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The Role of Low Temperature Waste Heat Recovery in Achieving 2050 Goals: A Policy Positioning Paper

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Abstract: Urban waste heat recovery, in which low temperature heat from urban sources is recovered for use in a district heat network, has a great deal of potential in helping to achieve 2050 climate goals. For example, heat from data centres, metro systems, public sector buildings and waste water treatment plants could be used to supply 10% of Europe's heat demand. Despite this, at present, urban waste heat recovery is not widespread and is an immature technology. Based on interviews with urban waste heat stakeholders, investors interested in green investments, and experience from demonstrator projects, a number of recommendations are made. It is suggested that policy raising awareness of waste heat recovery, encouraging investment and creating a legal framework should be implemented. It is also recommended that pilot projects should be promoted to help demonstrate technical and economic feasibility. A pilot credit facility is suggested aimed at bridging the gap between potential investors and heat recovery projects.

Keywords: district heating and cooling; urban waste heat recovery; data centres; metro systems; low temperature; excess heat

1. Introduction

The European Commission has proposed that the 2050 target of climate neutrality should become law [1]. One important contribution towards meeting this target is to expand the use of renewable district energy solutions. Heating and cooling are the largest energy-consuming sectors in the EU, representing half of total energy use. Industrial waste heat has huge potential for helping meet this demand in Europe with an estimated 2.7 EJ/year available [2]. This could meet approximately 25% of the heat and hot water demand in European buildings. Recently, another abundant heat source has been identified in the form of low temperature heat. Around 1.2 EJ/year of low temperature heat is available from urban heat sources in Europe (e.g., heat from infrastructure like sewage water and metrosystems, service sector buildings and data centres) [3].

The combination of industrial and urban waste heat sources provides great potential to contribute to the replacement of fossil fuel based heating in Europe and globally. The global extent of waste heat recovery potential from industrial sources is not known. However, it is estimated that, in 2014, around 331 PJ of industrial heat was recovered. Around 16 PJ of this was recovered in Sweden. The potential for industrial heat recovery in district heating systems has been estimated for the UK [4], Spain [5], Germany [5,6], China [7,8] and the EU as a whole [9].

Despite the great potential for urban waste heat recovery, uptake has, so far, been low. Research has shown that urban waste heat recovery investment is hindered by untested technical solutions, the absence of standardised contracts and the current cost of carbon, making the business model more appropriate for circumstances beyond 2050 [3].

Conventional district heating (DH) systems are a combination of heat from recycled sources (combined heat and power generation, waste to energy plants and industrial processes) and, increasingly, from renewable sources such as biomass fuels and solar collectors [10]. The conventional wisdom is that heat is collected or produced locally and distributed to customers in a citywide distribution network [11]. The most recent technological development is the use of local, low temperature, heat sources in city infrastructure such as metro systems and sewage and commercial activity from sources such as data centres [3]. Urban waste heat is carbon neutral and tends to create high political interest but has low utilisation. These characteristics imply that there are barriers preventing its greater utilisation. In a recent paper [3], the main barriers to urban waste heat recovery investments were identified: (i) low technical maturity of the existing system solutions, (ii) long investment payback periods, (iii) diverging views regarding the value of heat, (iv) competition from existing incentives for renewables and combined heat and power generation, (v) the absence of standardised contracts and (vi) the absence of a legal framework for urban waste heat recovery.

Low temperature heat recovery is referred to as fourth or fifth generation district heating technology, where the fifth generation represents lower distribution temperatures than the fifth. The technology shift is, at present, new and far from established [12]. However, utilisation of urban heat sources will become increasingly important in a future with no fossil fuels, lower available volumes of waste to incinerate and demand for alternative uses of biofuels. This presents an opportunity since waste heat sources are numerous and tend to be situated close to urban areas of high heat demand; aspects that reinforce the resilience of the energy system overall.

In order to meet the objectives of the 2016 Paris Agreement, it is estimated that approximately 27 trillion USD needs to be invested in renewable energy between 2016 and 2050 [13]. Urban waste heat recovery investments are typically smaller than those institutional investors look for and therefore will not automatically be appealing. Without policy support, there is a risk that investment will not be forthcoming and an important opportunity to support the transition towards carbon neutral societies will be lost.

This paper discusses measures that are needed to make urban waste heat investments attractive. The paper was written based on experience from the ReUseHeat project, funded by the European Commission. The project demonstrates four system innovations for recovering urban waste heat and conducts research into stakeholder perspectives, investment risks, requirements of investors and business models. The project is a forerunner in terms of low temperature waste heat recovery and showcases what the district heating sector may look like in 2050. The aim of this paper is to discuss the role of policy in encouraging urban waste heat recovery for the heating and cooling sector in Europe. This topic is of particular relevance since policy is lacking in this area.

2. Materials and Methods

Knowledge surrounding necessary policy for low temperature heat recovery is somewhat fragmented. Our aim is therefore to gather knowledge from multiple sources. The results described in this paper come broadly from three different sources: a literature review aimed at summarising existing policy in Europe (with a particular focus on five key countries: Denmark, France, Germany, Sweden and the UK), a set of stakeholder interviews, and information gained from discussions with the ReUseHeat demonstrator projects. The methodology behind each source is described below.

2.1. Literature Review

Our first approach was to carry out a literature review to summarise existing policies in European countries relating to low temperature heat recovery and more common infrastructure such as CHP and industrial waste heat recovery. The existing situation in five European countries is summarised in the results section and the lessons learned from this are discussed.

2.2. Stakeholder Interviews

An important part of the ReUseHeat project is to gather the views of existing and potential stakeholders for urban waste heat recovery. The views of stakeholders is an important input for project development and this is seen as an vital part of encouraging future waste heat recovery projects. Interviews were carried out with five categories of stakeholder in eight EU countries (Sweden, Germany, Denmark, France, Italy, Spain, Belgium and Romania). The categories are as follows:

- policy makers
- investors
- district heating companies
- waste heat owners
- customers

A total of 76 respondents were interviewed with a different set of questions defined for each type of stakeholder. These formed the basis of the interviews.

Alongside the stakeholder interviews, the following sources of information have also been taken into account:

1. Panel discussion at a ReUseHeat/HeatRoadMap Europe 4 (both EU funded projects under the H2020 program) joint event in Brussels in February 2019. Of particular interest was a panel discussion that included a representative from Belfius Bank, a bank owned entirely by the Belgian state, that has expressed an interest in investing in waste heat recovery.
2. A ReUseHeat Policy Workshop held in Brussels in October 2019 bringing together policy makers, academics, investors and consultants, aimed at encouraging waste heat recovery investment. The event consisted of three sessions: (i) designing a legal framework, (ii) creating a track record for waste heat recovery and (iii) promoting financial support and guarantees.
3. Discussions with a representative from Caixa Bank, a not-for-profit financial institution based in Valencia, Spain, which has expressed an interest in investing in waste heat recovery.
4. Information gathered from the 39th Euroheat and Power Congress, held in Nantes in May 2019.
5. Information gathered from the 2018 Global District Energy Days held in Helsinki in September 2018. Of particular interest was the session on "Business & Operations: Putting your money where your mouth is" that featured representatives from the European Bank for Reconstruction and Development (EBRD), Belfius Bank (Belgium) and Kyotherm investors in green project (France).
6. Discussions with consultants at Nordic Energy and IMCG, Sweden.
7. Experience with the development of a DHC framework in the UK under the supervision of the Department for Business, Energy and Industrial Strategy (BEIS) [14].

2.3. ReUseHeat Demonstrators

The ReUseHeat project involves four demonstrator projects, demonstrating low temperature heat recovery from urban sources. These are

1. Recovery from a waste water treatment plant to heat a new district in Nice, France. A decentralised heat-exchanger will be used to transfer heat from sewage to water which will then be upgraded using a reversible heat pump for use in a new district heating network.
2. Recovery from a data centre to heat a new commercial and residential development in Brunswick, Germany. A water to air heat-exchanger will be used to transfer the heat from the data centre to water which will then be upgraded using a CO_2 heat pump for use in a new district heating network. The network will be connected to an existing CHP which will provide an additional source of heat for the network as and when required.

3. Recovery from a metro station in Berlin, Germany to provide heat for a university. An air to water heat pump will be used which will upgrade the heat to the required temperature for use in the university's existing district heating network.
4. Recovery from a hospital cooling system in Madrid, Spain to be used for heating other parts of the hospital. Outlet water will be taken from the water to water chillers and upgraded using a booster heat pump for use in the existing district heating network. This will have the added effect of reducing dependence on cooling towers.

One of the aims of ReUseHeat is to gather knowledge from the demonstrators for use in future heat recovery projects. In this paper, we discuss the experience of the demonstrators in the context of policy.

3. Results

3.1. Heat Market Overview

In the EU, district heating has an overall 13% market share of the heating sector. However, in some markets, there is a longer tradition and the market is more mature. District heating contributes to over 50% of heat demand in Denmark, Sweden, Finland, Estonia, Latvia, Lithuania and Poland [10]. In terms of absolute numbers, however, the biggest district heating markets in the EU can be found in Germany and Poland [15]. In Germany, the prevalence of district heating is higher in eastern states (approximately 30%) than in western states (around 9%) [15]. The European district energy landscape can be split into four categories: consolidation countries, refurbishment countries, expansion countries and new developing countries [16].

3.1.1. EU Frameworks That Impact District Heating

Frameworks that impact the rollout of district energy in the EU originate both from EU directives and national legislation. Legal frameworks for district heating differ significantly between regions and countries. Laws explicitly targeting district heating are in place in Denmark, Sweden, Norway, Lithuania and Germany. In other countries, such as Finland, France, the UK and the USA, energy and competition laws dominate and apply to district energy markets [10]. In 2016, the European Commission drafted a strategy for heating and cooling which, among other things, aims to better integrate it with the overall energy system and improve its flexibility. Further, the strategy aims to reduce energy waste in industry by utilising waste heat in district heating systems and integrate renewable electricity (through heat pumps), solar thermal energy, geothermal, waste heat and municipal waste. It also offers the opportunity to cheaply store thermal energy in hot water tanks [3]. However, the directive is not currently implemented across the European Union in a structure that resembles its wording. In a study of 14 EU countries [16], directives that have an impact on district energy have been identified. These are:

1. Directive 2010/31/EU on the energy performance of buildings.
2. Directive 2004/8/EC on the promotion of cogeneration, based on useful heat demand in the internal energy market, amending Directive 92/42/EEC.
3. Directive 2006/32/EC of the European Parliament and of the Council on energy end-use efficiency and energy services and Energy Efficiency Directive 2012/12/EU.
4. Directive 2008/1/EC concerning integrated pollution prevention and control (IPPC).
5. Directive 2008/98/EC of the European Parliament on waste and repealing certain Directives.
6. Directive 2012/27/EU on energy efficiency.
7. Directive 2018/2001/EC of the European Parliament on the promotion of the use of energy from renewable sources.

Different countries within the EU have different traditions towards regulation. Below, countries adhering to the tradition of explicit heat regulation and those adhering to broader energy and competition regulation are discussed. At the end of the section, lessons that can be learned from these examples are identified.

3.1.2. Countries with Explicit Heat Regulations

Two examples of countries with explicit heat regulations and mature heat markets are Denmark and Sweden. In Denmark, the market is regulated whilst, in Sweden, it is privatised. Both are discussed below.

Denmark

In Denmark, there are several measures in place that support district heating. These are (i) heat planning regulation, (ii) taxation, (iii) subsidies, (iv) heat price regulation, (v) CHP requirements, (vi) a ban on electrical heating and (vii) a law on district cooling. There is a tradition of encouraging efficient use of energy by ensuring there is a market for collective heat supply. This is achieved through heat planning regulation. This also encompasses planning for the use of waste heat. Taxation is applied to energy as a fuel and on its emissions, promoting a shift from fossil fuels. Before 2000, there were different, direct subsidies impacting the usage of district heating, such as subsidies for converting older houses to DH, speeding up the process of planned networks, and conversion from coal to gas. The heat price is regulated to reflect the actual cost. The idea is to offset the disadvantage to consumers of the natural monopolies that come from district heating ventures. The current electricity act stipulates that CHPs should be built with the main ambition of generating electricity. However, heat recovery from CHPs is mandatory. A ban on electric heating in buildings also encourages DH. The last support mechanism for DH is that there is a law that allows municipalities to operate commercial district cooling schemes using the same infrastructure as DH [16].

In March 2012, the Danish parliament agreed a strategy to reach 100% renewable energy in the energy system by 2050. A new energy agreement was signed in 2018 with the support of all sitting parties in parliament, reaffirming and strengthening Denmark's climate and energy goals leading up to 2030. The energy agreement contains a wide range of ambitious green initiatives. Companies and consumers will, in the coming years, receive cheaper heating through a modernisation of the heating sector, where both the district heating sector and consumers will have a free choice to decide on future investments. This will result in cheap heating both for companies and consumers [17]. Since the Danish government imposes an energy tax on natural gas, solar district heating plants are given the opportunity to compete with natural gas boilers. Consequently, solar district heating plants are commercially viable solutions in Danish district energy systems [17]. In the interest of low temperature district heating investments, it is worth mentioning that, in Denmark, the 4DH research centre was active between 2012 and 2018 with contributions from several Danish and international universities, together with many Danish district heating companies. Researchers within this centre have written a 4GDH definition paper [18] and a 4GDH status paper [19]. Many papers have also been published in scientific journals from the annual international 4DH conferences since 2015 [20]. Besides this initiative, however, there are no dedicated low temperature district heating incentives in place.

Sweden

With the support of energy and climate policy, district heating systems have been developed since the 1970's and transformed from a dependence on fossil fuels to biomass. This progression has resulted in the DH sector being almost fossil free [11]. Sweden has the largest percentage of industrial heat recovery in its district heating systems in the world [21]. An energy and carbon tax was introduced on fuels used in heat production in 1991. From 2008 onwards, the carbon tax was gradually phased out for those combustion plants covered by the EU Emission Trading Scheme (EU-ETS), in order not to interfere with this policy. Two governmental investment grant schemes (1991–1996 and 1997–2002) played an important role in the construction phase of biomass-based CHPs. A scheme for Tradable Renewable Electricity Certificates (TRC) was introduced in 2003 in order to support electricity from renewable energy sources and peat. This led to additional CHP production and, consequently, a shift from fossil fuels to biomass in CHP plants [22,23].

In 1996, the Swedish heat market was deregulated. Prior to this, the largest challenge to the district heating industry was to improve its production technology to meet the increasing demand [24], but, since 1996, the industry has had to cope with challenges beyond technology. Examples of institutional challenges are a new district heating law (2008), the threat of price regulation (2009) and third party access (2009). The Energy Efficiency Plan 2011 and the Energy Efficiency Directive 2012/12/EU (also known as EED) promote effective heat recovery systems from electricity and industrial production processes as a way to help reach the EU target. The national proposal for the implementation of the EED in Sweden states that a cost-benefit analysis should be performed to evaluate investments in the use of waste heat in comparison to other thermal supply systems [25]. The Swedish government bill states that a DH company has no obligation to allow regulated access "if it can show that there is a risk that it will suffer damage as a result of the access". This means that Swedish policy currently neither promotes nor prohibits using waste heat recovery in DH [25]. On 4 December 2019 it was announced that new legislation placing a tax on waste incineration will be introduced from 1 April 2020. In combination with the new tax, the energy and CO_2 tax on CHP will increase from 30% to 100% and 11% to 91% respectively. These new taxes will be a challenge to Swedish CHPs. No explicit regulations supporting low temperature district heating investments are in place in Sweden [26].

3.1.3. Countries with Energy and Competition Law Regulation

Germany, France and the UK are examples of countries with energy and competition law regulation. Out of these, Germany is a mature market, France has had a district heating market for a long time which is currently experiencing significant expansion and the UK is a new district heating market. Each of these countries is discussed below.

Germany

The district-heating sector in Germany has a 14% market share of the heating market. Electricity and gas transmission and distribution networks are regulated in German Energy Law but no such regulation exists for district heating; instead, general rules of German competition law apply. Third party access to district-heating distribution grids is allowed but, at present, this has not been done to a major extent. The German government has put an emphasis on Combined Heat and Power and District Heating and Cooling as solutions for meeting environmental targets. The objective of the Combined Heat and Power Act (KWKG) is to increase the energy efficiency and thus to reduce CO_2 emissions. The Act also served as the implementation of Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market (Cogeneration Directive). Note that the Cogeneration Directive was replaced by the Energy Efficiency Directive in 2012). The system shares some similarities with the Act on Granting Priority to Renewable Energy Sources (EEG) [15]. The Wärmenetzsysteme 4.0 initiative has provided 100 million euro for funding feasibility studies and pilot projects related to low temperature heat recovery. The KWKG also provides funding for new and expended DHC networks.

United Kingdom

A key initiative in England and Wales is the Heat Network Delivery Unit (HNDU), which was formed within the Department for Energy and Climate Change (DECC) in summer 2013 to help meet 2050 targets [27]. The Carbon Reduction Commitment (CRC) is a mandatory scheme that aims to improve energy efficiency and reduce CO_2. Eligible organisations must buy allowances to cover their reported emissions; hence, green DH investments have benefited from the scheme. Another mechanism with which to meet the 2050 goal is national and regional planning for infrastructure. The plans set the policy framework for infrastructure decisions (including heating infrastructure) through Planning Policy Statements (PPS). District heating plays a part in this scheme. These statements are combined with the Climate Change Levy (CCL) tax which taxes supplies of energy within the non-domestic sector including industry, commerce and the public sector. In the CCL, there are exemptions for fuel inputs and energy outputs from CHPs.

An Enhanced Capital Allowances (ECA) scheme provides businesses with enhanced tax relief for investments in equipment that meet published energy-saving criteria. Eligibility for an ECA is a fiscal benefit available to new CHP schemes certified under the CHPQA programme. Since the most capital intensive element of distribution networks (the pipes) are not included, the scheme has limited overall effect in this sector. A number of funding programmes have been carried out in the UK. These include both grant capital support and assistance with pre-investment activities. One example is the Community Energy programme that aims to deliver new community heating schemes and refurbish old ones, thus reducing carbon emissions, alleviating fuel poverty and reducing frontline energy costs. Another similar scheme was provided through the Homes and Communities Agency [16].

The government is progressing policy incentives that will reduce the heat demand of the existing building stock while promoting the uptake of renewable heating technologies. The recently deployed Green Deal is expected to remove the barrier of initial costs for energy efficiency improvements while the Renewable Heat Incentive (RHI) attempts to support market roll out of renewable heat technologies. However, the success of these policy initiatives is uncertain and the impacts on technology deployment are yet to be identified [28]. The need for district energy market regulation has been discussed but, to date, there is no regulation of the heat market [27]. Taking the interest of low temperature district heating investments into account, it is notable that no regulation explicitly supporting such investments exists in the UK [26].

France

A large proportion of the supply of primary energy in France comes from nuclear power [29]. Use of renewables such as hydropower, wind and solar is growing, however. France is increasingly focusing on energy savings and the reduction of waste. The Grenelle laws focus on decreasing energy consumption in buildings. However, the use of central heating makes the incentives blunt [30]. France also offers tax credits for energy-efficient goods and zero-rate loans for energy efficiency renovations up to 30,000 euro per dwelling. The government has implemented energy performance contracts to be set up between owners and operators, establishing an energy efficiency target for a building. Such contracts are increasingly being considered by local authorities [31].

There are two direct support measures for DH in France. The first one is reduced VAT (from 20% to 5.5%) for thermal heat delivery through DH systems. France also has a heat fund for heat from renewable sources (biomass, geothermal, biogas, PV). The idea is to provide incentives for an increased share of renewables in the fuel mix. Taking low temperature district heating investments into account, no regulation explicitly supporting such investments exists in France [26].

3.1.4. Summary

District heating is widely acknowledged for its contribution to 2050 targets. Price regulation of heat has been implemented and discussed in two markets (Denmark and Sweden respectively) with explicit DH legislation. All five countries have put taxation in place to directly or indirectly support DH. In two of the five countries, there is explicit support for low temperature heat recovery (Denmark and Germany). These conclusions are summarised in Table 1.

Table 1. Lessons learned from frameworks in five countries.

	Explicit DH Legislation		Energy and Competition Legislation		
Policy type	Denmark	Sweden	Germany	France	UK
2050 targets	-	-	-	-	-
Price regulation	-	discussed	NA	NA	NA
Tax incentives	taxation makes DHC competitive	tax on carbon	Electricity from CHP has low primary energy factor	Reduced VAT on DH deliveries	climate change levy
Incentives for low temperature (4 & 5G)	2012–2018	-	100 million euro	-	-

The conclusions above are confirmed by a study performed in eight EU countries, in which interviews were carried out with DH stakeholders about low temperature district heating investments. A total of 76 respondents took part in the study and a major conclusion was that waste heat (both industrial and low temperature) is not explicitly mentioned in existing support schemes for DH. At national level, alternative technology is encouraged with incentives (e.g., for high efficiency cogeneration). Since there are explicit incentives for different forms of renewables, there is an unnecessary competition between DH with waste heat and DH with renewables emerges. This is an unfortunate situation that brings us back to the purpose of this paper, that is to discuss the role of policy in future proofing the heating and cooling sector in Europe, by allowing urban waste heat recovery.

3.2. Key Differences between High and Low Temperature Heat Recovery

Low temperature heat recovery is relatively untested compared with its high temperature counterpart. By now, high temperature recovery, e.g., from factories and power stations, should be standard as the concept is well developed. There are several key technical differences between low and high temperature heat recovery and these have an impact on policy decisions. First, whilst low temperature heat is directly suitable for meeting hot water demand and for use in space heating, the heat needs to be upgraded before it is able to be used in a district heating network. This requires the use of a heat pump adding potentially significant expense and exposing heat recovery projects to the risk of increases in electricity prices. Large differences between the temperature of the waste heat and that required for the district heating network can create significant expense. Variation in the temperature of the waste heat is also a risk but, to some extent, this can be mitigated with storage, ensuring that waste heat is collected when it is of a high temperature.

Despite the additional costs associated with the use of heat pumps, there are often financial benefits for low temperature heat recovery. Low temperature sources tend to be close to areas of heat demand, reducing transmission costs, and the technology required to recover the heat may be cheaper. Decisions regarding the size of the heat pump often hinge on cost versus efficiency tradeoffs [32].

3.3. The Role of Urban Waste Heat Recovery in Reaching 2050 Targets

A number of ‘Roadmaps’ have been designed defining options for achieving 2050 goals. An important example is the European Climate Foundation Roadmap 2050 project which sets out pathways to achieve an 80% reduction in greenhouse gas emissions by 2050 [33]. The Heat Roadmap Europe project (a series of commission funded projects mapping relevant heat sources for district heating) sets out approaches to the decarbonisation of the energy system in Europe. The examples provided in the literature review above indicate that DH can support reaching these targets. This is further confirmed by other sources. In 2050, the cost of carbon will be higher than it is today, fossil fuels will not be available and the fuels that are currently used (such as waste and biofuels) will be increasingly scarce. It is then that urban waste heat recovery will become crucial and, possibly, a critical component for reaching the desired targets.

Although the most prominent 2050 targets are set at national and EU level, their effects trickle down to local and organisational levels. Cities, for example, will be under pressure to contribute to carbon reduction as part of national targets and may also set their own targets. Businesses are also increasingly setting carbon reduction targets which increasingly makes business sense as consumers become more concerned about the effects of climate change. The ReUseHeat demonstrators are all partly motivated by carbon reduction. Companies such as Veolia and EDF, both partners on the project, recognise the need to be seen to be decreasing their carbon footprint whilst foreseeing major increases in demand for energy efficiency projects such as low temperature heat recovery. Public sector organisations, including those involved with ReUseHeat such as the cities of Nice and Brunswick, the Berlin metro operator and the hospital in Madrid, are also motivated to improve their energy efficiency through a number of mechanisms such as pressure from a national/EU level, demands from voters and a desire to be seen as 'green'.

3.4. Creating Awareness

A significant challenge for both industrial and urban waste heat recovery is a low level of awareness of the potential opportunities that it presents, both for owners of waste heat and for those that may wish to exploit it. Well targeted government policy may be able to improve this situation. For historical reasons, the prevalence of district heating varies significantly around Europe and the wider world and this has an important impact on the level of awareness of the opportunities of waste heat recovery.

It seems likely that the nature of low temperature heat recovery means that businesses are less likely to consider the idea without being prompted. It is perhaps intuitive that high temperature waste heat from, for example, heavy industry may have some value and that there ought to be some way of using it to increase the overall efficiency. The operator of a waste water treatment plant, on the other hand, is unlikely to be intuitively aware that their waste heat is worth anything at all. Increasing awareness for lower temperature heat sources may therefore be a bigger challenge. Despite this, one study on low temperature district heating business model development shows that it is often the owner of the low temperature waste heat that approaches the district heating company asking for their support to make use of the waste heat generated [11]. In conclusion, urban waste heat recovery is seen as a future proof solution and to achieve a greater uptake, awareness of its potential is imperative.

The UK government has attempted to gauge awareness of waste heat recovery among businesses. A report published in 2016 found that awareness of waste heat recovery in the UK is mixed [34]. Companies whose energy costs were relatively high tended to have significant interest in energy efficiency measures and most had a good awareness of waste heat recovery. Among companies with relatively low energy costs, most of which were smaller, awareness of waste heat recovery tended to be low.

Sweden has the highest volumes of industrial waste heat recovery in district heating systems in the world, though they are still fairly modest in comparison to available volumes. Among the research community, there is awareness about the available potential whereas awareness among other stakeholder groups is low. During the stakeholder interviews described in Section 2.2, 80% of respondents agreed that there is a legislative gap in promoting the use of urban waste heat. When asked about potential policy to improve this situation, many of the respondents suggested support schemes through, for example, "raising awareness by marketing actions on a national level". Others suggested action on a local level, pointing out that this can be done relatively quickly when compared with the EU level.

During the stakeholder interviews, one French policy maker emphasised the importance of raising awareness of waste heat recovery collectively to promote discussion among citizens. They also emphasised the importance of presenting waste heat recovery solutions in a simple way and to avoid making it a financial issue at an early stage.

In raising awareness of the benefits of low temperature heat recovery, the presence of existing infrastructure is important. Those countries that have a high level of district heating infrastructure have a much higher level of readiness for exploiting urban heat sources. Such countries are also likely to have a higher existing level of awareness.

3.5. Creating Demand for Green Energy

A question often asked is whether consumer preference can be changed by appeal to public good, in this case represented by low carbon solutions. Put simply, are consumers willing to accept higher prices for types of energy with a lower carbon footprint? Classical economic theory base would say "no", because this would be a distortion of the market. A "yes" would imply that there are issues other than price which affect decisions. In fact, there is some recent evidence that public good arguments can change behaviour such as the successful recent campaigns to curtail the use of plastic bags. Such campaigns, however, may not be enough to solve the problems as it may be hard to lay the moral issues at the consumers' door.

In general, consumers tend to value causes in which they can 'see' the impacts. The success of plastic bag campaigns has been the emotional reaction to stories of plastic pollution in the oceans, for example. In the context of waste heat recovery, it may be beneficial to emphasise the public good in a local context. The idea that locally sourced heat that would otherwise 'go to waste' can be recovered and used instead of non-renewables may be an appealing one. In some areas, this may create a demand for more expensive, but greener, heat.

Creating demand for green energy is a primary aim for the Nice demonstrator on the ReUseHeat project. The demonstrator involves the construction of an online dashboard for customers connected to a district heating network used in conjunction with heat recovery from a waste water treatment plant. The dashboard aims to make customers aware of the origin of their heat and the effect on carbon emissions. It is hoped that this will increase awareness of the issue and increase demand for green energy. Information about heat alternatives empowers the customers to make active choices (become energy citizens) and select green alternatives over others.

3.6. Capacity Building

Low temperature waste heat recovery is a young technology and its prevalence is low. Currently, there are a number of barriers and government intervention may be required to break them down. Whilst few measures are in place targeting waste heat recovery specifically, there are proven government measures that can help in the context of low temperature district heating. Examples are direct incentives such as tax breaks and investment subsidies. Other measures directly targeting urban waste heat sources are either voluntary, such as pilot projects, or mandatory, such as obligations to make use of urban waste heat whenever generated. Implementation of urban waste heat recovery is, at present, predominantly undertaken in the form of pilot studies. In an ongoing project for the International Energy Agency, more than 150 low temperature heat recovery pilot sites have been identified [35]. The advantage of pilot sites is that they provide data on operations and risk which act as important inputs for potential investors. The prevalence of pilot sites indicates that the urban waste heat recovery solution is increasingly relevant and the fact that they are appearing in multiple places simultaneously indicates that there is an emerging technology shift in the DH industry.

The European Commission is directly funding two large projects on low temperature heat recovery, with a total of 12 demonstrator sites across Europe (for more information please consult the ReUseHeat [36] and REWARDHeat [37] projects). Limits on greenhouse gas emissions by regulation would benefit urban waste heat recovery technology. Such regulation can be directly linked to taxes aimed at the phasing out of fossil fuels. Examples of both exist, as discussed in the policy overview above (the EU-ETS system) along with energy carbon taxes. In such a context, it is important to note that there may be social aspects to consider when making planning decisions. For example, the cost of decarbonisation should not disproportionately be borne by the poorest in society. In some cases, governments may see measures as opportunities to achieve social aims by, for example, building infrastructure to provide cheaper heat, paid for with taxation (a dominant tradition in both Sweden and

Denmark). To secure desirable and long term development in the DH industry, support for capacity building in urban waste heat recovery is needed.

The stakeholder analysis outlined in the methodology section highlighted the need for capacity building and knowledge sharing. Stakeholders were generally very supportive of pilot projects citing a need for guidance on good practice and sharing of experience to allow a future scaleup. A lack of technical knowledge was not generally seen as a problem, however.

Respondents showed interest in collaborations between academia, private companies and politicians suggesting that "More research studies in our universities and more interaction between the science and the city are needed". Another theme coming from the stakeholder analysis is that, when stakeholders such as city representatives and owners of heat are new to waste heat recovery, there is a hurdle in that the number of stakeholders makes contract negotiations complex. All interviewees pointed out that there is no legal framework in place to manage urban waste heat sources/make efficient contracts that responds to all specific issues of this type.

The diversity, size and technology of DH systems within the basic system of source, heat exchanger, heat pump and network, means that expert judgement is required. It may be that the main client, such as a city, may not have the necessary skill base, nor any long term experience in DH. Consultants provide a solution, either as advisors or embedded in a developer/contractor. Complexities include multiple sources, somewhat different technologies related to the source, but also new "smart" metering, district level control systems and modern heat storage. Knowledge gaps extend also to social economic modelling and risk allocation, issues which may be critical in preparing business cases for funding. Formal methods of expert judgement elicitation may be used [38], particularly in relation to risk and uncertainty and the design and management of scenarios [39].

It is more practical to adjoin low temperature heat recovery systems to an existing district heating network which typically will be powered by a CHP unit. This is partly because most of the network will be in place and there will be experience with optimal control, contracts with energy suppliers and the cessation of domestic gas boilers. But the distinction between the definitions of third, fourth and fifth generations may become less clear as systems gain in complexity and state intervention increases under low carbon prerogatives. In the longer term, the very existence of CHP may be in doubt.

3.7. Incentivising Investment

To meet 2050 goals, the nature of corporate governance must change to emphasise "climate optimisation" as well as "financial optimisation". An obvious approach, introducing measures along these lines, is to 'monetise' greenhouse gas emissions. The EU's carbon trading legislation, for example, places a monetary value on emissions, which can be traded at a cost, creating a financial incentive for reducing emissions.

There have been some attempts to prioritise public good in investment decisions. For example, the UK Public Services (Social Value) Act 2012, which applies only to government contracts, states that decision makers "should be taking a value for money approach - not lowest cost" and should therefore take into consideration any (positive or negative) externalities for the local area [40]. At present, the act does not specify a value for the reduction of greenhouse emissions but this may be a valuable addition.

The European Union has also pursued a 'socially responsible' policy on procurement. In 2011, its 'Buying Social' publication set out an agenda for taking social elements into account when considering procurement bids [41]. More recently, the EU have adopted reformed procurement rules that allow public authorities to take social elements into account when making procurement decisions. Guidance has been published, in the form of a "Buying Green Handbook", on how Green Public Procurement (GPP) can be implemented [42]. Although green considerations are, at present, voluntary, the EC aims to achieve a critical mass of demand for sustainable goods and services. The above legislation is not yet linked up to corporate governance, and to do so would require a heavy shift in stance. Such requirements are a far easier sell for government contracts than for private enterprise in general. However, it is easy to see such rules applying to carbon emissions, and legal requirements for a net zero-carbon economy by 2050 may make such legislation necessary.

In terms of policy, the most common approach is likely to be that which seeks to align the incentives of businesses and the public good. Taxes on carbon emissions, for example, attempt to make it financially advantageous for businesses to seek future proofed, low carbon alternatives. Policies that help reduce risk on environmentally friendly solutions should also be considered. For waste heat recovery, policy should be aimed at making it more financially viable than non-renewable alternatives.

Some forward looking financial institutions and companies have seen opportunities in investing in long term, low carbon, community based schemes. One example is the collaboration between energy company Engie (France) and Axium that secured a 50 year Comprehensive Energy Management Contract with Ohio State University in the US in 2017. Another is the collaboration between energy company VEKS (Denmark) and CP Kelco, a US-owned company that produces pectin, a natural starch. The company is located some 40 km from Copenhagen and produces a large amount of excess heat. CP Kelco and VEKS have different business models. CP Kelco is an entirely commercial company and this means that, as a starting point, a large focus on investments with a short payback period is required. In contrast, VEKS, as an operator of infrastructure in the form of district heating systems, has a longer time horizon for its investments; VEKS works with more patient capital. An agreement was able to be reached due to clear system boundaries and a contract detailing payment schedules. CP Kelco was responsible for the investment and the design of the technical installations up to the "connection point" with VEKS. VEKS was responsible for the investments and the design of the technical installations from the "connection point" with CP Kelco and to the existing district heating network (meaning a larger investment for VEKS since about 150 m of underground district heating piping was needed). In terms of payback periods, two time periods were established. In the first period of operation (3–4 years), CP Kelco received their payback and, in the second (some 4 years), the investment of VEKS was paid back.

It is useful to think of DHC funding as a special type of infrastructure spending. This has the advantage of making it part of the wider and current discussion, both nationally and internationally, about the need to renew infrastructure and its role as one particular mechanism to stimulate economies. Wider energy and transport infrastructure are similar examples. The common features are that a mixture of public and private funding is often preferred with the notion that companies are reluctant to invest unless initial investment, or at least a high proportion of it, is provided by the public sector. Lump sum grants, land grants, or grants tied to project milestones are more closely related to direct financing instruments; they reduce the need for privately-sourced capital expenditures for the project and can also reduce initial outlay. This has the effect of enhancing returns to investors and can also enhance creditworthiness and the viability of the financing structure.

A generic term describing the area is "project risk capital" or "risk capital funding schemes". Related to this is the growth of special funds such as green funds, often managed at the city level (see [43,44] for example). A summary is that with (i) project, (ii) fund and (iii) institutional investors, there is a double effort: the fund needs to attract institutional investment and the project sponsors need to attract resources from the fund. The methodology also includes "structuring": matching the type of funding to the type of asset; in the case of DHC, this means long term funding.

In view of the urgency of the 2050 objectives, the role of infrastructure and social value objectives (the latter being very relevant because many DHC projects are private-public partnerships), we are likely to see an increase in the requirement to cut carbon in all DHC contracts, with associated incentives. This is a win-win: increased incentives will improve the profitability of the relevant contracts for the private sector while, at the same time, directing investment into carbon-free technologies. An example would be tax incentives or cheap loans for domestic or community heat pumps. There are also important links between national and local schemes. For example, local heat storage can be used to store surplus renewable energy from the national grid such as from wind.

The lack of incentives for waste heat recovery is coupled with incentives for other competing technologies. This was cited as a problem in the stakeholder interviews in which the majority of respondents (69%) found that there are alternative technology incentives, such as for high efficiency CHPs. This suggests that, until incentives are offered on low temperature heat recovery, it will be hard for this technology to compete with other technologies in terms of attracting investment.

None of the ReUseHeat demonstrators were provided with incentives other than the investment provided by the EU in the form of the ReUseHeat project. In each case, the aforementioned funding was able to make the projects viable. It is hoped that the experience and knowledge gained from the pilot projects will make future projects viable. However, it may be the case that government incentives are needed.

3.8. What the Investor Wants

A common theme coming from the ReUseHeat project and on a wider level is that, although there is a desire to invest in waste heat recovery and that money is available to do so, project promoters do not adequately assess the investment risk to allow investment to take place. In short, investors need to be reassured that there is a high probability of receiving their money back.

Investors generally look for mature technologies with low degrees of legal, technological and economic risk. The track record, experience and financial strength of project partners is a key aspect in the decision to invest along with predictability and stability of cash flows and of the political framework. Talking to investors in the immature district heating market of the UK, we have found that even conventional district energy technology is perceived as new and risky. There is a knowledge gap that needs to be bridged between district heating practitioners and investors interested in green technology and this is true both for conventional district heating ventures and for the newer, low temperature, solutions.

The concept of bankability, that is the extent to which a project is attractive to investors, must be part of a wider discussion of the risks of DHC projects. The risk analyses presented in business cases for funding should be close to those carried out by the potential funder. Stakeholders, however, need to manage different objectives, for example medium term lending horizons versus long term infrastructure investment. A conventional district heating network has a technical lifetime of approximately 40 years and low temperature heat recovery investments have lifespans that are approximately half of that. Investors who are willing to lock in funds for several decades are rare but, as seen above in the case of VEKS and CP Kelco, there are ways to get around this. Technical risks arise from the novelty of projects, which feed off inventive sources of waste heat, and a lack of experience, which, itself, is a major source of risk. There is experience of waste heat recovery from data centres and sewers but not of, say, hidden underground rivers [45].

In the stakeholder interviews, 15 investors and potential investors in waste heat recovery were interviewed. From these, it was found that the biggest barriers were considered to be gaps in the legislation, regulatory issues and a lack of incentives. One major barrier is that procurement procedures are not adapted to energy efficiency projects and therefore energy service companies may not be interested in participating in the procurement process.

Several respondents suggested that there should be a special framework for the production of heat. For example, the cost of electricity for these technologies should be reduced or should be exempted from taxes. This would allow for the risk related to the electricity price to be reduced.

One respondent was keen to emphasise a preference for incentives at the local level, pointing out that EU funding can be a long and difficult procedure. Attempting to increase the pace at which EU incentives are agreed and paid out may therefore be a fruitful approach.

There was a notable difference between investor respondents in the Nordic countries and France and in the rest of Europe. In the former, respondents tended to be more likely see the value of the green aspect of waste heat recovery investments, perhaps reflecting local attitudes. It may therefore be useful to look to these countries to understand how to increase the value placed on the 'greenness' of investments in the rest of Europe.

3.9. Risk

Even if the styles of risk analysis and Key Performance Indicators are shared between the funder and funded, there remain some macro issues to be taken into account, most importantly zero carbon objectives and road maps. On the positive side, for some of these, we are all in the same boat, or in this case planet. A vehicle for trying to handle these larger scale issues is scenario analysis (SA) which has grown rapidly in the last few years particularly in the area of climate and energy. The Intergovernmental Panel on Climate Change's IS92 comprised six scenarios which were followed by the "Special Report on Emissions" (SRES) and the "Representative Concentrated Pathways" (RCPs).

It is becoming more common for mainstream risk methods to be supplemented with SA. This could be referred to as global sensitivity analysis as opposed to the simulation based local sensitivity analysis carried out on the spreadsheets of CAPEX and OPEX. Financial Institutions are familiar with this under the heading of the stress testing required by regulators. SA can be seen to fill, however roughly, the gap between local sensitivity, amenable to various statistical methods, and a less easily definable uncertainty about the future. All actual risk is predicated on particular scenarios. Some scenarios refer to future policies, such as tax incentives, whilst others may be contingent on events such as a sudden and unforeseen increase in electricity prices.

Actual investment needs to be checked against an agreed tapestry of scenarios. The agreement is that the investment needs to be robust, not just to local variation but against agreed scenarios, and the risk allocation made accordingly. The technical side of SA is a major research area but can at least be divided into various headings such as scenario design and scenario control and it is generally agreed to be a useful creative tool [39].

DHC itself is more closely related to climate scenarios, given the "climate emergency". This is likely to play a major role in the new accelerated agenda and the shared responsibility of cities and their funders ought to be a driver for investment, to add to the special incentives and stricter laws.

The ReUseHeat project has favoured the use of modelling as a foundation for contracts and demand forecasting. This extends to risk. Cities need to improve understanding of the risk of a project, particularly to facilitate the route from feasibility studies to a business case. The expertise that cities have may be less than that of financial institutions but increased harmony between the risk methods would be valuable for bankability. The contractors are experts at physical risk whereas the financial institutions are able to tier the financial risks and these are not the same thing.

Given the increasing insecurity arising with climate change, it is noticeable how the use of scenarios has gathered strength. The methodology of how to design and make use of scenarios is much less developed than risk theory. Despite this, energy companies and governments are working with them in order to supplement more formal risk analysis. The kinds of local sensitivity analysis which are commonplace in dealing with risk based spreadsheets needs to be extended to robustness with respect to major scenarios. We have already seen this with wind power where rapid development is faster than predicted by forecasts. Storage of electricity and heat is developing similarly quickly. We feel that, rather than scenarios describing events which instil anxiety, it is important that they be presented as commercial opportunities. Whilst waste heat recovery may be a more expensive option at present, future policies may reverse this situation and investing now may give companies a competitive advantage in the future. There may also be other opportunities such as selling heat storage to the national grid to observe peak outputs of renewables. Every data centre, metro system and canal is an opportunity to use heat pumps to provide heat.

3.10. Legal Framework

The lack of a systematic approach to regulation is a major impediment, perhaps the biggest, to investment in DHC, and to urban waste heat recovery in particular. Indeed, regulatory risk (also referred to as political risk) is usually included in risk analysis. A systematic approach to DHC should be part of a systematic approach to energy in general and the fact that low temperature DH consists of small local schemes does not aid integration. Local advantages may ignore negative externalities and national initiatives may ignore local DH, even to the extent that incentivising electricity may ignore heating and cooling, giving incentives for CHPs but not for heat pumps and waste heat recovery systems. It is very likely that this will be rectified when the importance of local DH to international roadmap objectives is realised.

An example of where a broad brush approach at the national level ignores DHC is in the Third Party Access (TPA) directives. Another lack of clarity is that economies of scale may make it more costly to produce heat at a local scale, rather than on a larger scale. Thus, incentives may apply when a heat pump is domestic but may not be valid for larger heat pumps at a community scale, which may be more efficient. In many cases, excess heat is not properly recognised as a heat source and there are no incentives at all. This ought to change as its contribution to CO_2 reduction is properly recognised. DH is, at present, routinely ignored in the climate debate. This is surprising because the DHC system can use sources such as geothermal, biomass and solar energy. At a technical level, energy efficiency indicators for buildings should take into account total energy consumption rather than just primary fossil fuel.

The lack of a legal framework has been identified by respondents in the ReUseHeat stakeholder analysis. In fact, each interviewee agreed that "there is no legal framework in place to manage urban waste heat sources and/or create efficient contracts.".

3.11. Measures and Evaluation

Measures, in the context of waste heat recovery, can be thought of as actions by government to encourage or force increased uptake. Formal assessment of the impact of a measure is crucially important to determining its effectiveness. Ideally, impact assessments should be performed before the measures are put in place and followed up once the policy is implemented. This can be done with mathematical models alongside risk assessment such as sensitivity analysis and Scenario Analysis. An important consideration is that different measures may interact with each other and therefore should be treated as part of a tree of decisions, rather than one stand alone decision.

The European Union's 'Better Regulation' initiative performs impact assessments on proposed laws that are expected to have economic, social or environmental impacts [46]. In addition, consultations with stakeholders and citizens are recommended. The EU commission also looks for areas of improvement in existing law. Key Performance Indicators are an important aspect of impact assessments, helping to quantify the performance of each measure. Often, multiple Key Performance Indicators create trade offs. Perhaps the most prominent of these concerns a trade off between reducing greenhouse gas emissions and the overall cost of a project since a more 'green' technology is often more expensive. A crucial target for government policy should therefore be to reverse this situation in such a way that businesses are motivated to pursue green options.

3.12. Proposal for a Credit Facility

Two related types of fund may be recommended as instruments for investment in Urban Waste Heat recovery. A credit facility is a one-time arrangement with a time and amount limit. When the credit is spent, the account is closed. A revolving fund is a dynamic vehicle, usually with many participants, for which consistency of repayments, eg from the end user cash stream, can give a continuing (revolving) access to funds. Such funds can be part of larger "green" funds or, for example, user-based cooperatives [47]. In both cases involvement of the local community and local or national government (for example via guarantees) should lead to favourable interest rates. Although such schemes are not yet very prevalent for low energy waste recovery there is experience with other infrastructure projects. But the UK HNIP "soft loans" [48] fall into the credit facility category and the "Stuttgart Fund" is a good example of a revolving fund [49]. Technical aspects of these funds is that they should support the role of consultant coordinators to support both sponsors and investors, and will typically carry out regular and independent assessment. It is likely that progress in investment schemes will be linked closely to the increasing support of heat pumps [50,51].

There is a desire from decision makers in Europe to reach 2050 targets. This means that investors are typically interested in green projects. Urban waste heat recovery projects have a significant green value. Hence, from an economic point of view, there appears to be both supply and demand for green investments. Within the ReUseHeat project, it has been found that low maturity of urban waste heat recovery investments requires support from the district heating community to make investors understand the business case, risk and the value of green. A possible approach to bridging the gap between urban waste heat recovery projects and investors was identified at the ReUseHeat policy workshop held in October 2019 in Brussels. A pilot credit facility is recommended, that covers some portion of the risk for waste heat recovery projects; with particular focus on risk related to waste heat source availability and technology for its exploitation. The facility would have a total size of 20–30 million euro with a maximum of 1–2 million euro per project and would help bridge the knowledge gap between urban waste heat recovery projects and potential investors.

4. Discussion

Between the first draft of this paper and writing these conclusions the COVID-19 virus has struck. We feel it is likely that the events and style of decision-making it engenders will have implications for other global crises and in particular climate change, already being described as the "climate crisis". A main lesson is that of preparedness. If governments had their time again, they would go far beyond standard emergency planning and massively increase the volume of items such as intensive care units and medical training.

We can, thus, assess the state of district heating in Europe from the standpoint of preparedness for its role in achieving the 2050 (or earlier) zero net carbon objectives. This makes the assumptions, of which we are sure, that (i) there will be a major role for DHC (ii) governments will take increasingly interventionist actions to meet the targets (iii) measures, in addition to being environmentally motivated, need to be economically and socially viable. At the time of writing, administrations are desperately trying to simultaneously preserve lives and economies.

The technology of district heating is mature: we understand CHP, heat pumps, heat exchangers, heat storage and insulated water pipes. For low temperature waste heat, the technological understanding is increasing as new sources are exploited: metros, sewers, data centres etc become the subject of more pilot demonstration projects. There is always scope for better integration, optimisation and control of systems, but the basic technology is in place.

What is not mature is the market. This suffers from the fact that different countries are at different stages of evolution, at different points of the private-public spectrum and have different levels of awareness. This variation of awareness extends into the finance and economics. There are some financial stakeholders that have taken a lead in funding DHC projects and who understand the route from small publicly funded projects to major investment: "from grants to contracts". Thus, one can identify best practice which can be a crucible for understanding, for example, the utility of incentives of various types and the benefits of green financing.

The project has given a key role to understanding the financial and economic side under the heading of "bankability". This studies the path from a feasibility study, via say a pilot study, to a fully fledged business case. A lot has to be in place to acquire the funding for a project: data on performance, some serious techno-economic modelling, social and environmental objectives, access to pump-priming public funds and a smooth political and legal aisle. It should be said that, if there was a single issue on which all project partners and respondents agree, it was the absence, or poor state, of the legal frameworks in place to support DHC.

Most also agree that despite the idiosyncrasies of different waste heat projects there should be an achievable level of standardisation for contracts and loan funding. We have responded by suggesting a urban waste heat recovery and supplied the main components of its design.

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