DISTRICT HEATING NETWORKS IN THE FRAMEWORK OF SPATIAL PLANNING

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Keywords

Energy transition, energy planning, heat mapping, heat density

Abstract

The way to a more sustainable energy future is running over a transition process that drives change in our views and actions on renewables, emissions and efficiencies. The interaction between energy and space evolves in this transition, with district heating taking up a growing role. Distributed (renewable) energy generation, the reuse of waste and excess heat significantly contributes to the sustainable energy system, but more than the former it is constrained by spatial dependencies.
In contrast to North and East European countries, Flanders has a highly centralised energy production profile. When focusing on thermal energy, decentralised supply such as district heating and cooling is rare. Adding to the poor transportability of heat and the high investment cost of network infrastructure, spatial factors such as proximity and density of heat demand play an important role. Meanwhile acknowledging the need for an integral approach, this paper explores the relationship between district heating and spatial planning. Via heat mapping, areas with sufficient heat demand are located and investigated for their spatial potential. First a linear heat density map is drawn and subsequently the preliminary district heating potential is represented in a heat tariff map. The latter proves to be prospective for screening district heating projects by network administrators.

1. Introduction

Driven by climate change issues, the scarcity of and our dependency on fossil fuels and the affordability associated therewith, Europe is currently going through an energy transition. The energy transition comprises a long term evolution from a fossil energy based economy to a renewable energy based economy. It impacts the environment we live in and in particular its spatial structure. While energy supply used to be a self-evidency in the fossil energy system – also because energy prices were relatively low – energy generation becomes challenging and more present in the environment in a renewable energy system.

There is a mutual dependency between energy and space. For distributed energy generation, it is clear that the conversion into a sustainable energy landscape affects the environment. The ‘footprint’ of renewable energy is much larger than that of fossil energy (Kann, 2008). But from a spatial planning point of view, the importance of energy is likewise growing. Energy never used to play a major role in spatial planning but now it has taken its place as one of the functions considered in policy and design. Similarly, spatial characteristics and organisation influence the way the energy transition develops (Noorman and Roo, 2011). Hence, it can be denoted as a reciprocal influencing of energy and landscapes. Stremke and Koh (2011) discuss three obstacles for the sustainable energy transition:

1. Fluctuating nature of renewable energy supply

2. Relatively low energy density of renewable energy
3. Limited utilisation of available energy by consumers

All three obstacles show – next to the connection with energy and landscapes – a link with district heating (DH) networks. Firstly, fluctuations in renewable energy production from wind or solar for example, can be compensated with the installation of DH. Heat can be stored relatively easy, therefore cogeneration plants providing heat and electricity for buildings used to balance the variable renewable energy supply (Veerapen and Beerepoot, 2011). When wind and/or solar energy supply is low, heat from the cogeneration plant can be stored. When there is plenty of renewable energy, the cogeneration plant can be turned down and the stored heat can be used in a DH network. Secondly, the low energy density of renewables such as biomass or shallow geothermal heat leads to large inefficiency when converted to high quality electricity, but shows corresponding exergy levels with heat in DH networks. This issue is further explained in ‘4. Sustainable and efficient energy supply: district heating. Thirdly, collective heat supply (DH) shows better efficiency levels than individual heat supply – providing it is realised under market conditions – and can therefore improve the utilisation of energy by consumers (Fraunhofer, 2010).

Noorman en de Roo (2011) describe three generations of energy landscapes. The first generation was built on muscular strengths, wind, wood and semi-fossil energy like peat. At this time, energy also had a significant influence on the environment which is still visible today. With the industrial revolution the second energy generation started, first with coal and later with oil and gas. The great transportability and development of an underground network made energy dispensable in the spatial planning framework. The spatial footprint became small and production was organised centrally, located far away from living areas. At this moment, we are evolving towards the third energy generation where renewable energy – wind, biomass, solar energy, geothermal energy, etc. – plays a major role. As already mentioned, the footprint of energy production will increase, production will be decentralised and space will be explicit in the energy system.

2. Energy transition and the international context

At first, the energy transition was framed internationally in the European climate and energy package, mostly known as the 20/20/20 strategy. The three targets for the year 2020 were: reduction of annual greenhouse gas emissions with 20% beneath 1990 levels, increasing the share of renewable energy in final energy consumption to 20% and reduction of the annual primary energy consumption with 20% compared to BAU projections for 2020 (European commission, 2011). They have recently been extended with targets for 2030. Greenhouse gas emission reduction is now set at 40%, the share of renewable energy should be at least 27% of our total final energy consumption and a new energy efficiency goal will be defined in a new energy efficiency directive expected in summer 2014 (European Commission, 2014). Figure 1 shows an overview of the different targets the EU set in its climate and energy policy.

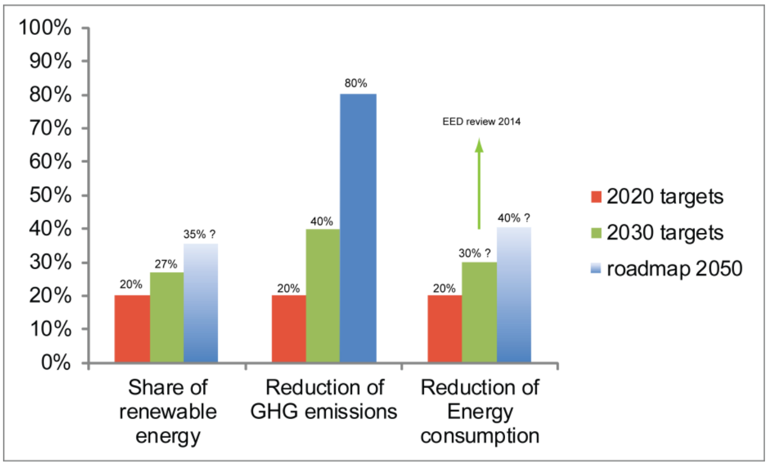

Figure 1: Overview of EU targets in the climate and energy policy

There is a high potential for energy saving through efficiency measures. A communication of the European commission (2006) states that respectively 27% and 30% of the potential energy savings are to be found in the residential sector and the tertiary sector. According to the European commission (Andrews et al., 2012) 43% of our total final energy consumption is used for space and water heating in buildings in the European Union. The highest share of space heating is found in countries with moderate winters such as Ireland, Belgium, Denmark and Germany and not in countries with colder winters (Pardo et al., 2012). The German AGEB (2013) for example defined the share of space and water heating in the final energy use of the residential sector at 88% and of the commercial sector at 63% in 2011. Most recent data in Flanders, date back to 2006. At that time on average 70% of the energy consumption in the residential sector went to space heating and 15% to heating of domestic hot water (MIRA, 2011a). If this part of our energy consumption could be made more efficient and sustainable, significant contribution to the sustainable energy system would be made. Cyx et al (2011) – in a study in the framework of the European IEE project – estimated the energy saving potential of 75% in the residential sector if all houses would be converted to low energy buildings

Furthermore, the European union is mainly depending on other countries for its energy supply. In 2009, 83% of the oil and 62% of the gas was imported (European commission - Directorate General for economic and financial affairs, 2013). Within Europe Flanders is one of the most energy dependent regions. An environmental study indicated that in 2011, 92.8% of the primary energy was imported (MIRA, 2011b). Because a significant part of the primary energy is supplied from countries having instable political connections with Europe, security of supply is one of the pillars of the European energy policy. The dependency puts a strain on our competitiveness in the global economy, on sustainability and on reliability of the system. This places energy transition high on the political agenda.

The transition of the energy system is drastic and precarious. Therefore it is important to create a coherent and controlled approach and to ensure a broad public support. First steps are to define who takes the responsibility for the large investments associated with energy transition and future organisations of regions and societies. Noorman and de Roo (2011) state that institutional action is required to achieve the coherent realisation of an energy transition in which different governments will have to cooperate and take responsibility. Energy transition will no doubt have its effect on our society and, in particular, its spatial organisation.

3. Flemish spatial context

Europe is one of the most urbanised continents of the planet. In 2006, approximately 75% of the population lived in urban areas and more than a quarter of the European union's territory has been directly affected by urban land use (European Environment Agency, 2006). Economic growth, developing transport system, globalisation and population growth are just few of the many factors causing urbanisation. However, our understanding of the archetypes 'city' and countryside' are gradually blurred by excessive urbanisation (Tempels et al., 2012). The scattered expansion of the urban area causes a chaotic spatial structure in which centrality is absent, this is called 'urban sprawl'. It is defined by the European environmental agency (2006) as: "physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas". As Figure 2 shows, the Flemish region in Belgium is almost entirely subject to sprawl. 70% of the Flemish population lives in an 'urban complex', an area structured by suburbanisation, while 10% lives in 'real' urban areas (Kesteloot, 2003).

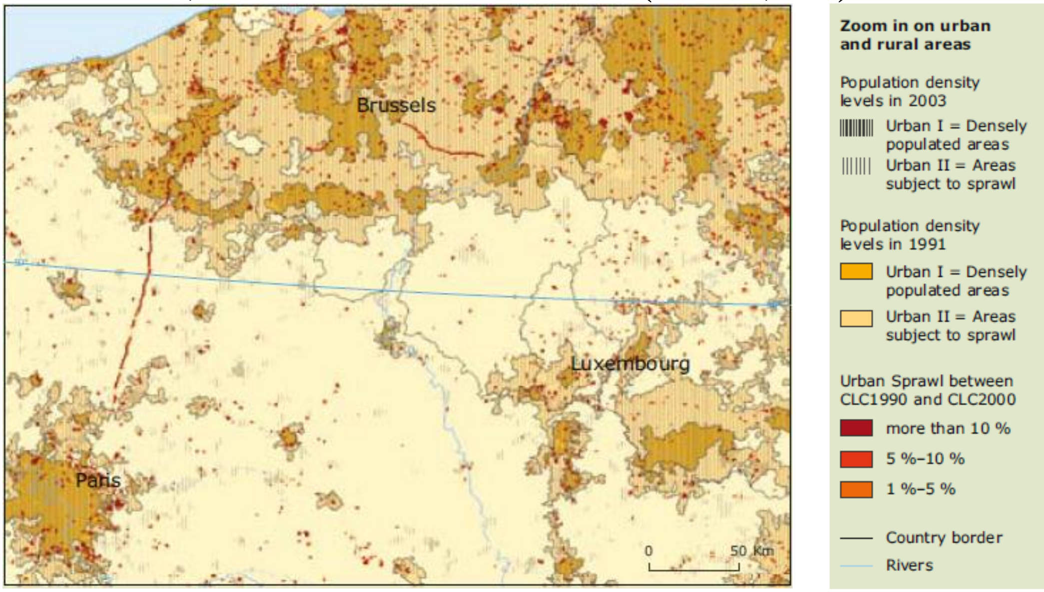

Figure 2: Urban sprawl in northeast France, Belgium, Luxembourg and northwest Germany (European Environment Agency, 2006)

According to Tempels et al (2012), (Flemish) sprawl is caused by five groups of driving forces: socio-economic, political, technological, spatial and cultural. The political factors are the most specific for the Flemish region. Flanders has a history of flexible permitting policies originating from the political choice of Christian-democrats and liberals already in the 19^{th} century. An impressive measure was to relocate the working class to the countryside, thus out of the city where they were subject to socialistic ideas. Real spatial planning gave way to an enabling system based on a range of policy priorities and political favours, despite attempts to create a plan based on a long term vision. This resulted in a spread building pattern of residential and commercial activities.

One of the environmental consequences of urban sprawl is the increased energy consumption. Compact high-density areas have lower energy consumption than low-density areas. Additionally, energy consumption related to transport increases due to urban sprawl (European Environment Agency, 2006).

However, the socio-economic disadvantages of an open horizontal city are nuanced (Boelens, 2013). A complex, meshed relationship exists between the city and its environs in the organically grown horizontal metropolis. This is visible in the Belgian mobility system that shows a denser and finer network of roads resulting in a more spread and diffuse mobility patterns compared to the Netherlands. The issues of congestion are thus more easy to develop into a sustainable structure, provided some technological and spatial measures are taken. Furthermore, the horizontal metropolis leads to ecological benefits such as higher bio capacity and lower environmental pressure, despite their spatial inefficiency.

An inconsistency emerges between the former notions and the general assumption of the feasibility of a DH network which is to a large extent relying on a compact, dense demand for heat in a defined area or over a controlled distance. Though if DH would only be possible in compact, vertical and rigidly planned cities, it would not be such an omnipresent heating system in northern Europe. The unique case of Malempré, a village in the south of Belgium, shows the possibility of DH in a low density building structure thanks to strong stakeholders (a residents cooperation), a tight planning and a technical opportunity (Jardinet, 2014). With the focus on the particular Flemish case the prospects of DH in a typical horizontal urban landscape can be studied.

4. Sustainable and efficient energy supply: district heating.

The amounts of heat lost in the EU27 energy system can be valued at €480 billion per year when compared to the European crude oil price (Andrews et al., 2012). At the same time, buildings are heated in an inefficient way, often with fossil fuels, as confirmed by the European commission (2006). Electricity coming from nuclear plants and natural gas is used to generate heat for space and water heating in buildings. Hence, in order to make our energy system more efficient, we should make use of what is abundantly available: waste heat.

In a sustainable energy system optimal energy use is reached when high quality energy and low quality energy are used for purposes requiring respectively high and low quality energy. The quality of energy is expressed by the term exergy (Fraunhofer, 2010). Therefore, in an efficient energy system, exergy losses should be as low as possible. Direct use of residual heat from waste incineration but also industrial plants or simply the collective generation of heat for a group of buildings with a combined heat and power installation (CHP) is more efficient than individual generation of heat with fossil or fissile fuels.

This collective supply of heat is called district heating. The share of citizens served by district heating in Europe is on average 12,4% (Connolly et al., 2012). Mainly in northern, eastern and central Europe collective heat supply is widespread. Denmark, Sweden and Finland have an higher DH profile with shares between 50 and 60% and, compared to former USSR countries, higher level of efficiency of the DH systems. Germany and the Netherlands have respectively 12 and 5% of their citizens connected to district heating networks, which is still significantly higher than the approximate 1% in Belgium (Euroheat&Power, 2013). The current situation of Belgium is totally different from the conditions in northern Europe, implying different approaches for further development of district heating networks.

District heating is indicated by the European commission as one of the means to reach energy efficiency and thus European energy objectives. The concept is also included in the energy efficiency directive EED 2012/27/EU (European Parliament and Council, 2012). Next to environmental assets such as the possibility to use residual heat, the low primary energy consumption and the reduction of local pollutants, district heating has a wide range of additional benefits. Firstly, there is an equipment and maintenance benefit: the in-house installation is small, simple to run and maintain and likewise the risk of fire, explosion or dangerous substances in the house is very small. Secondly, although district heating requires relatively large investment costs, the operating and maintenance costs are small and prices tend to be predictable and steady over time. Thirdly, the systems are reliable and can be fed by different fuels or a mix thereof. Additionally, the advantageous storage capacities are a convenient characteristic of heat (King and Parks, 2012).

One important challenge of district heating is the poor transportability of heat. In contrast to electricity, which is transportable over hundreds of kilometres, heat transport is limited due to the heat losses. Additionally, large investment costs of the infrastructure confine the extent of the system. As with many forms of renewable energy, proximity is an important factor of the feasibility of the system. Particularly the density of the heat demand is important because larger heat supply on a short distance is more profitable in technical as well as economic terms. These spatial factors invite to investigate the relationship between district heating and spatial planning.

5. District heating versus spatial planning

5.1. Energy planning

The term energy transition indicates the evolution from the second generation energy landscape to the third generation energy landscape i.e. from a dominative fossil and fissile fuel based energy system to an energy environment based on decentralised renewable and/or sustainable sources. Energy prices, climate change and security of supply are the main drivers for the political decision framing energy transition. The transition has a clear effect on our environment. As already stated, space is an implicit factor in the fossil economy. Centralised electricity production with nuclear or gas fuelled plants and underground gas network takes only a small part of the available space in our land. In contrary, decentralised energy production with renewables 'consumes' a lot of space hence it is stated that space is 'explicit' in the sustainable energy system.

The relation between energy and space is enhanced to the extent that energy demands a prominent role in spatial planning. Vandevyvere and Stremke (2012) indicate the importance of spatial planning in the energy equation. Firstly, as heat has a good storage profile but a poor transportation profile, space and terms as proximity and density become essential. Secondly, designing and planning building related energy infrastructure is an integrated task for, amongst others, spatial planning. Dobbelsteen et al. (2011) predict that in the future, local resources will have to be integrated in the planning and designing process so that they are utilised optimally. They advocate energy potential mapping as a support for exploring and valorising local resources and as a means for mutual comprehension between energy technology and regional and urban design. Spatial planning as a holistic discipline cannot exclude energy – or better yet, exergy – from its content.

Considering the importance of proximity in the new energy system on the one hand and the typical open, horizontal building pattern in Flanders on the other hand, the development of district heating is believed to become challenging. The lower the density of the building structures, the lower the density of heat demand (in general, in residential and commercial areas) and thus the less feasible the DH network will be. Therefore the building density and, more importantly, heat density need to be examined in order to find out the potential DH areas.

Van Kann (2010) indicates strategic concepts as an input for local design principles of sustainable spatial planning. Energy cascading is an example of a design principle that enables applying exergy planning in concrete situations. This paper particularly focuses on heat planning within energy planning considering the exergetic and environmental advantages of district heating networks compared to individual heating with fossil fuels as indicated before.

5.2. Heat mapping

theory

Mapping has always been an important means of presentation in spatial planning. Boelens (2009) defines four different navigation techniques to establish a new relationship between actors and institutions in a planning process: tracing, mapping, diagramming and agencying. Tracing focuses – based on what exists in the past and present – on seeking out the potentials of an area without suggesting future realities. Based thereon, mapping presents an image or vision on how the current regime can evolve into a new regime. The maps presented in this paper are thus part of the tracing activity.

Now that energy production and supply becomes a more decentralised matter, energy mapping will take a substantial part of the planning activity. A geographical system for data storage, retrieval and analysis is required considering the geographical nature of renewable energy systems (Möller, 2012). Stremke et al (2012) also include mapping the renewable energy potential in their framework for long term regional design. This paper focuses on heat and more specifically, the mapping of heat consumption in a potential future district heating network. Geographical information systems (GIS) are indispensable in heat planning and are used in many large cities including London and Paris (Nielsen and Möller, 2013).

In Denmark, the government reacted to the oil crisis of the seventies by making the energy system more efficient, reducing its oil dependency and improving the socio-economic state of the system. The energy plan of 1976 and the Heat Supply Act of 1979 has laid a first (legal) basis for heat planning. The latter imposed municipalities and counties to make heat plans specifying the heat supply in an area like a city or town district. All the data were stored in a heat atlas, which was revised each year. Hence Denmark managed to decrease the importance of oil in its heat demand from 90% in 1972 to 10% in 2010 thanks to decentralised heat planning. Although liberalisation of the energy market initially decreased heat planning activities, the general ambition to eliminate fossil fuels from the energy system stimulates strategic energy planning (Möller, 2012).

methodology

In Germany, a tool was developed for creating grid-based maps of heat demand in cities (Nielsen and Möller, 2013). The tool aims to represent the annual heat demand per grid cell of 200x200m² using a building database with information about use, height and age of buildings and estimations on specific heat demand of buildings in kWh/m².a. Thus the map shows a certain heat density, i.e., the heat demand per area unit of 4 ha, but does not take into account the length of the streets in the particular grid cells.

In contrast to the Danish heat planning, which is mainly focused on expanding existing DH systems, heat planning in Belgium is still in a starting phase. Hence heat maps will be significantly different. Therefore, Danish heat maps represent the potential of expanding existing DH areas and of connecting new buildings in existing DH areas. Nevertheless, it is worthwhile exploring advanced Danish heat map methodologies.

The Danish heat atlas is based on data from the Danish building register (BBR). Using this database, containing information on age, type and usage of the building, the heat demand of the respective buildings is calculated (Nielsen and Möller, 2013). When the individual heat demand of each building has been determined, the geographical position of the buildings relative to each other is considered. The heat demand per unit of area or unit of distance, in other words the heat density, is defined. When mapping the heat density, often a threshold value for heat density is set in order to find DH potential areas. Different institutions have put forward diverging threshold values: DECC in UK defines the minimal heat density at 30kWh/ha, the International Energy Agency sets this limit to 100MWh/ha (King and Parks, 2012) while Frederiksen & Werner (2013) indicate 400-500MWh/ha as a typical threshold value. Considering the large investment cost of the infrastructure, the linear extent of the heat density becomes interesting. Research shows that high linear heat densities cause lower distribution capital costs (Frederiksen and Werner, 2013). Likewise divergent threshold values are defined eg. 2000 MWh/km according to the UP-RES consortium (2013), 2500 MWh/km according to Sven Werner (Andrews et al., 2012) and between 3000 MWh/km (low density) and 15000 MWh/km (high density) according to US data (King and Parks, 2012).

Following former ideas about heat mapping, an own heat map was developed in a grid-based map. In Figure 3 the linear heat density is represented for Eeklo and Maldegem, two municipalities in Belgium. The heat demand is determined based on the gas consumption data of the municipalities in 2012. The roads along which the linear heat density is calculated are split by a grid with cells of 250*250m².

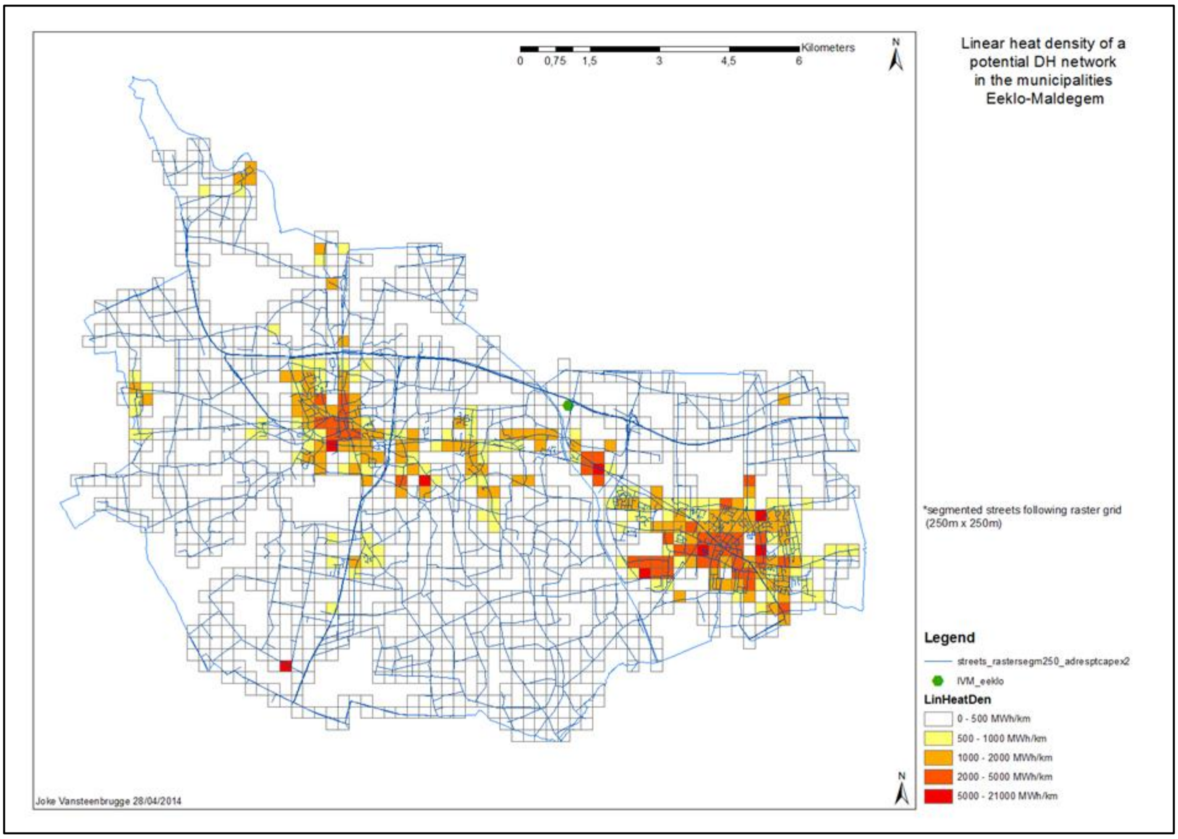

Figure 3: heat map of the municipalities Eeklo-Maldegem (Belgium) showing the linear heat density per cell of the raster grid

Although linear heat density thresholds are all set at minimum 2000MWh/km, the lowest category of the map is at 500MWh/km in order to give a differentiated map of different heat densities. Both municipalities do not belong to the urban cores of Flanders, yet they give evidence of the horizontal building structure in typical Flemish municipalities of ca. 20 000 inhabitants (FOD Economie, 2013). In general it is observed that heat density is the highest in the centres of both municipalities and also – due to some large consumers – in industrial areas outside of the urban centre.

Subsequently, a heat potential study is performed to determine DH potential areas. Nielsen and Möller (2013) present a cost model to examine DH potential in a geographical information system. The cost of DH is distributed into a heat production, a heat transmission and a heat distribution cost. The sum of these costs is compared to the cost of the least expensive individual supply option. Inspired by this methodology, a heat tariff map was developed as shown in Figure 4. This heat tariff contains a heat production as well as a heat distribution cost including heat losses, operation and maintenance costs and heat pump costs. The heat tariff is shown with asterisks in the map in order to secure privacy issues. Four asterisks represent a low minimal required heat tariff and thus higher feasibility for district heating networks.

Although the proportions are similar for Figure 3 and Figure 4, some differences can be noticed. Additionally, the heat tariff calculation makes it possible to draw a limit of potential and non-potential areas more easily comparing heat tariffs of costs of other heat supply technologies like individual gas boilers or heat pumps.

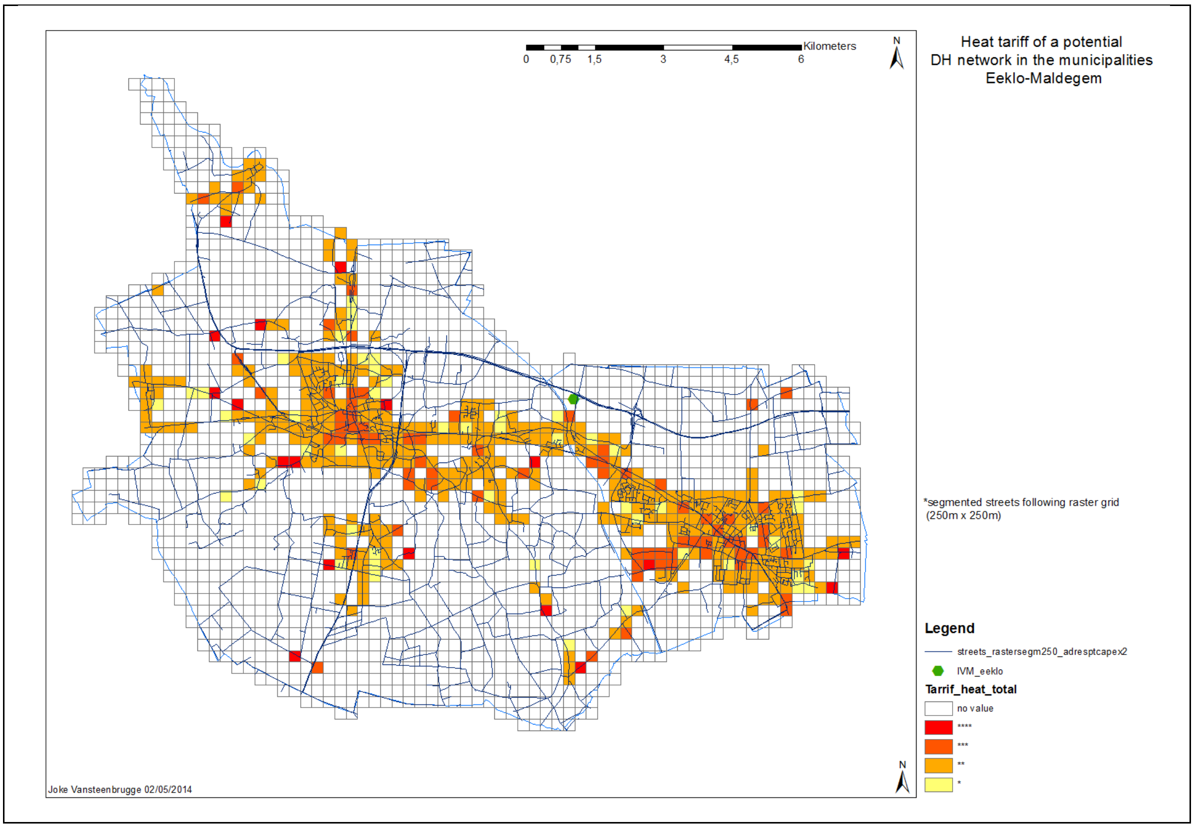

Figure 4: DH potential map of the municipalities Eeklo-Maldegem (Belgium) showing the heat tariff per cell of the raster grid

An important deficiency of the mapping methodology is that the calculation is made only for the distribution network within the cell and not relative to a heat source on a different location in the district or municipality. The next step is thus to include the transmission cost and to dimension the pipelines so that capacity corresponds to the heat demand along the entire pipeline from source to sink.

6. Conclusion

This paper started with the description of the (political) incentives and challenges for the energy transition. Firstly, there is a high potential for savings in energy consumption in the heating sector for space and water heating. Certainly when the large share of energy for heating in the total energy consumption of the residential and commercial sector is considered. District heating provides a more energy efficient heat supply and facilitates the use of renewables. It even plays a complementary role in its development. Secondly, the general energy transition, led by the European union, entails three obstacles in which district heating can play a complementary role towards a solution.

With the conversion from a fossil fuel based to a renewable energy system, the spatial factor becomes more important in the energy system and vice versa. This also applies for district heating where sufficient heat demands are required in order to design a feasible network. Mapping of this heat demand thus becomes a relevant means for the development of district heating networks.

The Flemish region in Belgium is defined by an open, horizontal building structure rather than a compact, vertical one. This should not necessarily be seen as a deficiency rather than as a quality for a lot of societal challenges. However, noting that the energy system of the future implies proximity and compactness of urban areas, the development of district heating networks may become challenging. Heat is not transportable over large distances like electricity, in technical as well as economic terms. Therefore district heating networks always start from small scale systems in medium or high density built areas.

The compactness of heat demand is expressed by the linear heat density. In this paper, a grid-based map is presented, showing the linear heat density in two Belgian municipalities. Following, an estimation of the heat tariff is made based on a calculation of heat production and heat distribution costs. Hence, clear comparison can be made with tariffs of individual heating systems such as natural gas boilers or heat pumps. In areas with low minimal heat tariffs the open building structure of Flanders can prove to be valuable because more space is left for infrastructure and decentralised heat generation, civil cooperation is possible, etc. The next step in the heat potential study is to determine the cost of the heat network relative to a heat source such as a waste incineration plant or a combined heat and power plant. This way, a more correct interpretation can be given on the potential of district heating in Flanders and an understanding of the position of the horizontal urban area in the future sustainable energy system can be shaped.

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