in the reference scenario 0 with high share of individual (decentral) heat pumps.

The results of the Hotmaps scenarios show that the ambitious district heating expansion in Milton Keynes with up to 78.2 % share in 2050 and ambitious district heating supply with regards to large scale heat pumps utilising low-temperature excess heat and other sources supplemented with solar district heating and backup biomass boilers are both, the most economically and environmentally feasible. This allows for up to 39.1 % cost reduction in comparison with the decentral heating supply, and simultaneously, it helps to achieve the 2050-targets and results in the lowest CO_2-emission from the heating sector as a whole – by the CO_2 abatement up to 63.0 % compared with the decentral heating supply.

6.2 Assessment of stand-alone scenarios

6.2.1 Current heat consumption

The current annual heat and electricity consumption figures are developed on a building level, using annual consumption indicators of different types of buildings and construction periods expressed in kWh per m^2 and the estimated gross floor areas of the buildings. The energy consumption data that was used is based on different sources including the good practice from the energy projects in the UK, energy display certificates or benchmark figures that were published by British public institutions such as CIBSE. A detailed overview of the sources used is given in chapter 8.1 Appendix B1 Energy demand benchmark source. In case of the Central Milton Keynes, the heat and electricity demands were derived using the information from the Summary report dated to 2012 (Centre for Sustainable Energy, 2012) and Milton Keynes Heat Network Project report (Ameresco study, 2017). These are then compared with the consumption estimates extracted from the **Hotmaps** tool.

The variety of the used sources depends on the analysed area which is explained in detail in the following section.

Central Milton Keynes:
Central Milton Keynes is the only area for which the historically measured data for energy consumption was available. This, however, was provided in the form of the annual thermal and

electrical output of the CHP and thermal output of the gas boiler at full load which could only be used to calculate the actual current consumption by reverse calculation. This was achieved by subtracting the spare potential for DH supply which was indicated in the study at full load from the total energy production potential (in 8760 hours per year) calculated based on the CHP's and boiler's efficiencies and installed capacities. Currently, only some buildings in the Central Milton Keynes are connected to the network as indicated in Figure 21. To see the other properties located in the area that are considered for future connection, refer to chapter 6.2.2.

Figure 21 Existing heat network from Thameswey plant to Central Milton Keynes (Source: Ameresco study, 2017).

Old Wolverton:
The heat consumption benchmark for swimming pool was applied to calculate the energy needs of the leisure centre. The Radcliffe school heat demand was estimated using the CIBSE Guide F 2012 benchmark for school and education buildings. A separate site called, Old Wolverton industrial site is to be entirely refurbished so no energy consumption characteristic was developed for the current state (reference case).

Fullers Slade:
The energy demand of the existing households located in the Fullers Slade district has been developed using the current footprint of houses and fossil fuel consumption benchmark CIBSE Guide F for existing residential buildings.

A comparison of the estimated annual heat consumption based on benchmark sources on the one hand and from the **Hotmaps** default data on the other hand is presented in the following graph. While for the Central Milton Keyens region large deviations can be seen, for the other regions the deviations are lower. The reason for this large deviation is supposed to be the high share of office buildings in this area, which is remarkably higher than usual shares of office buildings in central urban areas in the UK. In the leisure centre in the Old Wolverton area the **Hotmaps** database does not show any demand. For the other areas a reasonable match between the bottom-up calculation based on national benchmark data and the top-down **Hotmaps** default data can be seen.

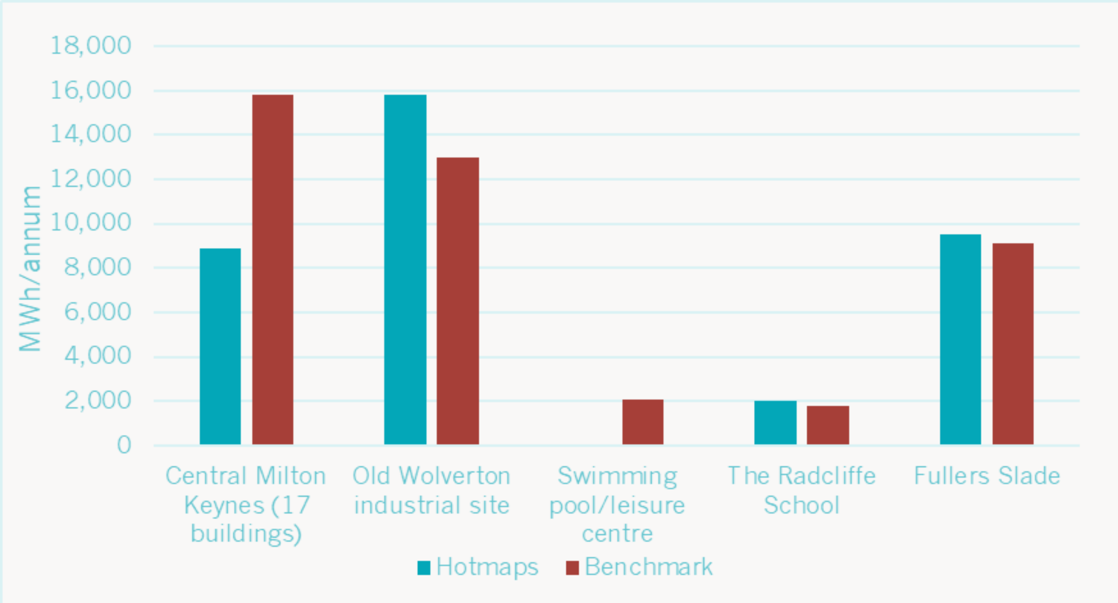
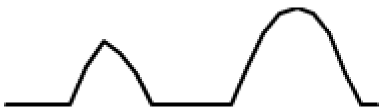


Figure 22 Existing heat consumption based on the Hotmaps and benchmark estimates.

The heating and - in case of the Central Milton Keynes also - the electricity profiles (because they have a private wire and can consume electricity directly from the energy centre, see 6.2.3) were built based on the typical energy demand profile corresponding to the type of the building. A daily typical characteristic for different building typologies have been obtained from the industrial good practice (Table 7) and extrapolated for the whole year using annual consumption of the analysed area. The thermal energy profiles have been also adjusted to the yearly weather fluctuation by applying weather dependence factor.

Table 7 Building type used for creating heating and electricity profile characteristic.

Profile type	Area	Type of building	Reference
Heating profile	Central Milton Keynes	Retail 	ARUP
	Old Wolverton	A mixed profile of General Non-Residential  and Leisure 	ARUP
	Fullers Slade	Residential 	ARUP
Electricity profile	Central Milton Keynes	Office 	ARUP

All developed heating characteristics (and also electric profile in case of Central Milton Keynes) are presented in 8.10 Appendix B4 Energy demand profiles.

6.2.2 Future heat consumption

Central Milton Keynes:
Future expansion of Central Milton Keynes will generate more users that can be connected to the DH network. This includes the commercial and public buildings in the city centre as shown in the following figure. The energy usage estimates are based on gas consumption data collected in the previous Ameresco study for the expanded area and the average 80% efficiency of gas boiler.

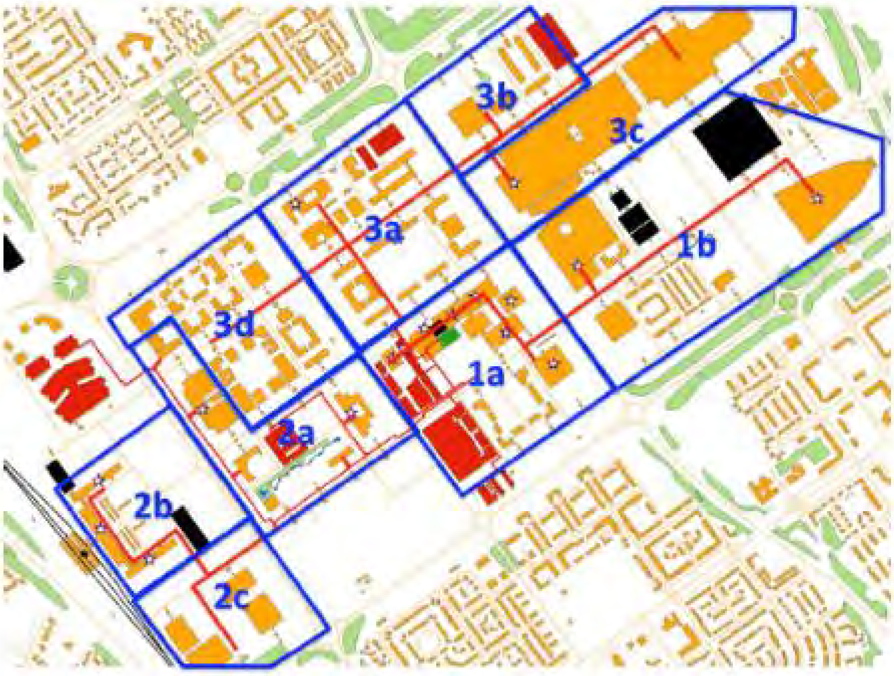


Figure 23 Future expansion area for the DH network in the Central Milton Keynes (Source: Ameresco study, 2017).

The current consumers in Central Milton Keynes that are connected to the Thameswey energy centre are envisaged to remain connected to the DH network and maintain the same energy demand profile. Neither the existing nor the future consumers anticipate implementing energy reduction measures which generate energy savings.

Old Wolverton:
The existing industrial site in Old Wolverton industrial site is expected to transform into a new development area consisting of a mixture of warehouses and commercial buildings. No changes to the heat demand at the leisure centre and Radcliffe School are anticipated.

Fullers Slade:
Four different variants of site redevelopment have been proposed at the residents steering meeting (Approach to the regeneration of Fullers Slade, 2019) which vary by the number of refurbished and newly built houses. Based on the feedback from the Milton Keynes Council, the middle solution (partial refurbishment and partial demolition-Approach 3) was selected as the most likely scenario for Fullers Slade, and this is used in this analysis.

Figure 24 Partial redevelopment scenario for the Fullers Slade (Approach to the regeneration of Fullers Slade, 2019).

Area Comparison Table

Existing House	Sq. ft	Sq. m	Proposed House	Sq. ft	Sq. m
Dining Room & Living Room	258.3	24	Dining Room	100.1	9.3
			Living Room	170.1	15.8
Kitchen	67.8	6.3	Kitchen	116.3	10.8
Store 1	10.8	1	Store 1	16.1	1.5
Store 2	9.7	0.9	Store 2	9.7	0.9
Bedroom 1	129.2	12	Bedroom 1	129.2	12
Bedroom 2	129.2	12	Bedroom 2	151.8	14.1
Bedroom 3	64.6	6	Bedroom 3	75.3	7
Hall & Stairs (1+2+3)	325.1	30.2	Hall & Stair	169	15.7
Bathroom 1	12.9	1.2	Bathroom 1	26.9	2.5
Bathroom 1	35.5	3.3	Bathroom 1	42	3.9
Rear Garden (Maximum)	558.6	51.9	Rear Garden	597.4	55.5
Rear Garden (Minimum)	328.3	30.5			
Front Garden & Parking Area	399.3	37.1	Front Garden & Parking Area	406.9	37.8
First, Second and Third Floor Gross Internal Area	**1031.2**	**95.8**	**First and Second Floor Gross Internal Area**	**1061.3**	**98.6**
Plot Area (Maximum)	**1444.5**	**134.2**	**Plot Area**	**1621**	**150.6**
Plot Area (Minimum)	**1215.2**	**112.9**			

Figure 25 Building Gross Internal Area (GIA) of the existing and new house in the Fullers Slade (Approach to the regeneration of Fullers Slade, 2019).

The energy demand estimates have been derived using the benchmark consumption and anticipated footprint for the combination of the new and existing houses. The unit heat demand data is sourced from the good practice of engineers in the UK for residential domestic customers covering both, domestic hot water and central heating.

The summary of anticipated energy needs for future customers is presented in the next figure.

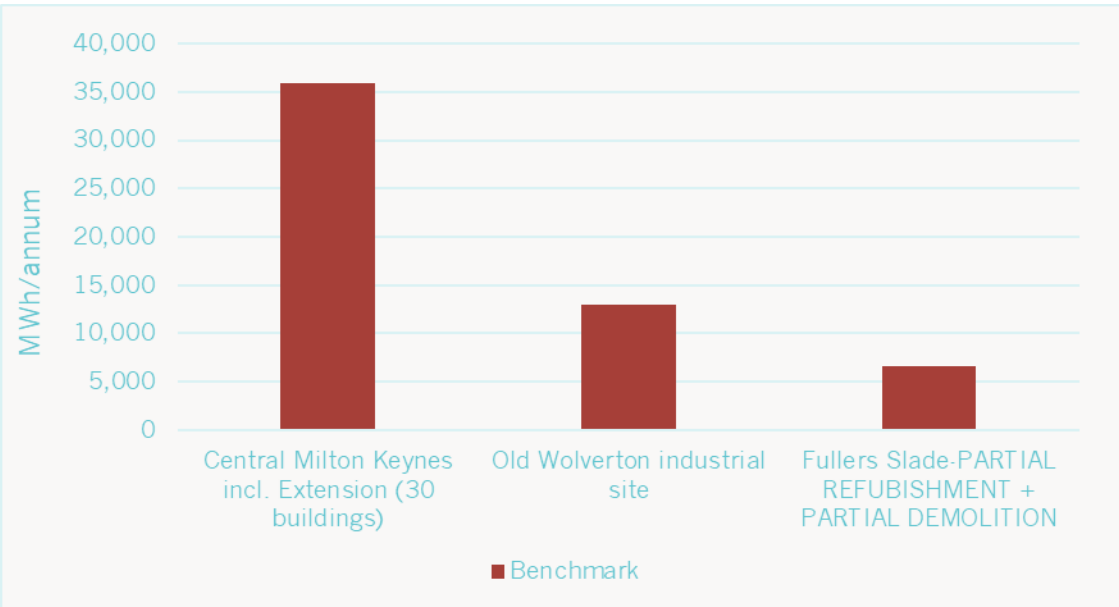


Figure 26 Future (new or replaced) heat consumption based on the benchmark estimates.

Overall, the projection of future energy consumption in Milton Keynes is demonstrated in the next chart. This is calculated as the sum of the existing demand that is aimed to remain in the future DH system ('Remained existing') and the energy needs of the future consumers ('Future (re)development'). This includes the expanded DHN in the Central Milton Keynes, school and leisure centre in the Wolverton suburb and fully redeveloped areas in Old Wolverton and Fullers Slade.

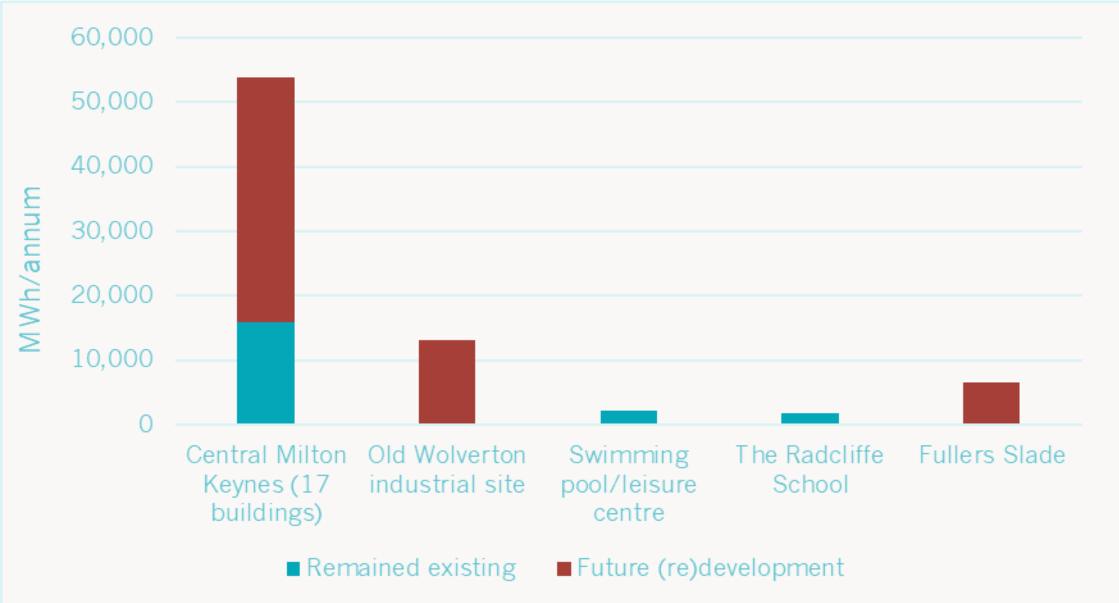


Figure 27 Total future heat (existing and future expansion) consumption in Milton Keynes areas.

6.2.3 Private wire

The DH customers in the Central Milton Keynes are also connected with the energy plant electrically. The future buildings planned for connection to the DH was assumed to also have extended private wire (PW). This local electricity demand was estimated and included in the later simulations.

Both, the existing and future annual consumption data are based on data collected in the previous Ameresco study. The existing consumption was approximated using the information on spare electricity potential of the CHP plant and the known capacity of the generator. The future electricity needs were directly sourced from the study.

Due to the fact that mainly office buildings are located in the Central Milton Keynes area, the electricity profile for office buildings was used to model the demand characteristic.

6.2.4 Heat sources

Some heat sources (Figure 28) were identified in the central part of Milton Keynes that could potentially supply the current and future heat demand in Central Milton Keynes. This includes the heat recovery from the wastewater treatment plant (Cottnvalley Alpheus Environmental) or from the oily wastes separated and stored onsite (Cottonvalley Waste Treatment Centre

Permit, 2007). The wastewater treatment plant has already been assessed as an insufficient heat source in the previous study (CSE study, 2012), which verified that most of the excess heat is already being utilised inside the anaerobic digestion (AD) plant. Therefore, within this strategy calculations were done on calculating the potential of combusting a biofuel from the oily waste was examined. The biofuel cost was estimated based on the storage capacity information and the physical properties of the assumed oily waste sources (sewage sludge @75%, animal manure @20% and tall oil pitch @ 5%).

The Willen Lake or/and undeveloped green plots in the proximity of the city centre could be used as a ground or/and water source for the heat pump installation. The lake was excluded from the scenario analysis due to lack of information about its temperature level and volume which would allow to estimate its potential as a heat source for the heat pump. Based on the rule of thumb, the lake size appears to be insufficient to handle the range of HP capacities investigated in the analysis. The environmental restrictions prohibiting from the use of the lake for energy processes are also likely to be in place. This, however, may be reconsidered at the future development of the district heating infrastructure in the city, and the potential of the lake to be the thermal reservoir for a heat pump.

The ground source and air source were assumed to be sufficient to produce up to 95% of the annual heat consumption via high-temperature heat pumps. Hourly temperatures of the ambient air were retrieved from the nearest weather station, ground supply/return temperatures have been estimated using experience from other projects.

Another potential excess heat source is the Pulsant Data Centre (Linford Wood). However, no detailed characteristic was available for this study.

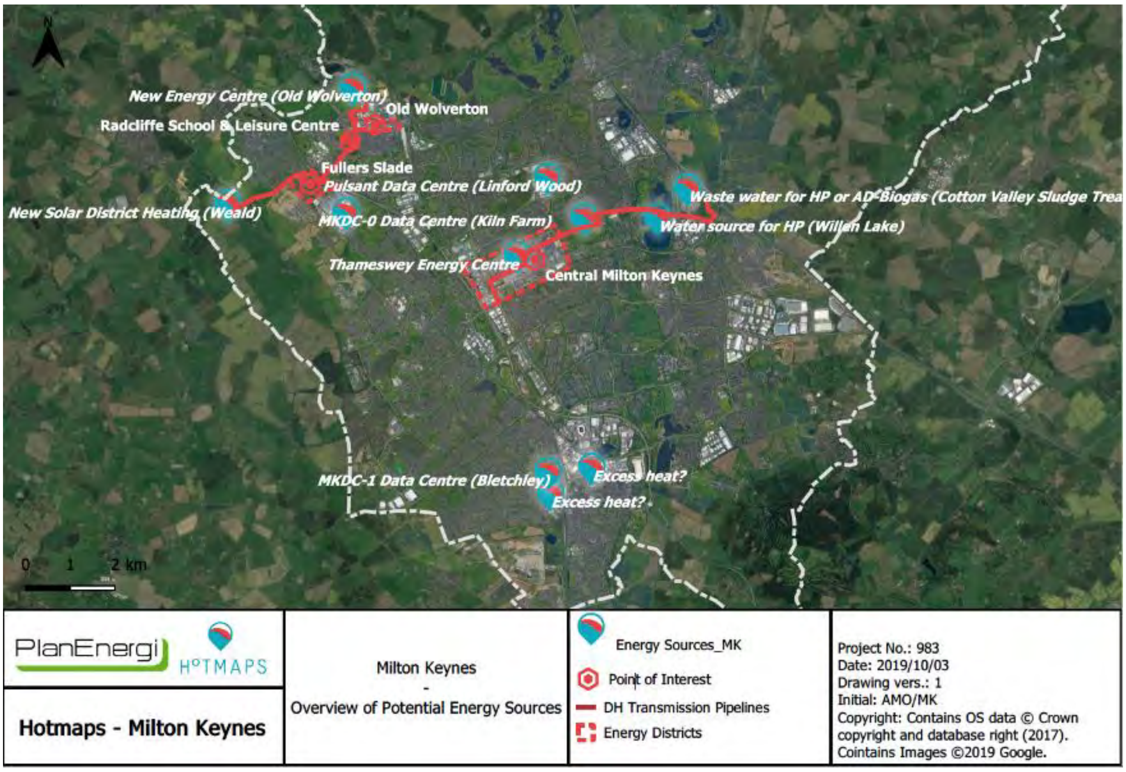


Figure 28 Overview map of the potential heat sources in the Milton Keynes area.

The Old Wolverton site has a neighbouring waste-to-energy CHP plant which treats any waste remaining which is not recyclable or compostable in an advanced thermal treatment (ATT) plant. The ATT process does not combust the residual waste but instead transforms it into a gas (synthesis gas or syngas), which in turn is combusted to generate high-temperature steam which creates renewable electricity in a turbine.. The heat produced as a by-product is partly used for the ATT plant and partly rejected to the environment. This excess heat could be utilised to feed a DH system (Amey, Milton Keynes, Advanced Thermal treatment).

Another potential excess heat source is the MKDC-0 Data Centre (Kiln Farm),. However, no detailed characteristic of the data centre was available for this analysis.

The land plots located in the south-west direction from the Fullers Slade provide an opportunity for a solar thermal installation.

6.2.5 District Heating network & Energy centre location

Central Milton Keynes:

The potential district heating network in central Milton Keynes will lead from the assumed energy centre situated in the wastewater treatment plant (Cottnvalley Alpheus Environmental) and follow the side roads and green plots up to the existing energy centre. The energy centre location was selected not only due to the potential heat source from the wastewater treatment plant, but also due to space limitations in the city centre.

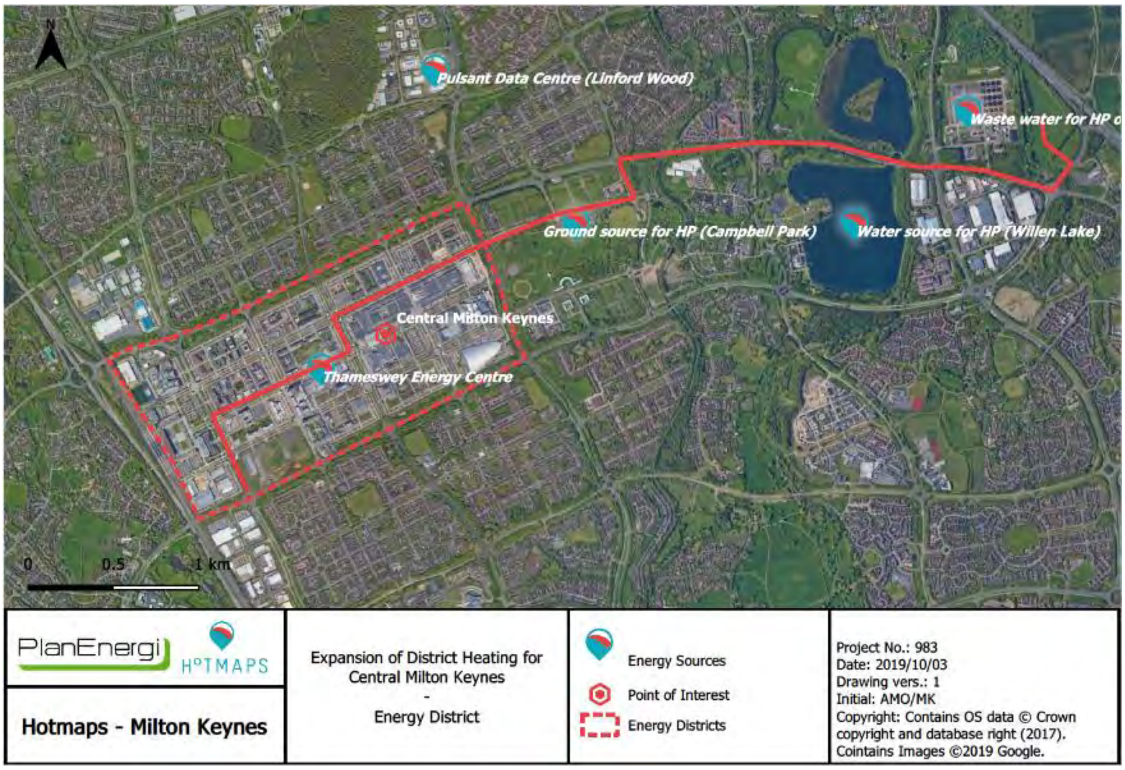


Figure 29 Potential district heating network path to supply buildings in Central Milton Keynes (GIS overview).

The pipe sizing for the central DH as well as detailed network route design was performed using the programme Termis[31] . The result is shown in Figure 30. The connected customers are represented by eight nodes of which four represent the existing users (buildings connected via current DH system) and future clusters (1a, 2a, 3a and 3b). Refer to Figure 23 for clusters division.

The detailed breakdown of length, diameter and cost for the corresponding pipe sections between the red nodes in Central Milton Keynes is collated in 8.13 Appendix B7 Pipe sizes and total cost.

Figure 30 Potential district heating network path to supply buildings in Central Milton Keynes (DH design in Termis).

Old Wolverton & Fullers Slade:
The DH network in the suburbs of Milton Keynes was modelled as the common line between the Old Wolverton and the Fullers Slade. The pipework leads to the current location of the waste-to-energy CHP plant where the new energy centre could potentially be located. An alternative solution (Scenario 5 in the later economic analysis) considers extending the system to the potential solar thermal plant in the south-west part of Milton Keynes.

[31] http://7t.dk/products/termis/Product-Information/termis-simulation-modes.aspx

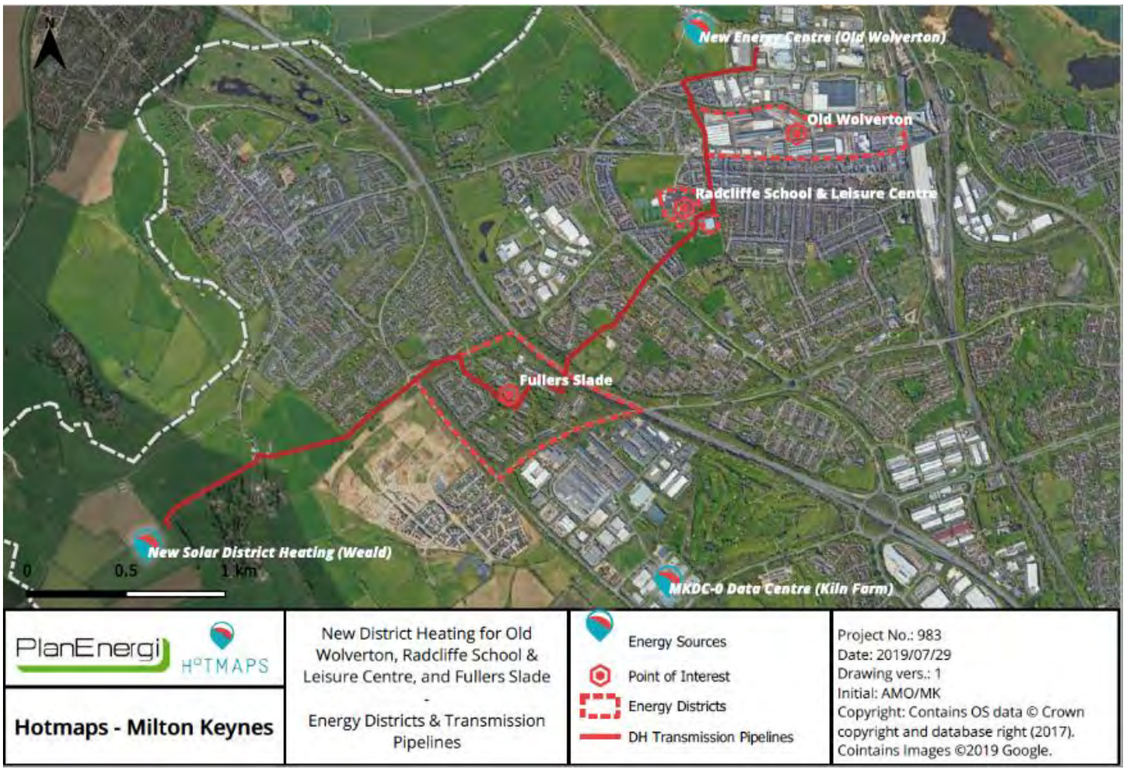


Figure 31 Potential district heating network path to supply buildings in Fullers Slade and Old Wolverton (GIS overview).

The next figure shows the DH design conducted in Termis. The customers in the industrial area have been geographically allocated based on the current buildings plan. However, the heat demand estimates are performed using a future mix of the commercial buildings, offices and warehouses (refer to section 6.2.2 for further explanations).

The DH distribution network in the Fullers Slade development was modelled according to Approach 3 of the refurbishment plan (partial refurbishment and partial demolition) and main buildings (new and existing) were indicated on the next drawing. Refer to section 6.2.2 for the Milton Keynes redevelopment plan details.

The detailed breakdown of length, diameter and cost for the corresponding pipe sections between the red nodes in Old Wolverton and Fullers Slade is collated in 8.13 Appendix B7 Pipe sizes and total cost.

Figure 32 Potential district heating network path to supply buildings in Fullers Slade and Old Wolverton (DH design in Termis).

The DH cost was estimated using pipework and installation cost for UK Series 2 and civil costs for the ground with Soft Dig. Please refer to 8.12 Appendix B6 Pipework dimension and price catalogue for District Heating system for the cost details of the indicated pipe type per pipe diameter.

Additionally, the cost of connecting the individual buildings was assumed. This incudes the work associated with entering the premises with the distribution pipework and connecting to the local heating system. The summary of the connection number in each area with the connection cost is shown in 8.13 Appendix B7 Pipe sizes and total cost, Table 16.

The DH system was designed for the assumed 85°C and 65°C flow and return water temperature, respectively.

6.2.6 Energy development scenarios

The energy transition scenarios for the investigated areas have been determined based on the available energy sources in the proximity of the consumers and the suitability of low carbon and renewable technologies. The cost savings for the modelled scenarios are compared with the business-as-usual case where the existing demand is supplied by the current heating system and new customers utilise individual gas-fired boilers.

Table 8 summarised the proposed energy transition scenarios for the Central Milton Keynes area.

Table 8 Energy transition scenarios for Central Milton Keynes (Thameswey).

	Existing heat demand	New future heat demand	Comments
Reference case	Existing DH, gas CHP & gas boiler	Individual gas boilers	N/A
Scenario 1*	CHP Biofuel combustion from the oil treatment plant Remaining and peak heat demand covered by biomass boiler		Thermal output capacity of the CHP based on the oily waste **daily** storage capacity (higher contribution from the biomass boiler)
Scenario 2*	CHP Biofuel combustion from the oil treatment plant (Higher Waste throughput and hence increased thermal production) Remaining and peak heat demand covered by biomass boiler		Thermal output capacity of the CHP based on the oily waste **weekly** storage capacity (lower contribution from the biomass boiler)
Scenario 3a*	(High Temperature) Air Source Heat Pump (ASHP) Remaining and peak heat demand covered by biomass boiler		ASHP sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)
Scenario 3b*	(High Temperature) Ground Source Heat Pump (GSHP) Remaining and peak heat demand covered by biomass boiler		GSHP sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)
Scenario 4*	Biomass CHP-plant (Analysis performed, however, unlikely in the city centre location; maybe in the area of the waste-water treatment plant and DH connection form there to Thameswey plant in Central Milton Keynes) Remaining and peak heat demand covered by Air Source Heat Pump		Biomass CHP plant sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)

* Scenarios 1-4: PW to the existing and future customers from the AD waste-water/oil treatment plant

Table 9 summarised the proposed energy transition scenarios for the areas of Old Wolverton and Fullers Slade.

Table 9 Energy transition scenarios for the Old Wolverton and Fullers Slade district.

	Existing heat demand	New future heat demand	Comments
Reference case	Central gas boiler + wood pellet boiler	Individual gas boilers	It is assumed that gas boiler and wood pellet boiler share their contribution to the heat supply for the existing consumers (school and leisure centre) in proportion 50%/50%.
Scenario 1	Excess heat from waste-to-energy CHP plant (Higher Heat Efficiency due to heat recovery unit installed in AD) Remaining and peak heat demand covered by extra biomass boiler		Thermal output capacity of the CHP based on information provided by the plant operator (Amey, Milton Keynes, Advanced Thermal treatment)
Scenario 2	Excess heat from waste-to-energy CHP plant Remaining and peak heat demand covered by extra biomass boiler		As above; The heat recovery unit was assumed to reduce the parasitic heat consumption in the AD process
Scenario 3a	(High Temperature) Air Source Heat Pump (ASHP) Remaining and peak heat demand covered by extra biomass boiler		ASHP sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)
Scenario 3b	(High Temperature) Ground Source Heat Pump (GSHP) Remaining and peak heat demand covered by extra biomass boiler		GSHP sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)
Scenario 4	Biomass CHP-plant Remaining and peak heat demand covered by Air Source Heat Pump		Biomass CHP plant sized to supply the base heat demand and major winter demand (appr. 90%-95% of annual heat consumption)
Scenario 5	Solar thermal installation in the allocated land and daily thermal storage tank		Capacity of the plant based on the available space for collectors.

6.2.7 Techno-economic assessment and results

The energy strategy scenarios have been modelled and simulated using software energyPRO[32].

The overview of the model set-up for Central Milton Keynes is presented in the next figure. This includes all key technology units, which were used independently, depending on the scenario as well as the current and the future heat demand. The direct supply of electricity via PW requires modelling of the electricity demand in the programme, which is indicated by green boxes 'Thameswey E' and 'Thameswey E_Ex'.

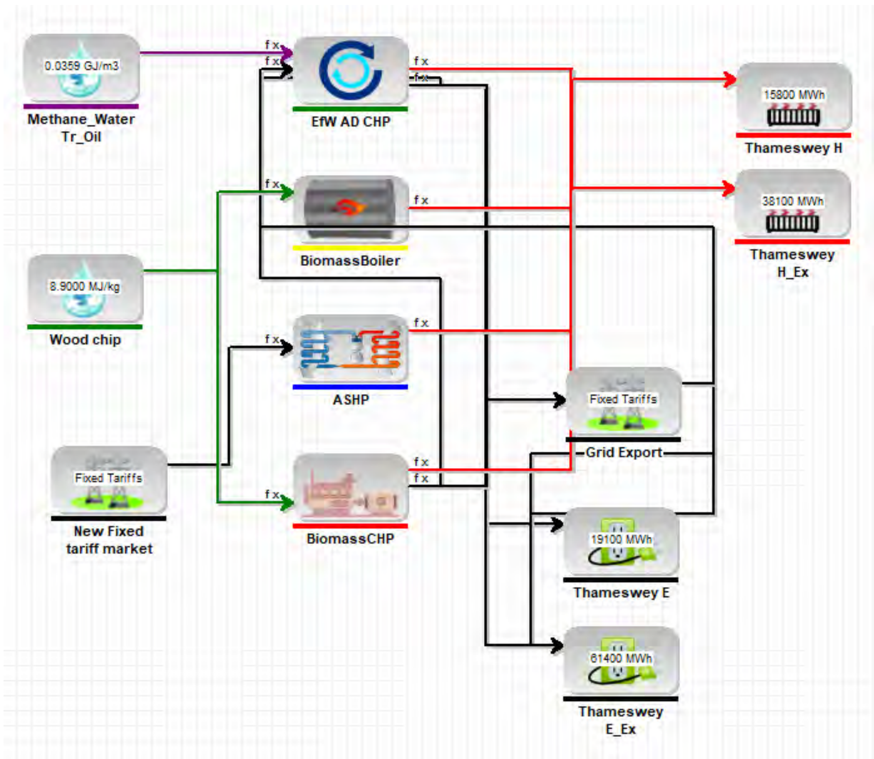


Figure 33 EnergyPRO layout for the model of Central Milton Keynes.

The other locations in the western part of the city have been modelled in the connected system with the common supply from the new energy centre, which was assumed to be situated in Old Wolverton (next to the waste-to-energy CHP plant). In the scenario with a solar thermal plant in the outskirts of Milton Keynes, the heat output is distributed via a heat network to the same sites.

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[32] https://www.emd.dk/energypro/

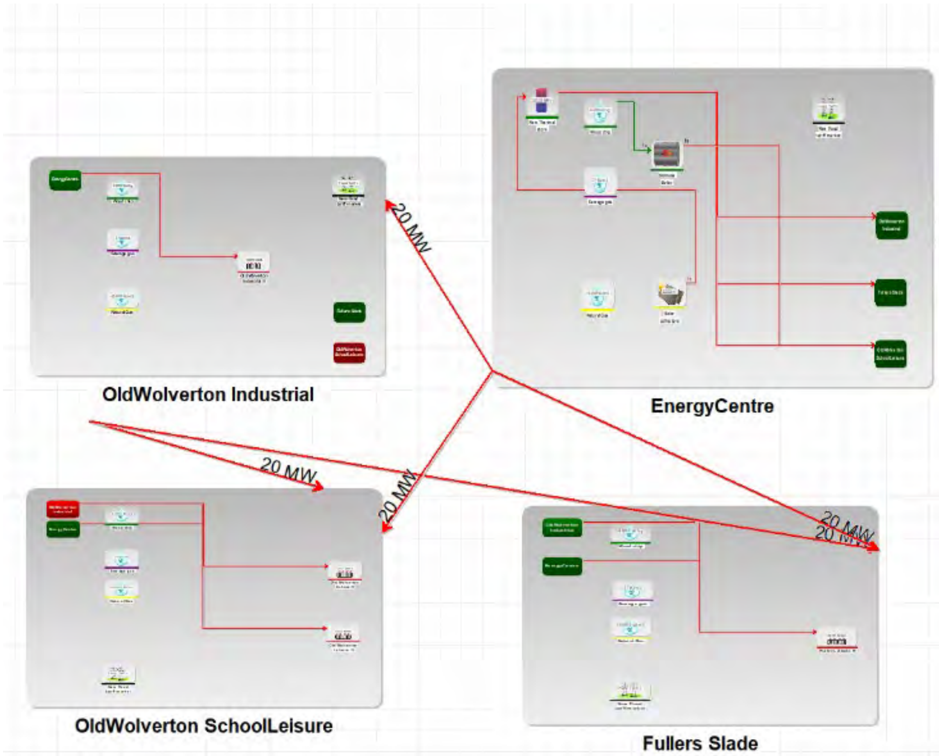

Figure 34 EnergyPRO layout for the model of the Old Wolverton and Fullers Slade.

The reference scenario is modelled according to the existing situation, which includes heating units that are currently in operation (the CHP and gas boiler in Central Milton Keynes, the biomass boiler in the Radcliffe School and the gas boiler in the leisure centre). All future or new customers in the reference scenario use individual gas boilers. The alternative scenarios are simulated as new energy generation solutions entirely replacing existing heating plants (or maintain the low-carbon units as the biomass boiler in the leisure centre) and delivering heat through a new DH connection.

The annual performance of each system and the corresponding investment and operation costs are compared against the reference case. This is shown in the following graphs. The economic indicators used for comparison of the different scenarios are a) the net cost savings and b) the anticipated heat prices. These are calculated according to the following formulae:

$$Net\ cost\ savings = (Additional\ annual\ revenues + Reduced\ annual\ O\&M\ costs) - Additional\ annualised\ investment\ cost; £/year$$

$$Price\ of\ heat\ delivered\ to\ customer = \frac{Total\ annualised\ investment\ costs + Total\ annual\ O\&M\ costs}{Annual\ heat\ consumption}; £/MWh$$

$$CO2\ emisssions = \text{Fuel or electricity consumption} \cdot CO_2 \text{ factor; tonnesCO2}/year$$

The most attractive energy strategy scenario for Central Milton Keynes is the biofuel combustion from the oily waste treated in the Cottonvalley Waste Treatment Centre topped up with biomass boiler (scenario 2). A large discrepancy between results for option 1 and 2 that vary only by the biofuel throughput (daily and weekly oil storage capacity) indicates a high sensitivity of this business case on the used assumptions, which were made due to unknown details of the biofuel production potential. In scenario 2 most of the heat demand is supplied from the biofuel CHP, which also offsets a great proportion of imported electricity via electricity generated in the CHP.

The second most financially viable solution was demonstrated in scenario 3a with base heat demand supplied from ASHP and biomass CHP plant delivering remaining heat needs and off-setting grid electricity.

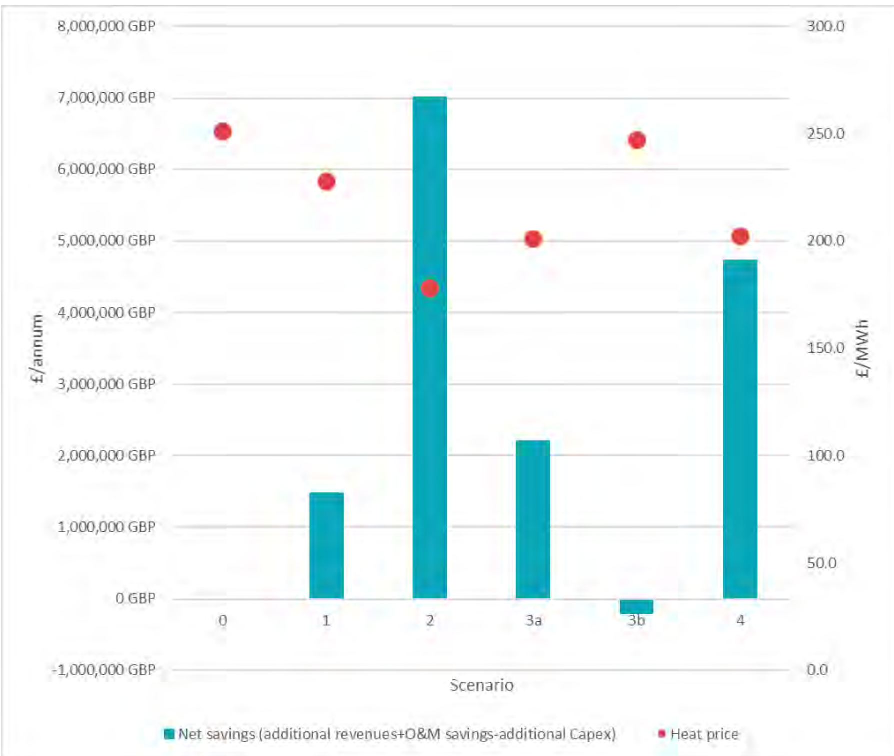

Figure 35 Net savings and heat price results for energy scenarios modelled for Central Milton Keynes.

The most profitable energy scenario for the Old Wolverton and Fullers Slade area is the ASHP supplemented with the biomass boiler (scenario 3a). This is followed by scenario 5, the solar thermal energy and scenario 2 Excess heat from waste-to-energy CHP plant, retained biomass boiler and peak ASHP. While heat pump solutions bring significant revenues due to the RHI (Renewable Heat Incentive) subsidy, the biomass CHP provides additional income from electricity export.

Please refer to 8.9 Appendix B3 Incentives and Tariffs.**Fejl! Henvisningskilde ikke fundet.** for the details regarding fuel price, electricity tariffs, taxes carbon emission factors and energy subsidies.

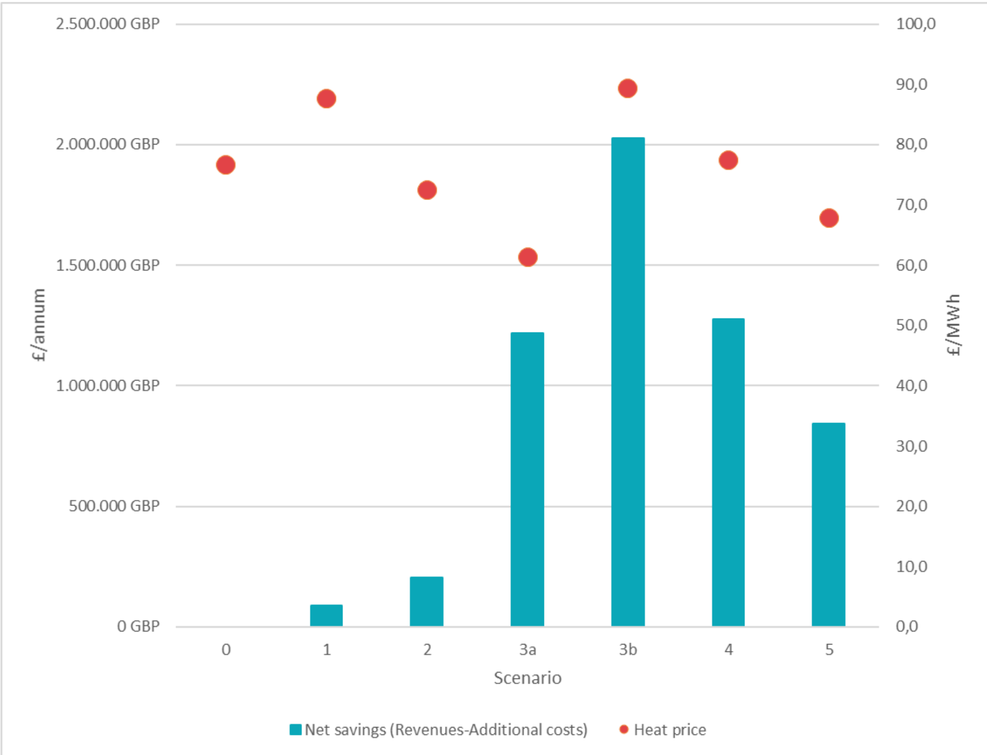

Figure 36 Net savings and heat price results for energy scenarios modelled for Old Wolverton and Fullers Slade.

The overview of the calculations behind the net savings and heat prices for the scenarios can be found in the background information in Appendix B2.

Assessment of the CO_2 emissions for the scenarios is presented in Figure 37 and Figure 38. These have been assessed based on the annual fuel and electricity consumption and the carbon emission factors (see tables 8.11 Appendix B5 Carbon emission factors) that are based on the British figures (CO2 factors, 2019).

The lest carbon-intensive is scenario 1 with the smaller biofuel combustion unit run on the oily waste treated in the Cottonvalley Waste Treatment Centre topped up with biomass boiler. This is due to a relatively low carbon emission factor for the oily waste source which is calculated based on the mixed composition of sewage sludge, animal manure, tail oily pitch. Almost exact carbon production can be expected in case of the leading biomass CHP system supplemented wit the ASHP (scenario 4).

Given electricity still the highest carbon-intense source of energy, the heat pumps are the most polluting technology among the investigated scenarios in Central Milton Keynes.

In Old Wolverton and Fullers Slade, the most environmentally friendly are solar thermal system (scenario 5) and smaller ASHP operated along with the biomass boiler (scenario 3a). Scenarios with the energy-from-waste CHP system are even more carbon-intense than in Central Milton Keynes case where these consume waste energy as a priority which is sourced from the municipal solid waste (higher carbon emission factor). Moreover, the process consumes also electricity to the advanced thermal treatment (ATT), and biomass for the peak heat production which results in the overall high carbon content.

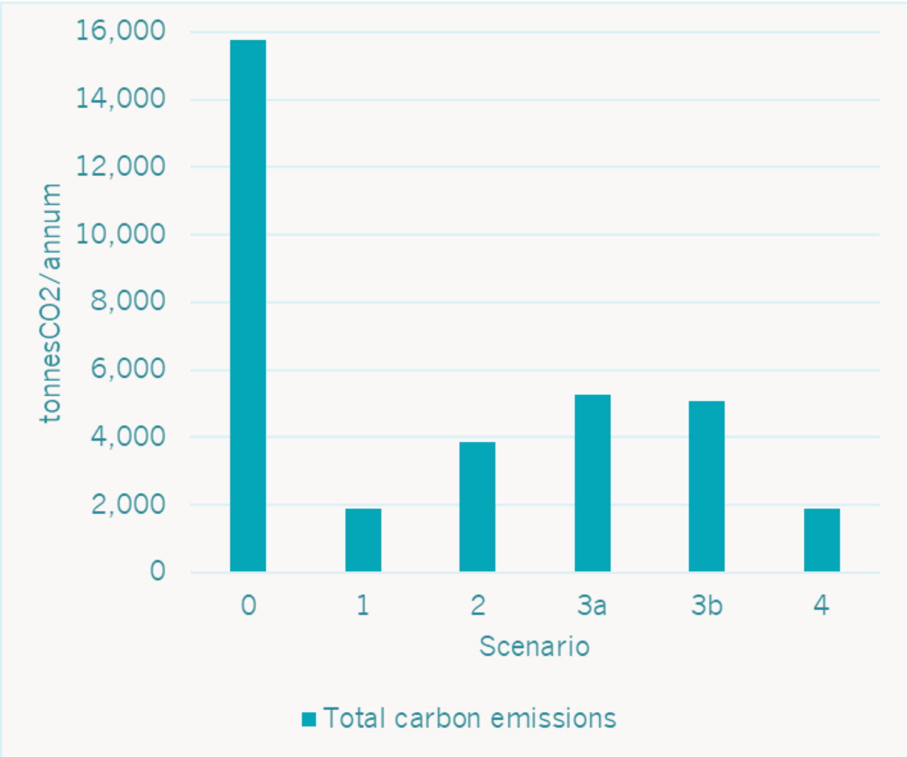

Figure 37 Carbon emission level for energy scenarios modelled for Central Milton Keynes.

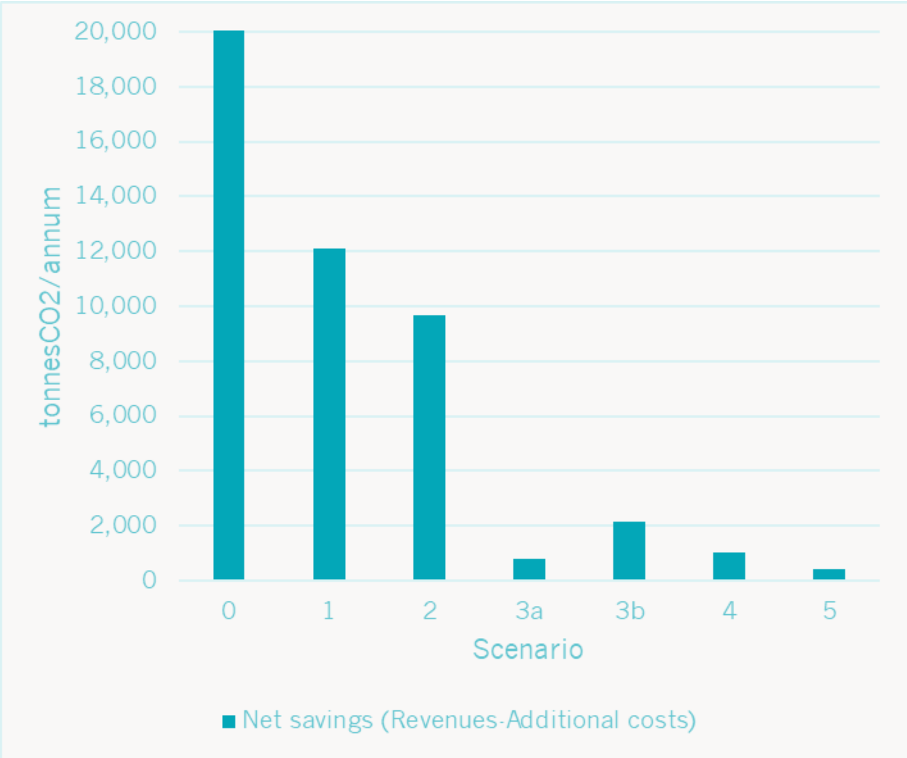

Figure 38 Carbon emission level for energy scenarios modelled for Old Wolverton and Fullers Slade.

6.3 Heating strategy roadmap

The recommendation from the overall heating strategy for Milton Keynes from the **Hotmaps** scenarios is to continue the process with expanding the district heating. The results of the Hotmaps scenarios shows that in order to achieve the 2050-targets, an ambitious district heating expansion in Milton Keynes with up to 78.2 % share in 2050 needs to take place. This also entails an ambitious district heating supply with regards to large scale heat pumps utilising low-temperature excess heat and other sources supplemented with solar district heating and backup biomass boilers. Such an approach proved to be both, the most economically feasible – with up to 39.1 % lower annual cost than decentral heating supply - and most environmentally friendly by generating up to 63.0 % less CO_2 emissions from the heating sector as a whole than decentral heating supply. In other words, the results show that without an ambitious district heating supply, Milton Keynes will not be able to fulfil its targets and should instead try to minimise the heat demand in buildings with the refurbishment and low carbon heat supplies like heat pumps – even though this solution is shown to be up to 39.1 % more costly and emitting 63.0 % more CO_2.

The standalone energy analysis finds also the high both, economic and environmental potential in the biofuel combustion from the oily waste treated in the Cottonvalley Waste Treatment Centre topped up with biomass boiler. This plant is not present in the Hotmpas database for the excess the sources, however, its potential for the district heating supply to the Central Milton Keynes area was individually assessed with the Milton Keynes stakeholders. The carbon emission from the plant performance is also lower than could be calculated using Hotmaps toolbox, due to a relatively low carbon emission factor for the oily waste source.

One of the recommendations for the Central Milton Keynes area is to reconsider implementing energy reduction measures which would reduce the energy demand of the existing and potential future DH consumers. This applies in particular to the current users connected to the Thameswey energy centre that envisage to the same energy demand profile. Neither the existing nor the future DH consumers in the Central Milton Keynes anticipate generating energy savings. The same situation is common for the Radcliffe school and the leisure centre in Old Wolverton area, which are likely to remain the existing energy demand

The next steps in the roadmap are the continuation of the work with the existing district heating area in Central Milton Keynes and the potential district heating areas of Old Wolverton, Radcliffe school, and possible Fullers Slade. In addition, the MK University has recently shown great interest in district heating and this should shortly be investigated. This is just the first step in the Milton Keynes journey to become the CO_2-neutral in 2030 and the carbon negative in 2050. To fulfil the targets, the results from the **Hotmaps** scenarios should be verified by Milton Keynes Council Civic Office or by South East Energy Hub at the next stakeholder meeting and hopefully implemented into a district heating action plan.

6.4 Stakeholder meetings

The first meeting with internal stakeholders was held at the Civic Offices on 7th October 2019. The meeting was attended by the Milton Keynes Council Housing Regeneration team and the Sustainability Team. On the agenda was the mapping of heat demand, resource potentials and existing plans for Milton Keynes. The Hotmaps database, toolbox, data sources and scenario calculation potential was introduced to the regeneration team.

The second stakeholder meeting took place on the 27th January 2020 at the Council Civic Offices. The meeting was held with members of the MK University Development team, the Milton Keynes Council planning team and the sustainability team. The discussion revolved around assessments and recommendations of the MK University proposal.

A third meeting is planned with planners to discuss a response to a call for projects supported by the South East Energy Hub[33]. At this meeting the Hotmaps results and purposed strategy roadmap will also be discussed.

[33] https://www.energyhub.org.uk/

7 References

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8 Annexes

8.1 Appendix A1 Hotmaps Demand projections

CM | 1.1 Demand projection

INPUT DATA

	Parameter	Unit	Default data	Run 1.1 A MK 2050	Run 1.1 B MK 2050	Run 1.1 C MK 2050
INPUTS	Select scenario		hotmaps_renovation_rate_0.5percnone	reference	reference	reference
	Select target year	-	2020	2050	2050	2050
	Reduction of floor area compared to reference scenario: Constr. period before 1977	%	100	150	200	200
	Reduction of floor area compared to reference scenario: Constr. period 1977-1990	%	100	125	150	200
	Reduction of floor area compared to reference scenario: Constr. period after 1990	%	100	100	100	150
	Reduction of specific energy needs compared to reference scenario: Constr. period before 1977	%	100	75	100	200
	Reduction of specific energy needs compared to reference scenario: Constr. period 1977-1990	%	100	75	100	175
	Reduction of specific energy needs compared to reference scenario: Constr. period after 1990	%	100	100	125	150
	Additional annual population growth compared to reference scenario	%	0	0	0	0
	Method to add newly constructed buildings to map		No new buildings	No new buildings	No new buildings	No new buildings
INPUT TYPE SELECTION	Type: country_id_number		country_id_number	country_id_number	country_id_number	country_id_number
	Type: nuts_id_number		nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number
	Type: lau2_id_number		lau2_id_number	lau2_id_number	lau2_id_number	lau2_id_number
	gfa_res_curr_density		gfa_res_curr_density	gfa_res_curr_density	gfa_res_curr_density	gfa_res_curr_density
	gfa_nonres_curr_density		gfa_nonres_curr_density	gfa_nonres_curr_density	gfa_nonres_curr_density	gfa_nonres_curr_density
	heat_res_curr_density		heat_res_curr_density	heat_res_curr_density	heat_res_curr_density	heat_res_curr_density
	heat_nonres_curr_density		heat_nonres_curr_density	heat_nonres_curr_density	heat_nonres_curr_density	heat_nonres_curr_density
	ghs_built_1975_100_share		ghs_built_1975_100_share	ghs_built_1975_100_share	ghs_built_1975_100_share	ghs_built_1975_100_share
	ghs_built_1990_100_share		ghs_built_1990_100_share	ghs_built_1990_100_share	ghs_built_1990_100_share	ghs_built_1990_100_share
	ghs_built_2000_100_share		ghs_built_2000_100_share	ghs_built_2000_100_share	ghs_built_2000_100_share	ghs_built_2000_100_share
	ghs_built_2014_100_share		ghs_built_2014_100_share	ghs_built_2014_100_share	ghs_built_2014_100_share	ghs_built_2014_100_share
	RESULTS_BUILDING_FOOTPRINT		RESULTS_BUILDING_FOOTPRINT	RESULTS_BUILDING_FOOTPRINT	RESULTS_BUILDING_FOOTPRINT	RESULTS_BUILDING_FOOTPRINT

OUTPUT DATA

CM - Demand projection				Layer name	Layer name	Layer name
	Heat density total	GWh/yr		**1_1A_MK2050_hdm.tif**	**1_1B_MK2050_hdm.tif**	**1_1C_MK2050_hdm.tif**
	Gross floor area total	m2		**1_1A_MK2050_gfa.tif**	**1_1B_MK2050_gfa.tif**	**1_1C_MK2050_gfa.tif**

CM - Demand projection			in 2020	in 2050	in 2050	in 2050
	Energy consumption	GWh/yr	2437.95	2657.66	2581.44	2571.33
	Heated area	Mio. m2	21.71	27.66	27.66	27.66

8.2 Appendix A2 Hotmaps Decentral heating supply

CM | 1.3.a Decentral heating supply

INPUT DATA

	Parameter	Subparameter	Unit	Default data	Run 1.3 A MK2050	Run 1.3 B MK2050	Run 1.3 C MK2050	Run 1.3 D MK2050
INPUTS	Buidling age			Before 1945	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010
	interest rate		1	0.03	0.03	0.03	0.03	0.03
	Gross Floor Area		m²	1000	123	149	85	98
	Building category			Multifamily houses	Single family- Terraced houses	Single family- Terraced houses	Single family- Terraced houses	Single family- Terraced houses
	year			2015	2050	2050	2050	2050
	savings for space heating			0	40	10	40	10
BASIC INPUTS	emission factor - Electricity			0.270224	0.041	0.041	0.041	0.041
	emission factor - Light fuel oil			0.2664	0.266	0.266	0.266	0.266
	emission factor - Biomass solid			0.312	0.312	0.312	0.312	0.312
	emission factor - Natural gas			0.20124	0.201	0.201	0.201	0.201
YPE SELECTION	Type: nuts_id_number			nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number

OUTPUT DATA

CM - Decentral heating supply			Run 1.3 A MK2050	Run 1.3 B MK2050	Run 1.3 C MK2050	Run 1.3 D MK2050
Useful energy demand		MWh/year	11.07	14.97	7.65	9.84
Useful enegy demand per sqm		kWh/m².year	90.0	100.4	90.0	100.4
Peak heat load (Q max)		kW	5	7	3	4

CM - Decentral heating supply		Run 1.3 A MK2050	Run 1.3 B MK2050	Run 1.3 C MK2050	Run 1.3 D MK2050
Levelized cost of heat (EUR/MWh)	Oil boiler	132.57	116.37	160.35	140.28
Levelized cost of heat (EUR/MWh)	Natural gas	97.09	89	110.96	100.94
Levelized cost of heat (EUR/MWh)	Biomass_Automatic	114.62	95.4	147.59	123.77
Levelized cost of heat (EUR/MWh)	Biomass_Manual	73.27	64.82	87.75	77.28
Levelized cost of heat (EUR/MWh)	Wood stove	80.19	71.79	94.6	84.19
Levelized cost of heat (EUR/MWh)	HP Air-to-Air	122.1	104.3	152.64	130.58
Levelized cost of heat (EUR/MWh)	HP Air-to-Water	131.43	111.19	166.13	141.06
Levelized cost of heat (EUR/MWh)	HP Brine-to-Water	143.81	118.79	186.72	155.72
Levelized cost of heat (EUR/MWh)	Electric heater	220.43	219.07	222.76	221.08
CM - Decentral heating supply					
Energy price (EUR/MWh)	Oil boiler	61.98	61.98	61.98	61.98
Energy price (EUR/MWh)	Natural gas	62.76	62.76	62.76	62.76
Energy price (EUR/MWh)	Biomass_Automatic	35.97	35.97	35.97	35.97
Energy price (EUR/MWh)	Biomass_Manual	35.97	35.97	35.97	35.97
Energy price (EUR/MWh)	Wood stove	35.97	35.97	35.97	35.97
Energy price (EUR/MWh)	HP Air-to-Air	215.21	215.21	215.21	215.21
Energy price (EUR/MWh)	HP Air-to-Water	215.21	215.21	215.21	215.21
Energy price (EUR/MWh)	HP Brine-to-Water	215.21	215.21	215.21	215.21
Energy price (EUR/MWh)	Electric heater	215.21	215.21	215.21	215.21
CM - Decentral heating supply					
CAPEX (EUR/yr)	Oil boiler	549.83	549.83	549.83	549.83
CAPEX (EUR/yr)	Natural gas	178.38	178.38	178.38	178.38
CAPEX (EUR/yr)	Biomass_Automatic	401.38	401.38	401.38	401.38
CAPEX (EUR/yr)	Biomass_Manual	338.39	338.39	338.39	338.39
CAPEX (EUR/yr)	Wood stove	236.6	236.6	236.6	236.6
CAPEX (EUR/yr)	HP Air-to-Air	375.73	375.73	375.73	375.73
CAPEX (EUR/yr)	HP Air-to-Water	596.45	596.45	596.45	596.45
CAPEX (EUR/yr)	HP Brine-to-Water	833.44	833.44	833.44	833.44
CAPEX (EUR/yr)	Electric heater	35.71	35.71	35.71	35.71
CM - Decentral heating supply					
Energy Costs (EUR/yr)	Oil boiler	779.35	1054.15	538.58	693.33
Energy Costs (EUR/yr)	Natural gas	730.95	988.68	505.13	650.28
Energy Costs (EUR/yr)	Biomass_Automatic	452.28	611.75	312.55	402.36
Energy Costs (EUR/yr)	Biomass_Manual	452.28	611.75	312.55	402.36
Energy Costs (EUR/yr)	Wood stove	530.68	717.79	366.73	472.1
Energy Costs (EUR/yr)	HP Air-to-Air	595.33	805.24	411.41	529.62
Energy Costs (EUR/yr)	HP Air-to-Water	595.33	805.24	411.41	529.62
Energy Costs (EUR/yr)	HP Brine-to-Water	529.18	715.77	365.69	470.77
Energy Costs (EUR/yr)	Electric heater	2381.31	3220.95	1645.62	2118.48
CM - Decentral heating supply					
Final Energy Demand (MWh/yr)	Oil boiler	12.57	17.01	8.69	11.19
Final Energy Demand (MWh/yr)	Natural gas	11.65	15.75	8.05	10.36
Final Energy Demand (MWh/yr)	Biomass_Automatic	12.57	17.01	8.69	11.19
Final Energy Demand (MWh/yr)	Biomass_Manual	12.57	17.01	8.69	11.19
Final Energy Demand (MWh/yr)	Wood stove	14.75	19.96	10.2	13.12
Final Energy Demand (MWh/yr)	HP Air-to-Air	2.77	3.74	1.91	2.46
Final Energy Demand (MWh/yr)	HP Air-to-Water	2.77	3.74	1.91	2.46
Final Energy Demand (MWh/yr)	HP Brine-to-Water	2.46	3.33	1.7	2.19
Final Energy Demand (MWh/yr)	Electric heater	11.06	14.97	7.65	9.84
CM - Decentral heating supply					
OPEX (EUR/yr)	Oil boiler	137.71	137.71	137.71	137.71
OPEX (EUR/yr)	Natural gas	164.94	164.94	164.94	164.94
OPEX (EUR/yr)	Biomass_Automatic	414.65	414.65	414.65	414.65
OPEX (EUR/yr)	Biomass_Manual	20	20	20	20
OPEX (EUR/yr)	Wood stove	120	120	120	120
OPEX (EUR/yr)	HP Air-to-Air	380	380	380	380
OPEX (EUR/yr)	HP Air-to-Water	262.47	262.47	262.47	262.47
OPEX (EUR/yr)	HP Brine-to-Water	228.6	228.6	228.6	228.6
OPEX (EUR/yr)	Electric heater	22.02	22.02	22.02	22.02
CM - Decentral heating supply					
Total Costs (EUR/yr)	Oil boiler	1466.89	1741.69	1226.11	1380.87
Total Costs (EUR/yr)	Natural gas	1074.27	1332	848.45	993.6
Total Costs (EUR/yr)	Biomass_Automatic	1268.31	1427.78	1128.58	1218.39
Total Costs (EUR/yr)	Biomass_Manual	810.68	970.15	670.95	760.76
Total Costs (EUR/yr)	Wood stove	887.28	1074.39	723.33	828.7
Total Costs (EUR/yr)	HP Air-to-Air	1351.06	1560.97	1167.13	1285.35
Total Costs (EUR/yr)	HP Air-to-Water	1454.24	1664.15	1270.32	1388.54
Total Costs (EUR/yr)	HP Brine-to-Water	1591.22	1777.81	1427.74	1532.81
Total Costs (EUR/yr)	Electric heater	2439.04	3278.68	1703.35	2176.21
CM - Decentral heating supply					
Anuity Factor	Oil boiler	14.88	14.88	14.88	14.88
Anuity Factor	Natural gas	14.88	14.88	14.88	14.88
Anuity Factor	Biomass_Automatic	14.88	14.88	14.88	14.88
Anuity Factor	Biomass_Manual	14.88	14.88	14.88	14.88
Anuity Factor	Wood stove	14.88	14.88	14.88	14.88
Anuity Factor	HP Air-to-Air	9.95	9.95	9.95	9.95
Anuity Factor	HP Air-to-Water	13.75	13.75	13.75	13.75
Anuity Factor	HP Brine-to-Water	14.88	14.88	14.88	14.88
Anuity Factor	Electric heater	19.6	19.6	19.6	19.6
CM - Decentral heating supply					
Efficiency heating system (%)	Oil boiler	88	88	88	88
Efficiency heating system (%)	Natural gas	95	95	95	95
Efficiency heating system (%)	Biomass_Automatic	88	88	88	88
Efficiency heating system (%)	Biomass_Manual	88	88	88	88
Efficiency heating system (%)	Wood stove	75	75	75	75
Efficiency heating system (%)	HP Air-to-Air	400	400	400	400
Efficiency heating system (%)	HP Air-to-Water	400	400	400	400
Efficiency heating system (%)	HP Brine-to-Water	450	450	450	450
Efficiency heating system (%)	Electric heater	100	100	100	100
CM - Decentral heating supply					
CO2 Emission (tCO2/yr)	Oil boiler	3.35	4.53	2.31	2.98
CO2 Emission (tCO2/yr)	Natural gas	2.34	3.17	1.62	2.09
CO2 Emission (tCO2/yr)	Biomass_Automatic	3.92	5.31	2.71	3.49
CO2 Emission (tCO2/yr)	Biomass_Manual	3.92	5.31	2.71	3.49
CO2 Emission (tCO2/yr)	Wood stove	4.6	6.23	3.18	4.09
CO2 Emission (tCO2/yr)	HP Air-to-Air	0.11	0.15	0.08	0.10
CO2 Emission (tCO2/yr)	HP Air-to-Water	0.11	0.15	0.08	0.10
CO2 Emission (tCO2/yr)	HP Brine-to-Water	0.10	0.14	0.07	0.09
CO2 Emission (tCO2/yr)	Electric heater	0.45	0.61	0.31	0.40

CM | 1.3.b Decentral heating supply

INPUT DATA

	Parameter	Subparameter	Unit	Default data	Run 1.3 E MK2050	Run 1.3 F MK2051	Run 1.3 G MK2052	Run 1.3 H MK2053	Run 1.3 I MK2054	Run 1.3 J MK2055
INPUTS	Buidling age			Before 1945	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010
	interest rate		1	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Gross Floor Area		m²	1000	4357	4045	2179	2023	545	506
	Building category			Multifamily houses	Appartment blocks	Appartment blocks	Other non-residential buildings	Other non-residential buildings	Offices	Offices
	year			2015	2050	2050	2050	2050	2050	2050
	savings for space heating			0	40	10	40	10	40	10
BASIC	emission factor - Electricity			0.270224	0.041	0.041	0.041	0.041	0.041	0.041
	emission factor - Light fuel oil			0.2664	0.266	0.266	0.266	0.266	0.266	0.266
	emission factor - Biomass solid			0.312	0.312	0.312	0.312	0.312	0.312	0.312
	emission factor - Natural gas			0.20124	0.201	0.201	0.201	0.201	0.201	0.201
PE SELECTION	Type: nuts_id_number			nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number

OUTPUT DATA

CM - Decentral heating supply		Run 1.3 E MK2050	Run 1.3 F MK2051	Run 1.3 G MK2052	Run 1.3 H MK2053	Run 1.3 I MK2054	Run 1.3 J MK2055
Levelized cost of heat (EUR/MWh)	Oil boiler	77.33	77.68	76.34	83.11	86.75	93.15
Levelized cost of heat (EUR/MWh)	Natural gas	66.14	66.37	65.54	69.99	72.41	76.72
Levelized cost of heat (EUR/MWh)	Biomass_Automatic	54.6	55.15	54.21	64.68	70.74	80.47
Levelized cost of heat (EUR/MWh)	HP Air-to-Water	70.98	71.49	72.04	81.88	87.94	95.78
Levelized cost of heat (EUR/MWh)	HP Brine-to-Water	70.88	71.53	72.67	85.18	93.05	102.95
Levelized cost of heat (EUR/MWh)	Electric heater	216.86	216.87	217.49	217.58	217.94	218.28
CM - Decentral heating supply							
Energy price (EUR/MWh)	Oil boiler	61.98	61.98	61.98	61.98	61.98	61.98
Energy price (EUR/MWh)	Natural gas	62.76	62.76	62.76	62.76	62.76	62.76
Energy price (EUR/MWh)	Biomass_Automatic	35.97	35.97	35.97	35.97	35.97	35.97
Energy price (EUR/MWh)	HP Air-to-Water	215.21	215.21	215.21	215.21	215.21	215.21
Energy price (EUR/MWh)	HP Brine-to-Water	215.21	215.21	215.21	215.21	215.21	215.21
Energy price (EUR/MWh)	Electric heater	215.21	215.21	215.21	215.21	215.21	215.21
CM - Decentral heating supply							
CAPEX (EUR/yr)	Oil boiler	927.85	882.5	1541.76	693.57	600.46	436.3
CAPEX (EUR/yr)	Natural gas	506.54	477.76	916.35	360.65	304.79	209.94
CAPEX (EUR/yr)	Biomass_Automatic	1666.1	1550.7	3448.72	1098.08	893.18	565.24
CAPEX (EUR/yr)	HP Air-to-Water	2437.24	2261.25	5209.65	1577.02	1271.11	788.32
CAPEX (EUR/yr)	HP Brine-to-Water	3683.98	3417.96	7874.58	2383.73	1921.32	1191.58
CAPEX (EUR/yr)	Electric heater	271.26	244.89	764.65	149.78	111.6	58.16
CM - Decentral heating supply							
Energy Costs (EUR/yr)	Oil boiler	12961.16	11740.17	24817.13	5304.13	3580.24	1884.62
Energy Costs (EUR/yr)	Natural gas	11321.98	10255.41	21678.54	4633.33	3127.45	1646.28
Energy Costs (EUR/yr)	Biomass_Automatic	7521.75	6813.17	14402.12	3078.15	2077.72	1093.7
Energy Costs (EUR/yr)	HP Air-to-Water	9900.68	8968	18957.14	4051.69	2734.85	1439.61
Energy Costs (EUR/yr)	HP Brine-to-Water	8800.61	7971.56	16850.79	3601.5	2430.98	1279.66
Energy Costs (EUR/yr)	Electric heater	39602.74	35872.02	75828.57	16206.75	10939.39	5758.45
CM - Decentral heating supply							
Final Energy Demand (MWh/yr)	Oil boiler	209.11	189.41	400.39	85.58	57.76	30.41
Final Energy Demand (MWh/yr)	Natural gas	180.41	163.41	345.44	73.83	49.83	26.23
Final Energy Demand (MWh/yr)	Biomass_Automatic	209.11	189.41	400.39	85.58	57.76	30.41
Final Energy Demand (MWh/yr)	HP Air-to-Water	46	41.67	88.09	18.83	12.71	6.69
Final Energy Demand (MWh/yr)	HP Brine-to-Water	40.89	37.04	78.3	16.73	11.3	5.95
Final Energy Demand (MWh/yr)	Electric heater	184.02	166.68	352.34	75.31	50.83	26.76
CM - Decentral heating supply							
OPEX (EUR/yr)	Oil boiler	341.28	326.01	540.22	260.92	228.8	171.43
OPEX (EUR/yr)	Natural gas	342.24	329.87	497	276.36	248.59	196.6
OPEX (EUR/yr)	Biomass_Automatic	860.35	829.26	1249.41	694.74	624.92	494.23
OPEX (EUR/yr)	HP Air-to-Water	723.36	687.3	1214.49	537.51	463.98	334.95
OPEX (EUR/yr)	HP Brine-to-Water	557.85	533.31	880.15	429.57	377.41	283.31
OPEX (EUR/yr)	Electric heater	31.35	30.8	37.56	28.27	26.86	23.97
CM - Decentral heating supply							
Total Costs (EUR/yr)	Oil boiler	14230.29	12948.68	26899.1	6258.62	4409.49	2492.35
Total Costs (EUR/yr)	Natural gas	12170.76	11063.04	23091.89	5270.33	3680.82	2052.81
Total Costs (EUR/yr)	Biomass_Automatic	10048.2	9193.13	19100.26	4870.97	3595.82	2153.17
Total Costs (EUR/yr)	HP Air-to-Water	13061.29	11916.56	25381.28	6166.22	4469.94	2562.88
Total Costs (EUR/yr)	HP Brine-to-Water	13042.44	11922.83	25605.52	6414.79	4729.71	2754.55
Total Costs (EUR/yr)	Electric heater	39905.35	36147.71	76630.78	16384.79	11077.85	5840.58
CM - Decentral heating supply							
Anuity Factor	Oil boiler	14.88	14.88	14.88	14.88	14.88	14.88
Anuity Factor	Natural gas	17.41	17.41	17.41	17.41	17.41	17.41
Anuity Factor	Biomass_Automatic	14.88	14.88	14.88	14.88	14.88	14.88
Anuity Factor	HP Air-to-Water	14.88	14.88	14.88	14.88	14.88	14.88
Anuity Factor	HP Brine-to-Water	14.88	14.88	14.88	14.88	14.88	14.88
Anuity Factor	Electric heater	19.6	19.6	19.6	19.6	19.6	19.6
CM - Decentral heating supply							
Efficiency heating system (%)	Oil boiler	88	88	88	88	88	88
Efficiency heating system (%)	Natural gas	102	102	102	102	102	102
Efficiency heating system (%)	Biomass_Automatic	88	88	88	88	88	88
Efficiency heating system (%)	HP Air-to-Water	400	400	400	400	400	400
Efficiency heating system (%)	HP Brine-to-Water	450	450	450	450	450	450
Efficiency heating system (%)	Electric heater	100	100	100	100	100	100
CM - Decentral heating supply							
CO2 Emission (tCO2/yr)	Oil boiler	55.71	50.46	106.66	22.8	15.39	8.1
CO2 Emission (tCO2/yr)	Natural gas	36.31	32.89	69.52	14.86	10.03	5.28
CO2 Emission (tCO2/yr)	Biomass_Automatic	65.24	59.1	124.92	26.7	18.02	9.49
CO2 Emission (tCO2/yr)	HP Air-to-Water	1.89	1.71	3.61	0.77	0.52	0.27
CO2 Emission (tCO2/yr)	HP Brine-to-Water	1.68	1.52	3.21	0.69	0.46	0.24
CO2 Emission (tCO2/yr)	Electric heater	7.54	6.83	14.45	3.09	2.08	1.10

CM | 1.3.c Decentral heating supply

INPUT DATA

	Parameter	Subparameter	Unit	
	Heat demand total (Final energy demand)		GWh/yr	2571
	CO2 price		EUR/tCO2	200

Parameter	Single family houses 1970 - 1979	Single family 2000 - 2010	Terraced houses 1970 - 1979	Terraced houses 2000 - 2010	Appartment blocks 1970 - 1979	Appartment blocks 2000 - 2010	Other non-residential 1970 - 1979	Other non-residential 2000 - 2010	Offices 1970 - 1979	Offices 2000 - 2010
Final energy consumption share per building type (in %)	20%	8%	20%	8%	8%	3%	13%	8%	10%	5%
Heat supply share for individual heating technologies (in % of final energy demand):										
Oil boiler	0	0	0	0	0	0	0	0	0	0
Natural gas	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
Biomass_Automatic	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Biomass_Manual	0.05	0.05								
Wood stove	0.1	0.05								
HP Air-to-Air	0.2	0.05								
HP Air-to-Water	0.15	0.25	0.35	0.4	0.35	0.4	0.4	0.4	0.35	0.4
HP Brine-to-Water	0.15	0.25	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Electric heater	0.05	0.05	0.35	0.4	0.35	0.4	0.3	0.4	0.35	0.4
check(1)	1	1	1	1	1	1	1	1	1	1

OUTPUT DATA

CM - Decentral heating supply				
	Efficiency heating system (%)	Oil boiler	%	93
	Efficiency heating system (%)	Natural gas	%	98
	Efficiency heating system (%)	Biomass_Automatic	%	88
	Efficiency heating system (%)	Biomass_Manual	%	88
	Efficiency heating system (%)	Wood stove	%	75
	Efficiency heating system (%)	HP Air-to-Air	%	400
	Efficiency heating system (%)	HP Air-to-Water	%	400
	Efficiency heating system (%)	HP Brine-to-Water	%	450
	Efficiency heating system (%)	Electric heater	%	100
CM - Decentral heating supply				
	costs	capex	EUR/yr	225,132,280
		opex	EUR/yr	98,174,374
		energy	EUR/yr	435,141,576
		CO2	EUR/yr	50,474,939
	CO2 emissions	Oil boiler	tCO2/yr	0
		Natural gas	tCO2/yr	77,315
		Biomass_Automatic	tCO2/yr	73,195
		Biomass_Manual	tCO2/yr	11,030
		Wood stove	tCO2/yr	19,051
		HP Air-to-Air	tCO2/yr	4,454
		HP Air-to-Water	tCO2/yr	31,791
		HP Brine-to-Water	tCO2/yr	8,630
		Electric heater	tCO2/yr	26,907
	final energy	Oil boiler	MWh/yr	0
		Natural gas	MWh/yr	384,217
		Biomass_Automatic	MWh/yr	234,643
		Biomass_Manual	MWh/yr	35,359
		Wood stove	MWh/yr	61,081
		HP Air-to-Air	MWh/yr	112,675
		HP Air-to-Water	MWh/yr	822,726
		HP Brine-to-Water	MWh/yr	218,701
		Electric heater	MWh/yr	700,687
	useful energy	Oil boiler	MWh/yr	0
		Natural gas	MWh/yr	377,986
		Biomass_Automatic	MWh/yr	206,478
		Biomass_Manual	MWh/yr	31,113
		Wood stove	MWh/yr	45,802
		HP Air-to-Air	MWh/yr	449,983
		HP Air-to-Water	MWh/yr	3,291,302
		HP Brine-to-Water	MWh/yr	983,534
		Electric heater	MWh/yr	700,687
SUMs				
	total CO2 emissions		tCO2/yr	252,375
	final energy		MWh/yr	2,570,088
	useful energy		MWh/yr	6,086,885
	costs		EUR/yr	758,448,230
	CO2 costs		EUR/yr	50,474,939
	total costs		EUR/yr	808,923,168
	Overall LCOH		EUR/MWh	133

					1.3.a Decentral heating supply				1.3.b Decentral heating supply					
	Parameter	Subparameter	Unit	Default data	Run 1.3 A MK2050	Run 1.3 B MK2050	Run 1.3 C MK2050	Run 1.3 D MK2050	Run 1.3 E	Run 1.3 F	Run 1.3 G	Run 1.3 H	Run 1.3 I	Run 1.3 J
INPUTS	Buidling age			Before 1945	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010	1970 - 1979	2000 - 2010
	interest rate		1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Gross Floor Area		m²	1000	123	149	85	98	4357	4045	2000	2000	500	500
	Building category			Multifamily houses	Single family- Terraced houses	Single family- Terraced houses	Single family- Terraced houses	Single family- Terraced houses	Appartment blocks	Appartment blocks	Other non-residential buildings	Other non-residential buildings	Offices	Offices
	year			2015	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050
	savings for space heating			0	0	0	0	0	0	0	0	0	0	0
BASIC INPUTS	emission factor - Electricity			0.270	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254
	emission factor - Light fuel oil			0.266	0.266	0.266	0.266	0.266	0.266	0.266	0.266	0.266	0.266	0.266
	emission factor - Biomass solid			0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312	0.312
	emission factor - Natural gas			0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201
YPE SELECTION	Type: nuts_id_number			nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number

Check	Parameter	SUMs	Unit	Category										
1	check(1)			**building share by a type:**	0.2	0.075	0.2	0.075	0.075	0.025	0.125	0.075	0.1	0.05
		SUM per technologie		**heat supply share for individual heating technologies:**										
		0	1	Oil boiler	0	0	0	0	0	0	0	0	0	0
		1.4	1	Natural gas	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
		0.8	1	Biomass_Automatic	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		0.1	1	Biomass_Manual	0.05	0.05	0	0	0	0	0	0	0	0
		0.15	1	Wood stove	0.1	0.05	0	0	0	0	0	0	0	0
		0.25	1	HP Air-to-Air	0.2	0.05	0	0	0	0	0	0	0	0
		3.45	1	HP Air-to-Water	0.15	0.25	0.35	0.4	0.35	0.4	0.4	0.4	0.35	0.4
		0.8	1	HP Brine-to-Water	0.15	0.25	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		3.05	1	Electric heater	0.05	0.05	0.35	0.4	0.35	0.4	0.3	0.4	0.35	0.4
				check(1)	1	1	1	1	1	1	1	1	1	1
		SUM per technologie		**useful energy for all buildings within a building class (MWh/yr):**										
		0	MWh/yr	Oil boiler	0	0	0	0	0	0	0	0	0	0
		377985.51	MWh/yr	Natural gas	50398	18899	100796	18899	37799	6300	62998	18899	50398	12600
		206477.799	MWh/yr	Biomass_Automatic	90511	33942	22628	8485	8485	2828	14142	8485	11314	5657
		31113.093	MWh/yr	Biomass_Manual	22628	8485	0	0	0	0	0	0	0	0
		45801.81563	MWh/yr	Wood stove	38570	7232	0	0	0	0	0	0	0	0
		449982.75	MWh/yr	HP Air-to-Air	411413	38570	0	0	0	0	0	0	0	0
		3291302.4	MWh/yr	HP Air-to-Water	308560	192850	719972	308560	269990	102853	514266	308560	359986	205706
		983533.725	MWh/yr	HP Brine-to-Water	347130	216956	115710	43391	43391	14464	72319	43391	57855	28927
6086885	sum	700687.425	MWh/yr	Electric heater	25713	9642	179993	77140	67497	25713	96425	77140	89997	51427
				useful energy per one building class (MWh/yr):										
					11.06	14.97	7.65	9.84	184.02	166.68	352.34	75.31	50.83	26.76
		SUM per technologie		**count of buildings:**										
		0	1	Oil boiler	0	0	0	0	0	0	0	0	0	0
		23051.17484	1	Natural gas	4557	1262	13176	1921	205	38	179	251	992	471
		14920.99792	1	Biomass_Automatic	8184	2267	2958	862	46	17	40	113	223	211
		2612.730773	1	Biomass_Manual	2046	567	0	0	0	0	0	0	0	0
		3970.427807	1	Wood stove	3487	483	0	0	0	0	0	0	0	0
		1272077.657	EUR/yr	Biomass_Manual	925322	346756	0	0	0	0	0	0	0	0
		2197417.703	EUR/yr	Wood stove	1850660	346758	0	0	0	0	0	0	0	0
		24219929.66	EUR/yr	HP Air-to-Air	22145243	2074687	0	0	0	0	0	0	0	0
		177074337.1	EUR/yr	HP Air-to-Water	16608932	10373436	38719457	16607656	14526036	5533882	27669332	16600556	19368646	11066405
		47040368.77	EUR/yr	HP Brine-to-Water	16608862	10373452	5531233	2075942	2075149	691736	3458666	2075068	2766952	1383308
435141576	sum	150785138.3	EUR/yr	Electric heater	5536287	2074681	38718986	16607656	14526043	5533885	20752002	16600545	19368628	11066424
		SUM per technologie		**total costs:**										
		0	EUR/yr	Oil boiler	0	0	0	0	0	0	0	0	0	0
		32649873.05	EUR/yr	Natural gas	4895219.938	1681618.902	11179147.92	1908365.868	2499929.859	418133.431	4128777.042	1322605.479	3649541.937	966532.6791
		21195780.53	EUR/yr	Biomass_Automatic	10379364.65	3237212.747	3338192.703	1050661.901	463334.8862	156002.0882	766651.2275	548825.8566	800365.4397	455169.0342
		2208480.366	EUR/yr	Biomass_Manual	1658573.877	549906.4889	0	0	0	0	0	0	0	0
		3613272.259	EUR/yr	Wood stove	3094244.596	519027.6626	0	0	0	0	0	0	0	0
		54278899.19	EUR/yr	HP Air-to-Air	50257086.58	4021812.615	0	0	0	0	0	0	0	0
		365290507.4	EUR/yr	HP Air-to-Water	40571402.6	21438270.64	119554946.3	43541397.05	19163205.71	7353349.706	37045834.54	25264193.02	31656830.9	19701076.92
		125484407	EUR/yr	HP Brine-to-Water	49942087.03	25765296.65	21595239.38	6759192.652	3075356.162	1034608.884	5255596.296	3695995.163	5383376.3	2977658.514
758447046	sum	153725826.4	EUR/yr	Electric heater	5670503.366	2111865.793	40077287.17	17060225.79	14637038.75	5576415.356	20971542.78	16782911.46	19613776.93	11224259.02
		SUM per technologie		**co2:**										
		0	tCO2/yr	Oil boiler	0	0	0	0	0	0	0	0	0	0
		77315.46006	tCO2/yr	Natural gas	10662.88238	4002.050991	21345.06409	4014.175386	7458.240337	1243.094895	12430.01677	3729.16258	9944.769271	2486.003354
		73195.24622	tCO2/yr	Biomass_Automatic	32079.78289	12039.3896	8015.827169	3009.553619	3008.296807	1002.892748	5014.071606	3008.363913	4010.930809	2006.137061
		11029.79312	tCO2/yr	Biomass_Manual	8019.945722	3009.847401	0	0	0	0	0	0	0	0
		19051.40552	tCO2/yr	Wood stove	16041.75136	3009.654165	0	0	0	0	0	0	0	0
		4454.477356	tCO2/yr	HP Air-to-Air	4091.809042	362.6683143	0	0	0	0	0	0	0	0
		31791.17488	tCO2/yr	HP Air-to-Water	3068.856781	1813.341572	7065.37926	2942.625835	2602.165849	990.1967713	4944.520064	2960.521501	3455.892029	1947.675216
		8630.252486	tCO2/yr	HP Brine-to-Water	3138.603526	1904.00865	993.5689584	372.4260823	371.7379784	123.7745964	618.2790194	373.0689636	491.3253091	243.4594021
252374.694	sum	26906.88396	tCO2/yr	Electric heater	1046.201175	368.7127862	6844.586158	2942.625835	2595.281812	988.7491152	3710.958185	2970.133584	3455.892029	1983.743276
		SUM per technologie		**final energy:**										
		0	MWh/yr	Oil boiler	0	0	0	0	0	0	0	0	0	0
		384216.6136	MWh/yr	Natural gas	53086.57253	19884.00729	106066.5222	19898.0177	37057.04046	6176.167126	61763.8808	18527.86496	49406.56558	12349.975
		234643.2277	MWh/yr	Biomass_Automatic	102868.0793	38566.85822	25703.8886	9649.542979	9642.319823	3214.177927	16070.95846	9642.538715	12856.34648	6428.517177
		35358.73438	MWh/yr	Biomass_Manual	25717.01983	9641.714555	0	0	0	0	0	0	0	0
		61080.71196	MWh/yr	Wood stove	51438.22446	9642.4875	0	0	0	0	0	0	0	0
		112675.2376	MWh/yr	HP Air-to-Air	103039.1913	9636.046293	0	0	0	0	0	0	0	0
		822725.5127	MWh/yr	HP Air-to-Water	77279.39349	48180.23146	179757.8149	77139.9	67490.07662	25713.3	128573.7979	77150.14298	90014.2554	51426.6
		218700.9359	MWh/yr	HP Brine-to-Water	77209.64675	48260.74656	25713.3	9657.186414	9641.701513	3214.1625	16071.26862	9639.286568	12861.70869	6431.928321
2570088.4	sum	700687.425	MWh/yr	Electric heater	25713.3	9642.4875	179993.1	77139.9	67497.4125	25713.3	96424.875	77139.9	89996.55	51426.6
2570.0884														

8.3 Appendix A3 Hotmaps DH economic assessment

CM | 4.2 DH economic assessment

INPUT DATA

	Parameter	Unit	Default data	Run 1.5 A1 MK2050	Run 1.5 A2 MK2050	Run 1.5 A3 MK2050	Run 1.5 B1 MK2050	Run 1.5 B2 MK2050	Run 1.5 B3 MK2050	Run 1.5 C1 MK2050	Run 1.5 C2 MK2050	Run 1.5 C3 MK2050
INPUTS	First year of investment	-	2018	2020	2020	2020	2020	2020	2020	2020	2020	2020
	Last year of investment	-	2030	2050	2050	2050	2050	2050	2050	2050	2050	2050
	Depreciation time	years	30	30	40	40	30	40	40	30	40	40
	Accumulated energy saving	-	0.1	0	0	0	0	0	0	0	0	0
	DH market share at the beginning of the investment period	-	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	DH market share at the end of the investment period	-	0.6	0.8	0.8	0.9	0.8	0.8	0.9	0.8	0.8	0.9
	Interest rate		0.05 (5%)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	DH grid cost ceiling	EUR/MWh	25	30	35	35	30	35	35	30	35	35
	Construction cost constant	EUR/m	212	212	200	200	212	200	200	212	200	200
	Construction cost coefficient	EUR/m²	4464	4464	4000	3500	4464	4000	3500	4464	4000	3500
	Full load hours	h	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
BASIC INPUTS	MIPGap*1e-2	-	10	10	10	10	10	10	10	10	10	10
INPUT TYPE SELECTION	Type: heat		Heat density total	1_1A_MK2050_hdm	1_1A_MK2050_hdm	1_1A_MK2050_hdm	1_1B_MK2050_hdm	1_1B_MK2050_hdm	1_1B_MK2050_hdm	1_1C_MK2050_hdm	1_1C_MK2050_hdm	1_1C_MK2050_hdm
	Type: gross_floor_area		Gross floor area total	1_1A_MK2050_gfa	1_1A_MK2050_gfa	1_1A_MK2050_gfa	1_1B_MK2050_gfa	1_1B_MK2050_gfa	1_1B_MK2050_gfa	1_1C_MK2050_gfa	1_1C_MK2050_gfa	1_1C_MK2050_gfa

OUTPUT DATA

CM - District heating potential: economic assessment	Unit	Run 1.5 A1 MK2050	Run 1.5 A2 MK2050	Run 1.5 A3 MK2050	Run 1.5 B1 MK2050	Run 1.5 B2 MK2050	Run 1.5 B3 MK2050	Run 1.5 C1 MK2050	Run 1.5 C2 MK2050	Run 1.5 C3 MK2050
Total demand in selected region in the first year of investme	MWh	1901085.18	1901085.18	1901085.18	0	1760599.15	1760599.15	0	1734636.21	1734636.21
Total demand in selected region in the last year of investme	MWh	1901085.18	1901085.18	1901085.18	0	1760599.15	1760599.15	0	1734636.21	1734636.21
Maximum potential of DH system through the investment pe	MWh	417318.75	1243395.69	1486600.48	0	1060815.54	1355172.74	0	1006845.7	1330194.13
Energetic specific DH grid costs	EUR/MWh	29.82	32.32	28.65	0	32.79	30.63	0	32.49	30.86
Energetic specific DH distribution grid costs	EUR/MWh	27.51	31.94	28.36	0	32.44	30.26	0	32.17	30.55
Energetic specific DH transmission grid costs	EUR/MWh	2.32	0.39	0.29	0	0.35	0.38	0	0.32	0.31
Specific DH distribution grid costs per meter	EUR/m	77.58	40.21	38	0	40.68	37.11	0	41.04	36.97
Specific DH transmission grid costs per meter	EUR/m	13.55	21.03	13.17	0	13.75	13.96	0	12.52	13.27
Total grid costs - annuity	EUR/yr	12446409.21	40192572.67	42594533.51	0	34782332.61	41510958.88	0	32714376.22	41050183.64
Total distribution grid costs - annuity	EUR/yr	11479289.44	39710820.5	42167133.54	0	34410029.66	41001878.19	0	32393132.52	40643549.63
Total transmission grid costs - annuity	EUR/yr	967119.77	481752.18	427399.97	0	372302.96	509080.69	0	321243.7	406634.01
Total distribution grid trench length	km	147.97	987.61	1109.73	0	845.86	1104.94	0	789.28	1099.39
Total transmission grid trench length	km	71.38	22.91	32.45	0	27.08	36.47	0	25.66	30.65
Total number of coherent areas		69	32	38	0	37	35	0	44	35
Number of economic coherent areas		64	29	38	0	34	35	0	41	35
Warning: Study horizon is longer than depreciation time. The calculation was done only till the end of depreciation time!		0						0		
DH potential % at 1st year of investment		22%	65%	78%	-	60%	77%	-	58%	77%
DH potential % at last year of investment		22%	65.4%	78.2%	-	60.3%	77.0%	-	58.0%	76.7%

8.4 Appendix A4 Hotmaps DH supply dispatch

CM | 3.2 DH supply dispatch

INPUT DATA

	Parameter	Unit	Default data	Run 1.7 A MK2050 medium WtE, high biomass boiler, low excess heat/HP, low SDH, high CO2 price	Run 1.7 B MK2050 low WtE, medium biomass boiler, medium excess heat/HP, medium SDH, high CO2 price	Run 1.7 C MK2050 low WtE, low biomass boiler, high excess heat/HP, medium SDH, high CO2 price
INPUTS	Thermal Output Capacity -Back Pressure CHP	MW	0	0	0	0
	Thermal Output Capacity -Waste Incineration Plant	MW	60	100	25	25
	Thermal Output Capacity -Heat Boiler	MW	350	445	295	120
	Thermal Output Capacity -Heat Pump	MW	100	100	325	500
	Thermal Output Capacity -Solar Thermal	MW	90	25	100	200
	CO2 Price	EUR/tCO2	30	200	200	200
	interest rate	1	0.07	0.03	0.03	0.03
	invest mode		invest	dispatch	dispatch	dispatch
Basic inputs	thermal efficiency -Back Pressure CHP	1	0.6	0.45	0.45	0.45
	electrical efficiency -Back Pressure CHP	1	0.2	0.3	0.3	0.3
	thermal efficiency -Waste Incineration Plant	1	0.6	0.31	0.31	0.31
	electrical efficiency -Waste Incineration Plant	1	0.2	0.24	0.24	0.24
	thermal efficiency -Heat Boiler	1	0.875	1.15 (1.0 used in CM)	1	1
	COP -Heat Pump	1	3	3.8	3.8	3.8
	thermal efficiency -Solar Thermal	1	1	1	1	1
	lifetime -Back Pressure CHP	years	25	25	25	25
	lifetime -Waste Incineration Plant	years	25	25	25	25
	lifetime -Heat Boiler	years	20	25	25	25
	lifetime -Heat Pump	years	25	25	25	25
	lifetime -Solar Thermal	years	25	30	30	30
	energy carrier -Back Pressure CHP		wood pellets	wood pellets	wood pellets	wood pellets
	energy carrier -Waste Incineration Plant		waste	waste	waste	waste
	energy carrier -Heat Boiler		bio gas	wood chips (entered as wood pell	wood pellets	wood pellets
	energy carrier -Heat Pump		electricity	electricity	electricity	electricity
	energy carrier -Solar Thermal		radiation	radiation	radiation	radiation
Advanced inputs: (Level 1)	emission factor -Bio Gas	tCO2/MWh	0.202	0.202	0.202	0.202
	emission factor -waste	tCO2/MWh	0.114	0.114	0.114	0.114
	emission factor -wood pellets	tCO2/MWh	0.312	0.312	0.312	0.312
	emission factor -radiation	tCO2/MWh	0	0	0	0
	emission factor -various	tCO2/MWh	0	0	0	0
	emission factor -electricity	tCO2/MWh	0.09	0.041	0.041	0.041
	energy carrier price - Bio Gas	EUR/MWh	40	40	40	40
	energy carrier price - waste	EUR/MWh	3	3	3	3
	energy carrier price -wood pellets	EUR/MWh	44	44	44	44
	energy carrier price -radiation	EUR/MWh	0	0	0	0
	energy carrier price - various	EUR/MWh	22	22	22	22
	electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price-Back Pressure CHP	EUR/MWh	45	45	45	45
	sale electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix sale electricity price-Back Pressure CHP	EUR/MWh	56	56	56	56
	sale electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Waste Incineration Plant	EUR/MWh	45	45	45	45
	sale electricity price -Waste Incineration Plant		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix sale electricity price -Waste Incineration Plant	EUR/MWh	45	45	45	45
	electricity price -Heat Boiler		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Heat Boiler	EUR/MWh	45	45	45	45
	electricity price -Heat Pump		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Heat Pump	EUR/MWh	45	45	45	45
Advanced inputs: (Level 2)	investment cost -Back Pressure CHP	EUR/MW_{th}	800000	1809000	1809000	1809000
	OPEX fix -Back Pressure CHP	EUR/(MW*yr)	46000	72000	72000	72000
	OPEX var -Back Pressure CHP	EUR/MWh	4.5	1.3	1.3	1.3
	ramping cost -Back Pressure CHP	EUR/MWh	100	100	100	100
	investment cost -Waste Incineration Plant	EUR/MW	3200000	5837000	5837000	5837000
	OPEX fix -Waste Incineration Plant	EUR/(MW*yr)	90000	162000	162000	162000
	OPEX var -Waste Incineration Plant	EUR/MWh	0.5	18.5	18.5	18.5
	ramping cost -Waste Incineration Plant	EUR/MWh	100	100	100	100
	investment cost -Heat Boiler	EUR/MW	60000	615000	615000	615000
	OPEX fix -Heat Boiler	EUR/(MW*yr)	4000	27900	27900	27900
	OPEX var -Heat Boiler	EUR/MWh	1.5	3	3	3
	investment cost -Heat Pump	EUR/MW	750000	761000	761000	761000
	OPEX fix -Heat Pump	EUR/(MW*yr)	34000	2000	2000	2000
	OPEX var -Heat Pump	EUR/MWh	0.5	1.7	2	2
	investment cost -Solar Thermal	EUR/MW	1030000	285600	285600	285600
	OPEX fix -Solar Thermal	EUR/(MW*yr)	30000	60	60	60
	OPEX var -Solar Thermal	EUR/MWh	0.5	0.35	0.35	0.35
Input type selection	Type: heat		Heat density total	1_1A_MK2050_hdm	1_1A_MK2050_hdm	1_1A_MK2050_hdm
	Type: nuts_id_number		nuts_id_number	nuts_id_number	nuts_id_number	nuts_id_number

OUTPUT DATA

CM - District heating supply dispatch - Data				Run 1.7 A MK2050	Run 1.7 B MK2050	Run 1.7 C MK2050
	Total LCOH	EUR/MWh		99	42.9	37.2
	Annual Total Costs	EUR/yr		207000000	82200000	70700000
	Total Revenue From Electricity	EUR/yr		19300000	668000	34700
	Total Thermal Generation	MWh/yr		1900000	1900000	1900000
	Total Electricity Generation	MWh/yr		469000	16200	761
	Total Investment Costs	EUR/yr		54000000	34500000	37400000
	Total O&M Costs	EUR/yr		42800000	16400000	11400000
	Total Fuel Costs	EUR/yr		33900000	21400000	18100000
	Total CO2 Costs	EUR/yr		73500000	9430000	3890000
	Total Ramping Costs	EUR/yr		3110000	403000	34100
	Total CO2 Emissions	t/yr		368000	47100	19500
	Total Heat Demand	MWh/yr		1900000	1900000	1900000
	Total Final Energy Demand	MWh/yr		2640000	695000	669000
	Heat load profile and electricity price profile	-		0	0	0
	Peak heat load - Pmax (MW)	MW		645	645	645

CM - District heating supply dispatch - Graphics				Run 1.7 A MK2050	Run 1.7 B MK2050	Run 1.7 C MK2050
	CM - District heating supply dispatch					
	Full Load Hours (h)	h	Heat Pump	8280	5220	3340
	Full Load Hours (h)	h	Solar Thermal Plant	1130	1130	1110
	Full Load Hours (h)	h	Waste Incineration Pant	6060	837	39.3
	Full Load Hours (h)	h	CHP	0	0	0
	Full Load Hours (h)	h	Heat Boiler	978	230	28.5
	CM - District heating supply dispatch					
	Installed Capacities (MW)	MW	Heat Pump	100	325	500
	Installed Capacities (MW)	MW	Solar Thermal Plant	25	100	200
	Installed Capacities (MW)	MW	Waste Incineration Pant	100	25	25
	Installed Capacities (MW)	MW	CHP	0	0	0
	Installed Capacities (MW)	MW	Heat Boiler	445	295	120
	CM - District heating supply dispatch					
	LCOH (EUR/MWh)	EUR/MWh	Heat Pump	20.1	23.4	28.2
	LCOH (EUR/MWh)	EUR/MWh	Solar Thermal Plant	13.3	13.3	13.5
	LCOH (EUR/MWh)	EUR/MWh	Waste Incineration Pant	157	683	12800
	LCOH (EUR/MWh)	EUR/MWh	CHP	0	0	0
	LCOH (EUR/MWh)	EUR/MWh	Heat Boiler	174	385	2330
	CM - District heating supply dispatch					
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Heat Pump	4370000	14200000	21900000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Solar Thermal Plant	364000	1460000	2910000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Waste Incineration Pant	33500000	8380000	8380000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	CHP	0	0	0
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Heat Boiler	15700000	10400000	4240000
	CM - District heating supply dispatch					
	O&M Cost (EUR/yr)	EUR/yr	Heat Pump	1610000	3530000	3840000
	O&M Cost (EUR/yr)	EUR/yr	Solar Thermal Plant	11400	45600	89900
	O&M Cost (EUR/yr)	EUR/yr	Waste Incineration Pant	27400000	4440000	4070000
	O&M Cost (EUR/yr)	EUR/yr	CHP	0	0	0
	O&M Cost (EUR/yr)	EUR/yr	Heat Boiler	13700000	8430000	3360000
	CM - District heating supply dispatch					
	Fuel Costs (EUR/yr)	EUR/yr	Heat Pump	8850000	18200000	17900000
	Fuel Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0	0
	Fuel Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	5870000	202000	9510
	Fuel Costs (EUR/yr)	EUR/yr	CHP	0	0	0
	Fuel Costs (EUR/yr)	EUR/yr	Heat Boiler	19200000	2980000	151000
	CM - District heating supply dispatch					
	CO2 Costs (EUR/yr)	EUR/yr	Heat Pump	1790000	3660000	3610000
	CO2 Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0	0
	CO2 Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	44600000	1540000	72300
	CO2 Costs (EUR/yr)	EUR/yr	CHP	0	0	0
	CO2 Costs (EUR/yr)	EUR/yr	Heat Boiler	27200000	4230000	214000
	CM - District heating supply dispatch					
	Ramping Costs (EUR/yr)	EUR/yr	Heat Pump	0	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	3110000	403000	34100
	Ramping Costs (EUR/yr)	EUR/yr	CHP	0	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Heat Boiler	0	0	0
	CM - District heating supply dispatch					
	CO2 Emissions (t/yr)	t/yr	Heat Pump	8930	18300	18000
	CO2 Emissions (t/yr)	t/yr	Solar Thermal Plant	0	0	0
	CO2 Emissions (t/yr)	t/yr	Waste Incineration Pant	223000	7690	361
	CO2 Emissions (t/yr)	t/yr	CHP	0	0	0
	CO2 Emissions (t/yr)	t/yr	Heat Boiler	136000	21100	1070
	CM - District heating supply dispatch					
	Thermal Generation Mix (MWh/yr)	MWh/yr	Heat Pump	828000	1700000	1670000
	Thermal Generation Mix (MWh/yr)	MWh/yr	Solar Thermal Plant	28300	113000	223000
	Thermal Generation Mix (MWh/yr)	MWh/yr	Waste Incineration Pant	606000	20900	983
	Thermal Generation Mix (MWh/yr)	MWh/yr	CHP	0	0	0
	Thermal Generation Mix (MWh/yr)	MWh/yr	Heat Boiler	435000	67800	3420
	CM - District heating supply dispatch					
	Electricity Generation Mix (MWh/yr)	MWh/yr	Heat Pump	0	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Solar Thermal Plant	0	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Waste Incineration Pant	469000	16200	761
	Electricity Generation Mix (MWh/yr)	MWh/yr	CHP	0	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Heat Boiler	0	0	0
	CM - District heating supply dispatch					
	Revenue From Electricity (EUR/yr)	EUR/yr	Heat Pump	0	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Waste Incineration Pant	19300000	668000	34700
	Revenue From Electricity (EUR/yr)	EUR/yr	CHP	0	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Heat Boiler	0	0	0
	CM - District heating supply dispatch					
	Fuel Demand (MWh/yr)	MWh/yr	Heat Pump	218000	446000	440000
	Fuel Demand (MWh/yr)	MWh/yr	Solar Thermal Plant	28300	113000	223000
	Fuel Demand (MWh/yr)	MWh/yr	Waste Incineration Pant	1960000	67500	3170
	Fuel Demand (MWh/yr)	MWh/yr	CHP	0	0	0
	Fuel Demand (MWh/yr)	MWh/yr	Heat Boiler	435000	67800	3420
	CM - District heating supply dispatch					
	CO2 Emissions by Energy carrier (t/yr)	t/yr	electricity	8930	18300	18000
	CO2 Emissions by Energy carrier (t/yr)	t/yr	radiation	0	0	0
	CO2 Emissions by Energy carrier (t/yr)	t/yr	waste	223000	7690	361
	CO2 Emissions by Energy carrier (t/yr)	t/yr	wood pellets	136000	21100	1070
	CO2 Emissions by Energy carrier (t/yr)	t/yr	bio gas	0	0	0
	CO2 Emissions by Energy carrier (t/yr)	t/yr	various	0	0	0
	CM - District heating supply dispatch					
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	electricity	828000	1700000	1670000
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	radiation	28300	113000	223000
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	waste	606000	20900	983
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	wood pellets	435000	67800	3420
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	bio gas	0	0	0
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	various	0	0	0
	CM - District heating supply dispatch					
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	electricity	218000	446000	440000
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	radiation	28300	113000	223000
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	waste	1960000	67500	3170
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	wood pellets	435000	67800	3420
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	bio gas	0	0	0
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	various	0	0	0

8.5 Appendix A5 Hotmaps results

Final table

OUTPUT DATA

	Parameter	Subparameter	Unit	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
CAPEX / OPEX:	**decentral**	capex decentral	M EUR/yr	63.28	21.89	24.23	13.80	13.46	21.89	24.23	13.80	13.46
		opex decentral	M EUR/yr	27.60	9.55	10.56	6.02	5.87	9.55	10.56	6.02	5.87
		energy decentral	M EUR/yr	122.31	42.32	46.83	26.67	26.02	42.32	46.83	26.67	26.02
		CO2 decentral	M EUR/yr	14.19	4.91	5.43	3.09	3.02	4.91	5.43	3.09	3.02
	central	capex central	M EUR/yr	0	34.99	28.33	41.83	37.43	24.23	19.62	28.97	25.92
		opex central	M EUR/yr	0	27.73	22.45	33.15	29.66	7.39	5.98	8.83	7.90
		energy central	M EUR/yr	0	21.96	17.78	26.26	23.50	11.73	9.50	14.02	12.55
		CO2 central	M EUR/yr	0	47.62	38.56	56.93	50.94	2.52	2.04	3.01	2.70
	Grid	grid costs	M EUR/yr	0	40.19	32.71	42.59	41.05	40.19	32.71	42.59	41.05
	Total		M EUR/yr	227.38	251.15	226.89	250.34	230.96	164.72	156.90	147.00	138.49
LCOH:	**decentral**	LCOH decentral	EUR/MWh	132.90	132.90	132.90	132.90	132.90	132.90	132.90	132.90	132.90
	central	LCOH central	EUR/MWh	0.00	154.34	154.53	150.26	152.71	77.05	77.23	72.96	75.42
	Total	LCOH total	M EUR/yr	132.90	146.92	145.45	146.47	148.09	96.39	100.61	86.05	88.84
CO2 Emissions:	**decentral**	Oil boiler, dec	tCO2/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	tCO2/yr	23906.1	8270.4	9151.9	5212.1	5085.8	8270.4	9151.9	5212.1	5085.8
		Biomass Automatic, dec	tCO2/yr	22632.1	7829.7	8664.2	4934.4	4814.8	7829.7	8664.2	4934.4	4814.8
		Biomass Manual, dec	tCO2/yr	3410.4	1179.9	1305.6	743.6	725.5	1179.9	1305.6	743.6	725.5
		Wood stove, dec	tCO2/yr	5890.7	2037.9	2255.1	1284.3	1253.2	2037.9	2255.1	1284.3	1253.2
		HP Air-to-Air, dec	tCO2/yr	1377.3	476.5	527.3	300.3	293.0	476.5	527.3	300.3	293.0
		HP Air-to-Water, dec	tCO2/yr	9829.9	3400.7	3763.2	2143.2	2091.2	3400.7	3763.2	2143.2	2091.2
		HP Brine-to-Water, dec	tCO2/yr	2668.5	923.2	1021.6	581.8	567.7	923.2	1021.6	581.8	567.7
		Electric heater, dec	tCO2/yr	8319.7	2878.2	3185.0	1813.9	1769.9	2878.2	3185.0	1813.9	1769.9
	central	Heat Pump, cen	tCO2/yr	0	5259.6	4259.0	6288.3	5626.7	10601.6	8584.7	12675.2	11341.7
		Solar District Heating, cen	tCO2/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Waste-to-Energy Plant, cen	tCO2/yr	0	131341.8	106354.7	157032.0	140510.5	212.6	172.2	254.2	227.5
		CHP, cen	tCO2/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	tCO2/yr	0	80100.9	64862.1	95768.4	85692.5	630.2	510.3	753.5	674.2
	Total		tCO2/yr	78034.7	243698.7	205349.6	276102.2	248431.0	38440.9	39141.1	30696.4	28844.6
Final Energy:	**decentral**	Oil boiler, dec	GWh/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	GWh/yr	108.0	37.4	41.3	23.5	23.0	37.4	41.3	23.5	23.0
		Biomass Automatic, dec	GWh/yr	66.0	22.8	25.3	14.4	14.0	22.8	25.3	14.4	14.0
		Biomass Manual, dec	GWh/yr	9.9	3.4	3.8	2.2	2.1	3.4	3.8	2.2	2.1
		Wood stove, dec	GWh/yr	17.2	5.9	6.6	3.7	3.7	5.9	6.6	3.7	3.7
		HP Air-to-Air, dec	GWh/yr	31.7	11.0	12.1	6.9	6.7	11.0	12.1	6.9	6.7
		HP Air-to-Water, dec	GWh/yr	231.3	80.0	88.5	50.4	49.2	80.0	88.5	50.4	49.2
		HP Brine-to-Water, dec	GWh/yr	61.5	21.3	23.5	13.4	13.1	21.3	23.5	13.4	13.1
		Electric heater, dec	GWh/yr	197.0	68.1	75.4	42.9	41.9	68.1	75.4	42.9	41.9
	central	Heat Pump, cen	GWh/yr	0	128.4	104.0	153.5	137.4	259.1	209.8	309.8	277.2
		Solar District Heating, cen	GWh/yr	0	16.7	13.5	19.9	17.8	131.3	106.4	157.0	140.5
		Waste-to-Energy Plant, cen	GWh/yr	0	1154.4	934.8	1380.2	1235.0	1.9	1.5	2.2	2.0
		CHP, cen	GWh/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	GWh/yr	0	256.2	207.5	306.3	274.1	2.0	1.6	2.4	2.2
	Total		GWh/yr	722.4	1805.6	1536.3	2017.5	1818.0	644.3	595.9	629.0	575.6
Useful Energy:	**decentral**	Oil boiler, dec	GWh/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	GWh/yr	106.2	36.8	40.7	23.2	22.6	36.8	40.7	23.2	22.6
		Biomass Automatic, dec	GWh/yr	58.0	20.1	22.2	12.7	12.3	20.1	22.2	12.7	12.3
		Biomass Manual, dec	GWh/yr	8.7	3.0	3.3	1.9	1.9	3.0	3.3	1.9	1.9
		Wood stove, dec	GWh/yr	12.9	4.5	4.9	2.8	2.7	4.5	4.9	2.8	2.7
		HP Air-to-Air, dec	GWh/yr	126.5	43.8	48.4	27.6	26.9	43.8	48.4	27.6	26.9
		HP Air-to-Water, dec	GWh/yr	925.2	320.1	354.2	201.7	196.8	320.1	354.2	201.7	196.8
		HP Brine-to-Water, dec	GWh/yr	276.5	95.6	105.8	60.3	58.8	95.6	105.8	60.3	58.8
		Electric heater, dec	GWh/yr	197.0	68.1	75.4	42.9	41.9	68.1	75.4	42.9	41.9
	central	Heat Pump, cen	GWh/yr	0	487.7	394.9	583.1	521.7	983.6	796.5	1176.0	1052.3
		Solar District Heating, cen	GWh/yr	0	16.6	13.5	19.9	17.8	130.8	105.9	156.3	139.9
		Waste-to-Energy Plant, cen	GWh/yr	0	356.9	289.0	426.7	381.8	0.6	0.5	0.7	0.6
		CHP, cen	GWh/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	GWh/yr	0	256.3	207.6	306.5	274.2	2.0	1.6	2.4	2.2
	Total		GWh/yr	1711.0	1709.5	1560.0	1709.2	1559.6	1708.9	1559.5	1708.4	1558.9
Shares:	decentral supply	RES share decentral (final ene	%	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
	DH supply	RES share central (final energy	%	0.0	93.5	93.5	93.5	93.5	90.7	90.7	90.7	90.7
	whole system	RES share total (final energy)	%	71.6	90.4	89.5	91.8	91.6	83.3	81.8	85.9	85.6
	whole system	DH share (useful energy)	%	0.0	65.4	58.0	78.2	76.7	65.4	58.0	78.2	76.7

renewable factor

Oil boiler		0
Natural gas		0
Biomass_Automatic		0.9
Biomass_Manual		0.9
Wood stove		0.9
HP Air-to-Air		0.85
HP Air-to-Water		0.85
HP Brine-to-Water		0.85
Electric heater		0.8
Back Pressure CHP		0.87
Waste Incineration Plant		0.98
Heat Boiler		0.94
Heat Pump		0.95
Solar Thermal		0.94

general efficiency factor

eta	0.9

for calculation of total useful energy demand out of total final energy demand

Grid losses

%	10	10	10	10	10	10	10	10	10

Green final energy

GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	59.36077426	20.53614313	22.72502496	12.94215166	12.62857407	20.53614313	22.72502496	12.94215166	12.62857407
GWh/yr	8.945162708	3.094621725	3.424467561	1.95027194	1.90301847	3.094621725	3.424467561	1.95027194	1.90301847
GWh/yr	15.45238868	5.345827601	5.915622274	3.369011947	3.287383586	5.345827601	5.915622274	3.369011947	3.287383586
GWh/yr	26.92132505	9.31356087	10.30626355	5.869530442	5.727316595	9.31356087	10.30626355	5.869530442	5.727316595
GWh/yr	196.5725693	68.0052184	75.25367721	42.85779684	41.81938802	68.0052184	75.25367721	42.85779684	41.81938802
GWh/yr	52.25388568	18.07748111	20.00430202	11.39267002	11.11663509	18.07748111	20.00430202	11.39267002	11.11663509
GWh/yr	157.5662989	54.51081301	60.32094629	34.35344235	33.52108697	54.51081301	60.32094629	34.35344235	33.52108697
GWh/yr									
GWh/yr	0	111.70536	90.45395785	133.5546223	119.5032404	225.4603595	182.5676213	269.5597881	241.1992009
GWh/yr	0	16.33468551	13.22709094	19.52970523	17.47497032	128.715013	104.227607	153.8913168	137.7002961
GWh/yr	0	1085.131051	878.69014	1297.379712	1160.88142	1.755033384	1.421146808	2.098313105	1.877548011
GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	0	240.8326568	195.0154137	287.9388645	257.6446009	1.893442957	1.533224632	2.263795211	2.025619621

factor for decentral due to DH

	0.281	0.097	0.108	0.061	0.060	0.097	0.108	0.061	0.060

portion of DH to dispatch_scenario

	0.000	0.589	0.477	0.704	0.630	0.589	0.477	0.704	0.630

8.6 Appendix A6 Hotmaps Sensitivity calculations

The sensivity calculations are made on the basis of a heat demand of 65 % of the total for Milton Keynes in 2050.

CM | 3.2 DH supply dispatch

INPUT DATA

	Parameter	Unit	Default data	Run 1.7 C MK2050 low WtE, low biomass boiler, high excess heat/HP, medium SDH, high CO2 price	Run 1.7 C MK2050 SENSITIVITY high excess heat, medium CO2 price
INPUTS	Thermal Output Capacity -Back Pressure CHP	MW	0	0	0
	Thermal Output Capacity -Waste Incineration Plant	MW	60	25	16
	Thermal Output Capacity -Heat Boiler	MW	350	120	78
	Thermal Output Capacity -Heat Pump	MW	100	500	325
	Thermal Output Capacity -Solar Thermal	MW	90	200	130
	CO2 Price	EUR/tCO2	30	200	200
	interest rate	1	0.07	0.03	0.03
	invest mode		invest	dispatch	dispatch
Basic inputs	thermal efficiency -Back Pressure CHP	1	0.6	0.45	0.45
	electrical efficiency -Back Pressure CHP	1	0.2	0.3	0.3
	thermal efficiency -Waste Incineration Plant	1	0.6	0.31	0.31
	electrical efficiency -Waste Incineration Plant	1	0.2	0.24	0.24
	thermal efficiency -Heat Boiler	1	0.875	1	1
	COP -Heat Pump	1	3	3.8	3.8
	thermal efficiency -Solar Thermal	1	1	1	1
	lifetime -Back Pressure CHP	years	25	25	25
	lifetime -Waste Incineration Plant	years	25	25	25
	lifetime -Heat Boiler	years	20	25	25
	lifetime -Heat Pump	years	25	25	25
	lifetime -Solar Thermal	years	25	30	30
	energy carrier -Back Pressure CHP		wood pellets	wood pellets	wood pellets
	energy carrier -Waste Incineration Plant		waste	waste	waste
	energy carrier -Heat Boiler		bio gas	wood pellets	wood pellets
	energy carrier -Heat Pump		electricity	electricity	electricity
	energy carrier -Solar Thermal		radiation	radiation	radiation
Advanced inputs: (Level 1)	emission factor -Bio Gas	tCO2/MWh	0.202	0.202	0.202
	emission factor -waste	tCO2/MWh	0.114	0.114	0.114
	emission factor -wood pellets	tCO2/MWh	0.312	0.312	0.312
	emission factor -radiation	tCO2/MWh	0	0	0
	emission factor -various	tCO2/MWh	0	0	0
	emission factor -electricity	tCO2/MWh	0.09	0.041	0.041
	energy carrier price - Bio Gas	EUR/MWh	40	40	40
	energy carrier price - waste	EUR/MWh	3	3	3
	energy carrier price -wood pellets	EUR/MWh	44	44	44
	energy carrier price -radiation	EUR/MWh	0	0	0
	energy carrier price - various	EUR/MWh	22	22	22
	electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price-Back Pressure CHP	EUR/MWh	45	45	45
	sale electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix sale electricity price-Back Pressure CHP	EUR/MWh	56	56	56
	sale electricity price-Back Pressure CHP		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Waste Incineration Plant	EUR/MWh	45	45	45
	sale electricity price -Waste Incineration Plant		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix sale electricity price -Waste Incineration Plant	EUR/MWh	45	45	45
	electricity price -Heat Boiler		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Heat Boiler	EUR/MWh	45	45	45
	electricity price -Heat Pump		hotmaps default hourly profile	hotmaps default hourly profile	hotmaps default hourly profile
	fix electricity price -Heat Pump	EUR/MWh	45	45	45
Advanced inputs: (Level 2)	investment cost -Back Pressure CHP	EUR/MW_{th}	800000	1809000	1809000
	OPEX fix -Back Pressure CHP	EUR/(MW*yr)	46000	72000	72000
	OPEX var -Back Pressure CHP	EUR/MWh	4.5	1.3	1.3
	ramping cost -Back Pressure CHP	EUR/MWh	100	100	100
	investment cost -Waste Incineration Plant	EUR/MW	3200000	5837000	5837000
	OPEX fix -Waste Incineration Plant	EUR/(MW*yr)	90000	162000	162000
	OPEX var -Waste Incineration Plant	EUR/MWh	0.5	18.5	18.5
	ramping cost -Waste Incineration Plant	EUR/MWh	100	100	100
	investment cost -Heat Boiler	EUR/MW	60000	615000	615000
	OPEX fix -Heat Boiler	EUR/(MW*yr)	4000	27900	27900
	OPEX var -Heat Boiler	EUR/MWh	1.5	3	3
	investment cost -Heat Pump	EUR/MW	750000	761000	761000
	OPEX fix -Heat Pump	EUR/(MW*yr)	34000	2000	2000
	OPEX var -Heat Pump	EUR/MWh	0.5	2	2
	investment cost -Solar Thermal	EUR/MW	1030000	285600	285600
	OPEX fix -Solar Thermal	EUR/(MW*yr)	30000	60	60
	OPEX var -Solar Thermal	EUR/MWh	0.5	0.35	0.35
Input type selection	Type: heat		Heat density total	1_1A_MK2050_hdm	1_1A_MK2050_hdm_SENSITIVITY
	Type: nuts_id_number		nuts_id_number	nuts_id_number	nuts_id_number

OUTPUT DATA

CM - District heating supply dispatch - Data				Run 1.7 C MK2050	Run 1.7 C MK2050 SENSITIVITY
	Total LCOH	EUR/MWh		37.2	37.2
	Annual Total Costs	EUR/yr		70700000	45900000
	Total Revenue From Electricity	EUR/yr		34700	22600
	Total Thermal Generation	MWh/yr		1900000	1230000
	Total Electricity Generation	MWh/yr		761	495
	Total Investment Costs	EUR/yr		37400000	24200000
	Total O&M Costs	EUR/yr		11400000	7350000
	Total Fuel Costs	EUR/yr		18100000	11700000
	Total CO2 Costs	EUR/yr		3890000	2530000
	Total Ramping Costs	EUR/yr		34100	22200
	Total CO2 Emissions	t/yr		19500	12700
	Total Heat Demand	MWh/yr		1900000	1230000
	Total Final Energy Demand	MWh/yr		669000	435000
	Heat load profile and electricity price profile	-		0	0
	Peak heat load - Pmax (MW)	MW		645	419

CM - District heating supply dispatch - Graphics				Run 1.7 C MK2050	Run 1.7 C MK2050 SENSITIVITY
	CM - District heating supply dispatch				
	Full Load Hours (h)	h	Heat Pump	3340	3340
	Full Load Hours (h)	h	Solar Thermal Plant	1110	1110
	Full Load Hours (h)	h	Waste Incineration Pant	39.3	40
	Full Load Hours (h)	h	CHP	0	0
	Full Load Hours (h)	h	Heat Boiler	28.5	28.6
	CM - District heating supply dispatch				
	Installed Capacities (MW)	MW	Heat Pump	500	325
	Installed Capacities (MW)	MW	Solar Thermal Plant	200	130
	Installed Capacities (MW)	MW	Waste Incineration Pant	25	16
	Installed Capacities (MW)	MW	CHP	0	0
	Installed Capacities (MW)	MW	Heat Boiler	120	78.4
	CM - District heating supply dispatch				
	LCOH (EUR/MWh)	EUR/MWh	Heat Pump	28.2	28.2
	LCOH (EUR/MWh)	EUR/MWh	Solar Thermal Plant	13.5	13.5
	LCOH (EUR/MWh)	EUR/MWh	Waste Incineration Pant	12800	12500
	LCOH (EUR/MWh)	EUR/MWh	CHP	0	0
	LCOH (EUR/MWh)	EUR/MWh	Heat Boiler	2330	2320
	CM - District heating supply dispatch				
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Heat Pump	21900000	14200000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Solar Thermal Plant	2910000	1890000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Waste Incineration Pant	8380000	5360000
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	CHP	0	0
	Investment Cost (with existing power plants) (EUR/yr)	EUR/yr	Heat Boiler	4240000	2770000
	CM - District heating supply dispatch				
	O&M Cost (EUR/yr)	EUR/yr	Heat Pump	3840000	2500000
	O&M Cost (EUR/yr)	EUR/yr	Solar Thermal Plant	89900	58400
	O&M Cost (EUR/yr)	EUR/yr	Waste Incineration Pant	4070000	2600000
	O&M Cost (EUR/yr)	EUR/yr	CHP	0	0
	O&M Cost (EUR/yr)	EUR/yr	Heat Boiler	3360000	2190000
	CM - District heating supply dispatch				
	Fuel Costs (EUR/yr)	EUR/yr	Heat Pump	17900000	11600000
	Fuel Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0
	Fuel Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	9510	6190
	Fuel Costs (EUR/yr)	EUR/yr	CHP	0	0
	Fuel Costs (EUR/yr)	EUR/yr	Heat Boiler	151000	98700
	CM - District heating supply dispatch				
	CO2 Costs (EUR/yr)	EUR/yr	Heat Pump	3610000	2340000
	CO2 Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0
	CO2 Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	72300	47100
	CO2 Costs (EUR/yr)	EUR/yr	CHP	0	0
	CO2 Costs (EUR/yr)	EUR/yr	Heat Boiler	214000	140000
	CM - District heating supply dispatch				
	Ramping Costs (EUR/yr)	EUR/yr	Heat Pump	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Waste Incineration Pant	34100	22200
	Ramping Costs (EUR/yr)	EUR/yr	CHP	0	0
	Ramping Costs (EUR/yr)	EUR/yr	Heat Boiler	0	0
	CM - District heating supply dispatch				
	CO2 Emissions (t/yr)	t/yr	Heat Pump	18000	11700
	CO2 Emissions (t/yr)	t/yr	Solar Thermal Plant	0	0
	CO2 Emissions (t/yr)	t/yr	Waste Incineration Pant	361	235
	CO2 Emissions (t/yr)	t/yr	CHP	0	0
	CO2 Emissions (t/yr)	t/yr	Heat Boiler	1070	700
	CM - District heating supply dispatch				
	Thermal Generation Mix (MWh/yr)	MWh/yr	Heat Pump	1670000	1090000
	Thermal Generation Mix (MWh/yr)	MWh/yr	Solar Thermal Plant	223000	145000
	Thermal Generation Mix (MWh/yr)	MWh/yr	Waste Incineration Pant	983	640
	Thermal Generation Mix (MWh/yr)	MWh/yr	CHP	0	0
	Thermal Generation Mix (MWh/yr)	MWh/yr	Heat Boiler	3420	2240
	CM - District heating supply dispatch				
	Electricity Generation Mix (MWh/yr)	MWh/yr	Heat Pump	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Solar Thermal Plant	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Waste Incineration Pant	761	495
	Electricity Generation Mix (MWh/yr)	MWh/yr	CHP	0	0
	Electricity Generation Mix (MWh/yr)	MWh/yr	Heat Boiler	0	0
	CM - District heating supply dispatch				
	Revenue From Electricity (EUR/yr)	EUR/yr	Heat Pump	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Solar Thermal Plant	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Waste Incineration Pant	34700	22600
	Revenue From Electricity (EUR/yr)	EUR/yr	CHP	0	0
	Revenue From Electricity (EUR/yr)	EUR/yr	Heat Boiler	0	0
	CM - District heating supply dispatch				
	Fuel Demand (MWh/yr)	MWh/yr	Heat Pump	440000	286000
	Fuel Demand (MWh/yr)	MWh/yr	Solar Thermal Plant	223000	145000
	Fuel Demand (MWh/yr)	MWh/yr	Waste Incineration Pant	3170	2060
	Fuel Demand (MWh/yr)	MWh/yr	CHP	0	0
	Fuel Demand (MWh/yr)	MWh/yr	Heat Boiler	3420	2240
	CM - District heating supply dispatch				
	CO2 Emissions by Energy carrier (t/yr)	t/yr	electricity	18000	11700
	CO2 Emissions by Energy carrier (t/yr)	t/yr	radiation	0	0
	CO2 Emissions by Energy carrier (t/yr)	t/yr	waste	361	235
	CO2 Emissions by Energy carrier (t/yr)	t/yr	wood pellets	1070	700
	CO2 Emissions by Energy carrier (t/yr)	t/yr	bio gas	0	0
	CO2 Emissions by Energy carrier (t/yr)	t/yr	various	0	0
	CM - District heating supply dispatch				
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	electricity	1670000	1090000
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	radiation	223000	145000
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	waste	983	640
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	wood pellets	3420	2240
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	bio gas	0	0
	Thermal Generation Mix by Energy carrier (MWh/yr)	MWh/yr	various	0	0
	CM - District heating supply dispatch				
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	electricity	440000	286000
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	radiation	223000	145000
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	waste	3170	2060
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	wood pellets	3420	2240
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	bio gas	0	0
	Final Energy Demand by Energy carrier (MWh/yr)	MWh/yr	various	0	0

Final table

OUTPUT DATA

	Parameter	Subparameter	Unit	Scenario 0	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 5 S	Scenario 6 S	Scenario 7 S	Scenario 8 S
CAPEX / OPEX:	**decentral**	capex decentral	M EUR/yr	63.28	21.89	24.23	13.80	13.46	21.89	24.23	13.80	13.46
		opex decentral	M EUR/yr	27.60	9.55	10.56	6.02	5.87	9.55	10.56	6.02	5.87
		energy decentral	M EUR/yr	122.31	42.32	46.83	26.67	26.02	42.32	46.83	26.67	26.02
		CO2 decentral	M EUR/yr	14.19	4.91	5.43	3.09	3.02	4.91	5.43	3.09	3.02
	central	capex central	M EUR/yr	0	24.23	19.62	28.97	25.92	24.22	19.61	28.96	25.91
		opex central	M EUR/yr	0	7.39	5.98	8.83	7.90	7.36	5.96	8.79	7.87
		energy central	M EUR/yr	0	11.73	9.50	14.02	12.55	11.71	9.48	14.00	12.53
		CO2 central	M EUR/yr	0	2.52	2.04	3.01	2.70	2.53	2.05	3.03	2.71
	Grid	grid costs	M EUR/yr	0	40.19	32.71	42.59	41.05	40.19	32.71	42.59	41.05
	Total		M EUR/yr	227.38	164.72	156.90	147.00	138.49	164.67	156.86	146.95	138.44
LCOH:	**decentral**	LCOH decentral	EUR/MWh	132.90	132.90	132.90	132.90	132.90	132.90	132.90	132.90	132.90
	central	LCOH central	EUR/MWh	0.00	77.05	77.23	72.96	75.42	49.85	49.97	47.20	48.79
	Total	LCOH total	M EUR/yr	132.90	96.39	100.61	86.05	88.84	71.06	76.44	60.33	62.65
CO2 Emissions:	**decentral**	Oil boiler, dec	tCO2/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	tCO2/yr	23906.1	8270.4	9151.9	5212.1	5085.8	8270.4	9151.9	5212.1	5085.8
		Biomass Automatic, dec	tCO2/yr	22632.1	7829.7	8664.2	4934.4	4814.8	7829.7	8664.2	4934.4	4814.8
		Biomass Manual, dec	tCO2/yr	3410.4	1179.9	1305.6	743.6	725.5	1179.9	1305.6	743.6	725.5
		Wood stove, dec	tCO2/yr	5890.7	2037.9	2255.1	1284.3	1253.2	2037.9	2255.1	1284.3	1253.2
		HP Air-to-Air, dec	tCO2/yr	1377.3	476.5	527.3	300.3	293.0	476.5	527.3	300.3	293.0
		HP Air-to-Water, dec	tCO2/yr	9829.9	3400.7	3763.2	2143.2	2091.2	3400.7	3763.2	2143.2	2091.2
		HP Brine-to-Water, dec	tCO2/yr	2668.5	923.2	1021.6	581.8	567.7	923.2	1021.6	581.8	567.7
		Electric heater, dec	tCO2/yr	8319.7	2878.2	3185.0	1813.9	1769.9	2878.2	3185.0	1813.9	1769.9
	central	Heat Pump, cen	tCO2/yr	0	10601.6	8584.7	12675.2	11341.7	16376.4	13260.9	19579.6	17519.6
		Solar District Heating, cen	tCO2/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Waste-to-Energy Plant, cen	tCO2/yr	0	212.6	172.2	254.2	227.5	328.4	266.0	392.7	351.4
		CHP, cen	tCO2/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	tCO2/yr	0	630.2	510.3	753.5	674.2	973.5	788.3	1163.9	1041.4
	Total		tCO2/yr	78034.7	38440.9	39141.1	30696.4	28844.6	44674.8	44189.1	38149.7	35513.7
Final Energy:	**decentral**	Oil boiler, dec	GWh/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	GWh/yr	108.0	37.4	41.3	23.5	23.0	37.4	41.3	23.5	23.0
		Biomass Automatic, dec	GWh/yr	66.0	22.8	25.3	14.4	14.0	22.8	25.3	14.4	14.0
		Biomass Manual, dec	GWh/yr	9.9	3.4	3.8	2.2	2.1	3.4	3.8	2.2	2.1
		Wood stove, dec	GWh/yr	17.2	5.9	6.6	3.7	3.7	5.9	6.6	3.7	3.7
		HP Air-to-Air, dec	GWh/yr	31.7	11.0	12.1	6.9	6.7	11.0	12.1	6.9	6.7
		HP Air-to-Water, dec	GWh/yr	231.3	80.0	88.5	50.4	49.2	80.0	88.5	50.4	49.2
		HP Brine-to-Water, dec	GWh/yr	61.5	21.3	23.5	13.4	13.1	21.3	23.5	13.4	13.1
		Electric heater, dec	GWh/yr	197.0	68.1	75.4	42.9	41.9	68.1	75.4	42.9	41.9
	central	Heat Pump, cen	GWh/yr	0	259.1	209.8	309.8	277.2	400.3	324.2	478.6	428.3
		Solar District Heating, cen	GWh/yr	0	131.3	106.4	157.0	140.5	202.9	164.3	242.6	217.0
		Waste-to-Energy Plant, cen	GWh/yr	0	1.9	1.5	2.2	2.0	2.9	2.3	3.4	3.1
		CHP, cen	GWh/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	GWh/yr	0	2.0	1.6	2.4	2.2	3.1	2.5	3.7	3.3
	Total		GWh/yr	722.4	644.3	595.9	629.0	575.6	859.1	769.9	885.9	805.4
Useful Energy:	**decentral**	Oil boiler, dec	GWh/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural gas, dec	GWh/yr	106.2	36.8	40.7	23.2	22.6	36.8	40.7	23.2	22.6
		Biomass Automatic, dec	GWh/yr	58.0	20.1	22.2	12.7	12.3	20.1	22.2	12.7	12.3
		Biomass Manual, dec	GWh/yr	8.7	3.0	3.3	1.9	1.9	3.0	3.3	1.9	1.9
		Wood stove, dec	GWh/yr	12.9	4.5	4.9	2.8	2.7	4.5	4.9	2.8	2.7
		HP Air-to-Air, dec	GWh/yr	126.5	43.8	48.4	27.6	26.9	43.8	48.4	27.6	26.9
		HP Air-to-Water, dec	GWh/yr	925.2	320.1	354.2	201.7	196.8	320.1	354.2	201.7	196.8
		HP Brine-to-Water, dec	GWh/yr	276.5	95.6	105.8	60.3	58.8	95.6	105.8	60.3	58.8
		Electric heater, dec	GWh/yr	197.0	68.1	75.4	42.9	41.9	68.1	75.4	42.9	41.9
	central	Heat Pump, cen	GWh/yr	0	983.6	796.5	1176.0	1052.3	1519.4	1230.3	1816.6	1625.4
		Solar District Heating, cen	GWh/yr	0	130.8	105.9	156.3	139.9	202.0	163.6	241.5	216.1
		Waste-to-Energy Plant, cen	GWh/yr	0	0.6	0.5	0.7	0.6	0.9	0.7	1.1	1.0
		CHP, cen	GWh/yr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Heat Boiler, cen	GWh/yr	0	2.0	1.6	2.4	2.2	3.1	2.5	3.7	3.3
	Total		GWh/yr	1711.0	1708.9	1559.5	1708.4	1558.9	2317.3	2052.1	2435.9	2209.8
Shares:	decentral supply	RES share decentral (final ene	%	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
	DH supply	RES share central (final energy	%	0.0	90.7	90.7	90.7	90.7	90.7	90.7	90.7	90.7
	whole system	RES share total (final energy)	%	71.6	83.3	81.8	85.9	85.6	85.2	83.8	87.3	87.1
	whole system	DH share (useful energy)	%	0.0	65.4	58.0	78.2	76.7	74.5	68.1	84.7	83.5

renewable factor

Oil boiler	0
Natural gas	0
Biomass_Automatic	0.9
Biomass_Manual	0.9
Wood stove	0.9
HP Air-to-Air	0.85
HP Air-to-Water	0.85
HP Brine-to-Water	0.85
Electric heater	0.8
Back Pressure CHP	0.87
Waste Incineration Plant	0.98
Heat Boiler	0.94
Heat Pump	0.95
Solar Thermal	0.94

general efficiency factor

eta	0.9

for calculation of total useful energy demand out of total final energy demand

Grid losses

%	10	10	10	10	10	10	10	10	10

Green final energy

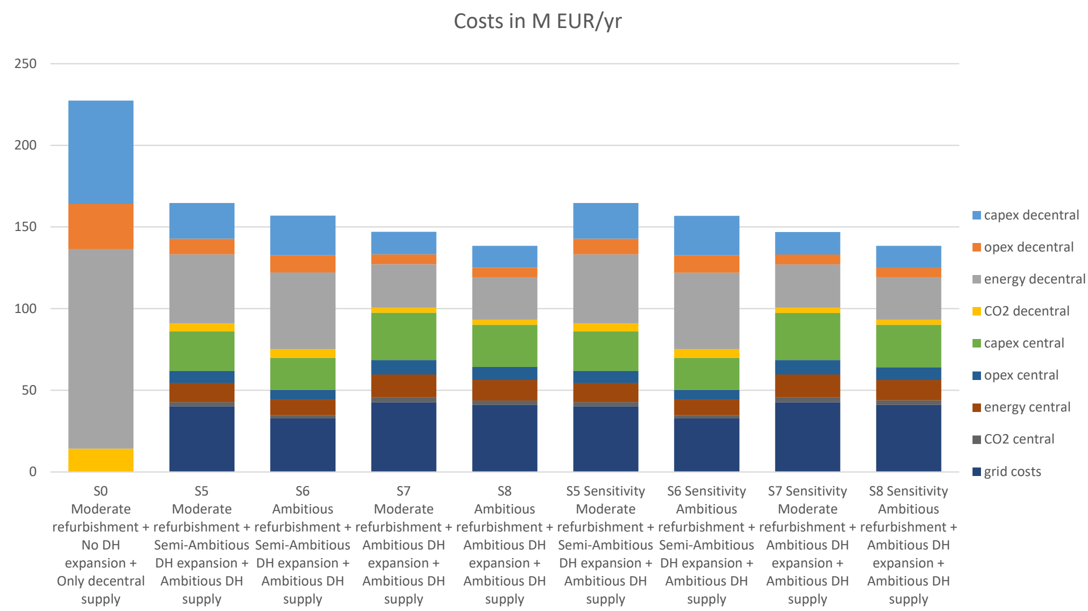
GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	59.36077426	20.53614313	22.72502496	12.94215166	12.62857407	20.53614313	22.72502496	12.94215166	12.62857407
GWh/yr	8.945162708	3.094621725	3.424467561	1.95027194	1.90301847	3.094621725	3.424467561	1.95027194	1.90301847
GWh/yr	15.45238868	5.345827601	5.915622274	3.369011947	3.287383586	5.345827601	5.915622274	3.369011947	3.287383586
GWh/yr	26.92132505	9.31356087	10.30626355	5.869530442	5.727316595	9.31356087	10.30626355	5.869530442	5.727316595
GWh/yr	196.5725693	68.0052184	75.25367721	42.85779684	41.81938802	68.0052184	75.25367721	42.85779684	41.81938802
GWh/yr	52.25388568	18.07748111	20.00430202	11.39267002	11.11663509	18.07748111	20.00430202	11.39267002	11.11663509
GWh/yr	157.5662989	54.51081301	60.32094629	34.35344235	33.52108697	54.51081301	60.32094629	34.35344235	33.52108697
GWh/yr									
GWh/yr	0	225.4603595	182.5676213	269.5597881	241.1992009	348.2721001	282.0150248	416.3931686	372.5841314
GWh/yr	0	128.715013	104.227607	153.8913168	137.7002961	198.8280688	161.0019946	237.7182943	212.7077745
GWh/yr	0	1.755033384	1.421146808	2.098313105	1.877548011	2.711027178	2.195267427	3.241296666	2.900277416
GWh/yr	0	0	0	0	0	0	0	0	0
GWh/yr	0	1.893442957	1.533224632	2.263795211	2.025619621	2.924830584	2.368395773	3.496919432	3.129005919

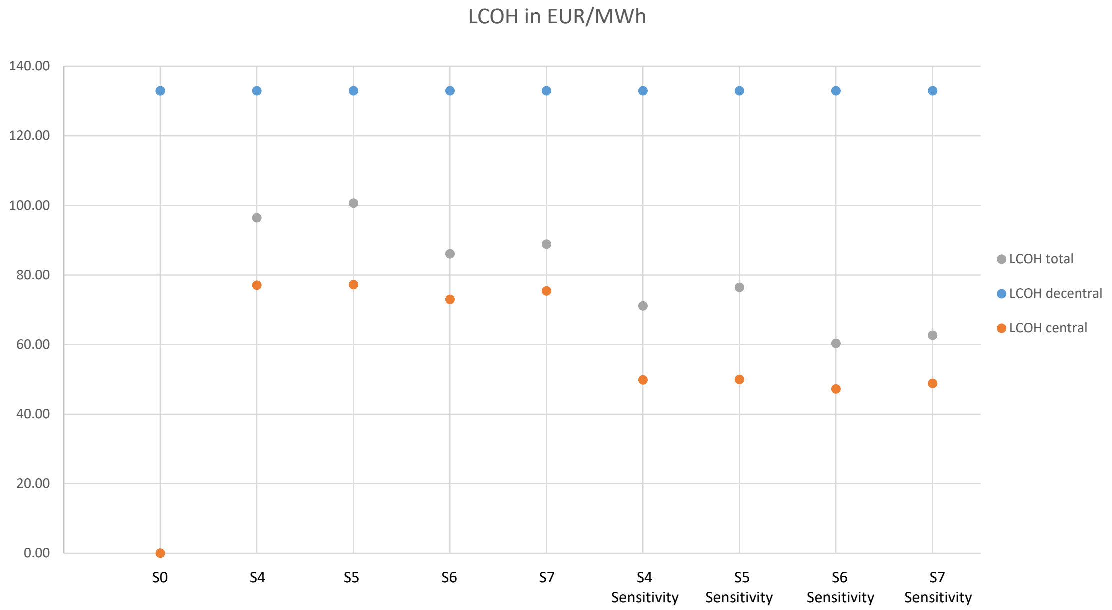
factor for decentral due to DH

	0.281	0.097	0.108	0.061	0.060	0.097	0.108	0.061	0.060

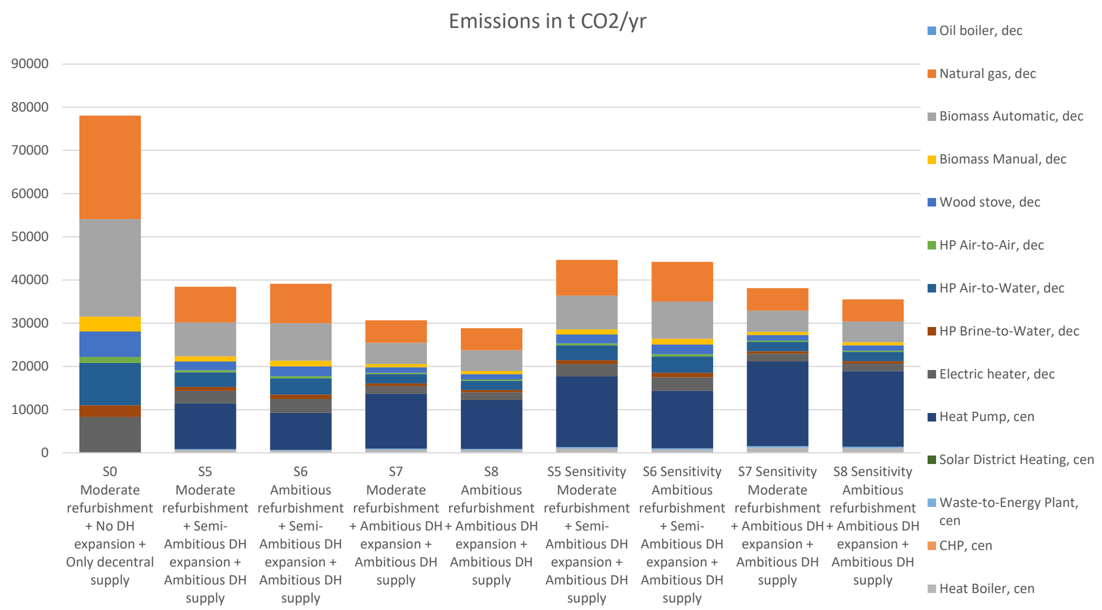
portion of DH to dispatch_scenario

	0.000	0.589	0.477	0.704	0.630	0.910	0.737	1.088	0.973

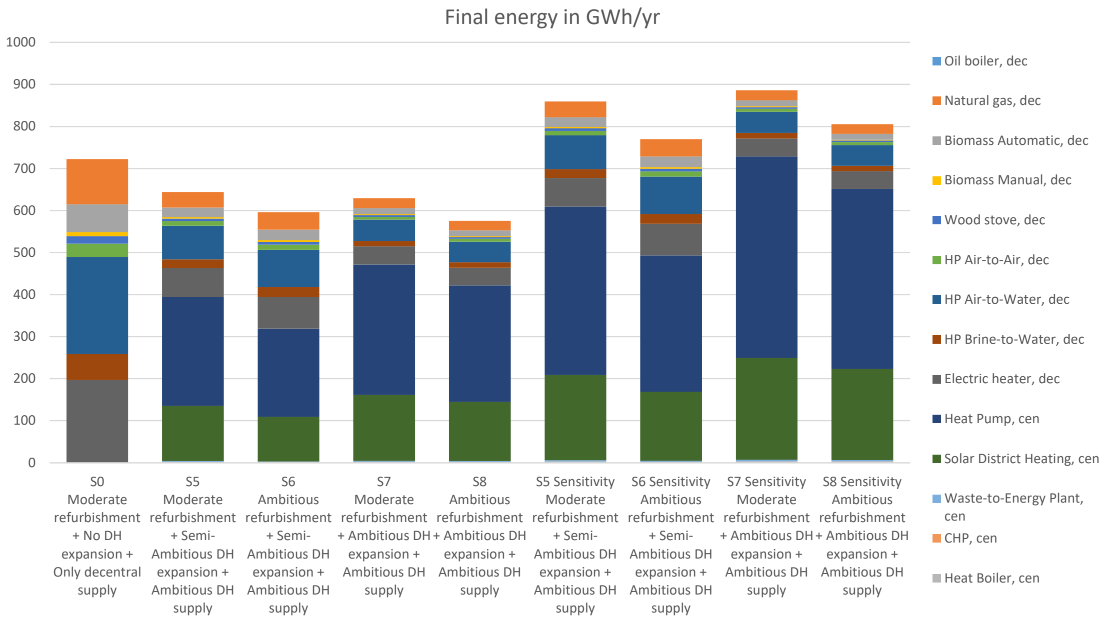




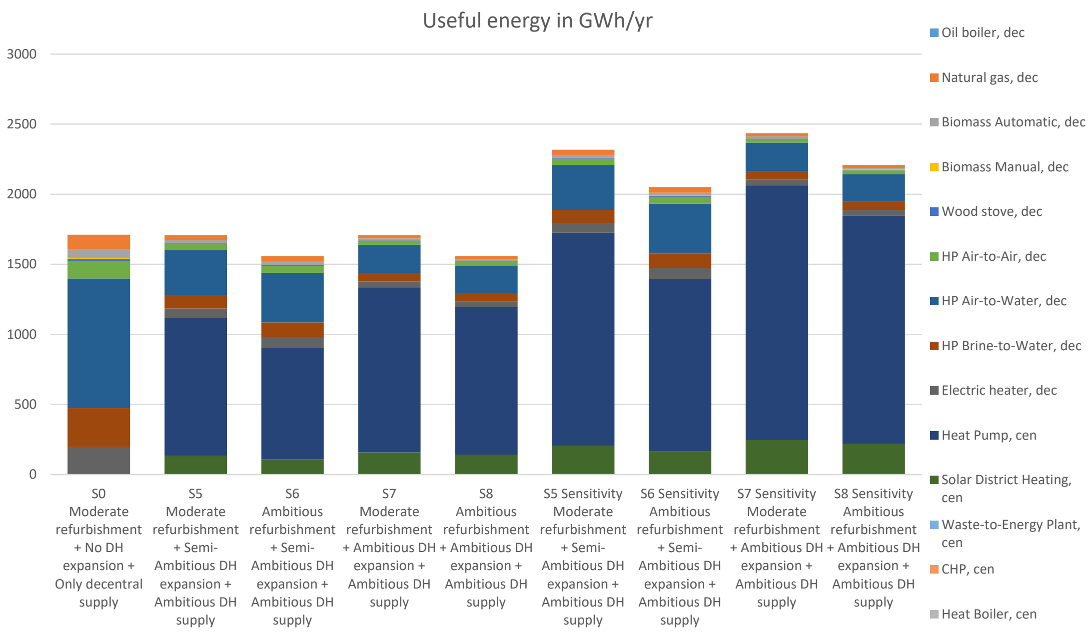
LCOH in EUR/MWh
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
S0
S4
S5
S6
S7
S4 Sensitivity
S5 Sensitivity
S6 Sensitivity
S7 Sensitivity
LCOH total
LCOH decentral
LCOH central



Emissions in t CO2/yr
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
S0 Moderate refurbishment + No DH expansion + Only decentral supply
S5 Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
S5 Sensitivity Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Sensitivity Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Sensitivity Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Sensitivity Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
Oil boiler, dec
Natural gas, dec
Biomass Automatic, dec
Biomass Manual, dec
Wood stove, dec
HP Air-to-Air, dec
HP Air-to-Water, dec
HP Brine-to-Water, dec
Electric heater, dec
Heat Pump, cen
Solar District Heating, cen
Waste-to-Energy Plant, cen
CHP, cen
Heat Boiler, cen



Final energy in GWh/yr
1000
900
800
700
600
500
400
300
200
100
0
S0 Moderate refurbishment + No DH expansion + Only decentral supply
S5 Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
S5 Sensitivity Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Sensitivity Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Sensitivity Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Sensitivity Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
Oil boiler, dec
Natural gas, dec
Biomass Automatic, dec
Biomass Manual, dec
Wood stove, dec
HP Air-to-Air, dec
HP Air-to-Water, dec
HP Brine-to-Water, dec
Electric heater, dec
Heat Pump, cen
Solar District Heating, cen
Waste-to-Energy Plant, cen
CHP, cen
Heat Boiler, cen



Useful energy in GWh/yr
3000
2500
2000
1500
1000
500
0
S0 Moderate refurbishment + No DH expansion + Only decentral supply
S5 Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
S5 Sensitivity Moderate refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S6 Sensitivity Ambitious refurbishment + Semi-Ambitious DH expansion + Ambitious DH supply
S7 Sensitivity Moderate refurbishment + Ambitious DH expansion + Ambitious DH supply
S8 Sensitivity Ambitious refurbishment + Ambitious DH expansion + Ambitious DH supply
Oil boiler, dec
Natural gas, dec
Biomass Automatic, dec
Biomass Manual, dec
Wood stove, dec
HP Air-to-Air, dec
HP Air-to-Water, dec
HP Brine-to-Water, dec
Electric heater, dec
Heat Pump, cen
Solar District Heating, cen
Waste-to-Energy Plant, cen
CHP, cen
Heat Boiler, cen

8.7 Appendix B1 Energy demand benchmark sources

SIte	Fossil fuel consumption (kWh/m^2/yr)	Source
Existing		
Old Wolverton mixed at proportion 50%/50%:		
Future redevelopment industrial site - commercial/office	120	CIBSE TM46 (2008)
Future redevelopment industrial site - warehouses	160	CIBSE TM46 (2008)
Swimming pool/leisure centre	1130	CIBSE TM46 (2008)
The Radcliffe School	150	CIBSE TM46 (2008)
Fullers Slade:		
Existing house	247	CIBSE Guide F (2012)
Future		
Fullers Slade:		
New house	57	Arup figures for Residential domestic, Heating and hot water, lighting, domestic appliances

8.8 Appendix B2 Background information on Techno-Economic assessments of scenarios

Economy_Th

Thameswey

				0	1	2	3a	3b	4
				Thameswey Reference	Thameswey Scenario 1	Thameswey Scenario 2	Thameswey Scenario 3a	Thameswey Scenario 3b	Thameswey Scenario 4
				Ind. Gas Boilers	AD heat	AD heat LargerCHP	ASHP	GSHP	Biomass CHP
Legend: Thameswey Current - Th Thameswey Extension- ThEx				*Th-exisitng gas CHP/ ThEx-ind.gas boilers*	*Biofuel combustion from the oil treatment plant +CHP (both elec.+heat) / Peak biomass boiler*	*Biofuel combustion from the oil treatment plant +CHP (both elec.+heat) /- HigherWasteThroughput Peak biomass boiler*	*ASHP/ Peak biomass boiler*	*GSHP/ Peak biomass boiler*	*BiomassCHP/ Peak ASHP*
Performance									
Key parameters-plant									
	Gas boiler efficiency	*%*	*80%*						
	Biomass (wood chip) efficiency	*%*	*80%*						
	Gas CHP el efficiency	*%*	*40%*						
	Gas CHP th efficiency	*%*	*41%*						
	AD CHP el efficiency	*%*	*25%*						
	AD CHP th efficiency	*%*	*30%*						
	Biomass CHP el efficiency	*%*	*17%*						
	Biomass CHP th efficiency	*%*	*70%*						
Key parameters-fuel									
	Natural gas LHV	*MJ/m3*	*40,5*						
	Biomass (wood chip) LHV	*MJ/kg*	*8,9*						
	Methane from Municipal Waste	*MJ/m3*	*35,89*						
	Waste biogas production	*m³/tonne*	*70,63*						
Heat							95%	95%	
	Consumption	*MWh/annum*		53.900	53.900	53.900	53.900	53.900	53.900
	Consumption for Heat rejection	*MWh/annum*							
	Production-gas boiler	*MWh/annum*		38.118					
	Production-gas CHP	*MWh/annum*		15.782					
	Production-EfW plant	*MWh/annum*			3.220	24.776			
	Production-HP	*MWh/annum*					51.076	51.398	53.491
	Production-biomass boiler	*MWh/annum*			50.680	29.124	2.824	2.502	409
	Production-biomassCHP	*MWh/annum*							
	Productio-solar thermal								
Electricity									
	Consumption	*MWh/annum*		80.500	80.500	80.500	80.500	80.500	80.500
	Consumption-HP; AD	*MWh/annum*						20.363	19.769
	Export-PW	*MWh/annum*		15.019	4.293	32.239			12.609
	Export-Grid	*MWh/annum*		262	0	796			0
	Import	*MWh/annum*		65.481	77.065	54.868	80.500	100.269	67.891
Fuel									
	Gas consumption	*MWh/annum*		85.850	10.734	82.588			
	Gas consumption	*Nm3/annum*		7.631.101	1.076.335	8.281.754			
	Waste consumption	*tonnes/year*			15.239	117.258			
	Biomass consumption	*tonnes/year*			25.625	14.725	1.632	1.265	30.910
Operational costs									
	Natural gas	*£/MWh*	*wholesale prices 2014*						
	Biomass	*£/MWh*	*19,5*						
	Waste	*£/GJ*	*17,70*						
	Electricity import	*£/MWh*	*wholesale prices 2014*						
	Heat rejection	*£/MWh*	*5*						
	Indiv. gas boilers	*£/MWh*	*10*						
	Gas boiler	*£/MWh*	*10*						
	Gas CHP	*£/MWh*	*15*						
	EfW plant	*£/MWh*							
	HP	*£/MWh*	*3*						
	Biomass boiler	*£/MWh*	*15*						
	Biomass CHP	*£/MWh*	*35*						
	Solar heating	*£/MWh*	*0,10*						
	Electricity	*£/annum*		£7.993.579	9.439.312	£6.701.970	£9.860.402	£12.316.410	£8.293.293
	Fuel	*£/annum*		£4.667.529	£1.325.962	£1.407.297	£68.845	£60.975	£1.490.115
	Heat rejection	*£/annum*		£0	£0	£0	£0	£0	£0
	O&M	*£/annum*		£610.394	£808.500	£808.500	£195.593	£191.719	£442.529
	Taxes	*£/annum*		£242.116	£0	£0	£0	£0	£0
Total operational costs (annualised)		*£/annum*		£13.513.618	£11.573.774	£8.917.767	£10.124.840	£12.569.104	£10.225.937
Revenues									
	Electricity sale PW	*£/annum*		£1.881.905	£537.961	£4.039.494	£0	£0	£1.579.866
	Electricity sale Grid	*£/annum*		£17.266	£0	£35.961	£0	£0	£0
	Incentives	*£/annum*		0	£1.576.147	£905.749	£1.404.576	£1.492.415	£2.423.697
Total revenues (annualised)		*£/annum*		£1.899.171	£2.114.108	£4.981.204	£1.404.576	£1.492.415	£4.003.563

Economy_Th

Thameswey

				0 Thameswey Reference	1 Thameswey Scenario 1	2 Thameswey Scenario 2	3a Thameswey Scenario 3a	3b Thameswey Scenario 3b	4 Thameswey Scenario 4
				Ind. Gas Boilers	AD heat	AD heat LargerCHP	ASHP	GSHP	Biomass CHP
Investment costs									
	Discount rate	*%*	*0,035*						
	Peak hours	*h/annum*	*2850*						
Plant (existing)									
	Indiv. gas boilers	*MW*							
	Gas boiler	*MW*		10					
	Gas CHP	*MW*		6,1					
	EfW plant	*tonnes/annum*			15.239	117.258			
	ASHP	*MW*							
	GSHP	*MW*							
	Biomass boiler	*MW*							
	Biomass CHP	*MW*							
	Solar heating	*m2*							
	Water tank diurnal storage	*m3*		560					
Plant (new)									
	Indiv. gas boilers	*MW*		42					
	Gas boiler	*MW*							
	Gas CHP	*MW*							
	EfW plant	*tonnes/annum*							
	ASHP	*MW*					20		15
	GSHP	*MW*						20	
	Biomass boiler	*MW*			40	35	20	22	
	Biomass CHP	*MW*							6
	Solar heating	*m2*							
	Water tank diurnal storage	*m3*							
	Heat recovery unit	*MW*							
	Indiv. gas boilers	*year*	*30*						
	Gas boiler	*year*	*30*						
	Gas CHP	*year*	*15*						
	EfW plant	*year*	*30*						
	ASHP	*year*	*20*						
	GSHP	*year*	*20*						
	Biomass boiler	*year*	*25*						
	Biomass CHP	*year*	*25*						
	Solar heating	*year*	*25*						
	Water tank diurnal storage	*year*	*40*						
	Heat recovery unit	*year*	*20*						
	Indiv. gas boilers	*£/kW*	*80*						
	Gas boiler	*£/kW*	*100*						
	Gas CHP	*£/kW_e*	*600*						
	EfW plant	*£/tonnes*	*354*						
	ASHP	*£/kW*	*600*						
	GSHP	*£/kW*	*1000*						
	Biomass boiler	*£/kW*	*615*						
	Biomass CHP	*£/kW_e*	*1530*						
	Solar heating	*£/m2*	*300*						
	Water tank diurnal storage	*£/m3*	*1200*						
	Heat recovery unit	*£/kW*	*50*						
	Indiv. gas boilers	*£*		£182.688	£0	£0	£0	£0	£0
	Gas boiler	*£*		£0	£0	£0	£0	£0	£0
	Gas CHP	*£*		£0	£0	£0	£0	£0	£0
	EfW plant	*£*		£0	£0	£0	£0	£0	£0
	ASHP	*£*		£0	£0	£0	£844.333	£0	£633.250
	GSHP	*£*		£0	£0	£0	£0	£1.407.222	£0
	Biomass boiler	*£*		£0	£1.492.581	£1.306.009	£746.291	£820.920	£0
	Biomass CHP	*£*		£0	£0	£0	£0	£0	£590.805
	Solar heating	*£*		£0	£0	£0	£0	£0	£0
	Water tank diurnal storage	*£*		£0	£0	£0	£0	£0	£0
	Heat recovery unit	*£*		£0	£0	£0	£0	£0	£0
DH network	Main branch	*m*			6950	6950	6950	6950	6950
	Building connections	*-*			47	47	47	47	47
	Connection cost	*£/building*	*10000*						
	Pipework and civils cost	*yaer*	*50*						
	Total DH cost	*£*		£0	£14.030.000	£14.030.000	£14.030.000	£14.030.000	£14.030.000
Electricity connection									
		£							
Energy centre building									
	Indiv. gas boilers	*m2/MW*							
	Gas boiler	*m2/MW*							
	Gas CHP	*m2/MW*							
	EfW plant	*m2/MW*							
	ASHP	*m2/MW*	20						
	GSHP	*m2/MW*	20						
	Biomass boiler	*m2/MW*	200						
	Biomass CHP	*m2/MW*	200						
	Solar heating	*m2/MW*							
	Water tank diurnal storage	*m2/MW*							
	Space requirement	*m2*		0	8000	7000	4400	4800	1573
	Building unit cost	*£/m2*	*1000*						
	Building cost	*£*		£0	£8.000.000	£7.000.000	£4.400.000	£4.800.000	£1.572.857
Total investment costs		*£*		£182.688	£23.522.581	£22.336.009	£20.020.624	£21.058.141	£16.826.912
Total investment costs (annualised)		*£/annum*		£9.933	£688.712	£677.392	£702.840	£746.973	£678.554
Summary									
	Additional investment costs	***£/annum***		**0**	**£678.779**	**£667.459**	**£692.907**	**£737.040**	**£668.621**
	Operational cost savings	***£/annum***		**0**	**£1.939.844**	**£4.595.851**	**£3.388.778**	**£944.514**	**£3.287.681**
	Additional revenues	***£/annum***		**0**	**£214.937**	**£3.082.033**	**-£494.595**	**-£406.756**	**£2.104.392**
	Net savings (Revenues-Additional costs)	***£/annum***			**£1.476.002**	**£7.010.425**	**£2.201.276**	**-£199.282**	**£4.723.452**
	Simple payback	***years***			**15,9**	**3,2**	**9,1**	**-105,7**	**3,6**
	Heat price	***£/MWh***		**250,9**	**227,5**	**178,0**	**200,9**	**247,1**	**202,3**

Economy_FS+OW

Old Wolverton & Fullers Slade

				0	1	2	3a	3b	4	5
				Old Wolverton & Fullers Slade Reference	Old Wolverton & Fullers Slade Scenario 1	Old Wolverton & Fullers Slade Scenario 2	Old Wolverton & Fullers Slade Scenario 3a	Old Wolverton & Fullers Slade Scenario 3b	Old Wolverton & Fullers Slade Scenario 4	Old Wolverton & Fullers Slade Scenario 5
				Ind. Gas Boilers	AD heat	AD heat HighEff	ASHP	GSHP	Biomass CHP	Solar+daily store
Legend: *OldWolverton Industrial-IS* *Radcliffe School-RS* *Leisure Centre-LS* *Fullers Slade-FS*				*IS-ind.gas boilers/* *RS-gas boiler/* *LC-biomass boiler/* *FS-ind.gas boilers/*	*AD waste food incinerator+CHP (both elec.+heat) / retained biomass boiler/* *Peak ASHP*	*Higher Heat Eff (heat recovery unit installed in AD) AD waste food incinerator+CHP (both elec.+heat) / retained biomass boiler/* *Peak ASHP*	*ASHP* *Peak demand by biomass boiler/*	*GSHP* *Peak demand by biomass boiler/*	*Biomass CHP/* *Peak ASHP*	*Solar thermal + tank storage*
Performance										
Key parameters-plant										
	Gas boiler efficiency	*%*	*80%*							
	Biomass (wood chip) efficiency	*%*	*80%*							
	Gas CHP el efficiency	*%*	*40%*							
	Gas CHP th efficiency	*%*	*41%*							
	AD CHP el efficiency	*%*	*25%*							
	AD CHP th efficiency	*%*	*30%*							
	Biomass CHP el efficiency	*%*	*17%*							
	Biomass CHP th efficiency	*%*	*70%*							
Key parameters-fuel										
	Natural gas LHV	*MJ/m3*	*40,5*							
	Biomass (wood chip) LHV	*MJ/kg*	*8,9*							
	Methane from Municipal Waste	*MJ/m3*	*35,89*							
	Waste biogas production	*m³/tonne*	*85,00*							
Heat										
	Consumption	*MWh/annum*		24.736	22.196	22.196	22.196	22.196	22.196	22.196
	Consumption for Heat rejection	*MWh/annum*		15.751			15.751	15.751	15.751	15.751
	Production-gas boiler	*MWh/annum*		22.110						
	Production-gas CHP	*MWh/annum*								
	Production-EfW plant	*MWh/annum*			15.751	19.341				
	Production-HP	*MWh/annum*			5.042	1.822	1.841	22.087	4.752	
	Production-biomass boiler	*MWh/annum*		2.626	1.404	1.033	20.355	109		14.520
	Production-biomassCHP	*MWh/annum*							17.444	
	Productio-solar thermal									7.676
Electricity										
	Consumption	*MWh/annum*								
	Consumption-HP; AD	*MWh/annum*			8.403	5.939				
	Export-PW	*MWh/annum*								
	Export-Grid	*MWh/annum*		23.099	23.099	19.850	23.099	23.099	27.211	23.099
	Import	*MWh/annum*			2.103	781	1.360	8.495	1.760	
Fuel										
	Gas consumption	*MWh/annum*		106.392	78.755	64.471				
	Gas consumption	*Nm3/annum*		10.354.094	7.897.428	6.465.065				
	Waste consumption	*tonnes/year*		92.911	92.911	76.060				
	Biomass consumption	*tonnes/year*			710	522	10.292	55	10.080	7.342
Operational costs										
	Natural gas	*£/MWh*	*wholesale prices 2014*							
	Biomass	*£/MWh*	*19,5*							
	Waste	*£/GJ*	*17,70*							
	Electricity import	*£/MWh*	*wholesale prices 2014*							
	Heat rejection	*£/MWh*	*5*							
	Indiv. gas boilers	*£/MWh*	*10*							
	Gas boiler	*£/MWh*	*10*							
	Gas CHP	*£/MWh*	*15*							
	EfW plant	*£/MWh*								
	HP	*£/MWh*	*3*							
	Biomass boiler	*£/MWh*	*15*							
	Biomass CHP	*£/MWh*	*35*							
	Solar heating	*£/MWh*	*0,10*							
	Electricity	*£/annum*		£0	263.436	£97.987	£99.157	£1.053.820	£212.956	
	Fuel	*£/annum*		£1.550.340	£421.422	£342.151	£496.151	£2.660	£485.934	£353.933
	Heat rejection	*£/annum*		£78.755	£0	£0	£0	£78.755	£78.755	£78.755
	O&M	*£/annum*		£260.490	£501.144	£405.048	£0	£67.897	£151.040	£218.572
	Taxes	*£/annum*								
Total operational costs (annualised)		*£/annum*		£1.889.585	£1.186.002	£845.186	£595.308	£1.203.132	£928.685	£651.260
Revenues										
	Electricity sale PW	*£/annum*								
	Electricity sale Grid	*£/annum*		£1.001.685	£1.001.685	£868.982	£1.001.685	£1.001.685	£1.184.411	£1.001.685
	Incentives	*£/annum*			£138.642	£50.108	£683.668	£2.114.900	£917.401	£451.582
Total revenues (annualised)		*£/annum*		£1.001.685	£1.140.327	£919.090	£1.685.353	£3.116.585	£2.101.812	£1.453.267

Economy_FS+OW

Old Wolverton & Fullers Slade

				0	1	2	3a	3b	4	5
				Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade	Old Wolverton & Fullers Slade
				Reference	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 4	Scenario 5
				Ind. Gas Boilers	AD heat	AD heat HighEff	ASHP	GSHP	Biomass CHP	Solar+daily store
Investment costs										
	Discount rate	*%*	*0,035*							
	Peak hours	*h/annum*	*2850*							
Plant (existing)										
	Indiv. gas boilers	*MW*								
	Gas boiler	*MW*		2						
	Gas CHP	*MW*			5,8	5,8				
	EfW plant	*tonnes/annum*		92.911	92.911	92.911	92.911	92.911	92.911	92.911
	ASHP	*MW*								
	GSHP	*MW*								
	Biomass boiler	*MW*		2	2	2				
	Biomass CHP	*MW*								
	Solar heating	*m2*								
	Water tank diurnal storage	*m3*								
Plant (new)										
	Indiv. gas boilers	*MW*		27						
	Gas boiler	*MW*								
	Gas CHP	*MW*								
	EfW plant	*tonnes/annum*								
	ASHP	*MW*			10	10	8		5	
	GSHP	*MW*						8		
	Biomass boiler	*MW*					5	5		12
	Biomass CHP	*MW*							8	
	Solar heating	*m2*								33.333
	Water tank diurnal storage	*m3*								15000
	Heat recovery unit	*MW*				14,5				
	Indiv. gas boilers	*year*	*30*							
	Gas boiler	*year*	*30*							
	Gas CHP	*year*	*15*							
	EfW plant	*year*	*30*							
	ASHP	*year*	*20*							
	GSHP	*year*	*20*							
	Biomass boiler	*year*	*25*							
	Biomass CHP	*year*	*25*							
	Solar heating	*year*	*25*							
	Water tank diurnal storage	*year*	*40*							
	Heat recovery unit	*year*	*20*							
	Indiv. gas boilers	*£/kW*	*80*							
	Gas boiler	*£/kW*	*100*							
	Gas CHP	*£/kW_e*	*600*							
	EfW plant	*£/tonnes*	*354*							
	ASHP	*£/kW*	*600*							
	GSHP	*£/kW*	*1000*							
	Biomass boiler	*£/kW*	*615*							
	Biomass CHP	*£/kW_e*	*1530*							
	Solar heating	*£/m2*	*300*							
	Water tank diurnal storage	*£/m3*	*1200*							
	Heat recovery unit	*£/kW*	*50*							
	Indiv. gas boilers	*£*		£117.442	£0	£0	£0	£0	£0	£0
	Gas boiler	*£*		£0	£0	£0	£0	£0	£0	£0
	Gas CHP	*£*		£0	£0	£0	£0	£0	£0	£0
	EfW plant	*£*		£0	£0	£0	£0	£0	£0	£0
	ASHP	*£*		£0	£422.166	£422.166	£337.733	£0	£211.083	£0
	GSHP	*£*		£0	£0	£0	£0	£562.889	£0	£0
	Biomass boiler	*£*		£0	£0	£0	£186.573	£186.573	£0	£447.774
	Biomass CHP	*£*		£0	£0	£0	£0	£0	£742.650	£0
	Solar heating	*£*		£0	£0	£0	£0	£0	£0	£606.740
	Water tank diurnal storage	*£*		£0	£0	£0	£0	£0	£0	£842.891
	Heat recovery unit	*£*		£0	£0	£51.012	£0	£0	£0	£0
DH network	Main branch	*m*			2366	2366	2366	2366	2366	4970
	Building connections	*-*			1112	1112	1112	1112	1112	1112
	Connection cost	*£/building*	*10000*							
	Pipework lifetime	*yaer*	*50*							
	Total DH cost	*£*		£0	£17.140.000	£17.140.000	£17.140.000	£17.140.000	£17.140.000	£17.630.000
Electricity connection										
		£								
Energy centre building										
	Indiv. gas boilers	*m2/MW*								
	Gas boiler	*m2/MW*								
	Gas CHP	*m2/MW*								
	EfW plant	*m2/MW*								
	ASHP	*m2/MW*	20							
	GSHP	*m2/MW*	20							
	Biomass boiler	*m2/MW*	200							
	Biomass CHP	*m2/MW*	200							
	Solar heating	*m2/MW*								
	Water tank diurnal storage	*m2/MW*								
	Space requirement	*m2*		0	200	200	1160	1160	1700	100
	Building unit cost	*£/m2*	*1000*							
	Building cost	*£*		£0	£200.000	£200.000	£1.160.000	£1.160.000	£1.700.000	£100.000
Total investment costs		*£*		£117.442	£17.762.166	£17.813.178	£18.824.306	£19.049.461	£19.793.733	£19.627.406
Total investment costs (annualised)		*£/annum*		£6.385	£760.446	£764.035	£765.825	£781.667	£790.653	£855.084
Summary										
	Additional investment costs	*£/annum*		0	£754.060	£757.650	£759.440	£775.282	£784.268	£848.699
	Operational cost savings	*£/annum*		0	£703.583	£1.044.399	£1.294.277	£686.453	£960.900	£1.238.325
	Additional revenues	*£/annum*		0	£138.642	-£82.595	£683.668	£2.114.900	£1.100.127	£451.582
	Net savings (Revenues-Additional costs)	*£/annum*			£88.165	£204.154	£1.218.505	£2.026.071	£1.276.759	£841.208
	Simple payback	*years*			201,5	87,3	15,4	9,4	15,5	23,3
	Heat price	*£/MWh*		76,6	87,7	72,5	61,3	89,4	77,5	67,9

8.9 Appendix B3 Incentives and Tariffs

Table 10 Electricity tariffs

Electricity tariffs	Unit	Date	Value	Source
Private Wire (PW) Export	p/kWh		12.53	
	£/MWh		125.3	
Export Grid sale-day				
	p/kWh		7.99	AMERESCO
	£/MWh		79.9	AMERESCO
Export Grid sale-night				
	p/kWh		4.4	AMERESCO
	£/MWh		44	AMERESCO
Import-wholesale market 2014				
	£/MWh	01-01-2014	47.67	
	£/MWh	01-02-2014	45.15	
	£/MWh	01-03-2014	44.41	
	£/MWh	01-04-2014	41.77	
	£/MWh	01-05-2014	39.62	
	£/MWh	01-06-2014	36.67	
	£/MWh	01-07-2014	35.46	
	£/MWh	01-08-2014	37.95	
	£/MWh	01-09-2014	43.28	
	£/MWh	01-10-2014	44.81	
	£/MWh	01-11-2014	48.43	
	£/MWh	01-12-2014	43.96	
Standing charge	p/KVA/day		3.97	AMERESCO
Additional charges	£/MWh		80	over wholesale price 2019/20 AMERESCO

Table 11 Fuel prices

Fuel tariffs				
Natural gas import-wholesale market 2014				
	£/MWh	01-01-2014	65.1	
	£/MWh	01-02-2014	58.86	
	£/MWh	01-03-2014	56.53	
	£/MWh	01-04-2014	49.89	
	£/MWh	01-05-2014	45.33	
	£/MWh	01-06-2014	39.5	
	£/MWh	01-07-2014	37.51	
	£/MWh	01-08-2014	40.61	
	£/MWh	01-09-2014	48.43	
	£/MWh	01-10-2014	50.42	
	£/MWh	01-11-2014	54.84	
	£/MWh	01-12-2014	53.62	
Standing charge	£/year		£60,000	AMERESCO
Wood chip tariffs				
Wood chip price	£/MWh		19.5	ARUP, Wick CHP project
Biogas Food incinerator				
Biogas from Municipal waste price	£/GJ		17.70	

Table 12 Taxes and CO_2 emission factors

Taxes	Unit	Value	Comments	Source
CRC		N/A	ceased in April 2019,replaced with higher CCL	UK GOV
CCL-el	£/MWh	8.47	Rates from 1 April 2019, paid on electricity consumption in case of electric boilers.	UK GOV
CCL-gas	£/MWh	3.39	paid on all gas used in the energy centre (both CHP and boiler)	UK GOV
EUETS-gas	£/TonneCO2	16	paid on all gas used in the energy centre (both CHP and boiler)	UK GOV
Gas emission factor	TCO2/MWh	0.184		ARUP

Table 13 Renewable Heat Incentive subsidies

Subsidies-RHI (new plant only)	Unit	Date	Value	Comments	Source
ASHP	p/kWh		2.75		
	£/MWh		27.5		
GSHP/WSHP	p/kWh	tier1 (15% of HP full load hours=1314h)	9.56	1314	Ofgem Tiers
	£/MWh		95.6		How to calculate Tier1/2, page 100
	p/kWh	tier2 (the rest)	2.85		
	£/MWh		28.5		
Biomass-large >1MW	p/kWh	tier1 (35% of HP full load hours=1314h)	3.11	3066	
	£/MWh		31.1		
	p/kWh	tier2 (the rest)	2.18		
	£/MWh		21.8		
Solid biomass CHP	p/kWh		4.51		
	£/MWh		45.1		
Biogas combustion-large >600kW	p/kWh		1.18		
	£/MWh		11.8		

8.10 Appendix B4 Energy demand profiles

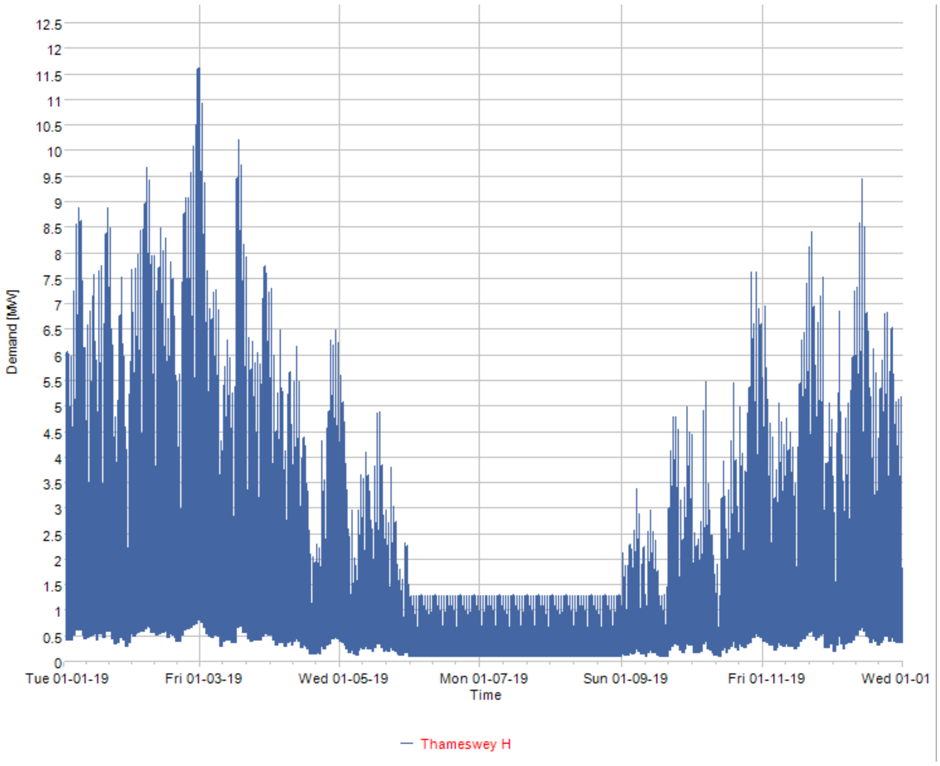


Figure 39 Heating demand profile based on current energy consumption for Central Milton Keynes

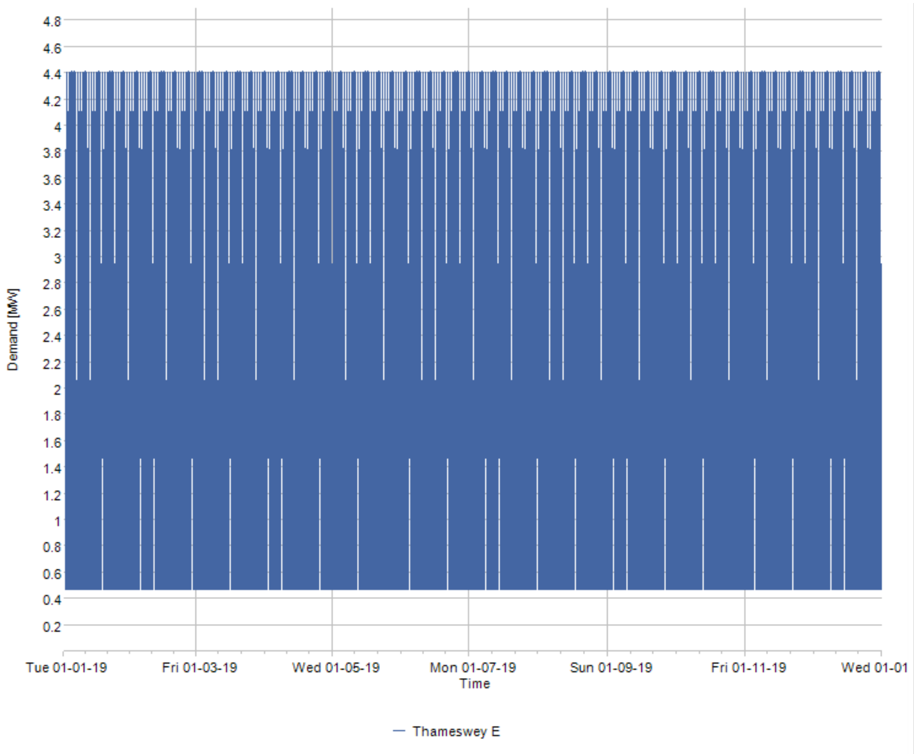


Figure 40 Electricity demand profile based on current energy consumption for Central Milton Keynes

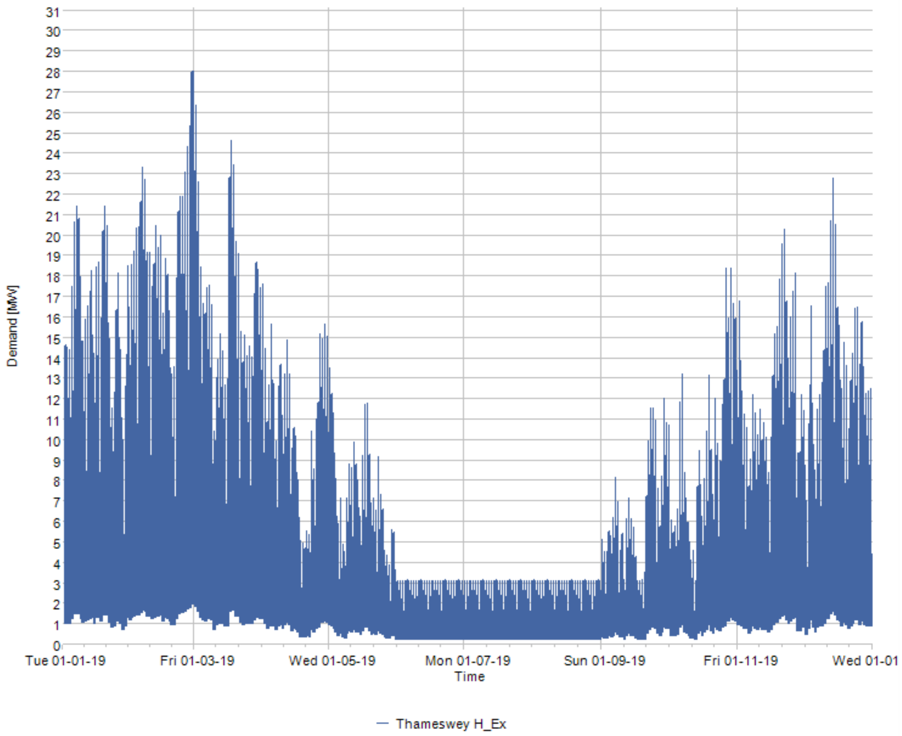


Figure 41 Heating demand profile based on future energy consumption (additional buildings to be connected to the DH) for Central Milton Keynes

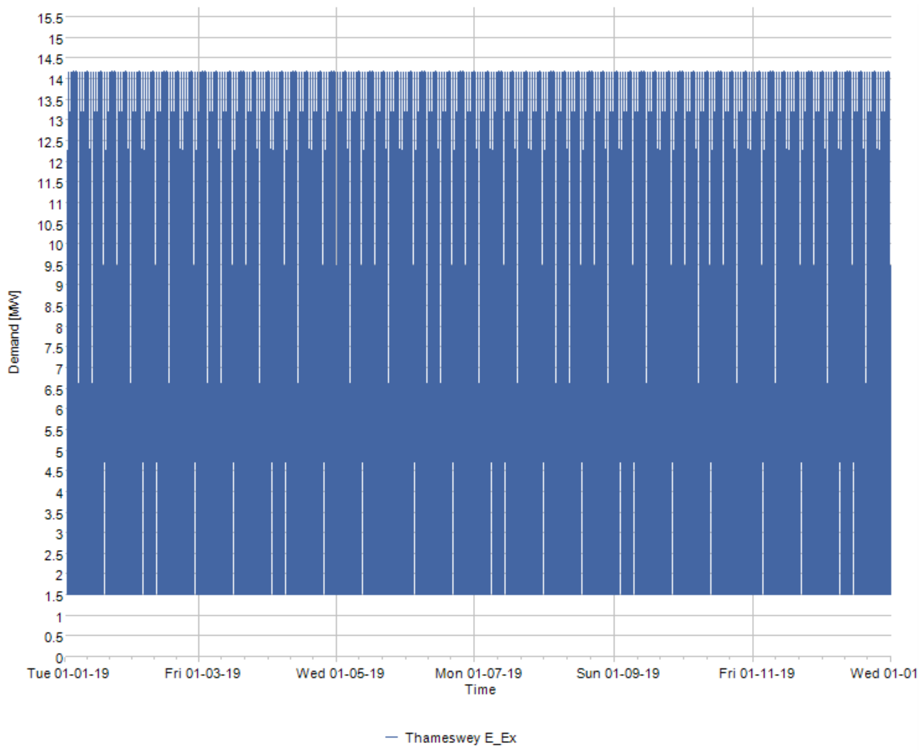


Figure 42 Electricity demand profile based future energy consumption (additional buildings to be connected to the DH) for Central Milton Keynes

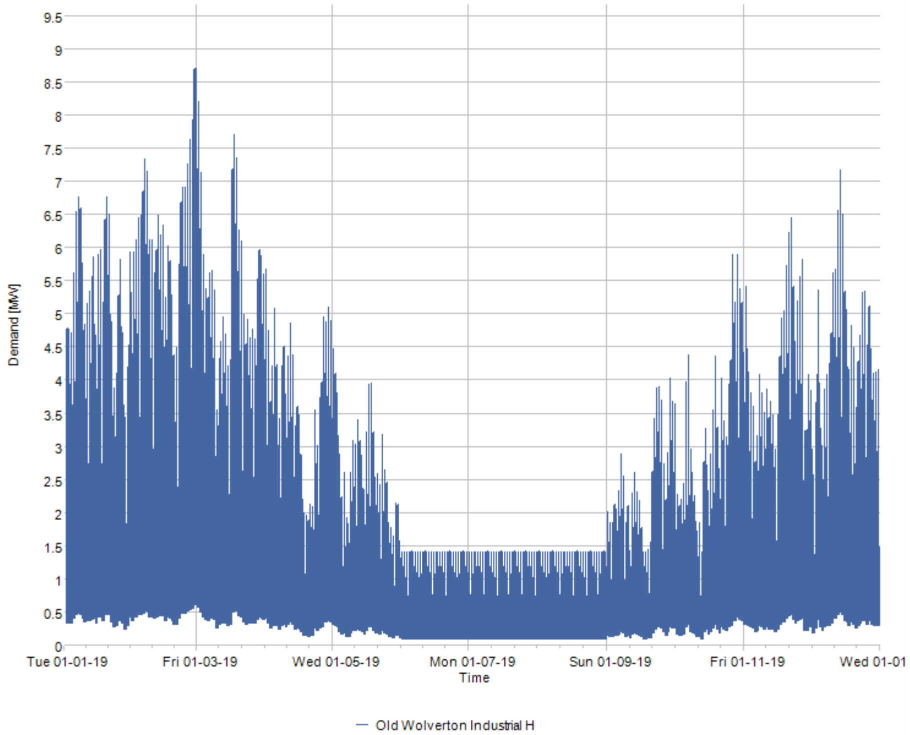


Figure 43 Heating demand profile based on future energy consumption (the area is to be entirely refurbished so only future demand characteristic is developed)) for Old Wolverton Industrial site

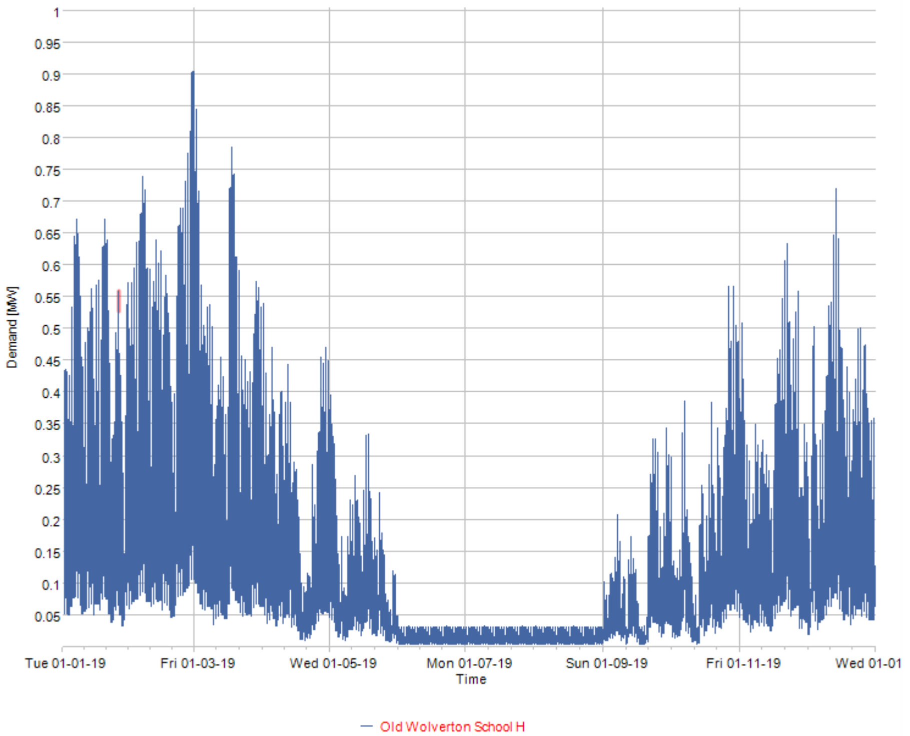


Figure 44 Heating demand profile based on current energy consumption (the area is to remain so this profile is the same for both, the current and future demand) for Old Wolverton Radcliffe school

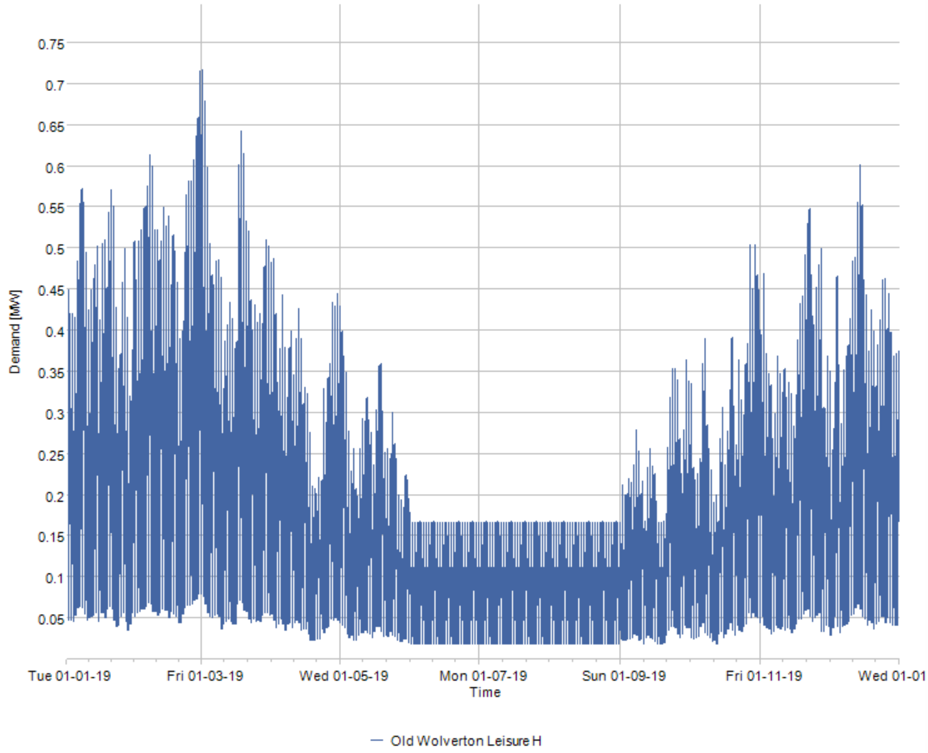


Figure 45 Heating demand profile based on current energy consumption (the area is to remain so this profile is the same for both, the current and future demand) for Old Wolverton Leisure centre (including the swimming pool)

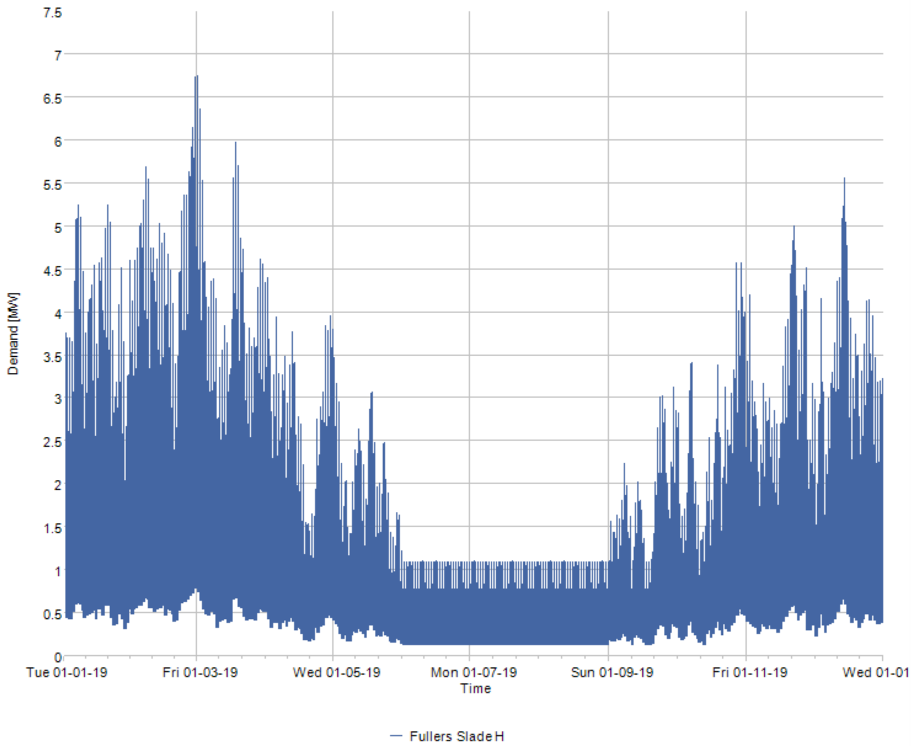


Figure 46 Heating demand profile based on future energy consumption (the area is to be entirely refurbished so only future demand characteristic is developed)) for Fullers Slade

8.11 Appendix B5 Carbon emission factors

Carbon emission factors (CO2 factors, 2019)	unit	value
electricity	kgCO2/kWh	0.254
natural gas	kgCO2/kWh	0.184
waste (sewadge sludge)	kgCO2/kWh	0.004
waste (sewadge sludge)	kgCO2/tonnes	25.355
biomass (wood chip)	kgCO2/kWh	0.016
biomass (wood chip)	kgCO2/tonnes	59.029

Figure 47 Carbon emission factors applied for Central Milton Keynes

Carbon emission factors (CO2 factors, 2019)	unit	value
electricity	kgCO2/kWh	0.254
natural gas	kgCO2/kWh	0.184
waste (municipal waste)	kgCO2/kWh	0.005
waste (municipal waste)	kgCO2/tonnes	107.100
biomass (wood chip)	kgCO2/kWh	0.016
biomass (wood chip)	kgCO2/tonnes	59.029

Figure 48 Carbon emission factors applied for Old Wolverton and Fullers Slade

8.12 Appendix B6 Pipework dimension and price catalogue for District Heating system

Name	Diameter Nominal (mm)	Ext. Diameter (mm)	Int. Diameter (mm)	Roughness	Heat Coefficient	Pipework and Installation Cost (£/m)			Civils Cost (£/m)						Mantle Diameter (mm)
						Series 1	Series 2	Series 3	HD S1	HD S2	HDS3	SD S1	SD S2	SD S3	
UK DN20(N)	20	26.7	20.9	0.06	0.154	£232	£242	£259	£385	£401	£421	£153	£159	£167	90
UK DN25(N)	25	33.4	26.6	0.06	0.19	£232	£242	£259	£385	£401	£421	£153	£159	£167	90
UK DN32(N)	32	42.2	35.1	0.06	0.19	£251	£261	£279	£418	£435	£457	£179	£186	£195	110
UK DN40(N)	40	48.3	40.9	0.06	0.221	£282	£294	£314	£431	£449	£472	£204	£213	£223	110
UK DN50(N)	50	60.33	52.51	0.06	0.241	£296	£308	£330	£447	£466	£489	£209	£218	£229	125
UK DN65(N)	65	73	62.7	0.06	0.278	£323	£336	£360	£480	£500	£525	£219	£229	£240	140
UK DN80(N)	80	88.9	77.93	0.06	0.285	£341	£355	£380	£538	£561	£589	£230	£239	£251	160
UK DN100(N)	100	114.3	102.26	0.06	0.297	£398	£415	£444	£621	£647	£679	£240	£250	£262	200
UK DN125(N)	125	141.3	128.19	0.06	0.34	£446	£465	£498	£696	£725	£762	£247	£257	£270	225
UK DN150(N)	150	168.28	154.06	0.06	0.391	£497	£518	£554	£786	£819	£860	£255	£266	£279	250
UK DN200(N)	200	219.08	202.72	0.06	0.435	£532	£555	£594	£911	£949	£997	£281	£292	£307	315
UK DN250(N)	250	273.05	254.51	0.06	0.401	£682	£711	£760	£915	£953	£1,001	£301	£314	£329	400
UK DN300(N)	300	323.85	304.8	0.06	0.46	£728	£759	£812	£922	£960	£1,008	£306	£319	£335	450
UK DN350(N)	350	355.6	336.6	0.06	0.444	£866	£902	£965	£948	£988	£1,037	£357	£372	£391	500
UK DN400(N)	400	406.4	387.4	0.06	0.592	£958	£999	£1,069	£1,021	£1,064	£1,117	£408	£425	£446	520
UK DN450(N)	450	457	438.2	0.06	0.695	£1,025	£1,068	£1,143	£1,061	£1,105	£1,161	£459	£478	£502	560
UK DN500(N)	500	508	489	0.06	0.661	£1,491	£1,553	£1,662	£1,127	£1,174	£1,233	£510	£531	£558	630

The pipework catalogue includes the technical parameters and associated price per pipe and cost of civil works by the pipe size. The cost of the material and installation is provided for three different series, varied by the British pipe standards (1, 2 and 3). The cost of the civils depends on the quality of the ground and the required workload. This is split by three different cost levels for hard dig (HD) and for soft dig (SD) each.

8.13 Appendix B7 Pipe sizes and total cost

Table 14 Pipe size and cost breakdown for Central Milton Keynes

Pipe section between red nodes (programme name, not displayed on the drawing)	Pipe normal diameter	Pipework and installation cost (£)	Civils cost (£)	Total pipe price per m (£/m)	Total length (trench) (m)	Total cost per pipe section (£)
		Series 2	SD S2			£13,560,000
PI_30	UK DN500	£1,553	£531	£2,085	195	£406,554
PI_45	UK DN250	£711	£314	£1,024	368	£376,713
PI_36	UK DN500	£1,553	£531	£2,085	232	£483,491
PI_41	UK DN500	£1,553	£531	£2,085	227	£473,764
PI_33	UK DN500	£1,553	£531	£2,085	667	£1,389,690
PI_42	UK DN500	£1,553	£531	£2,085	273	£569,802
PI_44	UK DN250	£711	£314	£1,024	273	£279,156
PI_32	UK DN500	£1,553	£531	£2,085	301	£627,113
PI_29	UK DN500	£1,553	£531	£2,085	196	£408,248
PI_25	UK DN500	£1,553	£531	£2,085	228	£476,186
PI_37	UK DN500	£1,553	£531	£2,085	694	£1,447,866
PI_40	UK DN500	£1,553	£531	£2,085	237	£493,263
PI_43	UK DN500	£1,553	£531	£2,085	355	£739,895
PI_34	UK DN500	£1,553	£531	£2,085	399	£832,064
PI_39	UK DN500	£1,553	£531	£2,085	688	£1,434,163
PI_35	UK DN500	£1,553	£531	£2,085	794	£1,655,869
PI_31	UK DN500	£1,553	£531	£2,085	419	£873,047
PI_38	UK DN500	£1,553	£531	£2,085	285	£593,258

Table 15 Pipe size and cost breakdown for Old Wolverton and Fullers Slade

Pipe section between red nodes (programme name, not displayed on the drawing)	Pipe normal diameter	Pipework and installation cost (£)	Civils cost (£)	Total pipe price per m (£/m)	Total length (trench) (m)	Total cost (£)
		Series 2	SD S2			£6,510,000
PI_9	UK DN250	£711	£314	£1,024	92	£94,593
PI_4	UK DN300	£759	£319	£1,078	13	£13,593
PI_32	UK DN300	£759	£319	£1,078	421	£453,163
PI_26	UK DN150	£518	£266	£784	112	£87,732
PI_5	UK DN300	£759	£319	£1,078	123	£132,579
PI_12	UK DN65	£336	£229	£565	418	£236,315
PI_7	UK DN200	£555	£292	£847	151	£127,873
PI_11	UK DN200	£555	£292	£847	95	£80,313
PI_16	UK DN200	£555	£292	£847	74	£62,659
PI_22	UK DN250	£711	£314	£1,024	149	£152,664
PI_19	UK DN200	£555	£292	£847	44	£37,509
PI_36	UK DN300	£759	£319	£1,078	170	£183,026
PI_15	UK DN200	£555	£292	£847	46	£39,292
PI_20	UK DN200	£555	£292	£847	245	£207,129
PI_33	UK DN300	£759	£319	£1,078	465	£501,076
PI_25	UK DN300	£759	£319	£1,078	102	£109,861
PI_24	UK DN300	£759	£319	£1,078	222	£239,634
PI_1	UK DN300	£759	£319	£1,078	130	£140,404
PI_10	UK DN200	£555	£292	£847	130	£109,834
PI_6	UK DN300	£759	£319	£1,078	75	£80,360

PI_18	UK DN200	£555	£292	£847	285	£241,657
PI	UK DN300	£759	£319	£1,078	749	£807,263
PI_23	UK DN250	£711	£314	£1,024	169	£173,127
PI_8	UK DN250	£711	£314	£1,024	98	£100,112
PI_28	UK DN125	£465	£257	£722	110	£79,629
PI_27	UK DN125	£465	£257	£722	117	£84,665
PI_13	UK DN65	£336	£229	£565	80	£45,382
PI_3	UK DN300	£759	£319	£1,078	80	£85,771
PI_17	UK DN200	£555	£292	£847	343	£290,705
PI_21	UK DN200	£555	£292	£847	106	£89,623
PI_30	UK DN300	£759	£319	£1,078	192	£206,681
PI_14	UK DN200	£555	£292	£847	180	£152,867
PI_31	UK DN300	£759	£319	£1,078	156	£168,486
PI_35	UK DN300	£759	£319	£1,078	108	£116,118
PI_2	UK DN300	£759	£319	£1,078	91	£98,306
PI_34	UK DN300	£759	£319	£1,078	634	£683,116

Table 16 DH connections to the buildings in all investigated areas

Cost of single main connection to the building	*£10,000*
No of main connections in Central Milton Keynes	*47*
No of main connections in Old Wolverton	*15*
No of main connections to the School in Wolverton	*1*
No of main connections to the leisure centre in Wolverton	*1*
No of main connections in Fullers Slade	*1095*