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Capturing the invisible resource: Analysis of waste heat potential in Chinese industry

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HIGHLIGHTS

- Determined maximum waste heat potential of three industrial sectors in China.
- Identified practical potential of waste heat to power generation of each sector.
- Summarized conditions to implement waste heat to power generation technologies.

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ABSTRACT

Waste heat recovery and utilization represents a missed opportunity to reduce China's total energy use, decrease carbon dioxide emissions, and improve air quality. Currently, China does not have a standardized or transparent methodology to quantify the waste heat potential in the industrial sector, which accounts for more than two thirds of China's primary energy consumption. This paper presents the results of thermal energy modeling to quantify the technical maximum waste heat potential in three energy-intensive industrial sectors: cement, iron and steel, and glass. In addition, this paper identifies the practical potential for producing electricity from waste heat in these sectors. The analysis finds that the glass sector has the highest waste heat to power generation potential per unit of production basis among the studied sectors. This paper provides key principles for managing waste heat in the industrial sector and key sector characteristics for implementing waste heat to power generation technologies.

1. Introduction

Many industrial processes generate unused or waste heat during manufacturing. Depending upon a number of factors, such as industry characteristics, fuel inputs, and operational practices, industrial waste heat accounts for 10–50% of total fuel consumption in various industrial sectors. Waste heat can be a valuable energy source if it is managed well. Through waste heat utilization, waste heat can be used to provide electricity, steam, space heating, and hot water.

In China, the potential to improve industrial waste heat management is significant. The industrial sector is the largest energy consumer and carbon dioxide (CO_2) emitting end-use sector in China, representing about 70% of China's total primary energy use and energy-related CO_2 emissions in 2012 [1,2]. In addition, coal is the dominant fuel supply in Chinese industry, accounting for about 71% of total fuel use in 2012 [1]. The industry sector is one of the most important sectors to address in order to reduce air pollutants, such as sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter, in China. Improving waste heat utilization in China's industry sector not only can reduce overall coal consumption but also can provide significant environmental and public health benefits.

Improving waste heat utilization supports China's targets related to energy and emissions. On November 12, 2014, in a joint statement with the United States, China announced its intention to peak CO_2 emissions around 2030 while striving to peak earlier [3]. Achieving this goal will require China to install an additional 800–1000 GW of zero-emission electricity generation capacity by 2030 [4]. The growth of coal consumption is also targeted to decrease, as China set a goal of reducing the share of coal in total energy consumption to below 65% by 2017 [5]. In the 12th Five-Year Plan

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(FYP) for 2011–2015, China is expected to reduce the national energy intensity (energy use per unit of GDP) and carbon intensity (CO_2 emissions per unit of GDP) by 16% and 17%, respectively, from the 2010 level [6].

1.1. Why this study is needed?

The concept of waste heat as a resource is similar to the concepts of oil reserves or wind power resources. However, the industrial waste heat resource is much more fragmented than other energy sources. The waste heat resource is dispersed geographically at the industrial plant level. Also, the supply and reliability of waste heat may fluctuate over time, mainly due to changes in industrial production or mismatches between supply and demand. In addition, the temperature and composition of the waste heat carrier streams varies from site to site.

There is a general consensus on the significance of the waste heat potential in industrial sectors. However, the literature on this topic reports minimal waste heat potential in only a few sectors in China, such as the cement sector. Technical analysis of waste heat potential of a full array of energy-intensive sectors in China does not exist at this time. More importantly, for those studies that have been conducted, the reported waste heat utilization potential is often presented without a clearly explained methodology. The use of vague and inconsistent methodologies across different sectors significantly impairs the ability of researchers, investors, or policymakers to accurately understand the reported waste heat potential.

This paper aims to fill the research gaps by identifying the available waste heat potential in key energy-intensive sectors in China through the use of a consistent and transparent methodology. Specifically, this paper focuses on waste heat to power generation and the primary objective is to analyze the technical potential of waste heat in three sectors: cement, iron and steel, and glass. In the sections below, the paper first summarizes the methods used for the technical potential analysis. Then, data, assumptions, and results are presented on the waste heat potential in the three sectors, including both the waste heat potential and the potential to produce electricity from waste heat. Lastly, this paper summarizes key technical findings, identifies research limitations, and describes needs for future research.

1.2. Review of international studies on waste heat potential

From a whole-society, whole-system perspective, in 1971, Cook estimated that about 50% of the energy input to the U.S. society was lost as waste heat [7]. This included energy losses from all sectors, such as power generation and industrial manufacturing. This study highlighted the need to understand the potential of waste heat. A later study conducted by the US Environmental Protection Agency (EPA) relied on EPA's National Emissions Data System, which collected stack temperatures from industrial sources, including boilers, internal combustion devices, and industrial processes [8]. The study found that about 30% of industrial input was lost as waste heat in 1974, and about 3% of the waste heat is available for recovery (at a temperature higher than 150 °C (300 °F)). However, this study used the stack temperature (from the emission database) instead of the exhaust gas temperature exiting the equipment. Stack temperature is normally much lower than exhaust temperature; thus, the findings of waste heat potential may very likely be underestimated.

Besides the studies conducted about 30–40 years ago [8,7], the United States Department of Energy (US DOE) and the Pacific Northwest National Laboratory (PNNL) conducted waste heat potential analyses in 2004, 2006, and 2008 [9–11]. The 2004 study identified key areas for improving energy efficiency and reducing energy losses in the US manufacturing sectors. Based on approximate assumptions on energy efficiency and improvement potential, it estimated about 20–50% of heat was lost [9]. The 2005 study conducted by PNNL focused on opportunities for recovering energy from chemical emissions and thermal emissions, such as the chemical energy in unburned carbon dioxide and methane [10].

The latest waste heat potential study conducted by US DOE was in 2008. This study analyzed the technical potential based on an enthalpy analysis, taking into account energy inputs, temperatures, and heat recovery practices. The study found the waste heat practical potential in aluminum, iron and steel, glass, cement, metal casting, boilers, and ethylene furnaces to be 5%, 6%, 23%, 11%, 33%, 6%, and 5%, of the energy use of that sector, respectively [11].

Most recently, Oluleye et al. [12] developed a methodology to identify waste heat potential in industry. This study illustrated the methodology by using a case study from a refinery. It would be useful for policy makers and other researchers if this methodology could be applied to other industrial sectors, regions, or countries using actual industry, regional, or country data and information. Miró et al. [13] collected industrial waste heat data from 33 countries and 6 sub-regions. The study identified that there is a lack of specification when reporting industrial waste heat data, which made data comparison of industrial waste heat potentials across countries difficult. This paper also recognized that there is a lack of data on industrial waste heat potential in Asian countries, especially China. While this paper's intention was not to estimate the industrial waste heat potential of a specific industry or country, it did provide recommendations on how the data should be reported, i.e., including the type of industrial waste heat potential, the methodology for calculating industrial waste heat potential, reference temperatures, year of data used, liquid or gas state of industrial waste heat, and boundaries and scope of studies on industrial waste heat. Brückner et al. [14] provided an overview of industrial waste heat potential, including definitions, main technologies, possible industrial waste heat sources, and temperatures of waste heat. This paper focused on an economic analysis of waste heat recovery technologies (including absorption chillers, electrical heat pumps, and absorption heat pumps) and estimated the maximum acceptable investment costs of each technology assessed. However, this analysis did not evaluate industry-specific potential or provide any discussion of the potential in China.

Besides governmental and research organizations, consulting companies also published estimations of waste heat potential. Frost and Sullivan [15] estimated the potential of waste heat in the United States. This study showed a much higher percentage of heat being wasted in the studied sectors, on average about 20%, 49%, 40%, and 19% in aluminum (primary), oil refining, steel, and pulp and paper sectors, respectively [15]. However, the methodology used to estimate the waste heat potential is not clearly described in the report.

The Norwegian utility Enova published a study in 2009 to assess the "usable waste heat potential" of the Norwegian industry by sending out questionnaires to 105 energy-intensive companies including the food processing, wood processing, cement and building block processing, chemistry, aluminum, and ferro alloy industries. Together, these companies represent about 63% of the Norwegian final energy consumption. The study received about 69% responses (72 companies out of 105 companies answered). The study reported that for metal production, basic chemistry, and processing of stone and earth, the waste heat (temperature at or above 140 °C) potential of the final energy use is estimated to be 30%, 8%, and 40%, respectively [16].

In Germany, two-thirds of final industrial energy use was used to produce process heat in 2007. Based on a Norwegian study's