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Environmental impacts of the infrastructure for district heating in urban neighbourhoods

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ABSTRACT

District heating is a technology for distributing centrally produced heat for space heating and sanitary hot-water generation for residential and commercial uses. The objectives are to identify which subsystems and components of a district heating grid are the main contributors to the overall impact of the infrastructure; and provide environmentally oriented design strategies for the future eco-redesign of these kinds of infrastructures. This paper performs a life-cycle assessment (LCA) to determine the environmental impacts of a district heating infrastructure in an urban neighbourhood context. The analysis covers seven subsystems (power plant, main grid, auxiliary components of the main grid, trench works, service pipes, buildings and dwellings) and twelve standard components. The results for the subsystems show that the sources of impact are not particularly located in the main grid (less than 7.1% contribution in all impact categories), which is the focus of attention in the literature, but in the power plants and dwelling components. These two subsystems together contribute from 40% to 92% to the overall impact depending on the impact categories. Concerning the components, only a reduced number are responsible for the majority of the environmental impact. This facilitates identifying effective strategies for the redesign of the infrastructure.

1. Introduction

District heating is a technology for distributing centrally produced heat for space heating and sanitary hot-water generation for residential and commercial uses. Heat is distributed to the consumers through a network of district heating pipes using water as the transport medium. The market for district heating is primarily based on apartment blocks in dense areas. As Gustavsson and Karlsson (2003) have noted, the development of district heating in single-family houses is restricted by distribution costs and heat distribution losses.

Domestic heat demand for about 6% of the population in the 15 member countries of the European Union in 1999 is covered by district heating (Euroheat and Power Unichal, 2003). However, there are significant regional variations. In countries with cold climates, such as the Scandinavian countries, Poland and Estonia, the district heating technology in urban areas has been used for many years and its use is widespread (Froning, 2003). More specifically, in Sweden about 40% of the space heating market is affected by district heating (Euroheat and Power, 2001). However, in southern European countries, where mild climates prevail, this technology is still fairly new.

Despite the milder weather, which implies shorter usage periods, governments support combined heat and power (CHP) plants and district heating by subsidies for investments, fuels, preferential feed-in tariffs and connection rights (Agrell and Bogetoft, 2005). Comparatively, high-energy efficiency in district heating projects, often combined with the use of renewable fuels, makes the technologies, especially, attractive in order to reduce emissions of greenhouse gases (Bowitz and Trong, 2001) and other benefits such as fewer chimneys and better air quality in dwelling areas. With this objective, in 2002 the Commission of the European Communities proposed a directive on the promotion of combined heat and power (Commission of the European Communities, 2002), because cogeneration of electricity and heat makes possible a more efficient utilization of fuel than electricity production alone. District heating is the way to make use of the collected heat in the cogeneration scheme.

In southern Europe some new urban developments that aim to achieve a better environmental performance choose district heating as an efficient option in the use of energy. In Catalonia (Spain), there is a successful experience of district heating for about 700 dwellings with centrally produced heat from biomass in the municipality of Molins de Rei (Barcelona). Most of the

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technical local data for this study has been gathered from this site. However, research evaluating the environmental impacts related to this kind of infrastructure from a life-cycle perspective is in its early stages.

Some of the most detailed life-cycle assessment (LCA) of district heating pipes (pipe production (Fröling et al., 2004) and network construction (Fröling and Svanstrom, 2005)) including the use phase (Persson et al., 2006; Perzon et al., 2007) has been done by researchers at the Department of Chemical and Biological Engineering at Chalmers University of Technology. However, this excellent work does not study a complete district heating grid within a neighbourhood, including all the components from the CHP plant to the heat exchangers, which is the aim of the current paper.

Additional research has been carried out on fuels for district heating rather than infrastructure research. Many different heat sources can be used to supply district heating networks with hot water. The most common fuels for district heating in Europe are natural gas and coal, but oil and renewables are also commonly used. Waste heat from industrial processes can also be utilized, as well as heat from waste incineration, geothermal heat and solar heat (Persson et al., 2006).

Eriksson et al. (2007) performed a life-cycle assessment comparing district heating based on waste incineration with combustion of biomass or natural gas. Their results indicated that combustion of natural gas in CHP plants is an alternative of interest if marginal electricity has a high fossil content. However, gas generally performs worse than bio-fuels. In addition, as Persson et al. (2006) point out, another advantage of central heat generation in large plants is that it makes possible the arrangement of highly efficient burning and flue gas treatment.

Regarding efficient technological options other than district heating, Pehnt (2008) states that the advantages of micro-cogeneration (cogeneration based on small conversion units in a single building) with regards to greenhouse gases are comparable to district heating with CHP. More focused on district heating, Gustavsson and Karlsson (2003) compare district heating using CHP with local fuel-based and electric heating systems for detached houses. The heat pump and district heating systems are found to be most energy efficient, followed by the local fuel-based systems. Furthermore, district heating, natural gas-fired boiler systems and heat pump systems exhibited the lowest costs.

The approach applied in this paper has been previously used by Oliver-Solà et al. (2009) to a natural gas grid, which resulted in a clearer picture of the sources of environmental impact in the infrastructure. In that paper, LCA proved to be a useful and practical tool for guiding planning processes with environmental criteria by facilitating our understanding of environmental impact on urban infrastructures.

2. Goal and scope

2.1. Objectives

There are several systems for providing heat to a neighbourhood. The two most extensively used in cities of developed countries – besides electricity – are either providing heat using a district heating scheme or distributing the fuel, mostly natural gas (methane) that provides heat after combustion in a domestic boiler. This paper aims to perform a LCA to determine the environmental impacts within a local neighbourhood context of a district heating infrastructure, from the central CHP plant to the heat exchangers in the dwellings.

Currently, we only know the environmental impact of isolated elements of a district heating infrastructure. We do not have a global vision that shows which system, subsystem or component has a greater impact. In addition, the urban population is increasing every year, which makes the building of new urban infrastructures necessary. Knowing the sources of environmental impact for these infrastructures may help to redesign them from an environmental perspective and reduce their environmental impact.

The results obtained should:

- Obtain inventory data of subsystems not studied in former papers on district heating networks.
- Answer which subsystems and components of a district heating grid are the main contributors to the overall environmental impact of the infrastructure.
- Provide environmentally oriented design strategies for the future eco-redesign of these kinds of infrastructures. This is in line with what was also asked for in the conclusions of Bardouille and Koubsky (2000).
- Determine whether building density is a determining factor for the environmental impact per dwelling in a district heating infrastructure.
- Put the impact of a district heating infrastructure into perspective by comparing it with the one for a standard infrastructure used for distributing natural gas (Oliver-Solà et al., 2009), which after combustion is a source of heat for domestic uses.

The results obtained in this study may be of interest to energy companies constructing and designing district heating infrastructures, as well as to public officials and decision makers trying to integrate environmental criteria into the municipal planning process of new and existing neighbourhoods.

2.2. Functional unit

The functional unit is the basis that enables alternative goods, or services, to be compared and analyzed. In this case, the functional unit is the neighbourhood infrastructure that serves to provide heat for satisfying the domestic requirements for space heating and sanitary hot water of a standard family in 240 dwellings[1] within a local urban neighbourhood for 50 years.

This functional unit does not directly reflect the function of the district heating infrastructure (i.e. heat distribution), as it refers only to the infrastructure for distributing heat, not the energy consumption, nor the heat losses during the use phase. This use is not considered.

2.3. Description of the systems under study

The district heating infrastructure has been studied in a section of urban neighbourhood corresponding to one hundred meters of street with ten blocks of 24 dwellings each.

The scenario boundaries are the limits of the defined neighbourhood. The paper differentiates between three systems: neighbourhood, building and dwelling (Fig. 1).

In turn, each system contains subsystems. There are seven subsystems in the scenario distributed as follows:

- Neighbourhood: power plant, main grid, components of the main grid and trench works.
- Buildings: service pipes and components in the buildings.
- Dwelling: components in the dwellings.

[1] Assuming that these dwellings are the main residence for this standard family.