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▶ To cite this version:

Antoine Fontaine, Laurence Rocher. Energy recovery on the agenda. Waste heat: a matter of public policy and social science concern. Journal of Environmental Planning and Management, 2021, 64 (8), pp.1392-1407. 10.1080/09640568.2020.1823345 . halshs-02971862

HAL Id: halshs-02971862

https://shs.hal.science/halshs-02971862

Submitted on 1 Dec 2022

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Summary:

Waste heat from industry or urban facilities represent a largely underused and long disregarded energy source, while heating and cooling count for half the final energy demand in Europe. From the early 2010s on, waste heat recovery (WHR) is being recognized as a key challenge for energy transition and tends to be integrated into energy strategies at different levels. This paper provides an analysis of how WHR became a matter of public policy in Europe and in France. Based on a literature review, the analysis shows that WHR has been framed as a techno-economic problem, while some barriers (legal, organizational) to its development remain largely unaddressed. A study of European and French energy agendas illustrates how WHR progressively started to be recognized as an energy resource next to renewables. As a result, questions are raised as to further social science contributions to an extended research agenda addressing WHR.

Keywords: waste heat recovery; energy policy; Europe; France; research agenda

1. Introduction

Heating and cooling represent nearly 50% of the EU's final energy demand (European Commission 2016, Heat Roadmap Europe 2017) and, as such, are responsible for tremendous carbon emissions. For a long time, the greening strategy of European heating and cooling mixes has mainly focused on the development of renewable heat production (biomass, solar, geothermal energy, heat pumps using electricity produced from renewable energy sources). For the past decade, attention has also been paid to the development of waste heat recovery (WHR) triggered by a renewed academic interest. Waste heat refers to unintentionally generated heat in the industrial or tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system (European Commission 2017). As a by-product, it represents an energy source provided that it is recovered and used, whether on site or delivered to neighbouring facilities such as district heating networks. Waste heat from metallurgy, chemistry and cementry presents high temperatures, which may help reduce industrial energy consumptions when recovered and reused on site, and can also meet external demand. For instance, industrial waste heat represents a potential of 2,7 EJ/year (Miro et al 2015) which could meet approximately 25% of the heat and hot water demand in European buildings (Wheatcroft et al 2020). Urban facilities such as sewage treatment and waste incineration plants, metrosystems or data centres also represent sources of waste heat which might be recover. Around 1,2 EJ/year is available from these urban sources in Europe (Lygnerud et al 2019). However, recovery opportunities prove to be limited because generated temperatures (from 20 to 40°C) are generally lower than average heat distributed in conventional district heating networks (from 90 to 160°C). Although it is noteworthy that temperature lowering in the more recent district heating networks (Lund et al 2014) may represent an opportunity to systematically recover and reuse urban waste heat. The overall energy reserve constituted by these sectors has long been disregarded and remains mostly untapped. Hence, the recovery and use of this energy might prove to be a great opportunity to decarbonize heating and cooling mixes. The meeting between this resource and a use depends on a series of factors such as the constancy of the temperatures generated, the local climatic conditions, the technical possibilities of capture and distribution,... but beyond technological answers, the feasibility of recovery relies on organizational and economic factors. If the recovery is above all a local matter of a heat source meeting a demand, we assume that these practices are to a large extent framed at a national and European level by public policies which are worth being looked at.

Our research originates on the assumption that efforts made to bring this tremendous stock of energy to light are worth considering, as they involve the framing of waste heat as an energy resource and partake in the structuring of a dedicated heat policy. The late recognition of the potential contribution of WHR to several challenges inherent to energy transition has led to its integration in energy strategies at different levels. Through these strategies, WHR is progressively becoming a central pillar of current and future heating and cooling strategies. Hence, understanding the setting of this peculiar issue on the energy agenda is paramount.

Which measures to include WHR in energy national strategies and induce its development were taken, and when were they taken? Which actors are playing key roles in the development of WHR strategies? This paper addresses these questions by viewing WHR agenda-setting as a framing process (Rochefort and Cobb, 1994) along which this energy resource is progressively defined and priority issues are determined while other issues might be under-prioritized. The aim is to identify the development of WHR as a fully-fledged energy policy issue by analysing how WHR-related questions have been addressed in Europe and France over the last two decades.

To inform this analysis, this paper is based on a twofold methodology: an in-depth academic literature review and a diachronic analysis of WHR-related energy policies at both the European and French levels. The latter relies on a broad review of the latest academic, institutional and expert literature; on 17 semistructured interviews held with institutional representatives and field experts (at regional and national levels in France); and on our attendance at three European and national meetings and events.

Next section of the paper provides insight into how the academic literature has addressed WHR; it shows a predominance of technical and economical approaches and a lack of attention from social and spatial approaches. The third and fourth sections respectively focus on the European and French contexts. They each provide evidence of rather autonomous but converging agenda setting processes and identify waste heat as a now self-standing energy policy issue. An ending discussion proposes avenues for future research aimed at developing a stronger understanding of WHR as an energy concern and at improving heat recovery policy-making.

2. Waste Heat Recovery: a techno-economic research topic to be further investigated on its social, political and spatial aspects

The challenge of WHR has received more attention in academic research over the last decade. A literature review was performed to broadly capture how WHR is addressed by academics[1]. Several lessons might be drawn from this state of the art (see Table 1). Recent research has mainly focused on technical assets of WHR and on assessing its contributions to current and future energy mixes. In the first instance, WHR has been framed as a technical issue. However, even though requiring innovations to scale up, the existing technologies allow efficient recover and reuse of waste heat. Thus, at this stage of development, barriers to WHR development are mainly legal, organizational and economic. For instance, the ReUseHeat European research program underlines the importance of innovative contracts and business models to support the development of WHR (Lygnerud et al 2019). While identifying and

[1] Our survey of the existing literature was based on a selection of keywords: "waste heat recovery," "excess heat," "industrial excess heat," and "district heating and heat recovery". An exhaustive literature review was performed on six major multidisciplinary journals addressing energy issues: "Energy", "Applied Energy", "Energy Procedia", "Journal of Cleaner Production", "Renewable and Sustainable Energy Reviews" and "Energy Policy". This literature review has been supplemented with a selection of papers from other journals regularly quoted in our first selection.

questioning these barriers, the development of models to evaluate the potential contribution of WHR to energy mixes consisted of the quantification and mapping of both WHR sources and heat demand. However, if techno-economic approaches highlighted the key importance of the spatial dimension in the development of WHR, the topic remains largely under-investigated in social sciences literature.

It appears that WHR has not been seized yet as a fully-fledged topic to be studied as such for instance by the expanding work in energy geography. Though recent research conducted in urban studies, geography, sociology and political science attests to a growing interest in heat supply years after Summerton’s seminal work (Summerton 1992) was published. In analyzing the deployment of heating systems at national and local levels, recent research has pointed to governance issues (Hawkey et al 2016, Hawkey and Webb 2014, Rocher 2014), has outlined the problematic extension of district heating to new urban areas such as eco-towns (Gabillet 2015, Guy and Karvonen 2016) and has focused on planning issues (Bush & Bale, 2019). This interest in district heating in reference to governance, urban and social factors has shed light on heating and cooling as an energy concern. In so doing, heat supply seems to have entered social science research agendas through the lens of district heating in parallel with a renewed interest from national and local governments in developing new district heating facilities or refurbishing or expanding existing ones.

Table 1: WHR state of the art sorted by academic approaches over the last decade

Field/ approaches	Analytical focus	Learnings
Physics, thermics, engineering	▪ Comparing technical methods allowing for the recoverability of waste heat (Jouhara et al 2018, Broberg Viklund et al 2014, Mahmoudi et al 2018) ▪ Identifying WH sources: traditional industrial sectors (Huang et al 2017, Papapetrou et al 2018, Woolley et al 2018, Zuberi et al 2018) as well as data centers (Carbo et al 2016, Yu et al 2019), urban services such as water networks (Andrés et al 2018, Somogyi et al 2018), underground stations (Andrés et al 2018, Davies et al 2019), or supermarkets (Zühlsdorf et al 2018) ▪ Assessing technical methods allowing for the reusability of waste heat: on-site use to reduce the energy consumption of industrial actors (Hammond and Norman 2014), industrial eco-park synergies (Stijepovic and Linke 2011, Stijepovic et al 2012) or external use through district heating (Broberg et al 2012, Bühler et al 2017, Chiu et al 2016, Fang et al 2013).	▪ WH might be recovered from a large array of sources (sectors and processes). The largest one is the industrial sector (e.g. chemistry, metallurgy, cementry) ▪ Recent innovations in the field of district heating allow for the recovery and reuse of high temperatures (above 400°C) as well as low temperatures (less than 100°C) (Lund et al 2014) ▪ The existing technologies allow to efficiently recover and reuse WH from the identified sources
Economics	▪ Creating models to evaluate the potential development of WHR with a techno-economic point of view (Brückner et al 2015, Sandvall et al 2016) and its role into future energy market scenarios (Svensson et al 2008, Jönsson et al 2008) ▪ Quantifying and mapping WHR sources (Goumba et al 2017, Dénarié et al 2019, McKenna et al 2010, Miro et al 2015) as well as heat demand (Dorotic et al 2017, Stratego 2018) to go further in identifying and measuring potential market developments ▪ Identifying hurdles and current limits to the realization of specific WHR projects: spatiotemporal mismatches between heat generation in industrial sites and heat consumption (Bühler et al 2018), uncertainty of heat generation risks facing an investor when a waste heat provider stops its activities (Lygnerud et Werner 2017, 2018), difficulties associated with developing WHR projects by gathering actors (public and private or industrial and institutional) with rather different approaches to operations and decision-making processes (Grönkvist and Sandberg 2006) ▪ Providing new business models and contracts to facilitate a rapid development of WHR operations (Lygnerud et al 2019)	▪ Barriers to the development of WHR projects are not so much technical but rather legal, organisational, spatial and economical ▪ The spatial dimension is central to assess the potential development of WHR ▪ Heat mapping tools are settled to support decision-making
Sociology, geography, urban studies	▪ Addressing the development of district heating in specific urban contexts such as eco-towns (Gabillet 2015, Guy and Karvonen 2016) ▪ Analysing district heating governance at different scales(Hawkey et al 2016, Hawkey and Webb 2014, Rocher 2014) ▪ Analysing heat mapping in use, as a crucial tool for energy planning (Bush et al, 2019) ▪	▪ Heat is exclusively addressed through the lens of district heating ▪ It is framed as a supply-demand issue, while generation and recovery of waste heat is unaddressed ▪ Heat supply through district heating is a privileged object to seize local energy governance moving issues

However, a comprehensive understanding of WHR as a public policy matter is still lacking. Some elements of explanation may be put forward. If renewable heat– the production of heat from renewable sources, including biomass, geothermal and solar energy – is a well-circumscribed subject, then WHR is less evidently categorized as such. It is achieved through several different activities, such as waste incineration and various industrial processes, urban services and electricity generation facilities. Unlike other forms of energy generation (be they renewable or not), waste heat cannot be assimilated to one circumscribed energy sector or to a bounded form of technology such as solar or wind power. Indeed, excess heat is generated through many industrial, urban and energy generation activities, which together do not constitute a sector with shared rules, habits, values or knowledge. It is an unintentionally generated energy resource that is already present, and it is unrealized until it is captured for use either internally (i.e., at the industrial site where it is available) or externally (sold to an end-user different from the producer).

In order to go further with these first elements, it is the goal of this paper to analyse the framing of waste heat as an energy resource by public policies. The following sections examine how WHR was progressively entered the agenda at the European and French levels. European policies apply broad guidelines on the development of a common heating and cooling strategy and have introduced waste heat assessment obligations (§3). In France, the development of a heat policy has involved quantifying and planning an energy mix and developing incentive tools directed toward renewable heat (§4).

3. Waste heat in European policy: a long-awaited energy concern

Over the last twenty years, waste heat, though not a primary energy issue, has been proven a matter of concern at the European level. This agenda setting process has involved three distinct phases: the first occurring in the 2000s when heat recovery was mentioned but not directly addressed; the second based the energy efficiency directive of 2012, which marked a decisive turn in recognition of the significance of WHR within the policy agenda; and the third occurring since 2012 as WHR has been more directly approached in European demonstration and research programs and as the European Heating and Cooling Strategy has been adopted.

In the “second legislative package” for the European energy market[2] for 2001 to 2006, waste heat is barely addressed and heat is only considered to be apprehended through measures supporting the development of electricity cogeneration. For instance, the directive on renewable energies (2001/77/EC) does not mention heat. The directive on the promotion of high efficiency cogeneration (2004/8/EC) mentions heat recovery mechanisms (Annex 1) but focusing on efficient electricity production rather than on heat production itself[3]. The

[2] Regarding the development of the European energy market, directives 96/92/CE and 98/30/CE are referred to as the first legislative package while the directive published between 2001 and 2006 is referred to as the second. Directives published between 2009 and 2012 constitute the third legislative package.

[3] The directive mainly requested that Member States implement a guarantee of origin devices for electricity produced from cogeneration facilities.

energy end-use efficiency and energy services directive (2006/32/EC) mentions heat recovery technologies as a means of contributing to the European energy efficiency policy (Annex 3), but heat production is only associated with cogeneration. The green paper for a European strategy for sustainable, competitive and secure energy (2006) points to the need for a new directive specifically addressing heating and cooling and allowing for the setting of operational development targets for the heating sector as part of a long-term road map for renewable energy sources (European Commission 2006:12). By 2006, heat appeared to be identified as a challenging issue within the European energy policy framework but was only indirectly addressed through measures and sectoral policies related to renewable energies and cogeneration.

It was only with the publication of the third package of energy directives that heat and WHR were truly considered. While the revised directive on renewable energies (2009/28/EC) still failed to mention WHR and heat, energy efficiency directive (2012/27/EC) represented a significant shift in agenda setting on heat and WHR issues. Member States were required to explore the potential to develop local and regional heat markets and to encourage the development of efficient heating and cooling systems. Cost-benefit analyses on WHR opportunities of internal reuse or public delivery needed to be carried for all new and refurbished thermal electricity generation units of over 20 MW (Article 14). In addition, Member States were required to produce national maps localizing heating and cooling demand points, existing or planned district heating and cooling infrastructure and potential heating and cooling supply points including electricity generation installations (reflecting more than 20 GWh of annual production), waste incineration plants and cogeneration installations (Annex 8). It must be noted that Member States were explicitly allowed to exempt nuclear power installations from cost-benefit analyses and from the mapping of WHR sources (Article 14.6). Such maps were thought of as helpful tools likely to enhance the realization of WHR potential. The 2012 directive reflected a major shift in the heat and WHR agenda setting process by defining WHR as a public policy object focused on dedicated measures shaping the energy efficiency agenda.

The process initiated in 2012 strengthened a close relationship between European research programs and the construction of European heating and cooling policy. Under Horizon 2020 funding, between 2012 and 2018 the Heat Roadmap Europe program developed a methodology for quantifying, modeling and spatializing the development potential of the European heating and cooling sector. According to this methodology, the research team involved released means to decarbonize European and national heating and cooling sectors (Connolly et al. 2012, 2013). Use of GIS mapping led to the identification of waste heat volumes to be recovered in strategic European heat synergy regions and to be used to fuel district heating in large urban areas (Persson et al 2014). These research results allowed Heat Roadmap Europe to discuss existing European heat development scenarios of the Commission (Connolly et al 2014) and to propose alternative scenarios (Stratego 2018). Together with other European research programs, technological developments and demonstrations (i.e., Celsius and Thermos), these contributions directly supported European agenda setting on

WHR and the publication of the EU strategy on heating and cooling (European Commission 2016). Heat recovery was introduced as one of the few main axes of the developed strategy even though no quantitative objectives or specific incentive devices were presented. The document rather identified what were perceived as barriers to the development of WHR to be overcome: a lack of information on available resources, adapted incentives and business models, limited development of district heating infrastructures, and a lack of cooperation between industrial and heat grid management actors (Ibid: 8).

The 2018 renewable energies directive (2018/2001/EC) made considerable progress in stabilizing WHR measures. The directive recalled the need for Member States to evaluate their national WHR potential. To adapt European objectives to 2030 targets specified by the Paris Agreement, Member States were required increase the renewable and recovery energy share of their heating and cooling mixes by 1.% each year (Article 23). Actors of renewable heat (e.g., biomass and solar) feared that only recovery energies could fulfil obligations and could threaten the development of other renewable heat sources. As a result, a threshold was introduced to ensure that only a partial share of WHR could be defined as renewable heat (Article 23.2). In addition to policy objectives, some specific WHR actions directed toward project implementation have been undertaken. Several European research and demonstration programs (i.e., ReUseHeat) have focused on WHR and have contributed to the specification of WHR potential and to the identification of measures that might support its development.

To conclude, WHR has slowly entered European energy policy agendas through existing and stabilized sectoral policies (renewable energy, energy efficiency, and cogeneration). However, if WHR is progressively being defined as a matter of public policy, its development may necessitate the adoption of dedicated development goals and specific incentives.

4. In France, a renewable heat policy is on its way to recognizing waste heat

In France, the penetration of district heating (5% of heat demand) is lower than the European average (10%) and much below some Eastern and Northern countries where it can supply up to 50 % of the national demand. Though not dominant, district heating network solutions are extending, as well as the development of recovery and renewable energy (such as biomass and waste incineration) in replacement of fossil fuels. The case of France is interesting since the greening of heat production and the rationalizing of its delivery, as part of the national energy transition policy, are experiencing an unprecedented impetus. The appraisal of WHR issues in France appears to be rather autonomous while evolving in parallel with European processes. Although heat and heat recovery have emerged as part of the planned energy mix since the 2000s, only since 2015 have quantified objectives and adapted policy measures been passed and has a self-standing WHR policy truly taken off.

In France, planning appears as an important way of addressing energy issues and especially through the setting of development targets in different fields and through the development of energy mix scenarios. The 2005 POPE law (*Programme fixant les orientations* *de la politique énergétique*) established a new national energy strategy according to the European objectives in terms of the reduction of CO2 emissions, energy efficiency and renewable energy development. The development of renewable heat was identified as a means of acting toward these objectives and an ambitious goal to increase the production of renewable heat by 50% by 2010 relative to 2005 levels (8,5 Mtep) was set. The 2005 law initially only introduced energy savings certificates as the means to support investments in renewable heat generation equipment, but this was to be followed with heat investment programming.

The year 2009 proved important for both the planning and implementation of renewable heat. In application of the 2005 law, *Multi-year heat investment programming for the 2009-2020 period* (Programmation pluriannuelle des investissements pour la chaleur) planned an increase in the renewable share of distributed heat from 9,6 Mtep in 2006 to 12,6 Mtep in 2012 and 19,7 Mtep in 2020 (Ministry of the Environment 2009:105). The *Renewable heat fund* (Fonds chaleur renouvelable) was created in the same year to foster recourse to renewable heat to fuel district heating. Based on a yearly regional call for projects, the funding instrument was structured as an incentive device lowering tax benefitting district heating units fueled by renewables by at least 50%. As a result, renewable heat entered national energy policy by triggering objectives and public policy instruments, though recovery concerns were not specifically addressed or prioritized. If 2009 represented a first step toward the recognition of heat as an essential facet of energy policy, priorities were directed toward the collective supply side through district heating while WHR was not addressed as such.

The 2015 *Energy Transition for Green Growth* law pledges to multiply the share of distributed renewable heating and cooling five-fold by 2030 (relative to 2012 levels) to secure 38% of the heating share. Following the 2015 law, the national energy plan released in 2016 (Ministry of the Environment 2016) revised renewable heat objectives downwards (19 Mtep levels in 2023 rather than 2020). However, from 2015 onward, national heat production targets started to distinctively address issues of renewable and waste heat recovery. The release of the first France-wide study on industrial waste heat (ADEME, 2015) was pivotal in acknowledging WHR issues. The unprecedented assessment provided evidence of industrial waste heat as a largely untapped[4] energy source while highlighting different industries concerned and regional profiles. As a result, in 2015 the national renewable heat fund introduced a dedicated budget for funding WHR projects. From this point on, this evolution of this main supporting tool accelerated the emergence of new projects and notably in industry where only a few operations have been completed.

At the same time, the nascent French heat policy needed to conform to EU policies in development. The abovementioned threefold mapping requirements outlined by the 2012 EU Directive focused on localizing sources of waste heat, demand for heat and assessing the proximity of DH needed to be translated into French law. Some mapping exercises were then

[4] It accounts for 51 TWh of available heat (above 100 °C) with part of this (20%) being situated within the proximity of an existing DH.

realized by public agencies (CEREMA in 2014[5]) or private DH operators (Via Seva in 2019) on behalf of the Ministry of Environment. This unprecedented mapping exercise of waste heat issues made available to local authorities contributed to the mediatization of waste heat as a broad energy resource and to recognition of its recovery as required commitment from public and private actors. Regarding the European obligation to assess heat recovery feasibility for waste heat producers generating more than 20 MW, the French government chose in 2014 to refer to an already existing environmental regulatory tool on the classification of facilities listed for environmental protection[6]. Through this decision, the French legal translation exempted certain industries from the European obligation (e.g., data centers). Although the approach was thought to contribute to the introduction of WHR through national environmental legislation, the measure is recognized by the public actors interviewed to have missed its expected effects due to a lack of expertise and awareness from local environmental administrations and industries.

In early 2019, a new French energy plan (Programmation pluriannuelle de l'énergie) was launched to reset energy orientations for 2019-2023 and to plan the desired energy mix for 2024-2028. The publicly released draft document (Ministry of Energy Transition 2019) plans a roughly two-fold increase in WHR capacity (4,4 TWh by 2023 and between 7,6 and 9,9 TWh by 2028) within the heat mix (Ibid:138). In October 2019, the Ministry of Environment confirmed the importance of district heating and cooling, renewable heat and WHR in the French energy strategy through the publication of a dedicated action plan resulting from working groups of representatives of relevant actors (Ministry of Energy Transition 2019).

This diachronic analysis reveals a progressive agenda setting of WHR issues in France. In the early 2000s, renewable heat was first envisioned as an energy issue but was neither prioritized nor addressed through specific policy instruments. During this period, WHR remained out of the picture. From 2009 and onward, renewable heat benefited from increased policy attention through the development of a few successive national energy plans and a specific national funding instrument. Long indistinguishable from renewable heat according to energy policies, the recovery of waste heat started to be addressed from 2015 onward by means of refined planning orientations and accompanying measures. This rapid trend confirms that step-by-step and rather discreetly, renewable heat has made its way onto the French energy agenda, and waste heat now stands as a fully-fledged object of recent heat policy. It also highlights a policy network composed of actors and institutions mainly originating from district heating and cooling efforts and focused on the supply side even if heat recovery has started to attract support.

Furthermore, this retrospective analysis shows that WHR is very unevenly addressed with regard to the different sectors concerned. Indeed, the intensity of practices (i.e., effective recovery) and levels of knowledge and debate vary considerably from one sector of activity to another. In brief, the waste-to-energy field, which represents the main share of heat

[5] http://reseaux-chaleur.cerema.fr/carte-nationale-de-chaleur-france

[6] The Decree of December 9, 2014 specifies the content of cost-advantage analyses assessing opportunities to recover waste heat energy from a DHC and the types of facilities involved.

recovered from existing incineration facilities (whether for cogeneration or heat only), benefits from a long history allowing for rather stabilized regulation and settled technical standards. Organized public and private actors involved in the running and control of incineration units and district heating and in the production of expertise (ADEME, AMORCE) form identified policy networks. On the other hand, heat recovery from industrial activities is a far less marked world with one main reason being that it covers very different activities, from those of the old chemical, metal or refinery industries to those of the newest data center units. While studies have recently been carried out on some regions (ADEME 2012, 2017) and/or sectors (De Carlan et al 2017) to evaluate potentials and mediating ideas among industrial actors, working habits are far less established and policy networks not structured at all. Finally, waste heat generated from nuclear plants[7] in France, in spite of certain scientific concerns (Leurent 2018, Leurent et al 2018), remains a largely unaddressed and unspeakable issue with the exception of a few local recovery practices adopted for farming or leisure.

5. Conclusion and discussion.

Investigations of WHR serve as evidence of this issue gradually entering the European and national energy arenas in parallel with growing academic concern. Now identified as a recognized class of energy distinct from other renewables, waste heat is recognized as a unique energy resource raising more questions for energy research to explore. Findings related to waste heat policy-making call for further development. In conclusion, we suggest extending an analysis in several directions consistent with policy agendas and with the designation of recovery as a facet of future energy development.

Extending the timespan of heat agenda analysis. In this paper, WHR agenda setting is examined with respect to the current energy transition agenda, which roughly started in the early 2000s with the strengthening of climate and energy policies in Europe. However, investigations highlight a need to look further back, as WHR was recognized as an issue in the 1970s (Commission of the European Communities, 1982). Developing a comprehensive understanding of the history of heat policy requires looking backward while paying attention to more discrete forms of expertise, law projects and institutional debates in a time when energy savings and national independence stood as main concerns. Such an investigation would allow to test the hypothesis of WHR as a long dormant issue characterized by some unsuccessful attempts made to place it on the agenda and by its eventual consideration based on current heat decarbonizing concerns. Renewed agenda setting theories highlighting the importance of discrete public concerns (Gilbert and Henry, 2012) may be fruitful in understanding non-linear and intricate patterns of waste heat agenda building.

The weight of sectoral configurations: Comparing national trajectories. Following the European agenda, energy policies have been implemented with a sectoral approach (i.e., solar, wind, CHP, coal, and nuclear). Every energy sector is organized around a spokesmen and networks of actors, its policy networks, and its own norms and shared interests. However,

[7] 0,4 Mtep/year valorised over 80 Mtep available across 8 sites (MEEDDAT, 2008).

WHR cannot be clearly identified from the current sectoral organization of the energy field. First, WHR remains an emerging matter with no clearly identified spokespeople and policy networks. Second, as WHR is intrinsically cross-sectoral, waste heat may be recovered from various sectors of activity and technology according to various logics. However, some sectors tend to be progressively open to WHR issues while others are not. The case of France reveals particularities of a central role played by a national energy funding and expertise agency (ADEME) and local representatives (AMORCE, FNCCR) in the acknowledgment of WHR. As a result, most industrial actors have paid more attention to WHR. At the same time, energy producers seem to be less invested in the issue while the recovery of waste heat from nuclear plants remains almost nonexistent. Beyond the French case, other national trajectories should be enquired to understand how WHR actor networks, policy networks and sets of norms emerge; how WHR is approached and how sectoral configurations are constructed. A comparison of such national trajectories is likely to shed light on the development of issues related to WHR.

The lock-in pitfall: Addressing the conflicts of a consensual issue. At a first glance, the development of WHR appears as a consensual and shared objective whose implementation suffers from a lack of organizational alignment rather than from frontal opposition between stakeholders. This observation must not conceal the fact that the most significant heat losses result from sectors (nuclear, waste incineration, and heavy industry) that face opposition not only due to being locally unwanted but also due to their global environmental impact. Intrinsically linked to a given activity and site of generation, heat recovery research cannot be disassociated from broader social and environmental struggles related to the activities and places from which it originates. Contributing to energy gains and avoidance of GHG emissions, WHR processes in some cases result from or converge with environmental emissions control (e.g., air pollution reduction or lowering temperatures of rejected water). Such environmental benefits, which are likely to play a role in the acceptance of such activities, should not overshadow the risk of locking-in unwanted solutions (Unruh 2000, Unruh 2002). Indeed, waste generation is designed to decrease over time, and some national governments have committed to restricting or ending nuclear energy use while many European regions are concerned with deindustrialization. As illustrated by the case of Sweden (Corvellec 2013, Dzebo and Nykvist 2017), dependence on nonlasting sourcing activities (e.g., waste) constitutes the most obvious pitfall of heat recovery. Conflicts and conflicting views should be taken seriously when studying WHR development not only at the site or facility level but also in terms of discourse, terminology, classification and assessment issues, and values. The difficult recognition of WHR as a renewable energy source testifies of these underlying struggles.

Examining local contexts that favor or hamper WHR realization. Thus far, the development of WHR occupies an early stage. Conditions of success appear to be very specific to each case and to be dependent on the nature of the heat source involved (temperature, form, and flow) and of locally expressed heat demands. Economic factors prove determinant, notably in industrial recovery projects which often meet development difficulties due to mismatches between return on investment time expectations from the industrial actors and guaranteeing supply time expectations from network investors. Fossil fuels (notably gas) competitive prices – as well as renewable energy prices in some regions – represent a significant challenge for the development of WHR projects. However WHR should not be set aside on the sole argument it might not be the least expensive solution at the moment. In the same vein, the prioritization of some heat sources and sectors over others, beyond techno-economic factors, should be regarded in the light of social organisation and land planning issues. Consequently, emerging supportive public policy instruments must be adjusted according to their local effects, and barriers to local projects still need to be identified. For this reason, more attention must be dedicated to local case studies conducted through qualitative enquiry. Such attention must highlight difficulties that may emerge when attempting to match heat supply and demand related to technological, market, financial, legal and spatial issues and local means of overcoming such difficulties. In this vein, contributions from political science, sociology or geography may specifically focus on the local governance of such projects and on actors' interactions. From an in-depth understanding of the importance of local contexts to the development of WHR projects, contributions from these academic disciplines might thus question how WHR might contribute to the energy transition and to energy decentralization.

Engaging with technology and use evolution. From this nonexhaustive and still to be supplemented collection of research questions, the social and human sciences must engage further with technical and engineering fields. If technology is not a barrier to WHR development, the valorization of the great untapped potential of new technical solutions and problems will keep emerging and constantly reformulate barriers to be overcome. New heat storage technologies may help re-address the problem of seasonal mismatches between heat production and heat demand. The development of a fourth generation of district heating and cooling systems might allow us to consider the use of low-grade temperatures (Lund et al 2014) and the value of several new heat sources. District cooling is likely to be extended over the near future to cities that suffer from repeated heat waves. Within this context of constantly evolving technologies, the social and human sciences have a key role to play in examining how untapped WHR potential might find a place in energy mixes and how waste heat sources may be converted into resources over a large scale.

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