Industrial Waste Heat District-Heating Design Based on Geographic Information System: Case Study in Vitoria-Gasteiz (Spain)

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Abstract: The use of georeferenced information system and Light Detection and Ranging (LiDAR) data in combination with traditional data analytics tools is very promising in urban scale engineering and especially in energy urban planning. This paper explores the use of new DH networks for industrial waste heat exploitation and for that purpose, a case-study in Vitoria-Gasteiz (Spain) is proposed. The methodology explained in this paper explores the incorporation of data from industrial emplacements, buildings and road network in order to identify optimal areas in the city for the construction of a new district-heating network. An area of influence of a buffer of radius 1.5km from the industry location is defined and the proposed algorithm divides this area into grids of different sizes. The path for the network is calculated by optimizing the economic performance of the network. The results show that the district-heating may be built in the south-west direction from the industry and among the 40 configurations studied, payback periods from 6 to 8.5 years are obtained.

1. Introduction

Energy consumption in buildings accounts for around 40% of the total energy consumption in the EU [1] and 36% of the CO2 emissions. Thus, increasing their energy efficiency and the way the energy is generated and distributed can lead to substantial energy reductions in the EU.

District Heating (DH) networks cover more than 13% of the heating energy demand in the buildings in the European Union (EU) [2]. Traditionally, DH networks have supplied heating energy above 100ºC, generating the energy in centralized large production plants. In the last years, the evolution of DH networks have resulted in low temperature (~60ºC) or Ultra Low temperature (~45ºC) heat supply; the so-called 4th generation DH networks [3]. The reduction of supply temperature reduces the distribution heat-losses and, consequently, the technology becomes more viable to be installed also in lower density areas. This decrease on the supply temperature also enables the connection of low grade energy sources, such as solar thermal energy and/or waste heat from different emplacements, like industries or data-centers.

Regarding excess heat from industry, it represents the main waste heat source in the EU. According to ref. [4], around 78% of the energy in the industry is used for heating and cooling processes from which an important part of it is now wasted as heat losses. Most of the IWH (66%) [5] is estimated to be low-grade energy (<100ºC) and, for its efficient exploitation, high thermal inertia systems such as
DH networks are promising. Previous studies have analyzed the viability of injecting IWH to already constructed district heating networks (see refs.[6] and [7] for case studies in Latvia and Germany, respectively). The results in [6] looked encouraging in terms of energy utilization, showing that IWH was able to cover up to 12% of the DH load in the heating season.

However, for the successful implementation of these networks, a complex strategic planning is required. Due to this limitation, most of the IWH-based DH systems are designed for new urban developments. Considering that new building construction increase in the EU is only around 2% per year [8], it is still necessary to evaluate case-studies that consider the existing building stock and urban net. This is especially important for highly-industrialized urban areas, where a large availability of IWH can be expected. These case studies should help to determine which dwellings can be included in the DH to use the waste heat from a fixed source location.

In view of that, it is herein presented a case-study of the design of a new DH network using IWH in the city of Vitoria-Gasteiz, a medium-size city from the Autonomous Community of the Basque Country, in the north of Spain. According to previous publications, this is a representative industrial region with a significant availability of IWH [9]. The herein employed methodology is based on Geographical Information Systems (GIS). This technique allows the integration of many kinds of data layers, including building data, road network or industrial emplacements, among others. This way, it can be considered optimal for this kind of energy urban planning analysis [10].

2. Methodology
A viability study for a new DH network construction is herein studied, combining GIS tools [11] and more traditional data-analytics tools [12]. This urban study is complemented with a basic economic assessment, determining the optimal area for the construction of a DH network.

The methodology presented in this paper is applied to a case study in Vitoria-Gasteiz (Basque Country Spain), presented in Section 2.1. Then, in Section 2.2 is explained the general methodology for the energetic characterization of the IWH in this region, as well as the methodology for the estimation of the demand in the buildings by means of Light Light Detection and Ranging data (LiDAR). Section 2.3 presents the algorithms for the calculation of optimal areas for the deployment of new DH networks. Each of the steps are detailed in the following subsections.

2.1. Presentation of Case-Study
The proposed approach is applied to the integration of a new DH network in the city of Vitoria-Gasteiz (249,176 inhabitants in 2018) in the Basque-Country, northern Spain. The building stock in that location is built in various decades, predominating buildings built in the 1970s. This location is chosen due to the high demand density of the city-center and the proximity of the industrial emplacements to the urban core. These two conditions make this location appropriate for a possible deployment of a new DH network using IWH.

An initial area defined by a 1.5km buffer with the center in the industrial emplacement is chosen, so that the demand to be covered is at least 10 times the IWH available. In this initial area defined by the circular buffer around the industry, 3733 buildings are generic construction buildings and 150 correspond with lightweight buildings. As the characterization method for the demand (presented in Section 2.2) in buildings is only valid for residential buildings, only generic & lightweight construction are taken into account from the whole building stock.
2.2. Industrial Waste Heat Characterization and Building Demand Estimation

The IWH characterization for the Basque Country (Spain) is carried out by means of a bottom up analysis based on general metrics available in open databases, such as: primary energy consumption in the industry, type of industry or size of the emplacement [13]. The result from the study is a geographically fixed multi-point heat source, which is used as input data for this Case-Study.

The industry chosen for this analysis is a foundry located near to the city center of Vitoria-Gasteiz, which has been in operation for more than fifty years. The location of this factory is shown in Fig. 1. This factory is responsible for the manufacture of grey iron and special alloys. The estimated technical waste heat available in the facility from the different manufacturing processes is 157.55 GWh/year, according to the bottom-up methodology for IWH characterization. The distribution in different temperature ranges is shown in Table 1.

Table 1. IWH energy and temperature range in the factory

| Temperature[°C] | 200-300°C | 300-400°C | 500-1000°C | >1000°C | Total |
|----------------|-----------|-----------|------------|---------|-------|
| IWH [GWh]      | 48.77     | 14.10     | 73.14      | 21.57   | 157.55|

As for buildings’ demand, this analysis is focused only on residential buildings. The heating energy demand in this type of building is estimated by the calculation of the heights of the buildings and the useful surface of each building to be heated. The equation applied for these calculations is the following:

$$Q_n = D_{En} \times F_n \times S_n \times 0.83$$

where, \(D_{En}\) is the nominal heat demand in kWh/m²; \(F_n\), number of floors; and \(S_n\), the total surface in m². The nominal heating energy demand \((D_{En})\) in each building is obtained from a national institution document [14], which fixes the demand in function of the results from various simulations of average building types in different climates.

The number of floors is estimated from the calculation of the heights of each of the building using LiDAR data. LiDAR is an optical remote sensing technique that uses laser light to obtain a dense sample of the earth’s surface, producing accurate point measurements of the elevation. Digital Surface Model (DSM) and Digital Terrain Model (DTM) are used for the calculation of the heights of the building. DSM present the real elevations on the surface, including all man-made features such as buildings. Furthermore, DTM is derived from DSM, where all the surface features are removed, so that elevation of the terrain is measured. Thus, the heights of the buildings can be calculated subtracting values from DTM to the DSM or, in other words, subtracting the terrain elevation to each of the elements in DSM. The height values obtained from the raster layer of the previous operation is assigned by localization to
the shape file of the buildings in QGIS [11]. The number of floors is estimated by assuming a minimum distance between slabs fixed for residential buildings. A unique building typology is considered. These GIS layers are illustrated in Fig. 2 for the Case-Study of this paper.

Figure 2. MDS (left) and MDT (right) of the Case-Study in Vitoria-Gasteiz (Spain)

2.3. Network Location Algorithms. Approach to economic viability
The goal of this section is to present the algorithm that will drive the DH network direction. This paper explores the directionality of the network as function of the road network, buildings demand density and yearly IWH available. The presented algorithm optimizes the economic performance of the network. According to [15], more than 50% of the total initial investment correspond to cost for civil works (specially, trenching) and installation the pipeline that will conform the DH network. These two costs are defined with the path of the network. In order to minimize the trenching costs, the pipelines of the network coincide with the existing road network.

The initial 1.5km buffer gathers a set of buildings and roads that will conform the boundary conditions for this new DH network. Usually, DH viability studies are made at regional level, but this study proposes to reduce the working scale by defining smaller sub-areas. For easing the computational implementation, squared cells conforming grids are proposed, so that each of the cell gathers a building or a set of buildings and roads. The studied surface is divided into grids of different sizes from 50x50 meters grid to 500x500 meters with a step of 50 meters.

Thus, the methodology proposes a multistep algorithm in which the path for the network is decided cell by cell. The starting point for this algorithm is the cell containing the factory. The following steps try to define the optimal path for the network and for this purpose, an economic balance for all the adjacent cells (8 cells) is developed, cell by cell. The cell with optimal economic results is chosen as starting points for the following step. This step is repeated until the IWH is the covered demand in the buildings. Moreover, with the objective of improving the results, in each of the steps more than one levels of adjacency are considered. In this study four levels of adjacency are used from starting grid. In each of the steps, economic costs derive from the trenching and pipelines to connect the building or buildings in that cell and the economic savings come from the energy saved in the buildings. The proposed algorithm is developed in a yearly basis due to the data availability and consequently, the obtained results are an approach for the detail design of the system.

3. Results & Discussion
The total heating energy demand in that area reaches 2528 GWh/year, whereas the IWH available in the industry is estimated to be slight above 150 GWh/year. The algorithm explained in Section 2.3 is applied to 40 different cases, considering 10 grid sizes and 4 levels of adjacency. Fig. 3a presents a heat-map with the 40 cases overlapped in the same figure, showing in a red colour, the most repeated buildings to be covered by the network.
The payback period among the 40 configurations range between 6 and 9 years. All the economic results for the 40 configurations are shown in Table 2. It is observed that optimization algorithm for the network is efficient, since the payback periods remains relatively constant throughout the different cases. A maximum value is observed in 50m cells with 2 adjacency levels, whereas minimum payback periods are observed 150 and 450m cells, both when considering 4 levels of adjacency.

Table 2. Payback Periods for the 40 configurations studied in Vitoria-Gasteiz

| Grid Size [m] | 50  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 Level of adjacency | 6.55 | 6.21 | 6.19 | 6.46 | 6.33 | 6.40 | 6.34 | 6.30 | 6.22 | 6.34 |
| 2 Level of adjacency | 8.29 | 6.25 | 6.22 | 6.41 | 6.27 | 6.34 | 6.33 | 6.39 | 6.29 | 6.37 |
| 3 Level of adjacency | 6.13 | 6.06 | 6.35 | 6.21 | 6.26 | 6.28 | 6.34 | 6.23 | 6.24 | 6.15 |
| 4 Level of adjacency | 6.21 | 6.17 | 6.01 | 6.28 | 6.16 | 6.23 | 6.21 | 6.12 | 6.01 | 6.25 |

Finally, in Fig. 4 the economically optimal case and the corresponding layout of the DH network is shown, roughly coinciding with the overlapped path presented in Fig. 3. The total length of this network is 11.75km, divided in 8.86km for the primary network and 2.89km in secondary side of the network.

Figure 4. DH Network Design for 150m cell and 4 levels of adjacency in Vitoria-Gasteiz (Spain)

4. Conclusions & Further Work
The incorporation of LiDAR data and georeferenced information for urban energy planning and especially for the design of DH network result very promising in the basic engineering phase. The DH network for the case-study is proposed to be developed using IWH as the main heat source in the network and the design phase is carried out for economic optimization. Promising economic results are obtained...
from this study, however, for future work, a more detailed economic analysis is proposed for the optimal case resulting from this study. The payback periods obtained from this first approach are below 10 years. Finally, due to the yearly basis of the energy coupling in this study, auxiliary/backup energy sources such as reversible and distributed heat pumps would be required along the network to ensure instant energy requirements in the buildings.

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