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EIDH-1A

A Preliminary Environmental Impact Evaluation Tool for District Heating Supply Options in Europe

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Summary: District heating systems can meet the heat and domestic sanitary hot water demands of the customers with lower resource use than the conventional individual supplies. They can also facilitate the integration of renewable energy sources and more efficient pollution controls (Frederiksen and Werner 2013). Despite these environmental advantages associated with district heating, these systems and their heat supply plants have associated other environmental impacts that may become overlooked when analysing and determining the heat supply options for new district heating systems, impacts that have a relevant importance if the inherent localism of district heating is accounted. The lack of comprehensive research on these environmental impacts that analyses them beyond the greenhouse gases emissions led to the following research question:

How environmental parameters other than greenhouse gases emissions can be incorporated in the heat supply selection for new district heating systems?

Therefore, this thesis aimed to create a model, EIDH-1a, to evaluate the environmental impacts associated with district heating supply options in a European context.

The Excel-based model incorporates *air quality* (both global and local impacts), *water quality* and *land use* indicators with the goal to provide tools and specific information to engineers, designers and decision-makers to select the most appropriate heat supply option for new district heating schemes in the early stages of the planning and design process. The model creation was based on a literature review that helped to select the fuels, technologies, and indicators to use alongside the inclusion of content in the tool.

EIDH-1a analyses heat supply options scenarios that are formed by a heat supply plant that provides the heat to meet the base demand and a peak plant to meet the peak loads of the system. The air quality indicators are determined by a ratio against a reference scenario minimising the errors inherent with the generalisations that the model encompasses. The water and land impacts are rated according the bibliography review. All indicators are pondered by the user of the tool allowing the introduction of specific particularities and goals.

In conclusion, although EIDH-1a requires some updating and polishment, the model can add value and insight to high-level studies aiming to implement new district heating schemes.

PREFACE

This thesis is realised in fulfilment of the requirements for the Sustainable Cities Master's Degree from Aalborg Universitet-Copenhagen and was written by the author between February and June of 2016.

The work was carried out in London as the author was working in the Energy Systems Department of Ramboll UK. This thesis is independent from the work performed in Ramboll although some interferences in both directions may have occurred. Nevertheless, the author takes full responsibility for the contents of the thesis, for its rights and wrongs (especially for the errors).

The development of the project and thesis writing has been arduous, challenging the background of the author, who is specialised in Strategic Environmental Assessment and does not have expertise in energy analysis.

The author also wants to acknowledge all the insights and reinforcement that the supervisor, Iva Ridjan, has provided. She took the author from a breaking point from where she wanted to drop to this final work. She has been inspiring and her wise visions on women and engineering very sharp and adequate. They were the right encouragement. Likewise, she also has been a good support for the technical and methodological part that every thesis entitles. Thank you, Iva; moltes gràcies per tot.

Finally, family, friends and colleagues of the author also need to be thanked for all the support, encouragement and patience professed.

June 2006

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1 INTRODUCTION

District Energy systems, as a means to provide heating, cooling, and sanitary hot water to individual buildings (residential or non-residential), produce steam, hot water or chilled water in a central plant that is distributed afterwards through a network of pipes (International District Energy Association 2016). District energy systems can meet the heat, cold, and domestic sanitary hot water demands of the customers with lower resource use than the conventional individual supplies. Other advantages of district energy systems are the potentiality to introduce renewables sources, the application of more efficient pollution control measures and the control of the fuel quality (Frederiksen and Werner 2013).

According to the Working Document for the EU Strategy for Heating and Cooling (European Commission 2016a), the energy supply composition for district heating at EU level is very country-specific although, in 2012, the main fuel used was natural gas (40%). Other fuels used are:

- Coal (29%),
- Biomass (16%),
- Waste heat (9%),
- Fuel oil (3%),
- Other fossil fuels (2%),
- Electricity (1%),
- Geothermal (0%) and
- Solar energy (0%).

The same Working Document establishes that around a 70% of these fuels are used in combined heat and power (CHP) plants and most of the other 30% is heat used directly from renewable sources or other fuel for heat production only (in heat boilers).

Despite this trend, or because of it, several European Union (EU) projects and studies[1] are promoting the use of renewable sources in district energy systems to strengthen their potential to decarbonise EU's energy system and reach EU's greenhouse gas (GHG) emissions targets (David Connolly et al. 2013). Many of these projects, studies, and research focus the attention on climate change and the costs of heating. Lowering the emission of CO_2 and other greenhouse gases ($CO_{2equivalents}$) is now on the agenda of decision-makers, at least in the European and country levels and it is becoming important at the local level as a means to comply with the national regulations and to improve urban conditions (improving air quality, fuel poverty fight, increase of liveability standards in dwellings).

Decentralised energy systems as district energy (or district heating) systems can have a strong influence in the decarbonisation of the national energy systems and their resilience although they have other inherent impacts. As Torchio et al (2009) describe, many studies have analysed the technical aspects of district heating and some environmental impacts that district heating (DH) can have. These environmental impacts analysed in the previous studies were partial and only relevant for certain pollutants and small-scale DH schemes. Posterior research

[1] Some examples are *Heat Roadmap Europe, Solar District Heating, Stratego, RES H/C Spread, SmartReFlex* and others.

broadened the study of the environmental benefits of DH, e.g. the sustainability assessment of power and heat technologies in (Dombi, Kuti, and Balogh 2014) ascertaining the good performance in environmental and economic impacts of geothermal district heating, the potentiality for decreasing GHG emissions by converting industrial processes to DH (Djuric Ilic and Trygg 2014) or the methodology proposition to estimate incremental air quality and health impacts of district energy systems (Petrov, Bi, and Lau 2015). However, all these studies are partial and either analyse solely a small range of DH systems or study a small range of environmental impacts and benefits of DH.

The lack of comprehensive research on DH environmental impacts detected led to the following:

Research Question

How environmental parameters other than greenhouse gases emissions can be incorporated in the heat supply selection for new district heating systems?

The literature review seems to indicate a lack of environmental background for decision-makers when choosing the supply assets that are to provide heat into the DH system. Economic and climate change parameters are usually employed when new DH systems are planned and designed. Yet, despite the inherent localism of DH and, specifically, of the heat supply plants, their potential effects are not accounted in the same degree despite their potential effects in the urban environment. Supply plants with large capacities had been located, in general, outside of the urban limits, away of populated areas and, therefore, their environmental impacts, especially those affecting the human health, did not have the same relevance. The analysis and estimation of the effects that new DH systems can have on the local environment and health are usually determined in later stages of the planning and design process, usually after the Design (see Figure 1) stage when the system is evaluated for permitting. Many environmental impacts are only analysed during the Environmental Impact Assessment (EIA) that accompany the permitting process of the installation of new supply plants. However, according to the EIA Directive (European Commission 2012), only combustion installations with a heat output over 300 MW are requested to undertake an EIA[2] while the heat supply plants with lower capacity the need of an EIA is screened by each state member. This results in a discrepancy between countries procedures and in neglecting the environmental assessment of heat supply plants in DH systems, which usually fall into the second category. Thus, the probability of evaluating the environmental impacts associated with DH supply assets is low in many stages of the process.

[2] Annex I of the EIA Directive

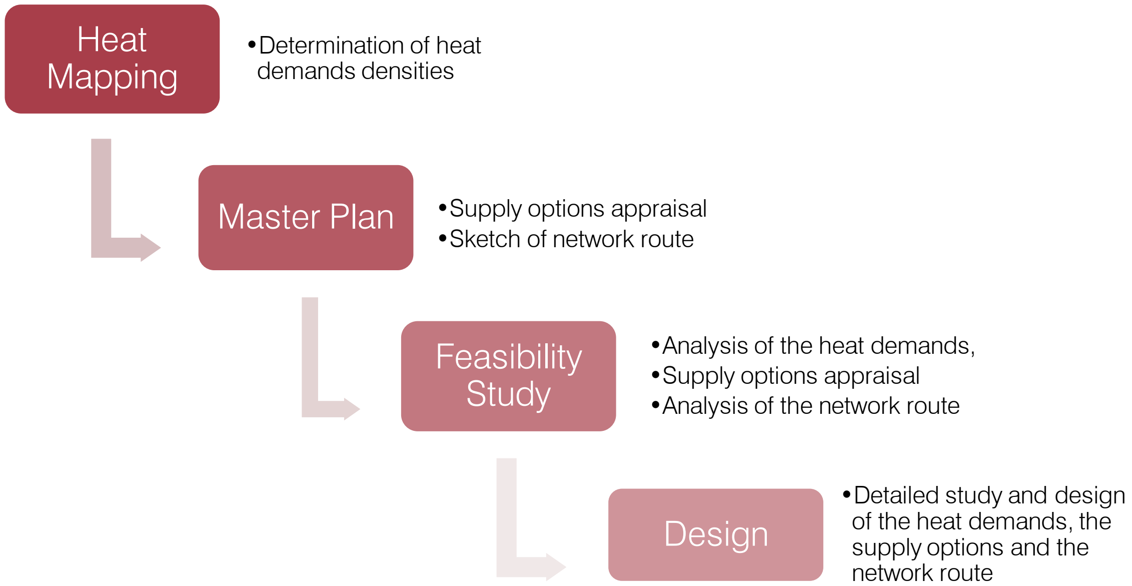

Figure 1: Outline of the Planning and Design Process for new DH Systems

Consequently, and in order to incorporate a larger number of environmental impacts in the decision-making process of supply options for new DH, an exploratory approach was engaged in chapter 3 to select the supply options and potential environmental impacts that this thesis would explore. These supply options and environmental impacts were introduced in an Excel-based model or tool that performs a preliminary analysis of the environmental impacts of a selected heat supply option and allows its comparison with other alternatives.

In order to create a model that could be used in the context of Europe and be used prior the performance of an EIA and the final decision-making stages, the scope was set to include only environmental impacts analyses that were comparable to all European countries and accessible to calculate in early stages of the DH system design. The goal was to give tools to decision-makers, engineers and designers to select with more knowledge, in early steps of the process (Masterplanning and Feasibility Study stages), the heat supply options that can be further analysed and explored.

Obviously environmental impacts are not the only subject that needs to be analysed in the supply options appraisal but they should be part of it beyond the calculation of CO_2 savings that the new systems may encompass.

2 FRAMEWORK

Despite the technical flexibility associated to DH and its potentiality to incorporate renewable energy sources (European Commission 2016a), DH systems follow mainstream trends in terms of fuel and technologies used as presented in chapter 1. There are not detailed studies analysing the reasons for such bias towards conventional heat production methods but it seems reasonable to think that the use of well-proven technologies such as boilers and CHPs and widely-used fuels as natural gas or coal is, at least partially, due to the familiarity that planners, engineers and designers have with them.

Several EU-funded programs and other European projects (as declared in chapter 1) work to spread the use of district energy and the incorporation of renewables in it. In a way, their activity aims to increase the awareness of district energy, to raise the awareness of the system itself and the renewable technologies and fuels that can be incorporated in such systems.

Lund (2014) in his **Choice Awareness Theory** argues that, at the societal level, when implementing radical technological changes such as renewable energy systems[3], existing organisations will influence the perception of choice that society holds, leading to a denominated False Choice. According to Lund (2014, 16), "*a* true *choice is a choice between two or more real options, while a* false *choice refers to a situation in which choice is some sort of illusion*." The false choice when implementing district energy systems and DH systems, would be the belief that only conventional systems can be used, i.e. individual boilers, and, specially, that only conventional fuels and technologies can be used in the DH systems since renewables are not well-proven and developed enough, i.e. DH schemes with boilers or gas fired CHPs as main heat supply.

The creation of a false choice is called by Lund as the first thesis of the Choice Awareness theory and it could involve the exclusion of technologies from the decision-making process or the design of feasibility studies in a way that they exclude the radical new technologies.

The second thesis states that society will gain profit from raising the awareness that alternatives exists, that they are feasible and there is a possibility to have a choice. It goes from a false choice to a true one. Lund (2014, 34) suggests the promotion of awareness by:

- *Promoting the description of concrete technological alternatives in various debates and decisions on new plans and projects at all levels*
- *Promoting feasibility study methodologies that include relevant political objectives in the analyses*
- *Promoting the concrete description of public regulation measures to advance new technologies*

It is in this framework, in the promotion of feasibility studies that include political objectives in the analysis, that this report fits. The model developed aims to increase the knowledge related to heat supply in district heating systems in the planning stage. By broadening the knowledge

[3] The implementation of renewable energy systems is considered by Lund as a radical technology change because involves an economic redistribution, displacing current fuel-based energy systems by investments in energy conservation and other energy plants that require different resources and, therefore, different types of management and investments. Lund exposes as an example the replacement of coal mining by the harvest of biomass resources.

and increasing the data available, decision-makers, engineers and planners could have a better understanding of the supply options in play.

This model is a first attempt to gain comparable knowledge between heat supply options for district heating. It aims to deepen the knowledge about the environmental impacts associated with the heat supply and to expand the data necessary to evaluate the heat supply options in the first stages of the planning process (see Figure 1) for the implementation of new DH schemes. Many district heating studies and projects are realised with the goal of reducing CO_2 emissions to reduce the contribution of heating and cooling to climate change. However, most of these projects only account for economic and CO_2 motives when studying and proposing the heat supply options for district heating. Impacts beyond CO_2 emissions are often dismissed in the first planning stage and it is not at the design stage of the district heating scheme and the Environmental Impact Assessment (EIA) comes into play that these impacts are analysed.

Regardless of the system manager being the public administration, an ESCo or a private company, the public (often local) administration has an important role in their implementation and is usually the final decision-maker. Since there are high probabilities that the decision-maker does not have the complete technical knowledge, the design of the feasibility and design studies that define the system and propose the alternatives have higher significance. Furthermore, district heating systems are long-term solutions for towns and cities and require of high economic investments to implement them. This high-risk profile demands of a deeper understanding of the system to be implemented.

Strategic Decision Making theories suggest methodologies for strategic intervention in collective decision-making that can be sided alongside Lund's theories about the need to promote feasibility studies that include relevant political objectives. Stokman et al (2000) propose a three-step methodology for collective decision making that starts with the decomposition of the problem into a few main issues. The second step is a process of systematic interviews of the subject area specialist and the third engages a computer simulation to select the optimal outcome.

The division of the problem or the decision-to-make into a few main issues or controversial points (first step of the Stockman's methodology) allow the determination of the "*contours of the chosen solution"* (Stokman, Knoop, and Harrison 2000, 133). In-deep knowledge or, at least, more specific information about all the elements that conform the problem to be solved is an essential process to make informed decisions.

Regarding district heating systems, these main issues are usually related to technological feasibility, economic concerns, and the influence of the systems in the climate change reduction policies and plans. They often overlook at social and local environmental issues that are highly linked with the localism that district energy incorporates intrinsically.

This thesis can be aligned in this first step of the decomposition of the problem by broadening the environmental issues that DH systems have beyond the climate change and take them into the local area where the district energy systems are bound to be implemented. It provides more information and data to be used in the analysis that all new DH system projects should incorporate.

3 THE MODEL BASIS

The Excel-based model presented in this project was developed to broaden the environmental issues that are usually associated with the DH systems design and analyses and, therefore, to contribute to the information that the first step of the Strategic Decision Making theory determines.

The base to create the model was the selection of the supply assets that were to be analysed and the indicators that would evaluate the supply options.

3.1 Selection of Supply Options

Since the EIDH-1a is aimed to be used for designers/engineers and decision-makers, the fuels and supply options that the tool incorporates are aligned to what is already well-developed and in use in the market nowadays regardless of its penetration. The Working Document for the EU Strategy for Heating and Cooling (European Commission 2016a) was determinant when selecting the supply technologies that were to be included in the model.

Table 1: Heat Supply Technologies Selected to Be Included in the Model

Technologies
CHP (engines and turbines CHP)
Water/Ground Source Heat Pumps (W/GSHP)
(Heat) Boilers
Solar thermal panels

Another limitation factor that played a major role in the fuel and technology selection was the data availability to estimate their impacts. The lack of air pollutant emission factors for some fuels in the EMEP/EEA database determined the inclusion or exclusion of fuels, for example. Experimental fuels such as syngas are not taken into account in this version of the model. Therefore, the range of fuels and technology options that the EIDH-1a analyses are:

Table 2: Combination of Fuels and Technologies that EIDH-1a Supports

Fuels	Technologies
Natural Gas	Engine CHP
	Gas Turbine CHP
	Medium sized boiler
	Individual boilers
Biomass	Medium sized boiler
	Engine CHP
	Individual boilers
Electricity	W/GSHP
Coal	Medium sized boiler
	Individual boilers

Fuels	Technologies
Gas oil	Reciprocating engine CHP
	Individual boilers
--	Solar thermal

The model does not analyse Energy from Waste and Heat Recovery technologies since there is a wide range of variability in the technologies itself and the emission gases released although their use in a DH system could be beneficial in economic and environmental terms.

3.2 Selection of Indicators

In a similar fashion of a preliminary EIA, this tool aims to give a first analysis of the potential environmental impacts of the heat supply plants during their lifetime based on non-detailed information about the heat supply options and the energy demands that the new system should meet.

This section aims to replicate the scoping of an EIA to determine the potential impacts that the new DH heat supply might incur and, therefore, identify the indicators that will assess their suitability.

Obviously, the environmental impacts of the supply options will depend on the fuel and technology used and the range of heat provided by them. To be able to assess all fuels and technologies selected in 3.1, the indicators chosen need to cover effects on the air, the land and the water.

3.2.1 Air impacts

Traditionally, effects on the air are the most analysed when studying DH, mainly because natural gas is one of the most used fuels and CHPs or boilers the most common technologies. Combustion technologies such as the previously mentioned have the emission of pollutants into the air as their main impacts and concern.

The composition of the exhaust gases depends on the fuel used (its chemical composition and its quality), the type and size of the equipment used for the combustion and the quality of the combustion process itself. So the combination between fuels and the technology used will determine the potential air impact related to DH. Operation condition of the plants also plays a role in the composition of the exhaust gases and its impacts.

The most common pollutants associated with the combustion of small combustion activities associated with DH schemes are usually oxides of carbon (CO_2 and CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), particulate matter under 10 microns and under 2.5 microns (PM_{10} and $PM_{2.5}$ respectively), volatile organic compounds (VOC), dioxins, hydrogen chloride and hydrogen fluoride, polycyclic aromatic hydrocarbons, and heavy metals as mercury and cadmium. Other pollutants with greenhouse effects such as methane (CH_4) and nitrous oxide

(N_2O) are also released (European Commission 2016b; Princeton University - The Art and Science of Motorcycle Design 2011).

Generally, the emissions into the air are divided into two main groups depending on their effect: Greenhouse gases (GHG) for their effect on the global scale and Local Air Quality for those pollutants that might cause adverse impacts on the local air quality and, therefore, on the local inhabitants' health. The latest have greater importance when talking about DH schemes where the heat supply plants are usually located in close proximity to inhabited areas and the network and buildings supplied.

Global Air Quality and Greenhouse Gases (GHG)

Carbon dioxide (CO_2) and other gases with greenhouse effect (methane, nitrous oxide, perfluorocarbons,…) are emitted as subproducts of combustion. As stated earlier, the exhaust gas will have different concentration depending on the fuel used and the combustion process chosen. The global impacts of GHG emissions can be evaluated by an estimation of their total annual emission, a total emission that contributes to the global concentration of these gases and their effect on the climate.

Local Air Quality

Similarly as the GHG emissions, other pollutants released in combustion processes are dependent on the fuels and technologies used.

Since these pollutants have a direct effect on the human health they require further analysis beyond the calculation of the total annual emissions. As Torchio, Genon, Poggio & Poggio (2009, 227) estate, "*the distinction between the local and global emissions is fundamental for some pollutants such as SO_x, PM and NO_x.*" They suggest a conversion of the emission factor (mg/kWh), useful for global analysis, to a source emission flux (mg/s)

Since DH systems and their heat supply plants are situated in the middle of the community they serve and, additionally, they have shorter stacks than larger power plants, there is a need to considerate their impacts at smaller spatial and temporal scales (Petrov, Bi, and Lau 2015). Petrov, Bi and Lau (2015) suggest the use of the *Inhalation Intake Fraction* (iF)[4] indicator as a tool to assess air pollution and public health since it has been widely used as a key metric for evaluating population exposure to pollutants from a stationary source. The authors also alerted about the importance of accounting for microclimatic characteristics and local orography when applying the iF. They conclude that "*it is thus essential to take into consideration temporal and spatial variations of atmospheric conditions and dispersion, population density and varying aspiration rates in accurately assessing the health impacts of DES* [District Energy Systems] *located at densely populated urban communities.*"

[4] The Inhalation Intake Fraction is a metric that summarizes the emission-to-inhalation relationship and facilitates comparisons among sources in terms of their exposure potential (Marshall and Nazaroff 2006).

Noise

Not only associated with combustion processes, heat production for DH can entail the emission of noise and vibrations. The location of the plant respect residential areas and sensitive buildings such as hospitals is key to determining noise impacts. The building that contains/encapsulates the plant plays also a major role since it can abate the noise perception in the neighbour areas.

3.2.2 Water impacts

Impacts on water bodies related to the use of energy plants to provide heat to DH schemes can be related to the direct use of the water body (basically water or ground source heat pumps) or to fuel spills into it (any type of supply plant located near a water body). While the second type is usually related to accidents and inaccurate management of the plant, the first type is dependent on the type and design of the plant.

The EU Water Framework Directive (European Commission 2000) defines heat as a pollutant and the temperature of water bodies as one of the conditions to account when determining the quality of the physicochemical elements. To reach high status, the temperature must not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed waters.

Generally, open-loop water or ground source heat pumps (W/GSHP) are the technology type that has a more direct use of water bodies since they take water through an inlet and return it later on through and outlet presumably with a difference in temperature. Temperature change in surface water bodies has effects on the physicochemical characteristics of the water body, which affect indirectly the biota of the ecosystem, and direct effects on its biological diversity and activity (Alabaster and Lloyd 2013; Abel 1996).

Close-loop W/GSHPs have an insulated piping inserted in a water body that contains water continuously circulating. Both systems can cause changes in water temperature and, therefore, impacts on the fauna and flora inhabitant the water body.

Open-loop W/GSHPs also carry the risk of accidental spills of antifreeze or other chemical products used in the daily management of the plant.

Finally, other impacts related to GSHP are directly linked to the drilling of boreholes, which can lead to hydrogeological impacts such as breaching aquitards[5], exposing aquifers to pollutants and enhanced salinity (Dehkordi and Schincariol 2014), water flow circulation interference and connection of aquifers when located in a multiple aquifer horizons (UK Environment Agency 2010).

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[5] A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water (U.S. Geological Survey 1989). In other words, an aquifer with low permeability that does not allow the transmission of water.

3.2.3 Other impacts

Other than the obvious impacts on air and water specified before, new heat plants can have other impacts depending on its location and the space that they require.

Loss of soil and agricultural land, diminution of rain-percolation and displacement of local species are directly related to the spatial area that is needed by the plant and the status of the parcel where it is located. Being a greenfield or a brownfield or the soil contamination status of the area where the heat supply plant will potentially be located is of relevance. These impacts are mainly related to the installation of solar panels, which usually require higher space availability, horizontal GSHPs and the heat storage that the DH scheme might require.

4 METHODOLOGY

The development process to create the EIDH-1a started with a literature review of the analyses of DH supply options, which showed a lack of literature about comprehensive environmental impacts of DH and the supply options linked to it. One can assume that EIA studies have been undertaken in the process of planning and constructing DH schemes but there is a lack of literature regarding their environmental impacts and the best approach to their quantification and the suitability of each supply option that is analysed in the early stages of planning

The methodology adopted in this thesis follows the process delineated in Figure 2 below:

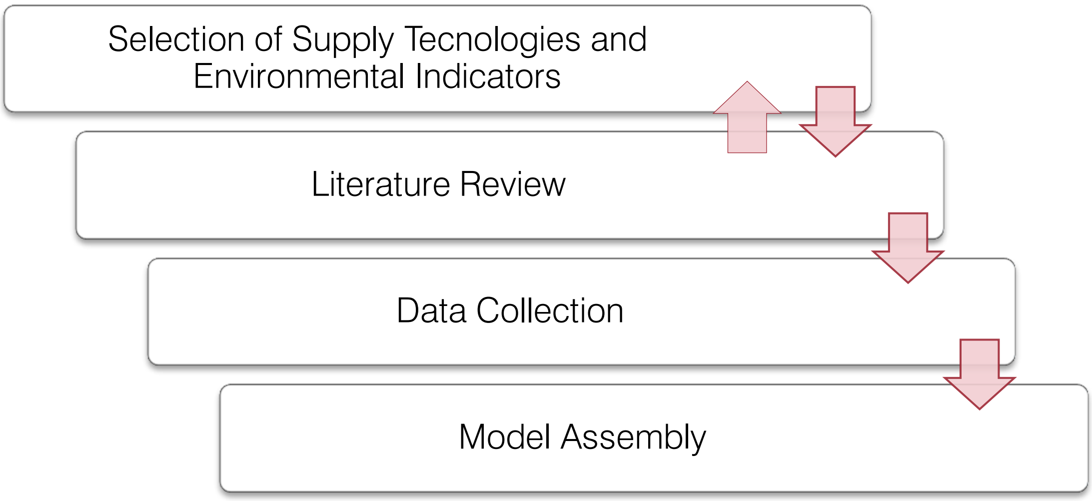

Figure 2: Schematic Methodology Process

4.1 Literature Review

First, a literature appraisal was undertaken to determine the extent of the current research status regarding the multiple impacts that the implementation of DH holds. Beyond the studies that endorse DH use and its social and economic benefits and its potentiality to reduce CO_2 emissions[6], not much research was available.

The review was conducted through an online search using AAU's library portal and Goggle Scholar being *supply, supply options appraisal, district heating, district energy, impacts, environment, air quality* and *emissions* the key research words.

In terms of environmental impacts of DH, the literature review highlighted two different lines of study regarding the environmental impacts of DH both linked to local air quality.

[6] Some examples are:

- The role of district heating in decarbonising the EU energy system and a comparison with existing strategies (David Connolly et al. 2013),
- Realising the social benefits of district heating through strategic planning (Bush and Bale 2014),
- Energetic, exergetic, economic and environmental evaluations of geothermal district heating systems: An application (Keçebaş 2013),
- The role of district heating in future renewable energy systems (H. Lund et al. 2010).

A first approach was to analyse the emissions of other gases than CO_2, gases than have a great potential as local air pollutants. Torchio, Genon et al (Torchio et al. 2009; Genon et al. 2009) analyse the impacts of district heating to the local air quality, mainly the emission and dispersion of nitrogen dioxides in Italy while Keçebaş (2013) includes in his study a quantification of the reduction in air pollutants emissions of a geothermal DH system in Turkey compared to fossil fuels. In both cases, but specifically in the Italian studies, there is an emphasis on how DH systems can help to reduce global environmental effects but they pose troubles in the local environment effects due to NO_x emissions of CHPs.

The second line of study is the proposed by Petrov et al (2015), who suggest a new methodology to study the impacts of district energy to the local/community health. They incorporate spatial and temporal dynamics of pollutant concentrations, site-specific geographical characteristics and population density variables in their analysis. They use the *Dynamic Intake Fraction* (iF) as an indicator to analyse and compare the effects of the previous variables.

4.2 Data Collection

Once the status of the research was established the following step was gathering the data necessary to shape the excel tool and fill it with contents.

The previous Literature Review helped in the recognition of the indicators to choose but also in the selection of databases to use.

4.2.1 Air Quality

Since the air quality indicators are basically an estimation of CO_2, NO_x, SO_x, CO, VOC, PM_{10} and $PM_{2.5}$ emissions for each supply option, the data collection was restricted to a recollection of emission factors (gr/kWh) for each pollutant and included in a database/tab of the excel-based tool.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories were the basis to stipulate the Europe general CO_2 emission rate associated with natural gas, wood/wood waste, gas/diesel oil and coal (anthracite) combustion.

Furthermore, United Kingdom's 2015 Carbon Factors from the Department for Environment, Food and Rural Affairs (DEFRA) and the Department of Energy and Climate Change (DECC) comprehended $CO_{2equivalent}$ intensities for a range of fuels used in the UK which was used to estimate more accurately UK's emissions. The same database contained CO_{2e} intensities of electricity for all other European countries and a Europe Average, which were selected to determine the CO_2 emissions associated with electricity consumption for the relevant technologies (basically heat pumps) and countries.

Spanish $CO_{2equivalents}$ emissions for electricity production and the carbon intensity of the natural gas consumed in the country were extracted from Magrama (Ministry of Agriculture and Environment) and added to the database.

The emission rates associated with the other range of pollutants were extracted from the *EMEP/EEA air pollutant emissions inventory guidebook 2013* (EEA 2013) from the European Environment Agency. The EMEP/EEA includes factor emissions for local pollutants (NO_x, SO_x, CO, VOC, PM_{10} and $PM_{2.5}$). This guidebook differentiates the emissions by fuel and, up to an extent, the technology used. The EMEP/EEA includes the plants that supply heat to DH schemes into the category 1.A.4 Small combustion and within this section in the commercial/institutional category. All emission factors can be checked in Appendix I.

4.2.2 Other indicators

The indicator values associated with the rest of indicators described in section 3.2.2 and 3.2.3 do not answer to direct rates or factors but to assessments based on the literature review.

Thus, the selection of the indicator values for the water quality was associated with the temperature ranges that Abel (1996) and Alabaster and Lloyd (2013) describe in their respective books.

Similarly, the indicators of impacts on the land surface were assigned without a direct relation to current factors, databases or catalogues.

4.3 Evaluation Criteria

EIDH-1a, as stated previously, is an excel-based model that aims to widen the range of indicators or data assessed during the selection of the potential heat supply assets for DH schemes. Therefore, the model incorporates the indicators identified in section 3.2 and associates them with the specific characteristics of the DH system analysed.

Table 3: Indicators Used in EIDH-1a

Group	Subgroup	Indicator
Air Quality	Climate Change	Total annual CO2 emissions
		CO2 emissions ratio against base scenario
	Local Air Quality	Total annual emissions of NOx, SOx, CO, VOC, PM10 and PM2.5
		NOx, SOx, CO, VOC, PM10 and PM2.5 ratio against base scenario
Water Quality		Temperature Change Impacts
		Discharge Water Temperature
Land Use		Land Use

Traditionally, the evaluation of the impacts related to the installation of DH schemes and the heat supply options associated with them is assessed comparing the new system to a previous scenario or traditional heating systems. This is due to the assumption that the heating needs of the population are to be met regardless of the system and, therefore, the impacts are related to the changes between systems instead of the system itself.

The tool is designed to compare different scenarios for each DH system studied, allowing for a better characterisation of the impacts of different heat supply plants.

The assessment of the Indicators identified in the previous section 3.2 is performed using a double evaluation. First, each indicator is evaluated according to a base or reference scenario that the user would define, for example, a Business as Usual scenario, creating a ratio for each. As an example, the GHG indicator estimates the CO_2 emissions for the scenario analysed and for the base scenario defined by the user of the tool. Posteriorly, the tool rates the scenario analysed emissions with the base scenario. Only one technology type can be selected for covering the base heat demand and only one for the peak demand since it seems this is the most common approach in Europe for geothermal heat pumps DH (Dehkordi and Schincariol 2014) and almost certainly other systems.

Water and Land Indicators are not analysed according to a base scenario since the most common base scenarios are the use of individual boilers in each building and, therefore, there is no comparison possible.

Afterwards, each ratio is pondered according to the user preferences. This user ponderation is deemed to account for a better adaptation to local characteristics and needs. The model assumes that the user is aware of the most important issues in the local area where the DH is being planned and, therefore, can identify the most relevant impacts. This allows for acknowledgement and adaptation to local features. The ponderation, a scale between 1 to 5 points, forces the user of the EIDH-1a to analyse what are the most relevant impacts in the particular case studied and to reflect the importance of the criteria selection has in the decision-making process.

Finally, the model sums up all indicators' values to get a range that allows for comparison with other scenarios. The lower the final value, the better hence it indicates that the new system has better performance than the Base Case scenario.

4.3.1 Air Quality

To assess the impacts of the DH scheme and its associated heat supply plant on the quality of the air, the main input needed is the fuel used, the efficiency of the plants, and the emission factors (Torchio et al. 2009). The model incorporates and uses the emission factors for each of the pollutants established in section 3.2.1 and allows the user to choose the fuel and efficiency of the plant.

EIDH-1a allows the user to choose between different heat supply technologies to meet the base and peak demands and the emissions estimation is calculated accordingly. The tool links each emission factor associated with a certain technology/fuel with the heat that each supply is supposed to provide.

The model has different hourly distribution profiles of the annual demands for Croatia, Czech Republic, Italy, Romania and the United Kingdom extracted from the Stratego project (Euroheat & power aisbl Coordination 2015). A generic distribution profile is linked to the rest of European countries (D. Connolly, Lund, and Mathiesen 2016). These hourly distribution profiles are adjusted to adapt to *Operating profiles* of the base heat demand supply plant. The different Operating profiles that EIDH-1a currently offers are:

- Permanently in operation. This assumes that the plant that covers the base heat demand would be functioning continuously throughout the whole year. This profile obviously overestimated the annual operating hours since scheduled stops for maintenance and failures can occur.

- 17 hours per day. This profile assumes that the plant would work continually throughout the year but only during 17 hours a day, ceasing activity during night time from 10 pm to 5 am. This profile is often used in urban areas to avoid noise and other nuisances to neighbours. It also allows the plant to be operating during the hours where the demand is usually higher.
- 17 hours per day excluding summer times. This profile follows the same principles as the above but it ceases activity during the three summer months when the heat demand is at a minimum. This should allow the design of the heat supply plant for a higher base load compared to the previous profile and, probably, design it for a better performance.
- 15 hours per day. Similarly to the two profiles above, in this case, the heat supply plant is functioning only 15 hours during daytime from 7am to 10 pm.
- 15 hours per day excluding summer. As above but ceasing function during the three summer months.

These operating profiles are used to index the country hourly distribution profiles so the base and peak loads can be defined. This is done by assuming that the base load heat supply plant would be functioning at its highest capacity continuously when operating. For example, a gas reciprocating engine CHP that would provide heat to meet the base heat demand with a 17h/day operating profile would work at its highest capacity during 17h each day and stop working during the rest of the time. This simplification of the reality allows for faster analysis of the consumption profiles and, therefore, of the emissions associated with them.

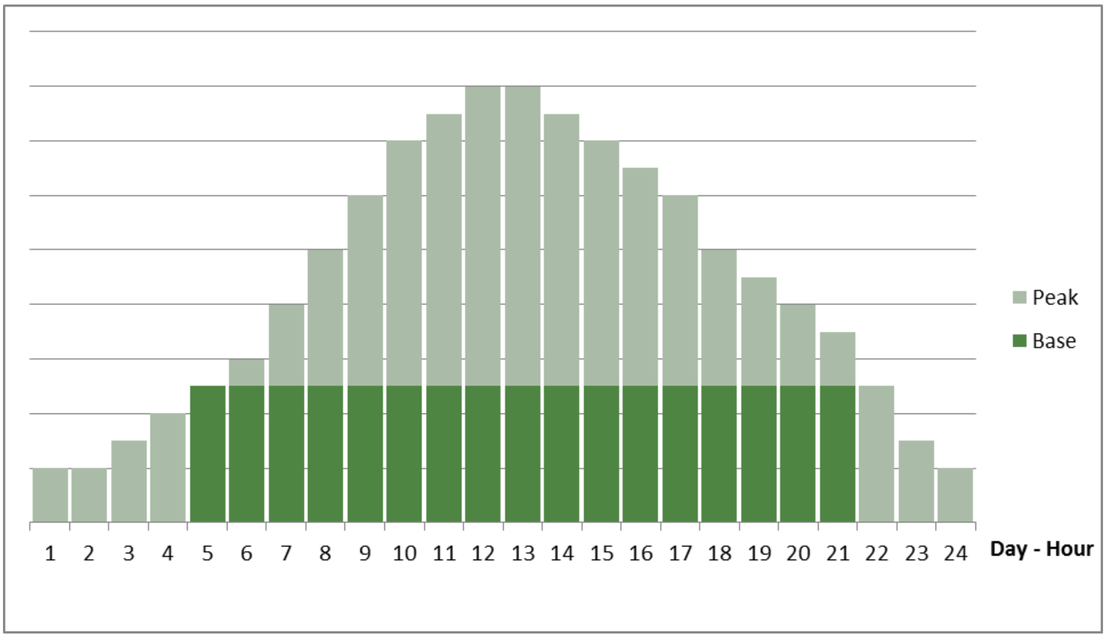

Figure 3: Example of Hourly Consumption for a 17h/day Operating Profile

The capacity of the base heat supply plant is calculated by establishing the lowest value of the consumption demand in the distribution profile and applying that constant value to the correspondent operating profile. Figure 3 exemplifies a 17h/day operating profile where the lowest demand was used to determine the constant heat production of the base plant while the rest of the demands would be met by the peak heat supply plant. Therefore, the peak demand proportion was calculated by extracting the proportion of the heat provided by the base supply from the total proportion of the country demand distribution profile.

The total annual demand of the potential DH systems analysed is then applied to the base and peak proportion taking into account the efficiency associated with each technology. This determines the capacity needed for the base and peak heat supply plant. The model also analyses the number of hours that each plant is functioning so it can determine the total annual kWh of each plant.

Global Impacts

The model calculates the total annual CO_{2e} emissions following the 2006 IPCC Guidelines (Gómez et al. 2006) for the heat supply technology selected by the user applying the emission factor of each fuel to the total annual heat production associated with each technology (base and peak heat supply plants) producing an estimation of their impact. Plants that supply heat to DH schemes can be included under section *1A1 a ii* (CHP) or *1A1 a iii* (Heat Plants) of the 2006 IPCC Guidelines. When country-specific data was located, the correspondent CO_2-equivalent emission factors were considered in the emissions calculation. Posteriorly the EIDH-1a compares the total CO_{2e} emissions of the proposed scheme with the estimated CO_{2e} emissions of the reference scenario, which were estimated following the same mechanism[7], realising an indicator value that has a positive impact if is lower than 1 and a negative impact if the new scheme emissions are larger than the base scenario and, therefore, the indicator has a value larger than 1.

The emissions estimation calculation followed the methodology established by the 2006 IPCC Guidelines where the total emissions are the summed over all emissions of the fuels used following the equations 1and 2.

$$Emissions_{GHG,fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,fuel}$$

Equation 1: Greenhouse Emissions from Stationary Combustion (reproduced from the IPCC Guidelines)

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,fuel}$$

Equation 2: Total Emissions by Greenhouse Gas (reproduced from the IPCC Guidelines)

[7] This version of the tool only allows the use of one technology and fuel for the base case scenario and, therefore, the emissions estimations are calculated assuming that the technology chosen meets permanently the heat demand established by the hourly distribution heat demand.

Furthermore, even though some of the plants analysed in the model do not have direct emissions since their production of heat does not involve combustion processes, indirect GHG emissions are accounted when they need electricity to operate as is the case of heat pumps. Country-specific electricity CO_{2e} content from the 2015 UK's conversion factors (Ricardo-AEA, DEFRA, and DECC 2016) has been used to determine the emissions generated to produce the electricity that feeds the heat pumps.

Local Air Quality Impacts

Emissions

In a similar fashion, the model estimates the total annual emissions of the pollutants identified according to the fuel selected and compares them with the emissions than the base scenario would produce. In this case, the indicator is considered positive if it has a value lower than 1 and negative if it has a value larger than 1.

The potential air pollutants that EIDH-1a evaluates are NO_x, SO_x, CO, VOC, PM_{10} and $PM_{2.5}$.

Since the potential impact on the population health of the air pollutants is not only determined by the total annual emissions but the concentration of such pollutant and its dispersion, a concentration estimation is performed taking into account the probable emission rate of each pollutant, the fuel type and the hourly consumption profile. The total annual emissions estimation is performed following the same methodology as for the GHG emission estimation.

The model has limited availability of emission factors ranges of fuels and technologies. Thus, when the fuel and technology selection does not comply with the combinations presented in Table 2, the tool assumes that the pollutant emission is 0.

The hourly consumption profile allows an estimation of the heat output of the plant (kW) each hour and taking into account the flow rate of the stack (m^3/s) and the emission factor (mg/kWh) of the pollutant, an estimation of the pollutant concentration (mg/m^3) by hour can be calculated. Moreover, an estimation of the pollutant flow rate (mg/s) is also calculated. The flow rate of the stack is calculated by using the approach suggested in a VGB Powertech report (Blank et al. 2014). This approximation allows an estimation of the fluctuation of the pollutant concentration in the stack, an identification of the maximum concentration that can be reached and its emission rate and suggests potential impacts on the surrounding population health. The dispersion of the pollutants in the nearby areas is not assessed by the EIDH-1a due to the increasing complexity of the calculation and data that needs to be entered by the user.

The total annual emission (Kg) for each pollutant is compared with the values for the Base Case scenario that, likewise as the Global Impacts indicator, realises an indicator value with a positive outcome if it is lower than 1 and a negative outcome if it is larger. The model also presents the maximum emission rate (mg/s) for each pollutant.

Dynamic Intake Fraction

Furthermore, the model also roughly estimates the Dynamic Intake Fraction for the new DH scheme and compares it with the value associated with the base scenario. Following Petrov et al (2015) approach, inhalation iF is calculated as the portion which is being inhaled by exposed population as per the following formula:

$$iF = \left\{ \sum_{i=1}^{m} \sum_{j=1}^{n} \left[P_{ij} \times C_{ij} \times BR_i \right] \right\} \div Q_i$$

Where:

- Q_i (kg/day) is the emission rate of a pollutant in a given time period i (hours) at a geographical area or location j,
- C_{ij} (mg/m^3) is the ambient air pollutant concentration in time period i at receptor location j,
- BR_i (m^3/person/day) is the breathing rate during time period i, and
- P_{ij} is the number of people at a specific location and time.

Since the iF demands local and specific knowledge of the area where the new plant is to be built, some assumptions need to be taken. Therefore, an average of 9,7 m^3/person/day was estimated according to the combined male and female average breathing rate stated in the US Environmental Protection Agency's Exposure Factors Handbook (National Center for Environmental Assessment 2011). Even though the Handbook is thought to be applied in the US, the Nordic Exposure Group Project consider them to be also valid for European Countries (Nordic Exposure Group Project 2011 2012). Referring at Q, the model assesses it considering its value as the average of the year, where the total emission mass of each pollutant is distributed equally throughout the year. The indicator also needs the input of the local pollutant concentration. Since there is no possibility to access this detail of data, this input needs to be included by the user. The model only allows the input of average concentrations for each pollutant to facilitate the collection and introduction of data. Since the aim of the tool is to compare the proposed scenario with a reference or base case, the errors that follow this simplification are reduced. For the emission rate, the same approach as in the previous indicators was taken.

4.3.2 Water

Although the risk of accidental spills is present in all type of plants, the affectation on water bodies, surface or ground, is higher in heat supply plants that use them directly to extract heat. Therefore, the impacts on water solely analyse heat pumps, water or ground source. It should be noted that some classes of GSHP do not use water bodies to extract heat but the ground. This is taken into consideration in the analysis.

While is quite easy to estimate the temperature that the reinjection water will reach in a W/GSHP system, the water body characteristics will determine how this plume[8] will affect the temperature of the receptor water. Due to the complexity of calculating the average increment of temperature in the receptor water body the model only takes into account the ΔT of the system.

Although dependent on the range of the temperature change, some physicochemical effects are the reduction of dissolved oxygen, an increase of the toxicity of elements and pollutants present in the water body and increase of dissolution of elements. Furthermore, temperature change also affects the capacity of the water body to dissolve or mobilise other pollutants, increasing the effects that other discharges, related or not to the plant, have on the body water. The temperature change can also affect directly the biota present in the water body although every species have different temperature ranges for their thermal lethal point and their temperature signals for migrations and reproductive cycles (Abel 1996). Further impacts of temperature change in fish are variation in metabolism rates, spawning trigger. Studies on fish and water quality have revealed that fish tend to acclimate themselves to temperature variation if its gradual, occurs over a limited range of temperature, and, obviously, it does not reach the lethal temperature although impacts can be perceived in fish richness and diversity (Abel 1996; Alabaster and Lloyd 2013; Teixeira, Neves, and Araújo 2012). Moreover, disparities between studies analysing the effects of discharge water from energy plants seem to indicate that the characteristics and, probably, the hydrodynamics of the water body play an important role in the effects of the heat plume. For example, Teixeira et al (2012) found significant impacts on their study of a cooling water discharge from a power plant in Brazil meanwhile Wright et al (2000) localised the effects of a power station cooling discharge on the Thames River in the close vicinity of the discharge point.

Other studies on impacts of groundwater heat discharge, specifically designed to analyse energy systems as heat pumps have found similar results (Dehkordi and Schincariol 2014; Brielmann et al. 2009), although Brielmann et al have assessed a ±6 °C temperature deviation as acceptable for bacterial indicators in groundwater.

The effects on groundwater quality depend on the type of GSHP used and the type of aquifer. Closed-loop systems do not use directly groundwater and, therefore, the risk of impacting the groundwater by adding chemical pollutants is lower than open-loop systems. However, they also can pollute the groundwater body with heat or leaks of the thermal transfer liquid or brine used in the loop. Again, the level of the effects depends heavily on the temperature changes on the water body and the water system itself. For example, since "*shallow geothermal systems are often realised in the same aquifers used for the production of drinking water*" (Bonte, van

[8] In hydrodynamics, a plume is a fluid structure developed in reaction to localised inputs of buoyancy and driven by its heat flux (Cushman-Roisin 2014).

Breukelen, and Stuyfzand 2013, 5089), the temperature change can affect the quality of the drinking water. Temperature is a key driver of hydrogeochemical and biological processes and, therefore, temperature changes can potentially influence groundwater systems (Brielmann et al. 2009) in the same way that can affect surface water systems. As Brielmann et al (2009) summarised, potential effects of the reinjection of heated groundwater can be carbonated precipitation, increase of silicate minerals dissolution, organic compounds mobilisation from sediments and decrease of groundwater oxygen saturation. In their study of an active temperature discharge facility in Germany (with a maximum reinjection temperature of 21 °C), Brielmann et al (2009) did not found a direct relation between the heat plume and the bacterial counts and activity although there was a clear impact on bacterial diversity and faunal community composition.

Furthermore, aquifers can also be linked to surface water bodies, being part of their recharging systems and, therefore, changes or impacts on the aquifers could lead to impacts on the surface water bodies.

Taking into account the groundwater studies analysed in Brielmann (2009) and the range of Disturbing Temperatures for freshwater fish collected by Alabaster & Lloyd (2013) and the existing legislation collected by Dehkordi & Schincariol (2014) and the UK legislation and guidelines for water discharges[9] (UK Environment Agency 2011), the following categories have been deemed appropriate for evaluating the impacts of energy systems on water bodies:

Table 4: Water-Temperature Indicator Categories and Correspondent Values

ΔT	Category	Value
0 – 2 °C	Very low Impact, potentially not noticeable	0
2 – 6 °C	Low Impact, low disturbance	0.5
6 – 11 °C	Medium Impact, perceptible disturbance	1
>11 °C	High Impact	1.5

As the other indicators, the user of EIDH-1a will have a certain amount of influence in the rating of the impacts when determining the ponderation value for each potential impact as specified in 4.3.

To account for the maximum tolerances by the biota in water bodies, an upper limit of 23 °C[10] for the discharge water in open/loop systems has been set. If the W/GSHP assessed by the model surpasses this temperature it is considered not viable.

[9] These guidelines establish a maximum ΔT of 8 °C reducing it to 2 or 3 °C for good quality water bodies with cyprinids or salmonids.

[10] 23 °C is the lethal temperature for *Salmo trutta* and the lower lethal temperature of all the species studied in the Water Quality Criteria for Freshwater Fish (Alabaster and Lloyd 2013).

4.3.3 Other Impacts

Loss of land

The loss of land due to the implementation of new supply assets and heat storage related to DH systems is relatively a small impact. DH is usually designed to be implemented in urban areas due to its better economic and technically performance in dense areas with high energy demands. This location results in a higher probability of minimising the impacts on the land itself.

The impacts of occupying land are mainly related to the loss of agricultural land (and the associated impacts on the food production), the reduction of water permeability of the soil (and the linked impacts on the aquifer recharges), and the modification of the surface run-off water.

Since the new schemes potentially are to be developed in urban areas, this loss is likely to be minimal because there is a high probability that the area where the heat supply is planned to be located it is neither cultivable land nor permeable. Therefore, the characteristics of the area where the supply asset is to be located are of key importance and the ones that determine the values assigned to the indicator. The other parameter that needs to be assessed is the amount of land that it is rendered to make impervious with the construction of the supply plant. Some technologies need larger areas than others and their impact is directly related to the space occupied and its previous characteristics.

Consequently, it is considered that the location of the supply plant in a greenfield has a bigger impact than if it is located in a brownfield, which in its turn has a bigger impact than if it is located in an already urbanised and impermeable parcel. The values associated with each plot characteristic can be seen in Table 5.

Table 5: Land Loss Indicator Values

Type	Characteristics	Value
Agricultural land or FOREST	The impacts building a new supply asset are the highest since there is a loss in agricultural land or vegetal coverage that can lead to further impacts.	1
Greenfield or Urban Park	Urban or semi-urban areas permeable usually do not hold agricultural activities but can play a role in aquifer recharges and surface run-off water.	0.6
Brownfield	Brownfields, because of its inner features, can be considered as almost innocuous land in terms of agricultural and permeability losses.	0.2
Impermeable plot or existing building	In occasions, the new supply assets can be situated in already constructed buildings, within old plant rooms not in use or roofs, etc. In this case, there is no loss of land and permeability.	0

This indicator, contrarily to the previous where the scores are rated against a Reference Case scenario, does not allow for comparison since it is assumed that the base scenario uses individual boilers and, therefore, there is no use of supplementary land to provide heat.

However, to account for the direct impact on the land loss associated with each technology, the actual square metres that the new plants and the associated heat storage will occupy are rated by the heat demand that they supply (MWh). This ratio is then lessened by the values indicated in Table 5.

The floor area needed to estimate the impacts on land is determined by the user although, in the case of solar thermal installations, the model can provide an estimation of the area needed for the installation. The estimation was based on the F-easy, one of the tools that the Solar District Heating project (Horizon 2020 project 2016) recommends. The tool estimates the surface needed for the installation of the solar panels as a relation between the heat that needs to be supplied annually (MWh) multiplied by 1.5.

Miscellanea

There are other potential environmental impacts that heat supply plants associated with DH can have but due to their nature are difficult to include in this version of the EIDH-1a model. Impacts such as noise pollution of the plants or the effects of nearby point sources emissaries in water bodies[11], for example, are difficult to quantify and include in this particular model and, therefore, they have been included as suggestions. These suggestions are reminders of environmental impacts that should be examined in further stages of the DH system design.

These suggestions are presented in bullet points and are technology related although may be coincidences between technologies. The tool presents the suggestions miscellanea associated to the technology used to supply the base demand heat. The list of the suggestions can be found in Appendix II.

4.4 Tool Assembly

The EIDH-1a model was built in an Excel file so all calculations are centralised in just one file.

The main parts of the model for the user are the Inputs and Outputs tabs. The first one allows the introduction of all the data necessary to perform the calculations defined in the previous sections. The Outputs tab presents the final values of the indicators and the suggestions miscellanea correspondent to the technology selected on the Inputs tab.

EIDH-1a only has one Output tab. However, the creation of copies of such tab or the creation of PDFs files facilitates the maintenance of each scenario analysis and, therefore, its appraisal and the comparative evaluation of the heat supply options.

A tab of the excel file was assigned to each indicator with three additional tabs to contain the hourly distribution demand profiles adapted to account for the different operating profiles, the CO_2 emission factors by fuel and country and the rest of pollutants emission factors in the third tab. There is an additional supplementary tab containing all the lists used in the Input tab.

[11] There is a clear impact of other pollutants point sources on the effect that the studied systems may have. Dehkordi and Schincariol (2014) exposed an example in France of the impact of these proximal systems have in the thermal efficiency of the system and the heat pollution on a groundwater system.

5 EIDH-1A

As explained in chapter 0, the tool is an Excel-based model that follows Figure 4 scheme:

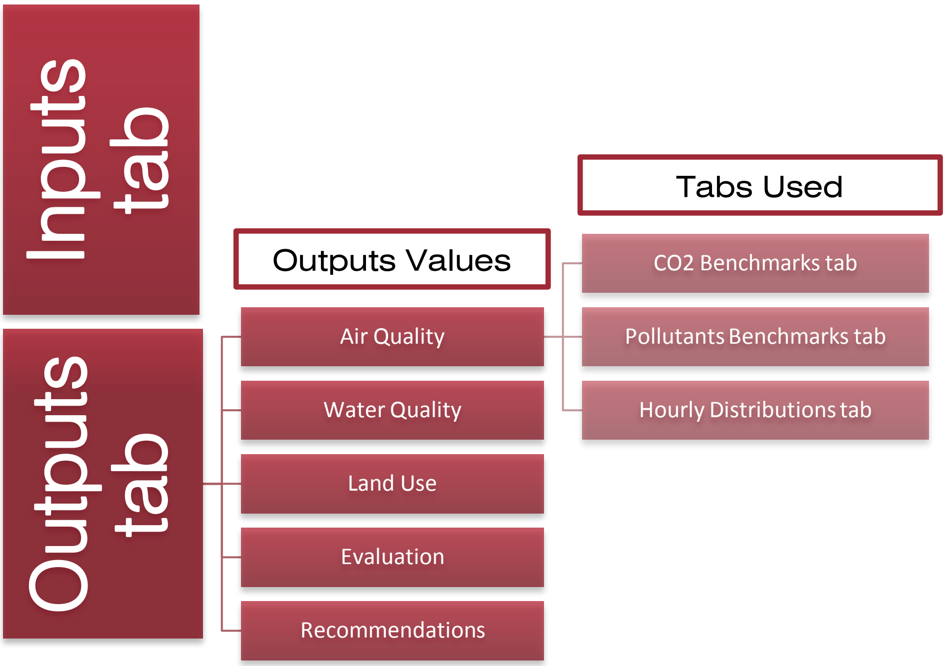

Figure 4: Model Schematics and Tabs Used

5.1 User inputs

Since EIDH-1a is aimed to be used in early planning stages when the design details are not defined, its outcomes are inherently general and broad. Therefore, EIDH-1a is designed so it can evaluate different types of supply assets with minimal information knowledge about the DH scheme characteristics and provide road-range parameters.

These high-level outcomes and values are meant to guide the engineer/planner/decision-maker into the next steps in the decision-making process when choosing the most suitable supply assets for the DH system studied. They allow preliminary examination of the impacts of the potential supply options so only those considered fit are analysed, studied and designed in further detail in the next steps.

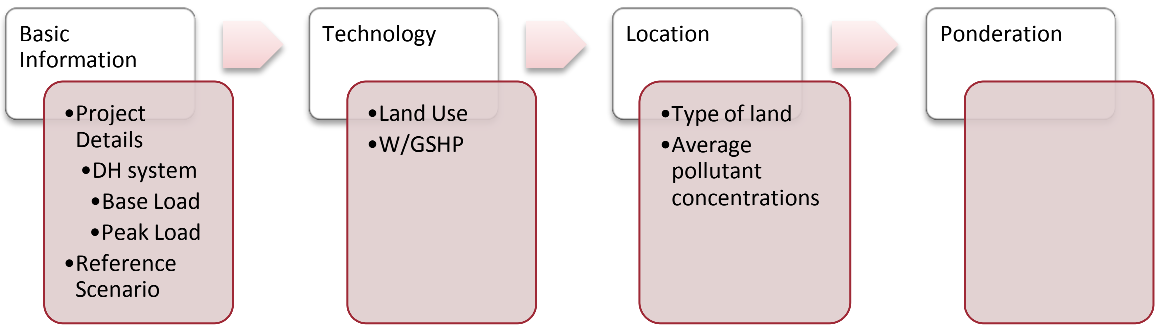

Figure 5: Schematics of the User Inputs

5.1.1 Basic information

Firstly the model asks for basic details about the scheme that is being evaluated including the Project Name, the country where the new DH is located, a scenario name, and the Total Annual Heat Demand in kWh for the DH. This basic information is the base for the majority of the calculations, especially for the Air Quality indicators. The Total Annual Heat Demand, the Project Name and the Country are to remain constant in all scenarios analysed to allow comparability.

It is worth noticing that the model asks for the heat demand and not the fuel consumption since this is analysed a posteriori taking into account the different efficiency rates that each technology has.

The Scenario name or code allows to keep track of different analysis for the same DH systems and to compare them. For example, for the same DH scheme, a Scenario 1a could analyse the use of a natural gas-fired CHP for the base demand, Scenario 1b could analyse the same system but using a biomass CHP for the base demand and Scenario 2a could cover the base heat demand with a WSHP.

The introduction of the country where the system is based will condition some of the calculation since some of the emission factors for the estimation of CO_2 emissions are country-based.

Afterwards, the model allows the selection of the technologies that are to be analysed in the present Scenario from a drop-down list. As introduced in section 4.3, only one technology type can be selected for covering the base heat demand and only one for the peak demand.

Once the technology types are selected, the model asks for the Operating profile of the Base-Load supply plant. Another drop-down list allows the user to choose between the 5 different scenarios that the model uses to analyse the plant performance and emissions associated. If the user does not select one profile the model uses the first profile, permanently operating.

The last set of information that the basic data part of the EIDH-1a asks for is the efficiency that the user wants to apply to the technologies previously chosen. This allows for a better fit in the efficiency of the plants studied in each scheme. The user can also choose to leave the efficiency field blank, in which case the model would use a set of general efficiencies as listed in Table 6.

Table 6: Average Efficiencies by Technology Type

Technology type	Average efficiency	Source
Medium sized boilers	90%	(The Greenage 2016)
Reciprocating engine CHP	80%	(CIBSE 2016)
Gas turbine CHP	90%	(Decentralised Energy 2016)
GSHP	300% (CoP 3.0)	(EHPA 2016)
WSHP	300% (CoP 3.0)	As per above
Individual boilers	85%	

5.1.2 Technology-related information

Once the basic information is entered, the user can also provide further information to calculate indicators that are not directly related to the heat production or data that it is only needed for the impact estimation of certain technologies.

The user can introduce the floor space needed for the heat storage and the plant itself if the information is available at that stage. For solar thermal systems, if the user does not have availability of the area needed to install the panels an estimation is calculated based on the formula established by PlanEnergi in its F-easy tool (Horizon 2020 project 2016).

In the scenarios where heat pumps, both water source and ground source, are analysed the user should enter the ΔT, the difference in temperature between the inlet and outlet in the case of open-loop systems or the difference in temperature between the flow and return section of the loop in close-loop systems.

The discharge temperature is also needed in order to ascertain the impacts of the discharge in relation to the lethal temperature limit for fish.

Again only for W/GSHP, the user can introduce his knowledge about the existence if nearby water extractions from the same water body where the heat pump works.

5.1.3 Area-based information

Furthermore, the user is asked to enter information on the location that the DH system is to be placed so the location-based indicators such as iF or the affectation on land can be calculated.

The user is asked to estimate the population that the DH scheme will serve in order to extrapolate this number as to the population that can be affected by the heat plant impacts.

Next, the user should enter the location characteristics of the heat plant and/or heat storage selecting a value from the drop-down list. This record, alongside the previously entered floor area used, allows for the calculation of the impacts related to land use.

Lastly, as the iF indicator needs information on the current local air quality, the user should introduce the concentration value in the area for each pollutant. These values are usually published by the local authorities in air quality reports, their websites and should be easily available by virtue of the *Directive 2003/4/EC on public access to environmental information*.

5.1.4 Selection of ponderation values

Since there are multiple variations in the schemes that the EIDH-1a cannot account a ponderation system has been put in place so the user can determine what impacts are the most relevant in the DH system analysed. Hence, a 5-point system determines the subjectivity of the user being 5 the value associated with those impacts with more relevance and/or higher susceptibility in the specific case analysed and 1 the value that should correspond to the indicators that have lower relevance in the specific case studied.

5.2 Outputs

The outputs tab in the model displays all the indicators values described in the sections above including the total values estimated and the rated ones for each indicator.

Furthermore, the Outputs tab also adds all indicators values to create a final score. This final score is only valid to compare scenarios between them and it does not provide information on its own. However, the lowest the final score is, the lowest are the environmental impacts associated with that specific scenario.

The output tab in the spreadsheet includes the Project Name and the Scenario analysed so the tab can be exported to PDF format and be kept to compare with other scenarios.

EIDH-1a needs to be run for each of the scenarios so it is recommended to save each Scenario output in a PDF file or to copy the output tab so it creates a new results tab for each Scenario. To facilitate the export of the tab into a PDF file, the model has a button to export it directly.

6 CASE STUDY

Trento, a medium town in northern Italy has been used to demonstrate the functioning of EIDH-1a. Trento was selected due to its size, which facilitates the analysis, and the fact that had surface water availability (Adige River).

Heat Roadmap Europe 3/ Stratego project created interactive Thermal Maps for the Czech Republic, Croatia, Italy, Romania and the United Kingdom. These interactive maps display the heat demands of each country but they also incorporate and analysis of the potential areas that can implement DH systems. Thus, the estimated Total Annual Heat Demand was extracted from Peta, The Pan-European Thermal Atlas for Italy[12].

According to Peta and with the prospective DH system ID 49,815 (see Figure 6), Trento has an estimated Annual Heat Demand of 3,385 TJ and a population within the DH system of 130,249. These two values were used as the base to evaluate different potential supply assets for this prospective DH system.

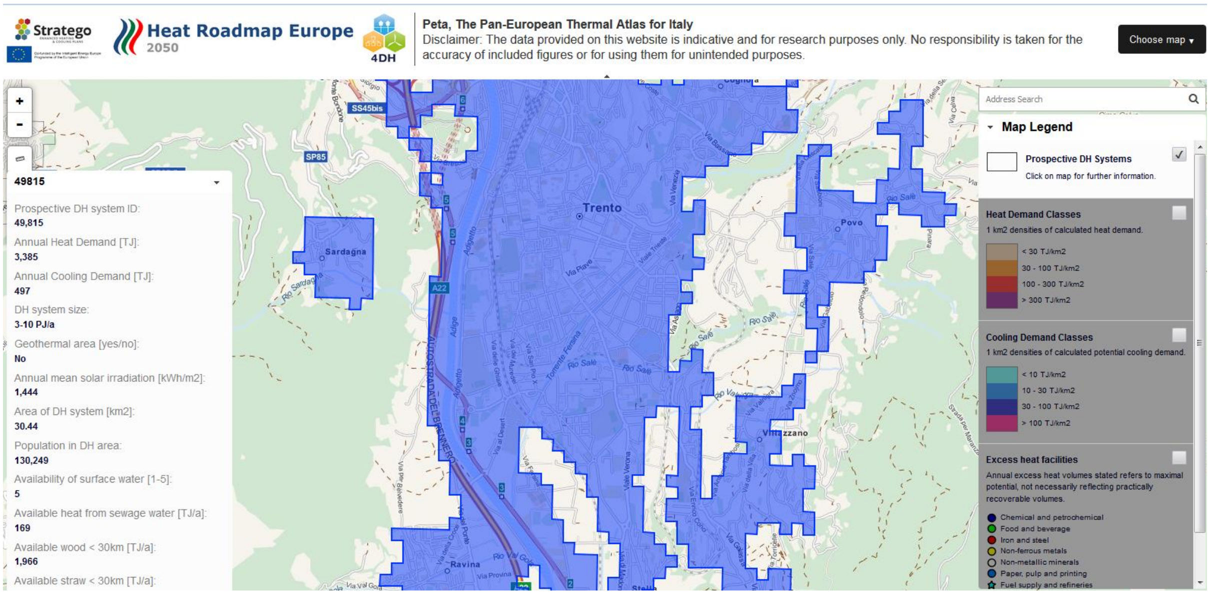

Figure 6: Screenshot of Trento Prospective DH System from the Italian Peta.

6.1 Scenario 1a

The first scenario analysed was a typical system where the base heat demand was supplied by a natural gas-fired reciprocating engine CHP with medium sized boilers fuelled with natural gas supplying the heat to cover the peak demands. A 17hours per day profile with a summer rest was chosen to determine the operating profile for the base demand. Since the town was medium it seemed feasible the hypothetical location of the gas engine CHP would be in a brownfield.

[12] http://maps.heatroadmap.eu/maps/30661?preview=true#

The pollutants background concentrations for the village were obtained from the Italian private organisation Il Meteo S.R.L. (Il Meteo 2016), which, among other activities, creates meteorological models and weather forecasts for Italian televisions and universities.

In order to analyse the land-based indicators, a hypothetical floor area of 50 m^2 for the energy centre and a 100 m^2 floor area for heat storage was determined.

The last step was deciding the ponderation values for each of the indicators group. Since this was a hypothetical case without any kind of background information, the selection was decided on the grounds of the larger "hypothetical" effects; therefore, health impacts were given the highest ponderation, land use was second since Trento is located in a mountainous area and agricultural land is scarce, and impacts on climate change and water quality the lowest as can be seen in Figure 7.

Ponderation of Indicators

GHG emissions	3
Local Air Quality	5
Water Quality	2
Land Use	4

Figure 7: Ponderation of Indicators in the Trento Case Study

For this first scenario, these were all the user inputs needed. Figure 8 shows the Inputs tab with all these data for scenario 1a entered.

EIDH-1a

Please select or enter data

Project Name	Trento Case Study - Prospective DH system ID 49,815
Scenario	1a - CHP
Country	Italy

Basic data

Total Annual Demand (kWh)	940,277,778
Estimation of population affected	130,249

Base load	
Select technology supplying the heat for the base load	Reciprocating engine CHP
Select the fuel for supplying base load	Natural Gas
Operating hours profile of base load	17h/day excluding summer months
Plant efficiency (%)	
Peak loads	
Select technology supplying the heat for the peak load	Medium sized boilers
Select the fuel for supplying the peak load	Natural Gas
Plant efficiency (%)	

Base Case	
Select technology supplying the heat	Individual boilers
Select the fuel for supplying base load	Natural Gas
Plant efficiency (%)	

Technology-based information

Plant building floor space / Solar thermal land area used (m2)	50
Heat storage floor space (m2)	100
For W/GSHP	
Delta T	
Discharge water temperature	
Are there other water extractions in the vicinity?	

Area-based information

Location of heat supply	Brownfield
Location of heat storage	Brownfield
Average concentrations in local area	
NOx	12.30 µg/m3
SOx	0.90 µg/m3
VOC	0.00 µg/m3
PM10	12.90 µg/m3
PM2.5	11.30 µg/m3
CO	182.00 µg/m3

Figure 8: Inputs Tab for Scenario 1a - Case Study

With that data entered, EIDH-1a estimated the emissions associated with the different heat supply options (gas engine CHP and gas boilers for the DH system and individual gas boilers for the base scenario). As established in section 4.3.1, the fuel associated with these technologies is natural gas. The results for the air pollution indicators, both GHG and local air quality indicators can be seen in Figure 9.

EIDH-1a

ENVIRONMENTAL IMPACTS FOR Trento Case Study - Prospective DH system ID 49,815

Scenario 1a - CHP Italy

AIR QUALITY					
CO2 total emissions	79,350.67	*Kg/year*	CO2 ratio	0.36	--
NOx total emissions	59,699.03	*Kg/year*	SOx total emissions	502.36	*Kg/year*
NOx ratio	0.36	--	SOx ratio	0.42	--
NOx maximum emission rate	46,991,740.13	*mg/s*	SOx maximum emission rate	1,182,516.84	*mg/s*
VOC total emissions	36,769.45	*Kg/year*	CO total emissions	52,576.70	*Kg/year*
VOC ratio	5.13	--	CO ratio	0.60	--
VOC maximum emission rate	11,734,170.41	*mg/s*	CO maximum emission rate	37,411,145.38	*mg/s*
PM10 total emissions	1,241.19	*Kg/year*	PM2.5 total emissions	1,241.19	*Kg/year*
PM10 ratio	1.56	--	PM2.5 ratio	1.56	--
PM10 maximum emission rate	686,872.92	*mg/s*	PM2.5.maximum emission rate	686,872.92	*mg/s*
Dynamic Intake Fraction ratio	0.75	-			

Figure 9: Air Quality Indicators for the Scenario 1a, Trento Case Study

Since this scenario does not have a direct impact on water bodies and the space needed for the energy centre was not included, the water and land indicators are invalid and the final indicator only includes air quality indicators. As can be seen in Figure 10, the main environmental impacts of this scenario are the local air quality.

WATER QUALITY		
Impact on Water Temperature	-	--

LAND USE	
Affectation on land surface	0.0001

EVALUATION	
CLIMATE CHANGE	1.0655
LOCAL AIR QUALITY	7.4096
WATER IMPACTS	-
LAND USE	0.0003
TOTAL SCORE	8.48

OTHER RECOMMENDATIONS

Check the existence of a local air quality management area or if the DH is within a low air quality area or within a air quality protection zone

Check the existence of sensitive buildings such as hospitals, schools,…

Include noise reduction measures, specially if the Energy Centre is located near a sensitive building.

Figure 10: Final Score and Suggestions for Scenario 1a, Trento Case Study

6.2 Scenario 1b

Scenario 1b is similar to 1a but instead of using gas boilers to meet the heat demands for peak hours, biomass boilers were analysed. The ponderation values were kept without modifications.

EIDH-1a

Please select or enter data

Project Name	Trento Case Study - Prospective DH system ID 49,815
Scenario	1b - CHP
Country	Italy

Basic data

Total Annual Demand (kWh)	940,277,778	Estimation of population affected	130,249

Base load	
Select technology supplying the heat for the base load	Reciprocating engine CHP
Select the fuel for supplying base load	Natural Gas
Operating hours profile of base load	17h/day excluding summer months
Plant efficiency (%)	
Peak loads	
Select technology supplying the heat for the peak load	Medium sized boilers
Select the fuel for supplying the peak load	Biomass
Plant efficiency (%)	

Base Case	
Select technology supplying the heat	Individual boilers
Select the fuel for supplying base load	Natural Gas
Plant efficiency (%)	

Technology-based information

Plant building floor space / Solar thermal land area used (m2)	50
Heat storage floor space (m2)	100
For W/GSHP	
Delta T	
Discharge water temperature	
Are there other water extractions in the vicinity?	

Area-based information

Location of heat supply	Brownfield
Location of heat storage	Brownfield
Average concentrations in local area	
NOx	12.30 µg/m3
SOx	0.90 µg/m3
VOC	0.00 µg/m3
PM10	12.90 µg/m3
PM2.5	11.30 µg/m3
CO	182.00 µg/m3

Figure 11: Inputs Tab for Scenario 1b, Trento Case Study

As can be seen in Figure 12, the biomass boilers have a much worse performance regarding the local air quality since biomass has a much higher emission rated for local pollutants than natural gas, which was the fuel analysed in scenario 1a.

EIDH-1a

ENVIRONMENTAL IMPACTS FOR Trento Case Study - Prospective DH system ID 49,815

Scenario 1b - CHP Italy

AIR QUALITY

CO_2 total emissions	136,610.69	*Kg/year*	CO_2 ratio	0.31	--
NOx total emissions	111,939.88	*Kg/year*	SOx total emissions	11,462.69	*Kg/year*
NOx ratio	0.67	--	SOx ratio	9.59	--
NOx maximum emission rate	100,274,147.55	*mg/s*	SOx maximum emission rate	41,426,405.74	*mg/s*
VOC total emissions	342,019.88	*Kg/year*	CO total emissions	605,715.06	*Kg/year*
VOC ratio	47.71	--	CO ratio	6.91	--
VOC maximum emission rate	323,070,590.24	*mg/s*	CO maximum emission rate	601,577,812.18	*mg/s*
PM10 total emissions	147,259.47	*Kg/year*	PM2.5 total emissions	144,186.48	*Kg/year*
PM10 ratio	184.89	--	PM2.5 ratio	181.03	--
PM10 maximum emission rate	149,616,425.42	*mg/s*	PM2.5.maximum emission rate	146,482,166.16	*mg/s*

Dynamic Intake Fraction ratio 0.02 -

WATER QUALITY

Impact on Water Temperature - --

LAND USE

Affectation on land surface 0.0001

EVALUATION

CLIMATE CHANGE	0.9189
LOCAL AIR QUALITY	307.7373
WATER IMPACTS	-
LAND USE	0.0003

TOTAL SCORE **308.66**

OTHER RECOMMENDATIONS

Check the existence of a local air quality management area or if the DH is within a low air quality area or within a air quality protection zone

Check the existence of sensitive buildings such as hospitals, schools,...

Include noise reduction measures, specially if the Energy Centre is located near a sensitive building.

Figure 12: Screenshot of the Outputs Tab for Scenario 1b, Trento Case Study

6.3 Scenario 2

This scenario was built around the use of a close-loop WSHP in Adige River supplying the heat to meet the base demands and gas boilers to supply the heat for peak demands. Again, a 17hours per day profile with a summer rest was chosen to determine the operating profile for the base demand. Since the WSHP was to be located near the water source, the location of the energy centre was situated in a greenfield while the heat storage was situated in a brownfield.

The ΔT of the WSHP was set at 10 °C without determining the maximum temperature of the discharge water since this scenario evaluates a close-loop WSHP.

Similarly to the previous scenarios, a hypothetical floor area of 50m^2 for the WSHP and a 100m^2 floor area for heat storage were determined.

The concentrations of the pollutants in the town and the ponderation values were the same as in scenario 1a and 1b.

EIDH-1a

Please select or enter data

Project Name	Trento Case Study - Prospective DH system ID 49,815
Scenario	2 - WSHP
Country	Italy

Basic data

Total Annual Demand (kWh)	940,277,778	Estimation of population affected	130,249

Base load	
Select technology supplying the heat for the base load	WSHP
Select the fuel for supplying base load	
Operating hours profile of base load	17h/day excluding summer months
Plant efficiency (%)	
Peak loads	
Select technology supplying the heat for the peak load	Medium sized boilers
Select the fuel for supplying the peak load	Natural Gas
Plant efficiency (%)	

Base Case	
Select technology supplying the heat	Individual boilers
Select the fuel for supplying base load	Natural Gas
Plant efficiency (%)	

Technology-based information

Plant building floor space / Solar thermal land area used (m2)	50
Heat storage floor space (m2)	100
For W/GSHP	
Delta T	10.0 °C
Discharge water temperature	
Are there other water extractions in the vicinity?	

Area-based information

Location of heat supply	Agricultural land or FOREST
Location of heat storage	Brownfield
Average concentrations in local area	
NOx	12.30 µg/m3
SOx	0.90 µg/m3
VOC	0.00 µg/m3
PM10	12.90 µg/m3
PM2.5	11.30 µg/m3
CO	182.00 µg/m3

Figure 13: Screenshot of the Inputs Tab for Scenario 2, Trento Case Study

This scenario, differently as the previous scenarios, adds the water impacts indicators values in the final indicator value. As can be seen in Figure 14, the values of the air quality indicators are lower than in the previous scenarios.

EIDH-1a

ENVIRONMENTAL IMPACTS FOR Trento Case Study - Prospective DH system ID 49,815

Scenario 2 - WSHP Italy

AIR QUALITY					
CO2 total emissions	66,112.35	*Kg/year*	CO2 ratio	0.30	--
NOx total emissions	40,973.21	*Kg/year*	SOx total emissions	307,299.09	*Kg/year*
NOx ratio	0.24	--	SOx ratio	0.26	--
NOx maximum emission rate	41,790,123.47	*mg/s*	SOx maximum emission rate	1,128,333.33	*mg/s*
VOC total emissions	2,048,660.58	*Kg/year*	CO total emissions	30,729,908.75	*Kg/year*
VOC ratio	0.29	--	CO ratio	0.35	--
VOC maximum emission rate	2,089,506.17	*mg/s*	CO maximum emission rate	31,342,592.60	*mg/s*
PM10 total emissions	460,948.63	*Kg/year*	PM2.5 total emissions	460,948.63	*Kg/year*
PM10 ratio	0.58	--	PM2.5 ratio	0.58	--
PM10 maximum emission rate	470,138.89	*mg/s*	PM2.5.maximum emission rate	470,138.89	*mg/s*
Dynamic Intake Fraction ratio	1.85	-			

WATER QUALITY		
Impact on Water Temperature	1.00	--

LAND USE	
Affectation on land surface	0.0002

EVALUATION	
CLIMATE CHANGE	0.8878
LOCAL AIR QUALITY	2.9631
WATER IMPACTS	2.0000
LAND USE	0.0008
TOTAL SCORE	5.85

OTHER RECOMMENDATIONS

Check the existence of other point sources in the same basin

Evaluate the distance between the existent point sources taking into consideration their nature and potential pollution type

Consider the use of the EFDC model, specially if ΔT is higher than 6 °C or there are other point sources in the vicinity

Check if tere is affectation to Natural Protected Areas

Include noise reduction measures, specially if the Energy Centre is located near a sensitive building.

Figure 14: Screenshot of the Outputs Tab for Scenario 2, Trento Case Study

6.4 Scenario 3

Scenario 3 assumes the use of solar thermal panels to provide the heat for meeting the base demands and gas boilers to supply the peak heat.

Since the solar thermal panels are a permanent infrastructure it seemed adequate to change the operating hour profile from 17h/day excluding the summer months from the previous scenarios to a 15h/day throughout the year one. The location of the heat supply, in this case, was also located on agricultural land around the town but the floor area needed by the solar installation was left blank and estimated by the model.

EIDH-1a

Please select or enter data

Project Name	Trento Case Study - Prospective DH system ID 49,815
Scenario	3- Solar thermal
Country	Italy

Basic data

Total Annual Demand (kWh)	940,277,778	Estimation of population affected	130,249

Base load	
Select technology supplying the heat for the base load	Solar thermal
Select the fuel for supplying base load	
Operating hours profile of base load	15h/day
Plant efficiency (%)	
Peak loads	
Select technology supplying the heat for the peak load	Medium sized boilers
Select the fuel for supplying the peak load	Natural Gas
Plant efficiency (%)	

Base Case	
Select technology supplying the heat	Individual boilers
Select the fuel for supplying base load	Natural Gas
Plant efficiency (%)	

Technology-based information

Plant building floor space / Solar thermal land area used (m2)	
Heat storage floor space (m2)	100
For W/GSHP	
Delta T	
Discharge water temperature	
Are there other water extractions in the vicinity?	

Area-based information

Location of heat supply	Agricultural land or FOREST
Location of heat storage	Brownfield
Average concentrations in local area	
NOx	12.30 µg/m3
SOx	0.90 µg/m3
VOC	0.00 µg/m3
PM10	12.90 µg/m3
PM2.5	11.30 µg/m3
CO	182.00 µg/m3

Figure 15: Screenshot of the Inputs Tab for Scenario 3, Trento Case Study

The logical increment in the surface needed to install the solar panels has a direct effect on the land indicator, which in this scenario shows a greater impact than the GHG indicators as can be seen in Figure 16. In this scenario, although the local air indicators still hold the major impacts, the land indicator also has an important influence on the final value.

EIDH-1a

ENVIRONMENTAL IMPACTS FOR Trento Case Study - Prospective DH system ID 49,815

Scenario 3- Solar thermal — Italy

AIR QUALITY

CO2 total emissions	67,371.49	*Kg/year*	CO2 ratio	0.30	
NOx total emissions	48,036.75	*Kg/year*	SOx total emissions	360,275.61	*Kg/year*
NOx ratio	0.29	--	SOx ratio	0.30	--
NOx maximum emission rate	41,790,123.47	*mg/s*	SOx maximum emission rate	1,128,333.33	*mg/s*
VOC total emissions	2,401,837.40	*Kg/year*	CO total emissions	36,027,561.04	*Kg/year*
VOC ratio	0.34	--	CO ratio	0.41	--
VOC maximum emission rate	2,089,506.17	*mg/s*	CO maximum emission rate	31,342,592.60	*mg/s*
PM10 total emissions	540,413.42	*Kg/year*	PM2.5 total emissions	540,413.42	*Kg/year*
PM10 ratio	0.68	--	PM2.5 ratio	0.68	--
PM10 maximum emission rate	470,138.89	*mg/s*	PM2.5.maximum emission rate	470,138.89	*mg/s*
Dynamic Intake Fraction ratio	1.58	-			

WATER QUALITY

Impact on Water Temperature	-	--

LAND USE

Affectation on land surface	0.6640

EVALUATION

CLIMATE CHANGE	0.9047
LOCAL AIR QUALITY	3.0513
WATER IMPACTS	-
LAND USE	2.6559
TOTAL SCORE	6.61

OTHER RECOMMENDATIONS

Check if there is affectation to Natural Protected Areas

Figure 16: Screenshot of the Outputs Tab for the Scenario 3, Trento Case Study

6.5 Analysis

As can be seen in Table 7, although all scenarios were analysed with the same ponderation values, the fuels choice and the specific characteristics associated with each supply system for the DH scheme have significantly different impacts and, therefore, different final values. Using these set of ponderation values, it seems that the WSHP scenario is the heat supply option with lowest negative environmental impacts for a hypothetical DH system in Trento.

Table 7: Summary of Indicators by Scenario

Scenario	Climate Change	Local Air Quality	Water Impacts	Land Impacts	Total
1a - CHP	1,065	7,41	-	0,0003	8,18
1b – CHP	0,92	307,74	-	0,0003	308,66
2 – WSHP	0,89	2,96	2	0,0008	5,85
3 – Solar thermal	0,90	3,05	-	2,66	6,61

A detailed analysis of the different indicators values displays the large value that the Local Air Quality indicator reaches for the Scenario 1b, where the peak heat demand is supplied by biomass boilers. This much larger value it due to the higher emission factors associated with the biomass combustion. Nevertheless, the fact that the biomass boiler was selected to supply the peak demand heat instead of the base demand has an important influence on the final emission rate and, therefore, indicator value.

It is also noticeable the fact that the solar thermal scenario has a slightly larger value in both the Climate Change and the Local Air Quality indicator than the WSHP scenario. This is especially interesting if the fact that WSHPs use electricity to function, with all the CO_2 emissions associated with them is accounted. The difference is due to the operating profile for the base supply asset, which is different in each scenario. The solar thermal scenario assumes that the plant will be operating 15 hours per day the whole year while all other scenarios assumed a 17h/day excluding the summer months operation profile. The difference in operating profiles brings a different base load, in this case, lower, which turns into a larger peak plant capacity with higher gases emissions.

Furthermore, the ponderation also has an important effect on the indicators values (see Figure 17). For example, if the Water Quality indicator is given a 4 punctuation instead of the 2 used in the previous scenarios, the final value for the Water Impacts indicator is 4, instead of 2 and the overall value increases to 7,85 in front of the 5,79 previous scenario analysed.

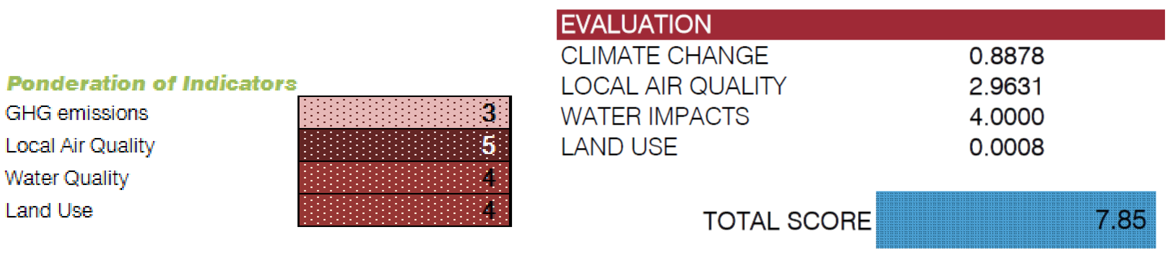

Figure 17: Indicator Ponderation and Final Values for a WSHP Scenario for the Trento Case Study

7 DISCUSSION

A tool or model that aims to evaluate and assess, even if it is in a preliminary approach, the environmental impacts of the heat supply plants for district heating systems is, in itself, an ambitious instrument. It is ambitious because of the wide range of environmental impacts that can be associated with DH systems but, specifically, due to the wide range of technologies, fuels, operating profiles and efficiencies and particularities of the technologies used. Such a tool is bound to overlook impacts or technologies or potential fuels used or specific characteristics of the supply plants.

Firstly and as highlighted in section 6.5, the selection of an impact ponderation by the user plays an important role in the outcomes of the model. The ponderation introduces subjectivity, which can diminish the value associated with the analysis that EIDH-1a performs. However, it allows the integration of local particularities, it allows the adaptation of the model to local circumstances that are difficult to quantify. This subjectivity is a sensitive issue and the user should be aware of the implications that it entails.

Nevertheless, subjectivity it is not the only drawback that EIDH-1a carries. Overall, the EIDH-1a's limitations can be grouped into four main groups depending on their characteristics:

- omitted impacts,
- missing technologies and fuels,
- calculations limitations, and
- other impacts.

Some environmental impacts related to the heat supply for DH systems are difficult to evaluate without detailed information on the design characteristics of the specific supply asset.

The noise production is intrinsically connected to the machinery that produces it but also to the building where it is enclosed and the receptor medium. The existent environmental noise plays an important role on the impacts produced by the installation of new machinery. Therefore, the quantification and evaluation of the noise impacts are difficult to assess in the early stages when this model is meant to be applied. Therefore, and although noise can be an important nuisance in urban areas, where DH systems are primarily planned, noise impacts are not included in the indicators that EIDH-1a evaluates.

Other environmental impacts that EIDH-1a omits are related to risks due to malfunctioning or wrongly operational uses. This group includes accidental spills of fuel from CHPs and boilers and antifreeze spills from the heat pumps. In a similar way, the model does not include the risk of fugitive emissions from drilling boreholes associated with vertical GSHPs. The interconnection of aquifers or the introduction of pollutants into the water beyond heat is also not characterised and evaluated quantitatively.

The quality or state of the affected medium where the heat supply plant would be constructed is also not introduced in the evaluation of the indicators.

These risks and impacts that were not included in this version of the tool are evaluated included in the recommendations and suggestions part of the model so the user is aware of the further environmental impacts that each supply option carries.

Related to the technologies and fuels that EIDH-1a incorporates, the model analyses a reduced group of the fuels and equipment that can produce heat to feed the DH system. Biogas and syngas are examples of omitted fuels by the model. The model analyses the most common fuels covering an important portion of the range of energy sources available. The range of fuels and technologies that the EMEP/EEA comprehends was also decisive when determining the fuels included and the omitted ones.

Furthermore, improvements in the equipment design and the soon-to-be-implemented Medium Combustion Plant (MCP) Directive[13] will lead to an improvement of efficiencies and emission rates that this model does not account. The selection by the user of the efficiency ratio that is used in the calculations of the heat provided by the base-demand plant and the peak-demand plant moderates the impact of the technology improvements can have on the model reliability. Nevertheless, the efficiencies also are dependent on the age, nominal power and fuel used by the plants (Torchio et al. 2009) and, therefore, are related to the specific characteristics and their management. Thus, the same model of engine, for example, can have different efficiency depending on the quality of the fuel used and the operating profile.

Related to the limitations in the model calculations, the first and most relevant issue is the assumption that the base supply asset functions at the same rate continuously during the operating hours. This facilitates the estimation of the capacities of the base and peak supply plants but it does not reflect the reality of many systems where the plants function under variable loads. It also underestimates the capacity of the plant that supplies heat to meet the base demands. This underestimation is especially relevant while calculating the emissions associated with heat pumps or solar thermal systems. A larger capacity associated with such base-supply plants, even if the operating profile is irregular and not as efficient as it could be when functioning continuously, could lower the overall emissions associated with the system.

Similarly, the model does not account for the effect that the heat storage has in the heat production, the operating profile of both the base and peak supply plants and, therefore, the pollutant emissions.

The hourly distribution profiles also have a relevant impact on the pollutant emissions and, more importantly, on the pollutant emission rates, which in its turn may have a more relevant impact on the air quality and the health problems associated with it. The model uses general profiles that are not case fitted to the buildings and consumption profiles of the DH systems analysed. Since the model uses these distribution profiles to determine the plants capacities and the heat produced by the base and peak supply plants, they have a large impact in the uncertainty and imprecision of the model.

However, although these emissions estimated by the model carry a degree of uncertainty, they have value for their part in raising awareness of the environmental impacts associated with the fuels and technologies analysed. For example, the case study in section 6.2 demonstrates the

[13] Directive (EU) 2015/2193 of the European Parliament and the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants

large impact of biomass combustion in the local air quality. This specific result can challenge preconceptions about the benefits and impacts of biomass.

Additionally, relevant to air quality, the tool does not incorporate dispersion models for the air pollutants, which plays a major role in the impacts that these can have on human health. The geographic dispersion of the gases determines their concentrations of these pollutants and, therefore, the relevance of their impacts.

Related to the Water Quality indicator, the model does not account for the effect that proximal point sources can have on the water indicator and the associated impacts. As stated in section 4.3.3, the presence of other pollutant sources in the vicinity of the supply plant can exacerbate its effects.

In general terms, the model also oversights the possibility of analysing multiple supply options to feed the DH system instead of an only supply option to cover the base demand and another to meet the peak demands of the system. Moreover, these multiple supply options could also be expanded to incorporate cooling supply in the options technology. Combined District Heating and Cooling is increasingly popular and it could signify an important modification in the technology and fuels supply for district energy systems as well as changes in the consumption profiles associated with these systems. Analysing multiple supply options could lead to the possibility of studying current district energy systems, not only new schemes.

Other valuable information that the model does not include are economic and social impacts associated with the heat supply options. Environmental impacts are relevant and necessary to acknowledge and correct or avoid them altogether although economic costs and social implications related to each system or scenario are equally important.

8 CONCLUSION

EIDH-1a is a model that presents a preliminary estimation of the gases emissions (both GHG and other pollutants) of a limited range of supply assets for DH systems alongside with a series of indicators that evaluate the impacts of these supply options on the air quality (global and local impacts), water ecosystems and land surface compared with a reference scenario.

As exposed in chapter 7, the model, as it is in this stage of development, has numerous limitations, especially regarding the estimation of total annual emissions associated with the new DH system analysed. The limitations on the rest of the indicators are neutralised by creating ratios between the new hypothetical district heating system and a reference (base case) scenario that ideally should be defined as the use of individual boilers supplying the whole total annual heat demand that is associated with the new district heating system.

The use of rated indicators allows too for comparison between scenarios that use different combinations of heat supply technologies and fuels facilitating the creation of knowledge and information that should be part of the strategic decision-making process when promoting a new DH system.

The omission of fuels and technologies is another important drawback that should be corrected in later versions of the model. The use of a wider range of fuels and technologies, especially the incorporation of cooling (combined district heating and cooling or solely district cooling). A model that aims to be used in all Europe needs to be able to provide analysis of all fuels and technologies that are relevant in each country due to its climatologic characteristics or its custom practices.

Furthermore, the range of indicators (extended beyond the classic GHG evaluation) adds value to the supply options appraisal that usually accompanies the planning and design of new district heating systems. This increase in the amount of information regarding the degree of environmental impacts of the supply options compared against a reference scenario aligns with Stokman's methodology and increases the value of the supply appraisal. A well-informed supply selection increases the effectiveness of the system designed. Having access to a wider range of information is always a more precise approach when attempting to make decisions regarding long-term and high-capital investment infrastructure such as district heating systems.

EIDH-1a neither aims to the selection of a preferred heat supply option nor excludes heat supply alternatives. However, it provides information to increase the awareness of the environmental impacts associated with each alternative analysed. This knowledge gain enhances the significance and worth of the final selection of a heat supply option for new district heating systems.

Simultaneously, although it is not its goal, EIDH-1a has the potentiality of increasing the awareness of the environmental impacts associated with heat supply fuels and technologies, challenging preconceptions.

The fact that the model works with non-specific data regarding the district heating system analysed conforms well with the stages of the planning process where it is supposed to be used although there is a loss in specific and adjusted information of the final environmental impacts. In the early stages of the planning and design process, the information available about the engineering design of the system is scarce and not detailed. Thus, a tool that evaluates preliminarily the impacts of s supply system corresponds with this stage. In addition, the fact that EIDH-1a evaluates different heat supply options comparing them among themselves grant the use of the model in the early stages of the decentralised heat systems where several heat supply options are presented and analysed. The model could be a valuable tool to further characterise the heat supply appraisal in early stage studies. This is a model with inherently general and broad outcomes that can guide the subsequent evaluations.

In conclusion, although EIDH-1a requires some updating and polishment, the model can add value and insight to high-level studies aiming to implement new district heating schemes.

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APPENDIX I – EMISSION FACTORS

CO2 Emission Factors			
Country	Fuel	Emission Factor (kg CO2eq/kWh)	Source
Europe Average	Natural Gas	0.2020	2006 IPCC Guidelines - Tier 1 for Stationary Combustion in the Commercial/Institutional Category
Europe Average	Biomass	0.4032	2006 IPCC Guidelines - Tier 1 for Stationary Combustion in the Commercial/Institutional Category
Europe Average	Gas Oil	0.2668	2006 IPCC Guidelines - Tier 1 for Stationary Combustion in the Commercial/Institutional Category
Europe Average	Biogas	0.1966	2006 IPCC Guidelines - Tier 1 for Stationary Combustion in the Commercial/Institutional Category
Europe Average	Coal - Anthracite	0.3539	https://euracoal.eu/coal/
United Kingdom	Natural Gas	0.1845	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Gas Oil	0.2515	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Coal	0.3285	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Bioethanol	0.0009	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Biodiesel	0.0022	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Biogas / Landfill gas	0.0002	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Biomass	0.0132	UK Government Conversion Factors for Company Reporting - 2015
United Kingdom	Electricity	0.4622	UK Government Conversion Factors for Company Reporting - 2015
Spain	Natural Gas	0.2020	Magrama - Spanish Ministry of Agriculture and Environment
Spain	Electricity	0.1265	Magrama - Spanish Ministry of Agriculture and Environment
Europe Average	Electricity	0.3505	UK Government Conversion Factors for Company Reporting - 2015
Italy	Electricity	0.3990	UK Government Conversion Factors for Company Reporting - 2015
Austria	Electricity	0.1870	UK Government Conversion Factors for Company Reporting - 2015
Belgium	Electricity	0.1894	UK Government Conversion Factors for Company Reporting - 2015
Denmark	Electricity	0.2930	UK Government Conversion Factors for Company Reporting - 2015
Finland	Electricity	0.1914	UK Government Conversion Factors for Company Reporting - 2015
France	Electricity	0.0586	UK Government Conversion Factors for Company Reporting - 2015
Germany	Electricity	0.4718	UK Government Conversion Factors for Company Reporting - 2015
Greece	Electricity	0.7182	UK Government Conversion Factors for Company Reporting - 2015
Ireland	Electricity	0.4193	UK Government Conversion Factors for Company Reporting - 2015

CO2 Emission Factors			
Country	Fuel	Emission Factor (kg CO2eq/kWh)	Source
Netherlands	Electricity	0.3990	UK Government Conversion Factors for Company Reporting - 2015
Norway	Electricity	0.0137	UK Government Conversion Factors for Company Reporting - 2015
Portugal	Electricity	0.2827	UK Government Conversion Factors for Company Reporting - 2015
Sweden	Electricity	0.0165	UK Government Conversion Factors for Company Reporting - 2015
Switzerland	Electricity	0.0315	UK Government Conversion Factors for Company Reporting - 2015
Hungary	Electricity	0.3183	UK Government Conversion Factors for Company Reporting - 2015
Malta	Electricity	0.8661	UK Government Conversion Factors for Company Reporting - 2015
Poland	Electricity	0.7739	UK Government Conversion Factors for Company Reporting - 2015
Turkey	Electricity	0.4644	UK Government Conversion Factors for Company Reporting - 2015

Local Air Pollutants[14]			
Pollutant	Fuel	Technology	Emission Factor (g/kWh)
NOx	Natural Gas	Medium sized boilers	0.144
	Natural Gas	Reciprocating engine CHP	0.1728
	Natural Gas	Gas turbine CHP	0.486
	Natural Gas	Individual boilers	0.1512
	Coal	Medium sized boilers	0.576
	Biomass	Individual boilers	0.288
	Gas oil	Individual boilers	0.2484
	Gas oil	Reciprocating engine CHP	3.3912
	Coal	Individual boilers	0.5688
	Biomass	Medium sized boilers	0.3276
CO	Natural Gas	Medium sized boilers	0.108
	Natural Gas	Gas turbines CHP	0.01728
	Natural Gas	Reciprocating engine CHP	0.2016
	Natural Gas	Individual boilers	0.0792
	Coal	Medium sized boilers	7.2
	Biomass	Individual boilers	14.4
	Gas oil	Individual boilers	0.01332
	Gas oil	Reciprocating engine CHP	0.468
	Coal	Individual boilers	17.2224
	Biomass	Medium sized boilers	2.052

[14] All Emission Factors are extracted from the EMEP/EEA Guidelines

Local Air Pollutants[14]			
Pollutant	Fuel	Technology	Emission Factor (g/kWh)
VOC	Natural Gas	Medium sized boilers	0.0072
	Natural Gas	Gas turbine CHP	0.00576
	Natural Gas	Reciprocating engine CHP	0.3204
	Natural Gas	Individual boilers	0.00648
	Coal	Medium sized boilers	0.72
	Biomass	Individual boilers	1.26
	Gas oil	Individual boilers	0.000612
	Gas oil	Reciprocating engine CHP	0.18
	Coal	Individual boilers	0.6264
	Biomass	Medium sized boilers	1.08
SO_x	Natural Gas	Medium sized boilers	0.00108
	Natural Gas	Gas turbine CHP	0.0018
	Natural Gas	Reciprocating engine CHP	0.0018
	Natural Gas	Individual boilers	0.00108
	Coal	Medium sized boilers	3.24
	Biomass	Individual boilers	0.0396
	Gas oil	Individual boilers	0.2844
	Gas oil	Reciprocating engine CHP	0.1728
	Coal	Individual boilers	3.24
	Biomass	Medium sized boilers	0.0396
PM_{10}	Natural Gas	Medium sized boilers	0.00162
	Natural Gas	Gas turbine CHP	0.00072
	Natural Gas	Reciprocating engine CHP	0.0072
	Natural Gas	Individual boilers	0.00072
	Coal	Medium sized boilers	0.684
	Biomass	Individual boilers	1.728
	Gas oil	Individual boilers	0.0054
	Gas oil	Reciprocating engine CHP	0.108
	Coal	Individual boilers	0.81
	Biomass	Medium sized boilers	0.5148
$PM_{2.5}$	Natural Gas	Medium sized boilers	0.00162
	Natural Gas	Gas turbine CHP	0.00072
	Natural Gas	Reciprocating engine CHP	0.0072
	Natural Gas	Individual boilers	0.00072
	Coal	Medium sized boilers	0.612
	Biomass	Individual boilers	1.692
	Gas oil	Individual boilers	0.0054
	Gas oil	Reciprocating engine CHP	0.108
	Coal	Individual boilers	0.7236
	Biomass	Medium sized boilers	0.504

APPENDIX II –SUGGESTIONS MISCELLANEA

Medium sized boilers
Check if the DH is located in a local air quality management area or a low air quality area or an air quality protection zone
Check the existence of sensitive buildings such as hospitals, schools,…
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land
Include noise reduction measures, especially if the Energy Centre is located near a sensitive building.
Reciprocating engine CHP
Check if the DH is located in a local air quality management area or a low air quality area or an air quality protection zone
Check the existence of sensitive buildings such as hospitals, schools,…
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land
Include noise reduction measures, especially if the Energy Centre is located near a sensitive building.
Gas turbine CHP
Check if the DH is located in a local air quality management area or a low air quality area or an air quality protection zone
Check the existence of sensitive buildings such as hospitals, schools,…
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land
Include noise reduction measures, especially if the Energy Centre is located near a sensitive building.
Solar thermal
Check if there is affectation to Natural Protected Areas
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land
GSHP
Check the aquifer quality status
Check the existence of aquifers in multiple layers and the risk of interconnection
If the aquifer is used to provide drinking water, check the presence of other extraction points and analyse the accumulative effect
Check if there is affectation to Natural Protected Areas
Check if there is affectation to Geologic Protected Areas
Check if the soil is contaminated
Include noise reduction measures, especially if the Energy Centre is located near a sensitive building.
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land
WSHP
Check the existence of other point sources in the same basin
Evaluate the distance between the existent point sources taking into consideration their nature and potential pollution type
Consider the use of the EFDC[15] model, especially if ΔT is higher than 6 °C or there are other point sources in the vicinity
Check if there is affectation to Natural Protected Areas
Include noise reduction measures, especially if the Energy Centre is located near a sensitive building.
Check if the Energy Centre (Supply Plant) is planned to be built on contaminated land

[15] US EPA's Environment Fluid Dynamics Code, a multifunctional surface water modelling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components.

APPENDIX III – GLOSSARY

ΔT	Delta T - Temperature Difference
°C	Grades Centigrade
CH_4	Methane
CHP	Combined Heat and Power
CIBSE	The Chartered Institution of Building Services Engineers
CO	Carbon Oxide
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide equivalent
DECC	Department of Energy and Climate Change - UK
DEFRA	Department for Environment, Food and Rural Affairs - UK
DH	District Heating
EEA	European Environment Agency
EFDC	Environment Fluid Dynamics Code
EIA	Environmental Impact Assessment
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency - US
ESCo	Energy Services Company
EU	European Union
GHG	Greenhouse Gases
h/day	Hour per day
iF	Inhalation Intake Fraction
IPCC	Intergovernmental Panel on Climate Change
Kg/kWh	Kilogramme per Kilowatt hour
kW	Kilowatt
kWh	Kilowatt hour
m^2	Square metre
m^3/s	Cubic metre per second - Flow rate
Magrama	Ministry of Agriculture and Environment - Spain
mg/kWh	Milligramme per Kilowatt hour
mg/m^3	Milligramme per cubic metre - Concentration
mg/s	Milligramme per second - Mass rate
MWh	Megawatt hour
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
PDF	Portable Document Format
PM_{10}	Particulate Matter under 10 mg
$PM_{2.5}$	Particulate Matter under 10 mg
SO_x	Sulphur Oxides
UK	The United Kingdom
US	The United States of America
VOC	Volatile Organic Compounds
W/GSHP	Water or Ground Source Heat Pumps