Assessing the heat pump market in the industry

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Keywords

heat pump, waste heat

Abstract

In the French Industry, the energy lost through waste heat accounts for roughly 25 % of its total energy consumption. Though recognized as of significant potential for recovery, heat wastes are at 50 % concentrated in low level temperature wastes, below 100 °C, too cold to be directly used through a heat exchanger for most industrial processes. Hence, EDF contributed to the development of heat pumps that were segmented in this study in three levels of maximum condensing temperature: 70 °C (HP 1), 100 °C (HP 2) and 150 °C (HP 3).

This paper proposes a three steps method to evaluate the potential of heat recovery with HPs in France for each industry sector and under consideration of technological and economic constraints.

In the first step, we build an indicator to show the statistical potential of each HP by cross referencing a heat waste with a heat consumption database taking into account the relevance of the HP compared to a heat exchanger, and the HP coverable share of the needs. In the second step, heat wastes and industrial processes are identified and matched to validate the technical feasibility of an HP. The third step consolidates the results by confronting them to the field: industrial references, energy audits and on-site visits.

This paper presents the results for HP1. The potential for this HP in the Malting sector (NACE 11.06Z) particularly stands out. Most of the heat needs come from drying: the malt's humidity is reduced from 45 % down to 5 % at a temperature range from 60 to 85 °C, generating heat wastes. The HP is integrated into the drying process recovering the hot exhausted vapour and using its remaining heat to fuel back the dryer. The malting industry counts at least two important references in France in Strasbourg and Vitry le François. For each 100 tons of product, the HP can roughly save 60 MWh of gas and consumes an additional 12.5 MWh of electricity preventing 2 tons of CO_2 emissions.

Introduction

As reducing the environmental impacts of human activities has become a global priority, greenhouse gas emissions come as one of the top target to mitigate climate change. For this reason, the French Energy Transition Policy [1] (Loi de transition énergétique pour la croissance verte) sets an objective of cutting greenhouse gases emissions by 40 % between 1990 and 2030, promoting carbon-free or less-carbon intensive energy sources among other measures. The ambition is to achieve 32 % of the final energy consumption, 38 % of the final heat consumption, 15 % of the final fuel consumption and 10 % of the final gas consumption as renewable energies.

EDF R&D plays a key role in improving the overall Group's performance regarding these objectives by working on disruptive technologies to prepare the future of energy; many of them run with external bodies through partnerships.

EDF R&D has been running several studies on the theoretical waste heat potential in France [2–8]. In fact, a greater lever could be achieved by simultaneously increasing the share of renewable energies in the energy mix and decreasing the overall energy consumption by targeting energy wastes, such as waste heat (heat that is released into the environment once it has served its purpose). Therefore, technologies such as heat pumps, heat exchangers and Organic Ranking Cycle have been subjects to many studies [9–12] because they allow for both energy waste reduction and renewable energy production.

This paper proposes a method to evaluate the potential of heat recovery with HPs in France for each industrial sector and under consideration of technological and economic constraints.

EDF has evaluated the potential market in France for heat pumps. It was assessed to reach 1 TWh/y increase in electricity consumption for compressors, roughly a 4 TWh/y decrease in fossil energy consumption and 1 Mt/y of CO_2 avoided.

Heat pump principle and capabilities

Industrial heat pumps (IHP) are heat-recovery devices able to increase the temperature of waste heat coming from an industrial process or other natural sources to a temperature at which this energy can be used either in the same process or elsewhere in the factory, and in some cases, out of the industrial site itself (in district heating network, for instance).

Heat pumping is recognized as a technology able to increase energy efficiency and, at the same time, reduce CO_2 emissions. The heat pump markets and applications are constantly growing but the available international data on HPs focuses however mainly on residential heat pumps for space heating and domestic hot water production. It is difficult to find reliable data on IHP's markets as well HP's installation references (see [18] which is, to our knowledge, the largest review of industrial heat pumps installations).

Industrial heat pumps use waste heat from industrial processes such as exhaust gas, cooling water from furnaces, cooling of the chillers condensers, cleaning waste water. This heat can then be used through operations such as heating or preheating of water for processes, or air for dryers or space heating. Recently, a new generation of Very High Temperature heat pumps (>100 °C) allows the production of steam at the condenser of the heat pumps.

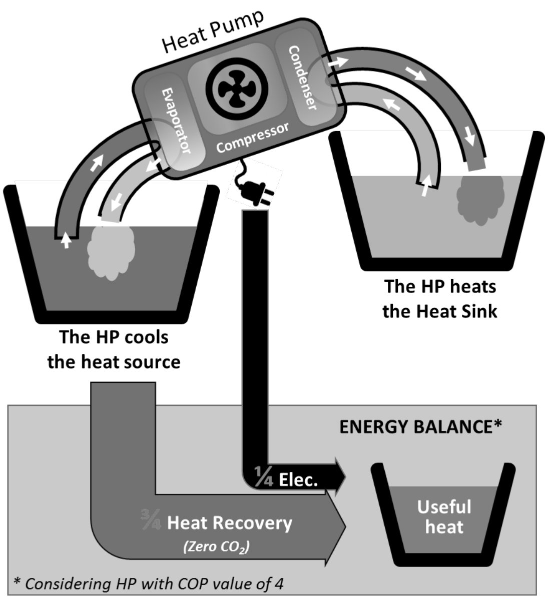

Figure 1. Heat pump principle, illustration of the energy performance of the HP.

By applying the first law of thermodynamics, one can consider that the input energy (mechanical energy for the compressor and heat source energy) are equal to the output energy provided to the heat sink (see Figure 1). Then, part of the energy produced by the heat pump comes from recovered energy (supposed free and with a zero CO_2 content). The balance is brought by mechanical energy given to the compressor, generally with electric motors. In industrial cases, the ratio between the produced energy and the electrical energy consumed is found between 2.5 and 6. This ratio is the COP or Coefficient of Performance.

Method

Assessing the HP market is a subject that has already been covered in various studies, including studies from EDF R&D. However, the industrial sectors found in these studies seldom developed into a real breakthrough in industrial HPs sales. A possible reason is that assessing the HP market based on the sole heat waste data does not enough reflect the realities of industrial sites and the logic behind their investments.

We consider a general methodology built simultaneously on knowledge about industrial processes, energy database (wasted heat, heat needs) and industrial heat pumps installations.

ENERGY DATABASE

This method to assess the heat pump market in France combines thermal equipment stock characterization database with a process energy needs characterization database. An expertise of industrial sectors and processes from EDF completes it.

The CEREN (Centre d'Etudes et de Recherches Economiques sur l'Energie) conducts studies [13] on the energy consumption of the French industry. Data is structured by industrial sectors (steel, food, chemical …), by energy types (electricity, natural gas, fuel …) and by energy uses (furnaces, boilers, dryers …).

The database regarding industry is built from about thousand investigations on the largest industrial sites. It is then completed with over six thousand annual phone surveys on the small and medium-size enterprises. About seventy specific questionnaires have been filled to evaluate the energy contained in the fumes of the furnaces and sixty others to evaluate energy contained in the steam of dryers.

Waste heat origin characterization

The waste heat is characterized by its energy value [14, 15]. This energy value is given by type of warm effluent, by temperature level, by availability of heat and by industrial sector. Energy data are analysed on the basis of these parameters.

Included warm effluents are:

- combustion gases from furnaces (without blast furnaces),
- combustion gases from boilers,
- steam from dryers,
- cooling fluids from air compressors,
- cooling fluids from refrigeration compressors,

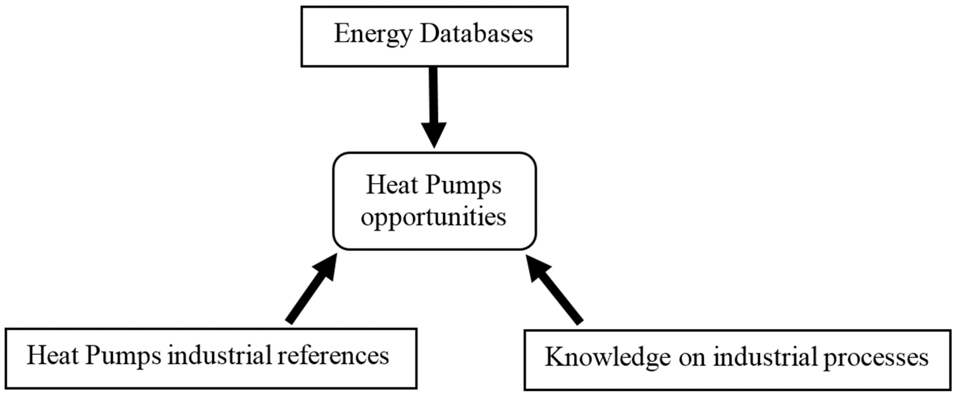

Figure 2. Illustration of the method used to stand out the relevant Industry Sectors for HP integration.

- cooling fluids from refrigeration condensers,
- cooling fluids from heat exchangers in desuperheaters of refrigeration groups,
- hot water from clean-in-place (CIP effluents).

The effluents which are not included are from processes (concentrators, from network of fluids of cooling, energy contained inside the products etc.), for which data is not available.

Process energy needs characterization:
Process needs are characterized by their consumption, number and installed power [16]. These values are given by type of equipment, by industrial function, by technology, by power level, by age, by temperature level, by running time, and by industrial sector. Data are analysed on the basis of these parameters.

INDUSTRIAL PROCESSES KNOWLEDGE

Databases cannot be fully trusted when assessing the HP potential of an industrial sector. Once the overall potential of a sector has been obtained through the databases, several considerations must be taken into account. Among them:

- **The concentration of the waste energy**: when waste energy is disseminated in many small sources the recovery gets complicated, for example the cooling of hot products stored at various places before packaging and transportation. Other example, if the heat is to be recovered from chillers and that chillers are under the form of numerous small units dispersed in the industrial site, then the recovery is expensive and inefficient.
- **The distances between source and sink**: when these distances are high the HP become economically inefficient because of tubing and other integration costs. In the paper industry, for example, the distances between the different operations of the process can be over hundreds of meters.
- **Regulation and standard**: some industrial sectors have rendered mandatory the use of gas. For example, in distilleries for fine alcohols –where high temperature HP could find an attractive market- standards impose the use of a flame in close contact with the boiling mixture in order to get high temperature and the production of the expected flavours.

Recently in France, the administration has requested an Energy Audit to all – non small business – industrials (standard EN16247). More and more industrials voluntarily apply for the ISO 50001 (Energy Management) and can provide detailed information about energy use in their industrial sites. These sources of information are very useful to understand a given industry sector and processes.

HEAT PUMPS REFERENCES

HP industrial installations, such as listed in [18], can be considered as the most complete source of information to fully understand the HP potential of a given industrial sector. For each industrial sector, whenever possible, heat pumps installations were extensively studied. Some of them were eliminated from framework of this study, for instance when the heat pump was used for space heating, as this was not considered as HP on process. This part of the work also relies on the work of the International Energy Agency – Annex 48.

Database operating method to select Industrial sectors for HP integration

To address this issue, we developed a database operating method based on the calculation of three criteria to determine industrial sectors of major interest for HPs.

By applying three selection criteria's in the Energy Databases, we selected the relevant industry sectors.

SELECTION CRITERION 1: OVERALL POTENTIAL FOR HP IN A GIVEN INDUSTRY SECTOR

Three types of heat pumps HP 1, 2 and 3, are considered. These three types of HP allow to connect a waste heat in which energy is recovered to a heat need to feed. Because we want the HP to have a COP (Coefficient of Performance) of 4 at least, the difference in temperature between the heat waste and the heat needs cannot be over 40 °C. Note that we had to follow to temperature ranges used by the database and some intervals could not be exactly 40 °C.

$$HP1\ (MWh) = \min\left(Waste\ heat_{[<40°C]}(MWh);\ Heat\ needs_{[40°C\ to\ 70°C]}(MWh)\right) \quad (1)$$

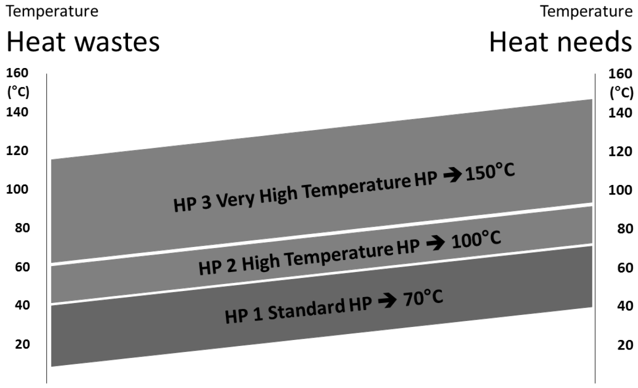

Figure 3. Segmentation of HP 1, 2 and 3 by temperature range of Heat Sources (or Wastes) and Heat Needs.

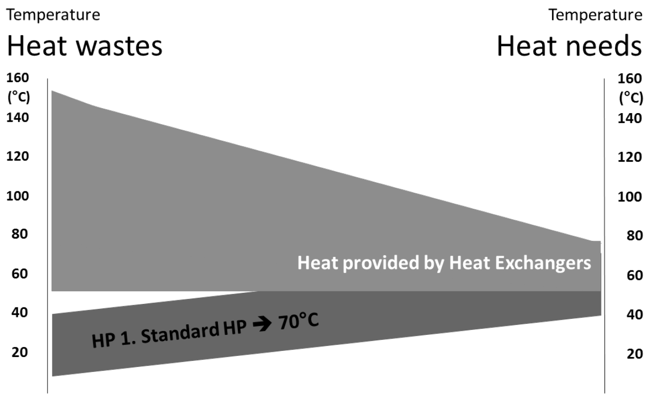

Figure 4. Illustration of the ratio waste heat for the HP2 (needs between 70–100 °C).

$$HP2\ (MWh) = \min\left(Waste\ heat_{\ [40°C\ to\ 60°C]}(MWh);\ Heat\ needs_{[70°C\ to\ 100°C]}(MWh)\right) \quad (2)$$

$$HP3\ (MWh) = \min\left(Waste\ heat_{\ [60°C\ to\ 100°C]}(MWh);\ Heat\ needs_{[100°C\ to\ 150°C]}(MWh)\right) \quad (3)$$

We use this criterion to assess the theoretical amount of energy that could transit through each heat pump for each sector. In our databases, we connect each waste potential with a need within temperature range. Then we add all these connections one to another for each HP to assess the total amount of waste heat that could be used through a heat specific HP for each sector. Each time, we take the minimum between the amount of waste heat that could be used through a heat pump and the amount of heat needed at the considered range of temperature in the same industry sector. We consider in this study that each sector is autonomous and cannot communicate its excess in waste heat to another sector, neither can it import waste heat from another site to fuel its HP.

This energy quantity gives an idea of the energy accessible volume for the HP 1, 2, 3 by industrial sector. This first criterion allows to rate the energy potential by sector. This raw targeting has to be refine to take into account of several parameters inherent to any HP project.

SELECTION CRITERION 2: COMPETITION BETWEEN HEAT EXCHANGER AND HP

HP are not the only existing technology to recover waste heat. Each time a heat exchanger is possible, it will always be a cheaper installation that makes HP irrelevant. For this reason, we introduce in our analysis a second criterion that aims at subtracting from the theoretical potential accessible to HP the amount of energy that could be recovered through a mere heat exchanger. HP are only used whenever there is a need to rise the temperature level of the waste heat.

The selection criterion 2 is first calculated by dividing the excess heat used by the HP by the excess heat used by heat exchanger to provide the same heat needs.

The ratios can be written as:

$$Ratio_{Waste\ heat\_HP1} = \frac{Waste\ heat_{<40°\ C}(MWh)}{Waste\ heat_{>60°\ C}(MWh)} \quad (4)$$

$$Ratio_{Waste\ heat\_HP2} = \frac{Waste\ heat_{40°\ \ to\ 60°\ C}(MWh)}{Waste\ heat_{>100°\ C}(MWh)} \quad (5)$$

$$Ratio_{Waste\ heat\_HP3} = \frac{Waste\ heat_{60°\ \ to\ 100°\ C}(MWh)}{Waste\ heat_{>150°\ C}(MWh)} \quad (6)$$

Then these ratios are normalized between 0 and 1. For each HP the "Ratio Waste heat HPi" is divided by the highest ratio of all the industrial sectors of the database. Consequently, the "best" sector will have the ratio equal to 1.

SELECTION CRITERION 3: STRATEGIC NATURE OF THE ENERGY EQUIPMENT NEED FOR THE INDUSTRIAL SECTOR

The HP requires a large investment and highly qualified personnel for the maintenance, which more often than not represent extra costs. The rule in the industry is to require a maximum payback time of three years for the investments on the utilities while the payback time of investments on the core processes can be much longer. Hence, HPs have to be used to supply the core process rather than less important spots. Only in this situation the industrialist will take the risk to invest in a HP. That is why we define for each type of HP a third non-dimensional criterion which represents the proportion of equipment energy needs covered by the HP on all the needs of the sector over the whole range of temperature.

This ratio is normalized between 0 and 1. If all the needs in heat of a sector are centred on a range of temperature corresponding to the operation of the HP, then the ratio of this sector associated with this type of HP will be equal to 1. On the contrary, if the range of operating of the HP covers only a small part of the energy equipment needs of the sector then the ratio will be narrow from 0. The ratios can be written as following:

$$Ratio_{Energy\ needs_{HP1}} = \frac{Energy\ needs_{<70°\ C}(MWh)}{Energy\ needs_{total}(MWh)} \quad (7)$$

$$Ratio_{Energy\ needs_{HP2}} = \frac{Energy\ needs_{<70-100°C}(MWh)}{Energy\ needs_{total}(MWh)} \quad (8)$$

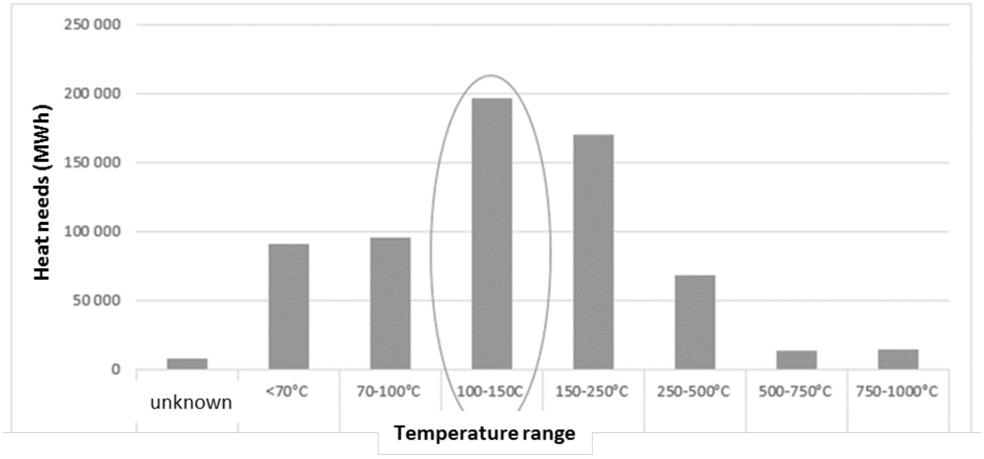

Figure 5. Energy equipment needs in the "Manufacture of rubber and plastic products" sector.

$$Ratio_{Energy\ needs_{HP3}} = \frac{Energy\ needs_{100-150°C}(MWh)}{Energy\ needs_{total}(MWh)} \quad (9)$$

The example of the Manufacture of rubber and plastic products shows that the ratio is favourable for the HP3. The energy consumption on the target temperature range are the highest. The main energy equipment needs are on this temperature range.

MULTI-CRITERIA ANALYSIS

The three criteria are combined to determine the most interesting industrial sectors for HP:

- Criterion 1: Overall potential for HP.
- Criterion 2: Competition between heat exchanger and HP.
- Criterion 3: Strategic nature of the energy equipment need for the industrial sector.

The criteria 2 and 3 are applied to each industrial sectors (NACE) for the HP (1, 2, 3). The criteria 1 addresses the evaluation of the market volume but doesn't give information on the sustainability of HP in the industrial sector.

The aim of the analysis is to classify the most interesting sectors for HP taking into account the pool of HP energy consumption of each sector. In the interest of readability, the criteria 2 and 3 were summed up to be able to represent the results on a single graph axis:

$$Ratio\ HP_i = Ratio_{Waste\ heat_{HPi}} + Ratio_{\text{Energy needs}_{HPi}} \quad (10)$$

The graph of Figure 6 shows on the X-axis the priority sectors and on the ordinate the Ratio HPi. The bubble size represents the pool of HP energy consumption.

HP1 collect the waste heat at less than 40°C and feed the equipment energy needs lower than 70 °C. HP1 has a high technical and financial maturity. It has been sold widely for several years, and is thus more affordable.

Only the first twenty sectors by decreasing "HP Ratio" are represented in Figure 6. Among the sectors of interest, there are: the Brewing and Malting sector (NACE 11.06Z) (141 GWh), Processing and preserving of fish, crustaceans and molluscs (NACE 10.2) (100 GWh), Processing and preserving of meat and production of meat products (10.1) (439 GWh et 408 GWh), Manufacture of electronic components and boards (26.1) (87 GWh), Manufacture of basic pharmaceutical products and pharmaceutical preparations (21) (167 GWh), Manufacture of beverages (11) (56 GWh), Manufacture of bakery and farinaceous products (10.7) (151 GWh).

It should be noted that numerous identified interesting sectors for HP1 are part of the food industry. Globally, this macro-sector loses a lot of waste heat at a temperature under 40 °C due to the prevalent use of cold production units. The waste heat is recovered on the condensing exchanger. The equipment energy needs scarcely exceed 100 °C. While it is unexpected to see the Manufacture of electronic components and boards (26.1), noted as "Electronics" on the graph, it shows the interest of this method. It allows for the discovery of HP interesting sectors based on an analytical method free of preconceived notions.

Application to the malting industry

The example of the malting industry was chosen because it appears as the most favourable to HP1 integration (see Figure 6). As discussed in §III about the method, the complete analysis does not only rely on the databases analysis but also on "Field references of installed HP's" and on "Knowledge on industrial processes" [17].

ENERGY DATABASE ANALYSIS

Figure 7 shows the wasted heat and the heat needs as given by the Energy Databases discussed for the malting sector. It seems obvious that the suitable role for a heat pump in that sector is to recover the energy of the exhaust humid air and to provide the heat for the drying process. The heat rejected by the chillers can also be used as a source for the heat pump.

KNOWLEDGE ON INDUSTRIAL PROCESSES

It appeared very important to analyse the process in order to understand if and how the wasted heat can be recovered in practice and how the heat needs can be delivered by the heat pump condenser. Most of the heat needs come from drying: the malt's humidity is reduced from 45 % down to 5 % at a temperature range from 60 to 85 °C, generating heat wastes. The HP is integrated into the drying process recovering the hot exhausted

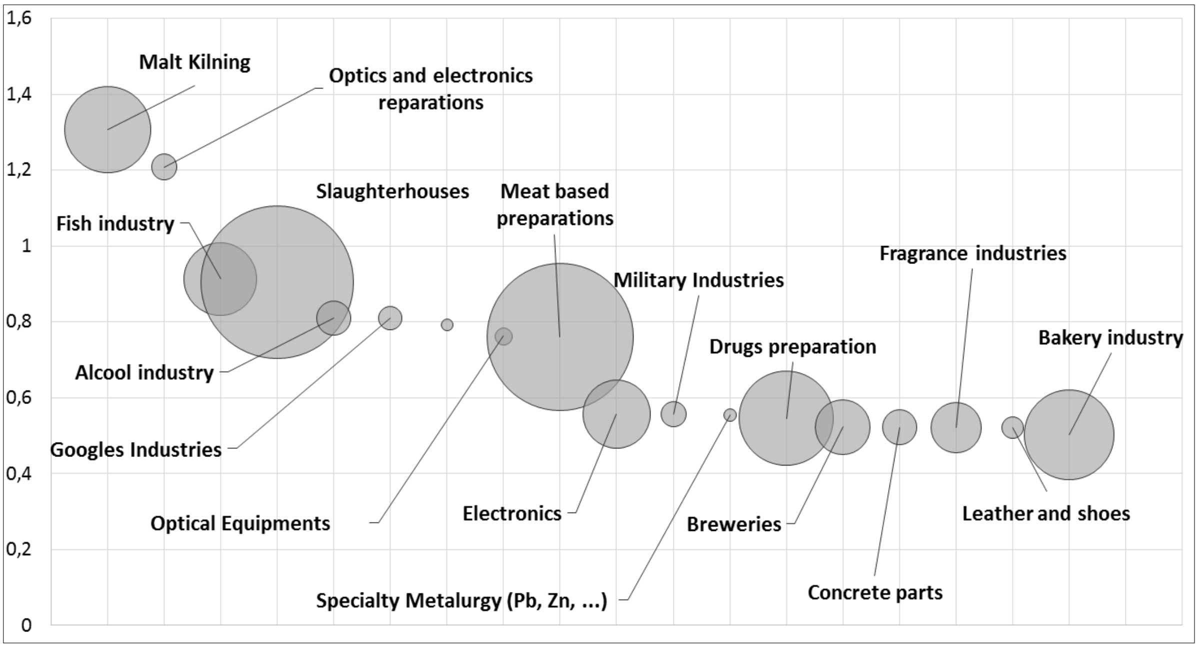

Figure 6. Multi-criteria analysis for HP1 – The Y-axis is the sum of selection criteria 2 and 3.

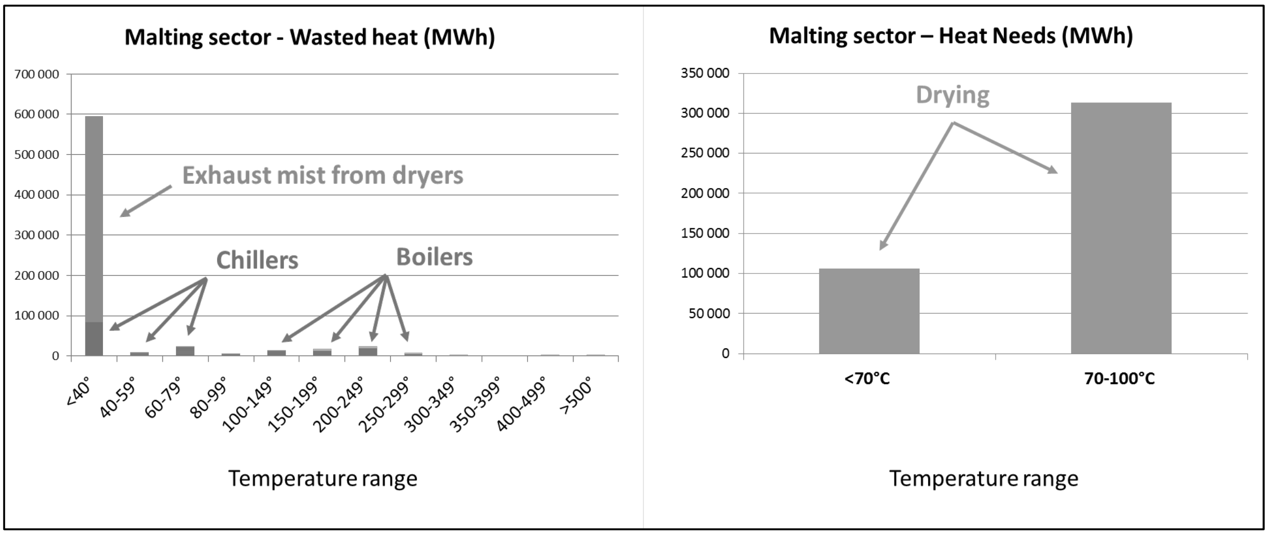

Figure 7. Wasted heat and heat needs for the malting sector.

vapour and using its remaining heat to fuel back the dryer. In the case of malting, as it is a drying operation, both the waste and the needs are present simultaneously. Then, no temporary heat storage is necessary. The waste heat is produced at the exhaust pipe near the location were the fresh air is taken. This is also a favourable situation to limit the piping costs.

INDUSTRIAL REFERENCES

In the case of malting, several references of already installed heat pumps in France were found like the Malteurop site in Vitry-le-François where a heat pump is used in addition with wood fuel [19]. In the frame of Annex 35 and now Annex 48 of the International Energy Agency, existing large number of already installed industrial heat pumps is listed [18]. Such report contributes to accelerate the heat pump dissemination efforts.

SYNTHESIS

Our methodology shows that standard HP1 is suitable for malting. The dry air entering the kiln is heated by the HP to 60 °C. The HP uses heat from the drying process, released through the exhausted air from the kilning unit. According to our analysis, there are 35 opportunities of HPs in the industry in France. The case studies allowed us to define most of the technical values thanks to their feedbacks. The fact sheet (Figure 8) has been designed to quickly assess from a marketing point of view the potential of each opportunity identified in a targeted segment. The data presented in these sheets comes from the combination of the data base analysis, the knowledge of industrial process and the industrial references.

Once identified through our multi-criteria analysis that the recycling of the heat in the dryer in the kilning unit in the malting industry represent potential market for the standard HP1,

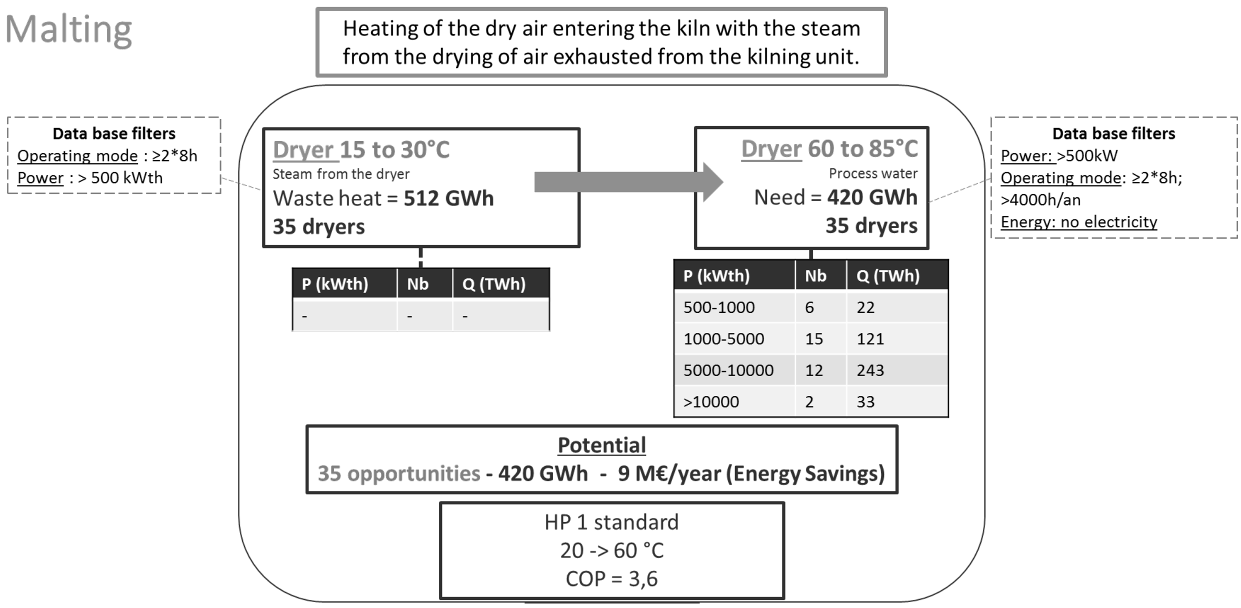

Figure 8. Marketing fact sheet.

we can then design this marketing fact sheet to help address it. With our heat waste database, we assess the amount of recoverable heat in the exhausted air from the kilning units. With our industrial equipment database, we can determine the number of installations that could be equipped, and their nominative power. Then, with hypothesis on the average price of gas and electricity, we compute an average amount for the annual savings (€9 M/year) that could be done with the HP.

Conclusion

Everywhere they operate using excess heat recovery, industrial heat pumps reduce the CO_2 emissions of industry processes by recovering waste energy and providing heat at the right temperature.

By the mean of this analysis, industry sectors giving HP opportunities can emerge. The purpose of the study is to select and target a restricted number of sectors in order to study them in depth according to several approaches discussed above.

The method used here finds interesting correlation with field results as already running several heat pumps were found in the malting sector. Nevertheless, we need to benchmark this for more sectors to really prove the efficiency of the proposed methodology.

In the remainder of the study, the methodology is illustrated by the example of Malting sector. Indeed, this sector ranks first in the HP1 list and has a sufficient potential number of HP devices. Several other industry sectors are under study. They will lead to a guide which aim is to facilitate the dissemination of industrial heat pumps wherever this technology can bring economic and environmental advantages.

References

[1] LOI n° 2015-992, 17 août 2015 relative à la transition énergétique pour la croissance verte, Titre Ier : Définir les objectifs communs pour réussir la transition énergétique, renforcer l'indépendance énergétique et la compétitivité économique de la France, préserver la santé humaine et l'environnement et lutter contre le changement climatique, Article 1

[2] Leang S., Berthou M., Jumel S., How to deal with technical and economic constraints to recover waste heat in France?, ECOS 2017: 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems, 2–6 July 2017, San Diego, California.

[3] Berthou M., Bory D., Overview of waste heat in the industry in France. eceee 2012: Summer Study on energy efficiency in industry, 11–14 September 2012, Arnhem, The Netherlands.

[4] ADEME, La chaleur fatale industrielle: connaitre pour agir, 2015

[5] Hita A., Seck G., Djemaa A., Guerassimoff G., "Assement of the potential of heat recovery in food and drink industry by the use of TIMES model", 2011 eceee summer study.

[6] Weng R., Bory D., M. Berthou, A method to evaluate the waste heat recovery potential across the industrial sectors. ECOS 2013: Proceedings of the 26th International Conference on Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems; 2013 July 16–19; Guilin, China.

[7] Dupont M., Sapora E., "The Low Temperature Heat Recovery in Industry – Which Potential and How to Access It?", 2011 eceee summer study.

[8] Samuel Chiche, Alain Goumba, Patricia Bonneau, Xiaofeng Guo1, Morgane Colombert, Recov'Heat : Outil d'estimation du potentiel de sources de chaleur fatale en milieu urbain, Congrès français de thermique, 2016, Toulouse, France.

[9] Shenoy UV, Sinha A, Bandyopadhyay S. Multiple utilities targeting for heat exchanger networks. Chemical Engineering Research and Design 1998; 76 (3): 259–72.

[10] Dupont M., Sapora E., "The heat recovery potential in the French industry: which opportunities for heat pump systems?", 2009 eceee summer study.
[11] A. Rettig, M. Lagler, T. Lamare, S. Li, V. Mahadea, S. McCallion, J. Chernushevich, 2011, Application of Organic Rankine Cycles (ORC), World engineer's convention, Geneva.
[12] Bourig A., Peureux J.L., "Technico-economic modeling of waste heat recovery chain including industrial heat pump systems and thermal energy storage", The 12th International Conference on Energy Storage, INNOSTOCK, May 2012.
[13] Profil énergétique des secteurs, Enquêtes sur le marché industriel de l'énergie (EMIE) 2011 à 2014, Centre d'études et de recherches économiques sur l'énergie, study for its members.
[14] Potentiel de récupération de chaleur à partir des effluents industriels 2011. Centre d'études et de recherches économiques sur l'énergie (CEREN), study for EDF and ADEME.
[15] Potentiel de récupération de chaleur dans l'industrie et quelques secteurs du tertiaire: UIOM, STEP et data center 2016. Centre d'études et de recherches économiques sur l'énergie (CEREN), study for EDF and ADEME (French Environment and Energy Management Agency).
[16] Extrapolation du parc des équipements en 2011 dans l'industrie Centre d'études et de recherches économiques sur l'énergie (CEREN), study for EDF and ADEME (French Environment and Energy Management Agency) (French Environment and Energy Management Agency).
[17] Industrial Energy Efficiency Accelerator – Guide to the maltings sector, The Carbon Trust, May 2011.
[18] H.J. Laue et al., IEA ANNEX 35 – Application of Industrial Heat Pumps, Part 1 & 2, HPP-AN35-2, Oct. 2014.
[19] https://www.malteurop.com/sustainable-development/energy

Acknowledgments

The authors would like to express their thanks to Aymeric Durand and Clément Albert, both students, for their great work within that project.