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Excess heat in Portuguese industry: Cement and Iron & Steel Sectors

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ABSTRACT

Carbon dioxide accounts for more than 50% of the greenhouse gas emissions attributable to man, making it one of the greatest contributors to climate change. By reducing primary energy consumption, we can reduce greenhouse gas emissions and recovering excess heat is one way of achieving this.
The efficient and rational use of energy within the industry is already an economic success story for many companies. In its various forms, it can lead to significant performance improvements in any given industrial process.
The aim of this paper is to identify the origin of industrial excess heat, quantifying it both thermally and energetically, to then analyse its potential uses within the industry. To this end, data was collected from two different sectors, the cement sector and the steel and iron sector. This data was then analysed and extrapolated in order to obtain overall excess heat values for these sectors. Questionnaires were distributed amongst a selection of the largest companies in each sector and the data collated using spreadsheet technology.
In addition to this, there is also a case study of a Portuguese steelworks company, where excess heat values in production were quantified and analysed and the viability of implementing excess heat recovery technologies was assessed.

Keywords: excess heat, energy efficiency, excess heat recovery, chemical process synthesis, industrial sector.

1. Introduction

Currently, carbon dioxide is responsible for more than 50% of greenhouse gas emissions and these emissions are in large part due to the burning of fossil fuels, the negative effects of which are already being felt and will continue to be felt in the coming decades. This poses a huge threat to the economic and social stability of our planet and the environmental consequences are no less dire [1]. Consequently, energy efficiency has become a buzzword in the industry and its prominence is growing ever stronger, providing not only potential economic and financial advantages but, crucially, environmental also. Companies are slowly moving towards greater energy efficiency but incorporating energy efficiency targets into existing company policies and creating more incentives on a fiscal and political level would also help to make companies take note and act faster.
The benefits of greater energy efficiency can be divided into four main levels:

- International (by reducing overall global greenhouse gas emissions);
- National (greater energy efficiency);
- Sectorial (greater competitiveness and cost efficiency);
- Individual (greater financial gains) [2].

This paper aims to quantify excess heat within the Portuguese industrial sector, forming part of Annex XV – Recovery of excess heat in the industry: Technology and Applications – Industrial Energy related Technology and Systems, an international agreement led by the International Energy Agency (IEA).
Data gathered from the cement and iron and steel sectors will help to estimate the overall production of excess heat in these sectors. After quantifying the data, studies were carried out to assess the viability of implementing solutions and processes for the recovery of excess heat, using the available technology. This recovery can either be done internally (where excess heat is reintroduced into the industrial process) or externally (where excess heat is exported), but internal repurposing is recommended and prioritized as it allows for a reduction in primary energy use and consequently contributes to lowering greenhouse gas emissions. [3].
The case study focuses on calculating and quantifying excess heat recovery values as well as examining the viability of implementing excess heat technologies for a Portuguese steelworks company – Lusosider – Aços Planos.

2. Literature review on excess heat

This section presents the literature review on which this study focuses. It includes a bibliographic review on excess heat concepts, methods of quantifying it and available technologies currently in use.

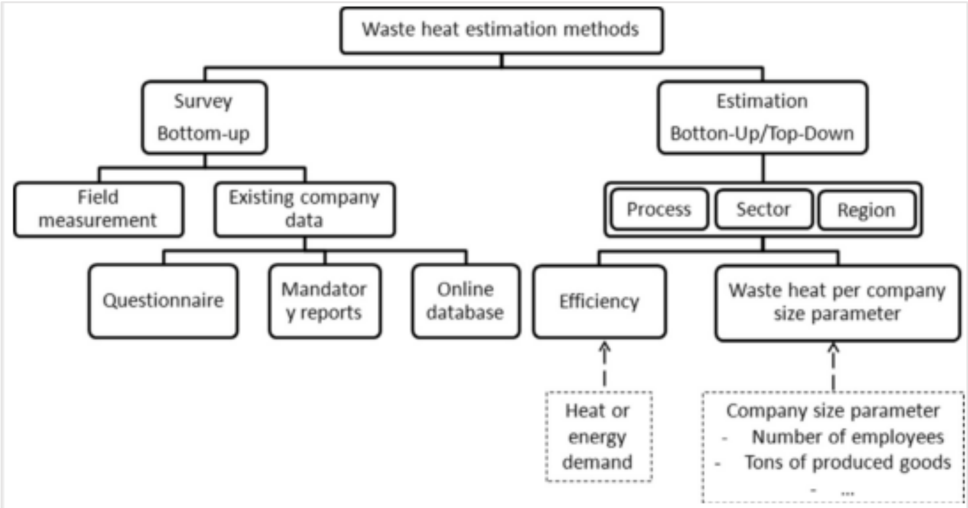

Figure 1: Methods to estimate excess heat [5].

Excess heat: basic concepts and sources of excess heat

Within various industrial processes excess heat is normally recovered via cooling systems [4]. There are various terminologies than can be used such as excess heat, secondary heat, surplus heat. For the purposes of this paper, the terminology used will be "excess heat" – as used by the IEA. There are also various definitions for excess heat, for example: "Excess heat is heat that has been released after a process has been thermodynamically optimized" or "excess heat is heat that cannot be directly employed in the industrial process" amongst others. For this paper, the definition intended will be the IEA's definition, whereby excess heat is heat released from any and all flows (gas, water, air etc.) at any given moment. The term "usable excess heat" is given to that heat which can be reused and repurposed and has an economic and technical viability. Usable excess heat can be divided into types; internally usable excess heat – this can be reintroduced internally into the industrial process and allows for economic and technical viability factors –, and externally usable excess heat – this is the leftover heat that can be utilized after withdrawing the internally usable excess heat, again allowing for economic and technical viability factors.

We can now define "non-usable excess heat" as the remaining excess heat after the internally and externally usable excess heat has been removed. It can also be called "residual heat". In the past, the hydrosphere was the most commonly used heat repository within industrial processes. The simplest and cheapest cooling method was to take water directly from a river, dam, lake or the sea and place it into a heat exchanger. The water was then returned to its source, after it had been used, but at a higher temperature. The permitted increase in temperature is limited however and this restricts the use of natural water sources, creating a need for alternative cooling methods.

In cases where there is no reuse of excess heat, the excess is removed either via cooling systems or via the natural cooling of effluents.

In this paper, the following types of cooling systems were considered:

- cooling towers;
- air-coolers;
- exhaust gas flow;
- radiation (from hot equipment);

Methods to estimate excess heat

In general, there are three different factors to take into consideration when classifying these methods, the scale of the study, the way the data is collected (questionnaires or estimates) and the approach taken (top-down or bottom-up).

- Scale of the study – can be classified by industry, region or country.
- Data collection – via questionnaires, reports or databases. When this is not possible or feasible, data is estimated. In these cases, two factors are at play, energy and efficiency. Efficiency is based on the amount of energy in the system. Energy data is based on things such as number of employees and sales correlated with the size of the company. Estimated data is generally more precise but much more difficult to obtain.
- Approach – Top-down or bottom-up, for example, associating a result to one particular case study is a top-down approach. Using a wide range of results (e.g. efficiency factors) to solve a particular problem is a bottom-up approach. Questionnaires are almost always bottom-up approaches. On the other hand, estimates can be both top-down and Bottom-up, depending on the scale of the problem (e.g. estimating the excess heat of a company based on the efficiency of each process is a bottom-up approach, however, considering processes is a top-down approach).

  A third approach can be taken whereby top-down estimates are justified as bottom-up (a significant sample taken via questionnaire and extended by estimate) [5].

Aside from the aforementioned approaches, a combination of top-down bottom-up approach can also be used. In these instances, data is collected on a much smaller scale and extrapolated onto a larger scale. A summary of the quantifiable methods can be seen in Figure 1.

Excess heat recovery technologies

This chapter focuses on technologies that can harness excess heat. Some have been in use for several years and some are still in development but with great potential when used and applied alongside future (more severe) measures for reducing greenhouse gas emissions.
There are three main groupings:

- those that use excess heat with no increase in temperature;
- those that use excess heat after a temperature increase (heat pump);
- those that use excess heat for energy production.

Excess heat has two main uses; internal use (where excess heat is reintroduced into the same processes within the same industry) and external use (where it is reused by other industries or district heating/cooling systems).
In systems where excess heat production is intermittent, energy storage is alternative way of recovering excess heat.
When choosing a heat recovery method, the main factors involved are fluid temperature, its phase, its chemical composition and the intended use for the heat [3].
The most common technologies are internal heat exchangers and heat pumps.

3. Quantifying excess heat: cement and iron & steel sectors

The work carried out in this paper focuses on two sectors of Portuguese industry: cement and steel and iron sectors. These sectors were selected specifically as together they produce high levels of excess heat. The work was carried out in three phases:

1. Data collection and validation;
2. Data treatment;
3. Data extrapolation.

Data collection and validation

This was done via questionnaires distributed to the group of the ten largest companies of each sector. The questionnaires were divided into two main sections:

- Section A – Summary of the organization, including basic information on company operation, some general financial data such as revenue and sales, as well as questions pertaining to its structure, dimensions and energy use.
- Section B – Excess heat in the facilities, including questions on current energy usage, framework and type of heat dissipation units in use. And questions regarding the existence of projects, current or future, to manage excess heat. Four responses were obtained, two from the cement sector and two from the iron and steel sector.

In order to validate these results, initial contact was made over the phone to confirm and clarify any questions or issues. When verifying the coherence of the data, a study was conducted based on the existing literature studying patterns in excess heat recovery in these industries. For the cement industry, three main sources of excess heat were identified [6]:

- Air-coolers used to cool cement clinkers;
- Exhaust gas;
- Radiation from furnaces.

It was hoped that the results from the questionnaires included these sources. That was not the case however. After checking with the companies directly whether they were using excess heat from these particular sources, it was confirmed that that was not the case and in many situations, there were simply not enough resources and available data to release. The questionnaires were deemed incomplete. In order to get around this and not skew the results, only one of the questionnaires was used as a basis for extrapolation, questionnaire from Company A.
In the steel and iron sector the main sources of excess heat are radiation from furnaces, exhaust gas and cooling towers [7]. Here, once again, only one of the questionnaires was deemed usable, but visits were made to the facilities of Lusosider, along with the energy manager, in order to gain first-hand experience and knowledge of how the plant works and to study in further detail the various sources of excess heat.

Data treatment

Data was collected via questionnaire. A top-down approach was taken in order to quantify the excess heat for industries in each sector, followed by a bottom-up approach to extrapolate the data and obtain global value for the entire sectors.
After the data had been collected and validated, spreadsheet technology was used (Excel) to chart the data.
The original plan was to calculate excess heat via the reduction in temperature caused by the dissipation units studied (cooling towers, air-coolers and exhaust gas from chimneys) in the fluids that work as refrigeration fluids, and via the external temperature and exposed areas (radiation in hot equipment).
As there was a lack of data relating to mass flows, for example, water in the cooling towers, the calculation method was changed to measure instead the reduction in temperature that the cooling water caused in the process effluents.
The first step in the data treatment was to create a database from the questionnaires. Each page of the database corresponds to a different dissipation unit.
The following equation was used to calculate excess heat, alongside the data collected:

$$\Delta H = m \times c_p \times \Delta T \quad (1)$$

Where:

$m - mass\ in\ kg/year$
$c_p - specific\ heat\ in\ \frac{J}{kg.℃}$

From the questionnaire data and equation (1), the following results were reached:

Table 1: Excess heat in refrigeration towers.

Entity	Excess Heat (GWh/year)
Lusosider	**10.4**
Company A	**10.9**

When dealing with the exhaust gases/fumes, the calculations were more complex in nature, as it was necessary to calculate the mean specific heat of the mixture of the gases. The following equations were used:

$$\overline{cp}_i = \bar{R}\times[\alpha + \beta T + \gamma T^2 + \delta T^3 + \varepsilon T^4]$$

(2)

$$\overline{cp}_{i\ med} = \frac{\int_{T1}^{T2} \overline{cp}.dT}{\Delta T}$$

(3)

$$\overline{cp}_{med} = \sum_{i=1}^{n} x_i \times \overline{cp}_i$$

(4)

Where:

$\bar{R} - ideal\ gas\ constant$
$T - Temperature\ in\ K$
$\alpha, \beta,, \gamma, \delta, \varepsilon - constants$
$x - percentage\ of\ gas\ i\ in\ the\ mixture$

From the data and equations above, the following specific heat values were reached:

Table 2: Specific heats.

Entity	Specific Heat (kJ/kg.K)
Lusosider	**1 052**
Company A	**1 026**

In order to calculate the excess heat from the exhaust gases, the last element needed was to calculate the density of the mixture.
A mean was estimated taking into consideration the percentage of gases in the mixture and the ideal gas equation was used to calculate the density of each gas in the mixture:

$$\rho = \frac{p\times M}{\bar{R}T}$$

(5)

Where:

$p - pressure\ in \frac{N}{m^2}$
$M - molar\ mass\ in\ kg/kmol$
$\bar{R} - ideal\ gas\ constant\ in\ \frac{J}{kmol.K}$
$T - temperature\ in\ K$

The data from equation (5) gave the following density mass for the gas mixture:

Table 3: Density of gas mixture.

Entity	Density (kg/m^3)
Lusosider	**0.54**
Company A	**0.65**

From this it was possible to calculate the excess heat in the exhaust gases:

Table 4: Excess heat in exhaust gases.

Entity	Excess Heat (GWh/year)
Lusosider	**4.2**
Company A	**66.3**

In order to calculate the excess heat from radiation and convection in hot equipment, the following formula was applied:

$$Q = q_{rad} + q_{conv} =$$
$$= \varepsilon\times A\times\sigma\times(T_s^4 - T_{sur}^4) + h\times A\times(T_s - T_{sur})$$

(6)

Where:

$q_{rad} - heat\ lost\ by\ radiation$
$q_{conv} - heat\ lost\ by\ convection$
$\varepsilon - material's\ emissivity$
$A -$ surface area in m^2
$\sigma - Stefan - Boltzman\ constant\ in \frac{W}{m^2.K^4}$
$h - heat\ transfer\ by\ convection\ coef.in\ \frac{W}{m^2.K}$
$T_s - surface\ temperature\ in\ K$
$T_{sur} - surrounding\ temperature$ in K

The above equation allows us to arrive at a thermal power value, which when multiplied by the number of hours in a year the equipment is running, leads us to the following results for excess heat by radiation in hot equipment:

Table 5: Excess heat by radiation in hot equipment.

Entity	Excess Heat (GWh/year)
Lusosider	**3.3**
Company A	**383.2**

Results from the questionnaire show that both companies utilize air-coolers, Company A however, uses the heat from its air-coolers to dry fuel made from waste, so it cannot be considered. In relation to Lusosider, the results for excess heat from aerial cooling were as follows:

Table 6: Excess heat in air-coolers.

Entity	Excess Heat (GWh/year)
Lusosider	**14.6**

Lastly, we come to excess heat from the natural cooling of effluents. Company A was found not to use this type of process but Lusosider does cool its steel plates naturally. The mass flow used to calculate this excess heat production corresponds to the annual production of the product, giving the following result:

Table 7: Excess heat by effluent's natural cooling.

Entity	Excess Heat (GWh/year)
Lusosider	**2.6**

A final excess heat value was calculated for each of the companies studied, by adding the excess heat present in each of the dissipation units:

Table 8: Excess heat in industrial sites.

Entity	Excess Heat (GWh/year)
Lusosider	**35**
Company A	**459**

Data Extrapolation

With the aim of reaching a global excess heat value for each of the sectors, the data extrapolation was based on two sets of data:

- Annual sales volume of the companies and sectors;
- Annual energy consumption for the companies and sectors.

First, an extrapolation via energy consumption was made.
The following equation for energy consumption was used:

$$Energy\ consumption = LHV \times Quantity \tag{7}$$

Where:

$LHV - lower\ heating\ value\ in \frac{J}{kg}$
$Quantity - during\ one\ year$ in kg

From the data and equation (7) above, the following energy consumption values for each company were obtained:

Table 9: Surveyed companies energy consumption [8][9].

Entity	Energy consumption (GWh/year)
Lusosider	**119.8**
Company A	**2 801.9**

Next, we looked at the energy consumption values for each of the sectors. These values were taken from the Energy Balance provided by the Geological and Energy Directorate General:

Table 10: Sectors energy consumption [10].

Sector	Energy consumption (GWh/year)
Cement	**6 647**
Iron and Steel	**2 577**

After collect this data, we made a linear extrapolation: it started by marking a starting point that corresponded to the value of excess heat in the company, in the axis of the ordinates, and an energy consumption value (or turnover, depending on the extrapolation factor), in the abscissa axis. Then, this point was extrapolated linearly to obtain an ordinate value corresponding to the excess heat when the abscissa value is equal to the energy consumption (or turnover) value of the entire sector for which it is sought to extrapolate the data. From a linear extrapolation of energy consumption, the global excess heat values for each sector were obtained:

Table 11: Sectors excess heat, extrapolating through energy consumption.

Sector	Excess Heat (GWh/year)
Cement	**1 088**
Iron and Steel	**754**

In order to extrapolate data from sales volume for each of the companies and sectors, the following data was taken industrial production statistics from the National Office for Statistics, year 2015:

Table 12: Data used to extrapolate through revenues [11]**.**

		Iron and Steel	Cement
Revenues (Million €)	**Company**	**180**	**260**
	Sector	**2 299**	**560**

With the above data and, again, a linear extrapolation, the following results were achieved:

Table 13: Sectors excess heat, extrapolating through revenues.

Sector	Excess Heat (GWh/year)
Cement	**988**
Iron and Steel	**449**

Table 14 shows global excess heat values for each of the sectors analysed, using a simple mean with the values obtain extrapolating with each of the factors (energy consumption and turnover).

Table 14: Final values of excess heat in cement and iron and steel sectors.

Sector	Excess Heat (GWh/year)
Cement	**602 ± 45 (5%)**
Iron and Steel	**1 038 ± 152 (25%)**

The values for extrapolation via energy consumption and via sales volume are quite different, namely in the steel and iron sector. This is because there are companies in that sector producing products of higher value than the average company in that sector.
In the case of cement, it being a low differentiated product, the difference was much less.

Because of these facts, the error for the cement sector (5%) is much smaller than the error for the iron and steel sector (25%).

4. Case study: Lusosider

Quantification and sources of excess heat

Lusosider – Aços Planos is one of the largest steelwork plants in Portugal. They are currently pursuing and focusing heavily on energy efficiency and harnessing their excess heat production. The plant has an extensive covered area of 65 000 m^2 and they produce three products, all made from steel coils:

- Galvanized steel plates (hot-dipped);
- Laminated steel plates (cold-rolled);
- Anodised and/or oil-coated steel plates.

Its primary raw materials are laminated steel coils that go through various processes, including:

- Pickling;
- Cold-rolling on a reversible rolling mill;
- Vertical annealing furnaces, skin pass mills (where the end product is cold-rolled laminated steel plates);
- Hot-dipped galvanized steel plates.

From the analysis of the current state of the company and the thermal potential of its processes, several excess heat sources were identified as well as the economic potential of some of these sources. In the pickling process for example, periodic discharges of water solutions are carried out from tanks once they are saturated with iron. This solution is the sent to an Industrial Residual Waste Treatment Station (IRWTS) at a core temperature of 85 ºC, making it an excess heat source.

Table 15: Excess heat in the purge mixture.

Mass flow (ton/year)	Specific heat (kJ/kg.ºC)	∆T (°C)	Excess heat (GWh/year)
8 173	2.53	60	**0.6**

The exhaust gases from the blasting of natural gas used in the heating of the annealing furnaces (vertical or galvanized) constitute another excess heat dispersion source.

These gases are sent into the external environment via chimney with a flow of approximately 9000 m^3 per hour. Unfortunately, it was not possible to retrieve any data relating to the corresponding flow of the exhaust fumes from the vertical furnaces. From its composition and temperature however it was possible to calculate the excess heat being dispersed.

Table 16: Excess in exhaust gas.

Mass flow (ton/year)	Specific heat (kJ/kg.ºC)	∆T (°C)	Excess heat (GWh/year)
39 786	1.05	325	**3.8**

The annealing and galvanizing processes hold the greatest material potential. In the annealing process the steel plate is pre-heated up to 600 ºC, by open flame, and then heated up to 750 ºC via radiant tube heaters. They are then cooled to 470 ºC via six jets (heat exchangers) that use water as fluid. Because the water in these cooling systems is part of a closed circuit, it was again not possible to obtain data on the water flow to calculate excess heat values. In order to get around this, the excess heat was calculated from the reduction in temperature forced on the steel plate. The annual production of hot-dipped galvanized sheet metal was used as mass flow, the specific heat of the steel and the temperature intervals as corresponding to the difference in temperature before and after jet processing.

Sheet metal naturally loses more than 10 ºC in core temperature after exiting the furnace (due to excess heat loss from the natural cooling of effluents), going into the zinc vats at 460 ºC (when referring to hot-dipped galvanized steel plates). As for the vertical furnaces, once again it was not possible to gather data on the sheet metal cooling system.

Therefore, the excess heat balance for this phase will be taken from the reduction in temperature caused by the jets and the natural cooling of the sheet metal before it enters the zinc vats.

Table 17: Excess heat after annealing and before immersion into the zinc vat.

Description	Mass flow (ton/year)	Specific heat (kJ/kg.ºC)	∆T (°C)	Excess heat (GWh/year)
Excess heat dispersed in jets	253 376	0.48	280	**9.4**
Steel plate natural cooling	253 376	0.48	10	**0.3**

After the zinc bath, the sheet metal passes through air-coolers, further reducing its temperature to around 70 ºC. This reduction constitutes excess heat, as exemplified by the following.

Table 18: Excess heat dispersed in air-coolers.

Mass flow (ton/year)	Specific heat (kJ/kg.ºC)	∆T (°C)	Excess heat (GWh/year)
253 786	0.48	390	**13.2**

Once this temperature has been reached, the stretching process begins and is followed by chroming. After leaving the chroming process at 70 ºC, there is new potential for excess heat recovery in the form of natural cooling of effluents.

Table 19: Natural cooling of effluents before chroming/after passing air-coolers.

Mass flow (ton/year)	Specific heat (kJ/kg.ºC)	∆T (°C)	Excess heat (GWh/year)
253 376	0.48	45	**1.5**

Finally, the existence of radiation in hot equipment was also verified as the table below shows:

Table 20: Excess heat by radiation (from hot equipment).

T_s (K)	T_{sur} (K)	ΔT (°C)	Excess heat (GWh/year)
348.15	298.15	390	**3.0**

Viability of implementing excess heat technologies

Following the quantification of excess heat, the next objective of this paper is to present viable solutions for the recovery and reuse of excess heat.
To this end, two sources were identified as having economic potential: the thermal power of the compressors and the exhaust gases from the combustion of natural gas in the pre-heating phase of the galvanization process.
There are other sources with material interest but little to no economic viability, mostly due to the physical distance between the sources of the excess heat and the point from which they can be reused.
In order to assess the benefits of the thermal power of the compressors, a study was conducted to assess the viability of implementing a heat exchanger that would allow for the full power of the compressors to be effectively channeled to pre-heat water to be used for steam production. Hot water would leave the compressors and enter into the energy recovery system, giving heat to the heat exchanger, alternating with the water being heated, before being resent to same place. It is in the heat exchanger that the relevant heat savings are reached. Once the process and functioning of this technology was fully understood, it was possible to calculate the saving potential.
Data from Lusosider reveals that the annual steam production is approximately 30 tons, for which 33 tons of water are needed and 23GWh of energy. Currently, the water that feeds the central steam boilers is at 18 ºC, meaning the energy saving potential corresponds to the following:

$$Annual\ energy\ savings = \text{Annual water consumption}\times (h_{\text{water }62.5^\circ\text{C}} - h_{\text{water }18^\circ\text{C}})$$

(8)

Where:

$Annual\ water\ consumption\ (\frac{kg}{year})$

$h_{\text{water}} - water\ enthalpy\ (\frac{kJ}{kg})$

The temperature value of 62.5 ºC corresponds to the average temperature interval to be gained from converting the water feeding the boilers (between 60 and 65 degrees). From the above calculations, there was an annual energy saving of 1.7 GWh, approximately €63 00/year. The initial investment being €75 000, the payback period is 15 months or less.
In terms of repurposing the excess heat from the exhaust gases, there is a potential use for this excess heat to be used in the drying of sludge produced by the IRWTS.

Every year, Lusosider faces huge costs associated with the logistics, warehousing, loading and unloading and transportation of the sludge. Using excess heat from the exhaust gases to treat the sludge could go some way to abating their high costs. The excess heat would essentially remove water from the sludge, reducing the sludge's volume and mass and weight and, therefore, make it cheaper and easier to handle, store and move.
In order to properly assess the viability of this particular solution, construction costs would have to be taken into consideration, such as construction costs involved in building the necessary infrastructure to house and protect the sludge from external forces, namely precipitation (once dried, the sludge cannot be exposed to the elements). However, with no official quote for construction costs, the estimated cost would be around €30 000. The total cost of investment would rise to €80 000 (this includes the heat exchanger, the ventilator and the necessary infrastructure). The logistical costs of handling and transporting the sludge are €27 per metric ton. The total saving (gained from the reduction in volume of the dried sludge) is evidenced in the equation below.

$$\frac{Savings}{year} = \frac{27€}{ton}\times(Total\ mass\ (ton) - Wet\ mass\ (ton))$$

(17)

In conclusion, there is a total annual saving of €100 000 in logistical and associated costs. When paired with the total investment figure of €80 000, this works out at a payback period of just 10 months.

5. Conclusions and future work

The main objective of this paper was to quantify excess heat values in both the cement and iron and steel industries in Portugal and assess the viability of implementing heat recovery technologies in these sectors. As the work progressed, it became abundantly clear just how crucial and relevant this subject matter is in reducing the use of primary energy consumption and lowering greenhouse gas emissions.
Excess heat is usually dissipated either via cooling towers, air-coolers, exhaust gases, radiation from hot equipment and via the natural cooling of effluents.
The most common and traditionally used technologies for recovery of excess heat are heat pumps and heat exchangers.
Where excess heat cannot be reutilized internally, it can be exported to other local industries or used in heating/cooling systems in local communities.
Given the enormous potential and importance of excess heat recovery in terms of sustainability and financial and economic rewards, it was imperative that we quantified excess heat values for the sectors aforementioned. The methodology that was initially proposed was a bottom-up approach where the largest 10 companies of each sector were sent questionnaires. It was only possible to use the data from two of those companies, Lusosider and Company A, as the results from the other questionnaires could not be substantiated and did not pass data validation.
Once the available data was collected and validated, calculations were carried out taking into account physical, chemical and thermodynamic concepts. From

the data spread sheet, it was possible to conclude excess heat values of 35 GWh/year for Lusosider and 459 GWh/year for Company A.

In order to obtain a global value for the entire sector, a top-down approach was taken (taking into consideration data on energy use and volume of sales). The steel and iron sector has a potential excess heat recovery value of 602 ± 152 (25%) GWh/year and the cement sector a potential of 1 038 ± 45 (5%) GWh/year. These values were obtained via extrapolation, with two different factors: sales volume and energy consumption. After the extrapolations were made, their results were utilized to do a simple mean and obtain the values above.

The values for extrapolation via energy consumption and via sales volume were quite different, namely in the steel and iron sector. This is because there are companies in that sector producing products of higher added value. In the case of cement, it being a low differentiated product, the difference was much less. Because of these facts, the error for the cement sector (5%) is much smaller than the error for the iron and steel sector (25%).

In the case of Lusosider (one of the largest metalworks company in Portugal and one of the largest iron and steel companies in the industry) it was also possible to conduct a further study into the viable alternative uses of their excess heat potential. This potential was identified in their exhaust gases, radiation from hot equipment, cooling towers, air-coolers and the natural cooling of effluents.

Further study was then done on the viability of implementing excess heat recovery technology and systems, directed at utilizing excess heat from the exhaust gases and the thermal power of the compressors (which is dissipated in the water that flows to the cooling towers).

The potential use of heat exchanger technology to harness the compressors thermal power is particularly interesting, offering a very short payback period (under 15 months). Utilizing the exhaust fumes excess heat for the drying of sludge in IRWTS also proved appealing, with huge annual savings in logistical costs and again, a very short payback period, of under a year.

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