Energy efficiency improvement potentials through energy benchmarking in pulp and paper industry

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\textbf{A B S T R A C T}

This study aims to highlight the energy improvement potentials of Pakistan’s paper sector that is one of the most energy intensive industries by benchmarking its specific energy consumption (SEC) to produce a similar grade of paper. To address issues such as the lack of indicators for energy efficiency benchmarking in Pakistan’s paper industry. Furthermore, energy saving potential was estimated by comparison with paper industries in the United Kingdom and Canada, where energy benchmarks have already been established and data on energy benchmarking is readily available. This study energy consumption data accounts for 75\% of the total energy utilized in Pakistan’s paper industry and is compared with the energy consumption of the UK and Canada paper sectors where the most up-to-date energy-saving techniques are used. The calculation shows that when compared to the paper industries in the UK and Canada, Pakistan’s paper industry utilizes an additional 1.3 MWh of energy for every tonne of paper produced. With a total yearly paper production of 314,549 metric tonnes, this equates to an additional 408,913 MWh of overall annual energy use. It is concluded that if the proposed energy benchmark in this study is applied within the country’s mill comparison, savings of 16.4\% of overall energy consumption in the Pakistan paper sector can be achieved. It is also shown that the implementation of the best available techniques used in the UK and Canada in Pakistan’s paper sector could result in a potential energy saving of 43\% of the total energy consumed by this sector.

1. Introduction

The world faces stringent energy and environmental challenges including depletion of fossil fuel reserves, volatile energy prices and concerns about energy security and global warming. The role of energy conservation and management is becoming extremely important in a changing global energy environment as the world’s industrial energy consumption is anticipated to increase by 30\% by 2050 (US Energy Information Administration (EIA), 2019). As the industrial sector imposes a huge burden in terms of energy demand, energy-intensive industries are required to focus on improving their energy efficiency performances. Energy efficiency standards are a useful tool to compare the amount of energy required to produce per unit of product through the same set of production processes and technology, especially in energy-intensive industries. Energy efficiency indicators are the most effective way to specify and compare the efficiency of energy-intensive systems (Boyd, 2017). These indicators can be used to help develop energy efficiency measures at the national level, or even to identify possible savings at the industry level. However, their usefulness is dependent on the similarity of the manufacturing processes involved (Ghobakhloo and Fathi, 2021). They are divided into four main categories, i.e., thermodynamic indicators that measure energy output (work) from energy input (heat), physical-thermodynamic indicators that measure energy input per tonne of product produced, economic-thermodynamic indicators that measure energy input per gross domestic product (GDP) and economic indicators that measure energy input in terms of market values ($) (Patterson, 1996). The physical-thermodynamic indicator known as specific energy consumption (SEC) is the most commonly used and is considered the best indicator for evaluating the energy efficiency and performance of energy-intensive industries among the various energy efficiency indicators.

Despite difficulties in establishing SECs in highly integrated production processes (Laurijssen et al., 2013), many researchers have investigated energy saving potentials of energy-intensive industries through international comparisons. Energy audits were carried out to compare Swedish chemical wood pulp mills to similar Scandinavian pulp mills

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to identify energy-saving opportunities (Klugman et al., 2007). It was concluded that 1% of the country’s electricity use could be saved if all Swedish pulp mills become energy-efficient as the most energy-efficient Scandinavian pulp mills. Energy decomposition analysis and an energy efficiency index approach to compare the Brazilian pulp and paper sector to other significant paper-producing countries (Canada, the United States of America, Finland, and Sweden) (Fracaro et al., 2012). They concluded that despite a significant increase in different energy efficiency levels, saving potentials of 7.8 PJ and 146.2 PJ related to the annual consumption of electricity and fuels could be achieved correspondingly.

Based on the best available technologies, an international comparison of energy efficiency and CO₂ emission performance for energy-intensive industries. i.e., iron and steel, non-metallic minerals, pulp and paper, and non-ferrous metals are also performed by International Energy Agency (US Energy Information Administration (EIA), 2019). While due to differences in the economic structure; availability of local feedstocks; carbon emission laws; and incentives for energy efficiency, comparing energy efficiency between countries is not straightforward (Phylipsen et al., 1997). Though, energy benchmarking models developed from energy-efficiency indicators still can be used as valuable tools to keep track of energy efficiency improvements at different levels (i.e., countries, sectors, or processes) when managing energy consumption (Federspiel et al., 2002).

The pulp and paper industry consumes around 5.6% of total world industrial energy which makes it the world's fourth-largest industrial energy user (US Energy Information Administration (EIA), 2019). It is also regarded as a capital-intensive and energy-intensive sector with a very low efficient scale of production (Szabó et al., 2009). Several initiatives have been made to increase the pulp and paper industry’s energy efficiency. For instance, Szabó et al. (2009) determined the contribution of specific electricity and heat consumptions for each paper grade and studied improvements in the energy use of the global pulp and paper industry up to 2030 by considering different energy efficiency improvements. In the Netherlands energy benchmarking was applied to paper mills in order to place them among the top 10% of the most energy-efficient mills in the region (Saygin et al., 2011). An energy performance indicator (EPI) for the pulp and paper industry has been established in the United States to track how efficiently a paper mill uses energy in comparison to other mills (US Department of Energy, 2015).

The Canadian office of energy efficiency also released an energy standard for pulp and paper mills to help them reduce costs, improve energy efficiency, and contribute less to industrial greenhouse gas emissions (Pulp and Paper Research Institute of Canada, 2008). Similarly, carbon trust in the UK investigates energy improvement potentials in the paper sector to identify and accelerate the take up of innovations in the paper industry to reduce CO₂ emissions. To achieve this benchmarks based on specific energy consumption for the UK paper sector were developed using data from the Canadian office of energy efficiency for paper production as a baseline standard (Carbon Trust, 2011). The UK and Canadian paper sector benchmarks are regarded as the ideal energy benchmarks for improving energy efficiency in Pakistan paper sectors in this study due to the general similarities of paper mill’s production processes, raw materials used, and final products produced.

This study investigates the SEC of similar mills (i.e., raw materials consumed, and products generated) within different paper mills to find energy improvement opportunities in Pakistan’s paper sector. Among the top five energy-consuming industries, Pakistan’s pulp and paper industry consumes around 7% of the country’s industrial energy (Shabbir and Mirzaeian, 2017) indicating that energy efficiency improvements in this sector can result in significant energy savings at the country level. This will in turn influence the total energy consumption of the country. Hence, by measuring the energy usage of Pakistan’s major paper mills, this study intends to discover energy improvement potential in the country’s paper industry. The specific steps that will be taken to attain the key objectives are as follows: (1) Investigating the current energy consumption of paper mills in Pakistan, (2) Benchmarking the specific energy consumption in Pakistan’s paper sector based on the type of materials used and pulping processes applied and (3) Comparing the specific energy consumption of paper mills in Pakistan with similar mills in the UK and Canada where best available technologies are applied. This will allow evaluating the potential energy savings in the Pakistan paper industry in comparison to those in the UK and Canada.

The methodology to develop energy benchmark for Pakistan’s paper sector in this research is based on the widely applied approach used by carbon trust in the UK (Carbon Trust, 2011) and Pulp and Paper Research Institute of Canada (2008). This approach has been also used by Farla et al. (1997) for general energy benchmarking and by Laurijssen et al. (2013) for energy benchmarking in pulp and paper industries before. The method allows the international comparison of paper mills in terms of physical-thermodynamic measures (energy input per tonne of product produced) and also indicates their potential to improve their energy efficiency. Although SEC as an energy benchmark is widely used to compare the performance of paper mills in one country to another it has some limitations i.e., uncertainty whether SEC value is only the energy used by the main equipment or overall energy including all auxiliary equipment, type of mill (pulp mill, paper mill or integrated pulp and paper mill), different types of fuels used in the boiler which impacts boiler efficiencies etc.

2. Overview of Pakistan pulp and paper industry

2.1. Production capacity of paper sector

Pakistan’s paper industry is comprised of over 57 pulp and paper mills with a combined installed capacity of 1,050,499 metric tonnes per annum (Pakistan Bureau of Statistics (PBS), 2019). Fig. 1 shows the wide range of products produced by the industry as a percentage of total paper production. According to The World Bank (2022), Pakistan’s forest area makes up only 4.8% of the country’s total land area, indicating a shortage of forest resources suitable for pulp production. Hence crop straws (wheat and rice), bagasse and cotton linter are the most frequent agricultural-based raw materials, and in most situations, a blend of these raw materials is utilized in paper production.

In this respect, wheat straw makes up around 46% of the fundamental raw materials with wastepaper accounting for 29% and imported pulp accounting for roughly 10% of the total, all of which is used entirely in the production of specialty grade products. Bagasse, rice straw, and cotton linter are among the remaining 15% of agricultural-based raw materials used (Pakistan Bureau of Statistics (PBS), 2019). As the chemical process is the most suitable method used for the production of pulp from these raw materials, 96% of total pulp in Pakistan in 2019 was produced through the Neutral Sulphite Semi-Chemical (NSSC) process. Despite a significant increase in paper production in the country in the last 10 years as shown in Fig. 2, the actual production of around Fig. 1. Share of different paper grades in the Pakistan paper sector (Shabbir et al., 2016).
703,863 metric tonnes in 2019 represents only 67% of the country’s total installed capacity (Pakistan Bureau of Statistics (PBS), 2019).

2.2. Energy consumption of paper sector in Pakistan

In Pakistan, the paper sector utilizes 7% of total industrial energy (Shabbir and Mirzaeian, 2017) and due to a steady increase in paper demand in line with the government’s new education programs, paper mill energy consumption is expected to rise to 11% in 2025 (Ministry of Planning, 2021). Despite the increase in energy use in Pakistan’s paper sector, there have been few attempts to standardize, benchmark, or optimize energy consumption. The amount of energy input and overall energy efficiency of the pulp and paper industry highly depends on the type of raw materials used, type of processes involved and quality of the finished products. Fig. 3 depicts the contribution of several types of energy sources used in Pakistan’s paper sector.

In the current benchmark study, the data shown in Fig. 3 is being utilized to calculate the energy consumption of paper mills. As furnaces and diesel fuel are only used to heat the boilers before the primary fuel is burned, therefore they make a very small contribution. Steam and electricity are the primary forms of energy in Pakistan’s paper industry. Steam provides process heating for pulping and drying while electricity is used to power mechanical drives (pumps, conveyors, paper machines and fans) as well as general lighting. Their shares to the total energy use are 71% thermal and 29% electrical where high thermal energy consumption is mainly due to a high ratio of water to raw materials in the process (e.g., 95:5 w/w) and requirements for fully dried final products (paper). According to Rogers et al. (2018), drying consumes two thirds of the total thermal energy used in the process while the rest is used in pulp preparation. Fire-tube boilers produce thermal energy in the form of steam by burning fossil fuels or biomass (rice husk) as indicated in Fig. 4. Rice husk used as a primary fuel is beneficial because of its low cost, easy availability and special significance in terms of energy balance and environmental sustainability.

3. Methodology

The methodology used to produce an energy benchmark for Pakistan’s paper sector is based on the widely used approach employed by the Carbon Trust in the UK and the pulp and paper research institute of Canada. Three steps methodology is used for energy benchmarking in this study as explained before. The first stage is to determine theoretical energy savings potentials by developing a specific energy consumption benchmark based on the raw materials used and the types of papers generated. The data is then analysed by dividing it into two types i.e., specific heat consumption and specific electric consumption, which provides a precise representation of the process’s overall energy usage. The second phase involves a comparison between Pakistan’s paper sector energy efficiency performance to that of Canada and the United Kingdom, where the European Commission’s best available techniques (BAT) are used (Suhr et al., 2015). This stage of the study allows investigation of higher energy consumption in Pakistan’s paper sector with the energy consumption of Canada and the UK paper industries and possible actions to improve its energy efficiencies. The third step determines the energy efficiency improvements in Pakistan’s pulp and paper sector where the energy benchmarks found in this study are applied.

To the best of our knowledge, no meaningful attempt has ever been taken to benchmark the energy usage in Pakistan’s paper sector, and this work is the first to achieve this. Both virgin and recycled pulps are used in Pakistan’s paper sector. Crop straws (Wheat and rice), cotton linter, and bagasse are used to make virgin pulp, whereas recycled pulp is manufactured from recycled paper. Data collected for recycling mills in Pakistan’s pulp and paper mills are compared to data collected in the United Kingdom (UK mills only use recycled paper) and the virgin pulp data is compared to pulp and paper mills in Canada, where the virgin pulp is made using the Kraft process, which is identical to Pakistan’s NSSC (Neutral sulphite semi-chemical) technique. Since both the UK and Canada define their benchmarks based on median values, the same practical approach is being used in the study to make the benchmark results comparable.

4. Data collection

The data used in this study is obtained from the Cleaner Production Institute (CPI) Pakistan (Cleaner production institute (CPI), 2013). The CPI is a not-for-profit non-governmental organisation helping industries in Pakistan to implement cleaner production techniques for energy efficiency, wastewater treatment and corporate social responsibilities. The data for this study were collected from 15 different paper mills, which account for 75% of the country’s total paper and paper board production (Pakistan Bureau of Statistics (PBS), 2019) and can thus be considered a fair reflection of the country’s overall paper industry. The collected
data are based on each mill’s annual average as follows: Purchased energy (electricity and fuels for thermal energy), type and quantity of all fuels used for the mill’s thermal energy (natural gas, rice husk, furnace oil, diesel oil), Boilers total steam generation and efficiencies, annual utilities consumption (electricity, fuel, water and instrument air), pulp and paper production rates and type of processes and their products.

Electricity values used in this study are obtained from the main meter readings at the gate which do not include phase imbalances and transmission losses. Due to the unavailability of the data for individual processes (i.e., energy use in stock preparation, chemical injection unit, different sections of the paper machine, pumps and compressors, etc.) involved in a mill, the calculation of specific energy consumption (electric and thermal) and energy benchmarks are based on the overall energy use of each particular mill. The authors believe that the use of rice husk as a renewable fuel and the analysis of its energetic benefits from a sustainable energy balance presented and discussed in this paper will have a significant impact on research into the energy improvement potentials of Pakistan’s paper sector as an energy-intensive industry. This investigation is thus timely, both from a scientific standpoint and because of the present interest in energy conservation and management in this energy-intensive industry.

4.1. Energy benchmark based on specific energy consumption

The raw data gathered on the energy consumption of paper mills are compared to a benchmark to allow the calculation of their specific energy consumption and energy-saving potentials. The proposed benchmark in this study is selected based on the specific energy consumption of each mill as a processing unit with a process producing similar products. The following relation (Eq. (1)) is used to calculate a process unit’s specific energy consumption (SEC).

\[
SEC = \frac{E_p}{P_l}
\]

(1)

where \(E_p\) is the process’s total yearly end-use energy (in gigajoules (GJ) per year) and \(P_l\) is the annual production rate of the products produced in the specific process (in tonnes (t) per year). This analysis is further broken down to the specific electricity consumption (SEC_e) and the specific heat consumption (SEC_h) that was calculated using Eq. (2) and Eq. (3), respectively.

\[
SEC_e = \frac{E_p}{P_l}
\]

(2)

\[
SEC_h = \frac{E_h}{P_l}
\]

(3)

where \(SEC_e\) is the specific electric energy consumption of a processing unit and \(E_p\) is the total annual end-use electric energy in the process (in kilowatt-hour (kWh) per year). \(SEC_h\) is the specific thermal energy consumption of a processing unit and \(E_h\) is the total annual end-use thermal energy in the process (in gigajoules (GJ) per year). As the main source of thermal energy used in Pakistan’s paper sector is natural gas and rice husk, the total annual end-use thermal energy of the mills is calculated using Eq. (4). Furthermore, thermal energy \((T_h_{N,G})\) from natural gas in GJ/year calculated by Eq. (5).

\[
E_h = T_h_{N,G} + T_h_{R,H}
\]

(4)

\[
T_h_{N,G} = V_{N,G} \times C_{F,N,G}
\]

(5)

where \(V_{N,G}\) is the volume of natural gas used per annum in \(\text{Nm}^3/\text{year}\) and \(C_{F,N,G}\) is the calorific value of natural gas in GJ/Nm\(^3\). Likewise, \(T_h_{R,H}\) is thermal energy corresponding to the annual use of rice husk in GJ/year calculated from Eq. (6).

\[
T_h_{R,H} = Q_{R,H} \times C_{F,R,H}
\]

(6)

5. Results and discussions

All paper mill’s specific energy, heat and electric consumption (SEC), (SECh) and (SECe) are calculated and compared to equivalent values for mills in the United Kingdom and Canada, using Best Available Techniques (BAT) to benchmark the paper industry’s energy performance in Pakistan.

5.1. Specific energy consumption (SEC) of paper mills

SEC values are used as a benchmark and described as “the amount of energy consumed per unit of product” based on the physical-thermodynamic indicator (Patterson, 1996) for all mills classified according to their final products are presented in Table 1. Based on the range and average value of SEC for mills producing similar paper grades. Analysis of data indicates that on average the total (e.g., electric and heat) unit energy consumption of the paper mills in Pakistan is 5.3 MWh/tonnes of paper produced. This value excludes the speciality paper as it requires special raw material, pulping process and finishing treatment.

As can be seen, there are significant variations in energy consumption among mills producing different paper grades and even in some cases among mills producing the same type of paper. For example, mills producing writing and printing paper show a significant SEC variance; though, there is consistency in per unit energy consumption for mills producing other paper types of papers such as packaging board, liner/fluting paper and unbleached paper and cone board. In the case of kraft paper and specialty paper where only a single SEC value is reported, there are no SEC variances presented. The ranges of SEC for different grades of papers shown in Table 1 underline a real need for establishing energy benchmarks for Pakistan’s paper sector not only for energy-saving purposes but also for its viability in both local and global markets.

5.2. Specific thermal and electrical energy consumptions benchmarks

Table 2 summarizes the calculated specific thermal and electrical energy consumption (SECh) and (SECe) for all paper mills by using Eqs. (2) and (3). SECh values are calculated by using Eqs. (4)–(6) based on the type of fuels and proportion of that fuel used in each paper mill. The values for the upper and lower quartiles given in the table exhibit the difference between the highest and the smallest values of SECs (e.g.,
thermal and electrical) with the median values respectively. The total average of Pakistan’s paper industry’s electrical and thermal unit energy consumptions are 0.68 MWh/tonnes of paper produced and 4.58 MWh/tonnes of paper produced respectively.

Table 2 shows the median SECe and SECf values for each mill, which can be used as a benchmark. This is used as a guide to reflect the mill’s performance and allows for comparisons with mills in the United Kingdom or Canada. Table 2 also shows the deviations from the median values for specific electricity and specific thermal consumption of mills producing various types of papers. Mills that produce writing and printing paper had the biggest deviations from median figures for particular electricity and specific thermal consumption, with variances of (+120% / -20 MWh/tonnes of paper) and (+140% / -57%), correspondingly. These differences mean that similar mills could save a huge amount of total energy by reducing their electrical and thermal energy usage.

5.3. Energy benchmarking comparison of Pakistan’s paper sector with other first world countries

A comparison of Pakistan’s and UK/Canada’s paper sectors based on SEC values for different paper products is shown in Table 3. According to the results, Pakistan’s overall average energy consumption is 5.3 MWh/tonne, while the UK and Canada’s overall average energy consumption is 4 MWh/tonne (Carbon Trust, 2011). When compared to the average energy use for the same amount of paper produced in the UK and Canada, Pakistan’s paper mills spend 1.3 MWh more energy per tonne of paper produced on average. Considering Pakistan’s annual paper production of 314,549 metric tonnes, this higher SEC value equates to an additional total annual energy consumption of 408,913 MWh in the paper sector, which can be interpreted as the scale of potential energy savings for the Pakistan paper mills analysed in this study. To gain a better understanding of the SEC variations and potential energy savings of different paper grades in Pakistan’s paper sector, the electrical and thermal energy consumptions of paper mills producing similar paper grades in Pakistan and the United Kingdom/Canada are compared, with the results shown in Table 3.

The results of this comparison show that specific electrical energy consumption values when producing different paper grades in Pakistan are considerably lesser than the respective values in the UK and Canada. It’s also worth noting that the values of specific thermal energy consumptions for Pakistan mills producing different paper grades compared to the analogous mills in the UK/Canada are almost twofold. This highlights that improving the thermal energy use and supply system can be considered an effective strategy for the improvement of the mills’ energy efficiencies by lowering their overall energy consumption. The improvement strategies to achieve this are discussed in detail below.

5.4. Thermal energy consumption comparison

As shown in Table 3, the average values of specific thermal energy consumption SECf for Pakistan mills are significantly higher than the corresponding values published for the UK and Canada (Carbon Trust, 2011; Pulp and Paper Research Institute of Canada, 2008). Through a detailed examination of the mills’ boiler efficiencies and energy incentives, the average SECf values can be considered as one of the potential factors for improving the mills’ performance and energy efficiency. The efficiency of boilers used for steam generation is a key factor contributing to a large variation in specific thermal energy consumption values for Pakistan mills compared to the UK and Canadian mills. As indicated in Table 4, 76% of average boiler efficiencies (range 53.8 to 85.3%), in Pakistan’s pulp and paper sector is significantly lower than the international boiler efficiency requirements compared to international standards (Wohlfarth and Kohan, 2021).

According to the carbon trust guidelines, all modern boilers must achieve an efficiency of around 80% when operating correctly (based on the fuel’s gross calorific value) and even higher standard efficiencies of up to 85% are established for condensing gas boilers and the boilers fitted with economisers. Compared to higher thermal efficiencies of modern gas boilers, thermal efficiencies of boilers in Pakistan mills are significantly lower than the standard values mainly due to poor control of their operation when using rice husk with lower calorific value as a fuel (Cleaner production institute (CPI), 2013). Despite significant costs and difficulties in achieving high efficiencies from a rice husk fuelled boiler such as lower bulk density of fuel which results in low heating values per unit volume making boiler feeding control difficult, fuel’s high moisture content increases the demand for oxygen resulting in a
significant increase in the volume of flue gas produced per unit energy and ash deposition and corrosion due to presence of potassium and chlorine in the fuel.

Recent advancements in boiler design and operation have made it possible to achieve higher efficiencies from a variety of biomass-based fuels, and thus boiler efficiency improvements can still be considered an effective strategy for energy conservation and, as a result, energy cost reduction by converting thermal loss into significant expedient energy (Beno Wincy et al., 2022). The potential annual energy savings for different boilers when upgraded to the standard efficiency of 85% are shown in Table 4. These energy-saving values can be achieved by implementing improvement strategies recommended by Carbon Trust as: (1) Regular maintenance of boilers, (2) The use of boiler burner management systems, (3) Preheating the combustion air and (4) Boiler water conditioning through water treatment including total dissolved solids (TSD) control (Wohlfarth and Kohan, 2021). As shown in Table 4, the improvement of boiler efficiencies to the carbon trust standard level results in an annual energy saving of 230,882 MWh which is equivalent to 13.8% of the actual annual thermal energy requirements of the mills (1,667,109 MWh). This indicates that an energy-saving potential of up to 14.5% of the overall thermal energy consumption in Pakistan’s paper sector is achievable when the same efficiency improvements are applied to all boilers in Pakistan’s paper mills.

A comparison of thermal energy production for the current and modified boiler efficiencies given in Table 4 indicates the effect of boiler efficiencies on their thermal energy production for paper mills. The overall thermal energy use of the mill is affected by the scale of steam generation and also by the way that steam is supplied to the mill where the steam distribution has a significant impact on the mill’s overall energy balance. Unsatisfactory conditions of the steam supply in most Pakistan’s mills due to leakage, non-insulated lines and pipe fittings as stated by CPI (Cleaner production institute (CPI), 2013) can be considered as one of the main reasons for the higher thermal energy of the mills. Due to the lack of metering and controlling at the steam main lines and sub-lines in most Pakistan’s paper mills (Cleaner production institute (CPI), 2013), the data for steam generations and consumptions are mostly based on estimations /or reverse calculations.

These unidentified steam losses result in significant energy and cost estimation errors and would increase boiler fuel consumption remarkably. An example given by the United States Department of Energy for steam leakage through a small hole with a diameter of 0.8 mm at 10.5 bar pressure (the required pressure in Pakistan’s paper mills) results in a loss of 2.2 kg/h of steam (US Department of Energy, 2004) can roughly echo the scale and related cost of these unidentified losses. Considering Pakistan’s average cost of steam production of 4.41 US$/tonne, this translates to an annual loss of 772 US$ for steam leakage through a small hole in steam distribution lines in Pakistan paper sector. Consequently, the overall related cost of these unidentified losses for the entire steam distribution lines in the Pakistan paper sector is significant.

5.5. Electrical energy consumption comparison

In terms of electrical energy usage, the SEE values in the Pakistan paper sector are significantly lower than those in the UK and Canada, as shown in Table 5. Water treatment is critical in UK mills for removing/reducing pollutants to a standard level in the manufacturing process (Department for Environment Food & Rural Affairs (DEFRA), 1996) and results in an additional 29 kWh/t of electrical energy consumption (Carbon Trust, 2011) compared to paper mills in Pakistan, where fresh groundwater is utilized without treatment. The energy consumed to transform paper into end products (wrappings, paper bags, cartons, containers, and a variety of other products of a similar nature) throughout the procedure in which highly specialized machinery is used is another explanation for higher SEE values in the UK and Canada. While no conversion procedure is employed in Pakistan’s paper mills, the final product is exclusively in the form of paper rolls. The conversion stage, according to Carbon Trust (2011), needs an additional 87.2 kWh/t of paper. This has a significant impact on the UK/electrical Canada’s energy requirement. In the UK, paper mill effluent is treated with an average of 49.4 kWh/t of electrical energy though, no real attempts are made in Pakistan’s paper mills to treat effluent. All of this contributes to Pakistan’s paper mills having lower overall electric usage than those in the United Kingdom and Canada.

A cumulative contribution of water and effluent treatment and converting paper into final products results in a 30% difference between Pakistan and the UK electrical energy consumption. More details on individual components (i.e., pumps, paper machines, fans etc.) are required if one wishes to fully compare the electrical energy consumption of Pakistan’s paper mills with the UK and Canada. Paper drying consumes 80% of the energy used in paper production. Modern industrial dryers and drying processes (such as steam, hot air against or through the web, infrared dryers, or hot rollers) utilise energy in the form of electricity, gas, or an indirect heat source like steam (Austin et al., 2011). In the UK and Canadian mills, both electric and steam dryers are used Carbon Trust (2011), Pulp and Paper Research Institute of Canada (2008). Though, in the Pakistan paper sector, steam dryers are the only drying technologies used, resulting in high electric energy and, as a result, low thermal energy use in the UK and Canadian paper sectors, which is mostly due to the difference in the type of drying section.

5.6. Energy saving potential of Pakistan’s paper sector

The difference between actual and benchmark energy intensities can be characterized as the energy-efficiency potential (Kong et al., 2013). Following the same approach and considering the median SEEs as a
benchmark in this study, the energy-saving potentials are calculated as the difference between the value of maximum SEC within each product category and its corresponding specific energy consumption median value. The calculated energy-saving potentials for different paper grades with an overall annual production capacity of 314,549 tonnes are shown in Table 5. The results show that a total annual energy saving of 327,140 MWh including 137,099 MWh electrical energy saving and 189,999 MWh thermal energy saving is achievable if the proposed energy benchmark is based on the median specific energy consumption is applied to all paper mills. This total energy saving comprises 16.4% of the total energy demand in Pakistan’s paper sector.

To standardise and improve the energy efficiency of the paper sector in Pakistan, a detailed comparison of the specific energy consumption between Pakistan and the UK paper sectors including the amount of electrical and thermal specific energy and also total specific energy consumption based on the median SEC values as the benchmarks is performed and the results are given in Table 6. Considering the difference between the value of specific electrical energy consumptions (SEC_e) in Pakistan with those in the UK as the electrical energy saving potential for each paper grade, the negative values shown in Table 6, indicate that the Pakistan paper sector consumes less electrical energy compared to the UK. Nevertheless, as the electrical energy consumption of the UK paper sector is attributed to other factors that are not the case in the Pakistan paper sector as discussed in the “Electrical energy consumption comparison” section above, the negative values indicated here do not reflect a better overall performance in terms of electrical energy consumptions for Pakistan paper sector.

By applying the same methodology to the thermal energy consumption, the results show that for all paper categories the amount of specific thermal energy consumption for Pakistan paper mills is almost two folds higher than the corresponding values for the UK mills when producing similar paper grades. This can be simply explained by the higher amount of steam consumption by paper mills in Pakistan (ranging from 2.6 to 11.9 tonnes of steam/tonne of paper produced) compared to the steam consumption in the UK ranging between 1–3 tonnes of steam per tonne of paper produced for different varieties of products (Carbon Trust, 2011). The rationale behind this is fully explained in the “Thermal energy consumption comparison” section above.

Table 6 shows that using the UK median values as a baseline, a significant potential energy saving of 854,000 MWh, or 43 per cent of the Pakistan paper sector’s total energy consumption, can be obtained.

6. Conclusions

This research aimed to analyse the SEC of similar processes in several paper mills to identify energy-saving opportunities in Pakistan’s paper sector. Overall, the results show that energy inputs in the Pakistan paper sector range from 2.5 to 17.5 MWh/tonne of paper produced. The overall energy consumption of mills studied shows that electric energy consumption ranges from 0.29 to 0.88 MWh/tonne of paper produced, while thermal energy consumption ranges from 2.37 to 6.76 MWh/tonne of paper produced. When compared to the ranges of electric and thermal energy consumption for the UK paper industry, which are 0.96–1.76 MWh/tonne and 1.96–2.90 MWh/tonne of paper produced, correspondingly, the results show poor control of energy use in Pakistan paper industry, highlighting the need to define benchmarks for energy efficiencies in this sector. The results of energy benchmarking revealed that Pakistan’s paper mills utilize 1.3 MWh additional total energy per tonne of paper generated than the average value of energy consumption per tonne of paper produced in the UK and Canada. This additional use of energy equates to an additional amount of total energy consumption of 408,913 MWh per year by Pakistan’s paper sector compared with the UK and Canada paper sectors when making the same amount of products. The results also show that the specific thermal energy (SEC_t) consumption in Pakistan is almost double that in the UK mainly due to the poor average efficiencies of boilers in Pakistan’s pulp and paper sector compared to the boiler efficiency of 85% considered as a standard by Carbon Trust energy improvement guidelines used in
the UK paper industry. The energy-saving potentials calculated based on this standard efficiency show that an overall saving of 14.5% of total thermal energy requirements can be achieved through the improvement of all boilers in the whole country's paper sector. In terms of the overall energy consumption of the country, the results show that an overall 854,000 MWh of energy saving which corresponds to 43% of the total energy usage of the entire Pakistan paper sector can be achieved when all best available techniques such as heat recovery, boiler efficiency improvements, steam traps and economisers used in the UK and Canada are applied. It is also concluded that in future research the energy benchmarks established for paper mills of Pakistan through this paper would be raised with the ministry of commerce in Pakistan to further assess their implications from an implementation point of view to increase Pakistan’s paper mill efficiency.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Austín, P.C., Mack, J., McEwan, M., Afshar, P., Brown, M., Maciejowski, J., 2011. Improved energy efficiency in paper making through reducing dryer steam consumption using advanced process control. In: Proceedings of the Paper Conference and Trade Show 2011, PaperCon 2011.

Beno Wincy, W., Edwin, M., Arunachalam, U., Joseph Sekhar, S., 2022. Energy based performance analysis of rice husk fuelled producer gas operated boiler for thermal application in parboiling mills. Fuel doi:10.1016/j.fuel.2021.123018.

Boyd, G.A., 2017. Comparing the statistical distributions of energy efficiency in manufacturing: meta-analysis of 24 case studies to develop industry-specific energy performance indicators (IEPI). Energy Effic. doi:10.1007/s12053-016-9450-y.

Carbon Trust, 2011. Industrial energy efficiency accelerator guide to the paper sector. URL https://www.polybags.co.uk/environmentally-friendly/industrial-energy-efficiency-accelerator-guide-to-the-paper-sector.pdf (accessed 6.16.22).

Cleaner production institute (CPI). 2013. Responding to the environmental challenge Pakistan’s pulp & paper sector. URL http://www.cpi.org.pk/ (accessed 6.17.22).

Department for Environment Food & Rural Affairs (DEFRA), 1996. Pulp and paper manufacturing works.

Farla, J., Blok, K., Schipper, L., 1997. Energy efficiency developments in the pulp and paper industry: a cross-country comparison using physical production data. Energy Policy doi:10.1016/s0301-4215(97)00065-7.

Federpsiel, C., Zhang, Q., Arens, E., 2002. Model-based benchmarking with application to laboratory buildings. Energy Build. doi:10.1016/S0378-7788(01)00092-5.

Fracaro, G., Yakkilainen, E., Hamaguchi, M., de Souza, S.N.M., 2012. Energy efficiency in the Brazilian pulp and paper industry. Energies doi:10.3390/en509350.

Ghobakhloo, M., Fathi, M., 2021. Industry 4.0 and opportunities for energy sustainability. J. Clean. Prod. doi:10.1016/j.jclepro.2021.126427.

Klugman, S., Karlsson, M., Mosfírehg, B., 2007. A Scandinavian chemical wood-pulp mill. Part 2. International and model mills comparison. Appl. Energy doi:10.1016/j.apenergy.2006.07.004.

Kong, L., Price, L., Hasanbeigi, A., Liu, H., Li, J., 2013. Potential for reducing paper mill energy use and carbon dioxide emissions through plant-wide energy audits: a case study in China. Appl. Energy doi:10.1016/j.apenergy.2012.07.013.

Laurijssen, J., Faaij, A., Worrell, E., 2013. Benchmarking energy use in the paper industry: a benchmarking study on process unit level. Energy Effic. doi:10.1007/s12053-012-9163-9.

Ministry of Planning, Government of Pakistan, 2021. IEF report-1 Pakistan energy demand forecast (2021-2030).

Pakistan Bureau of Statistics (PBS), 2019. Pakistan Statistical Yearbook 2019. Pakistan Bureau of Statistics (PBS) URL.

Patterson, M.G., 1996. What is energy efficiency? Concepts, indicators and methodological issues. Energy Policy doi:10.1016/0301-4215(96)00017-1.

Phylipsen, G.J.M., Blok, K., Worrell, E., 1997. International comparisons of energy efficiency methodologies for the manufacturing industry. Energy Policy doi:10.1016/s0301-4215(97)00063-3.

Pulp and Paper Research Institute of Canada, 2008. Benchmarking energy use in Canadian pulp and paper mills. URL www.paprican.ca (accessed 6.16.22).

Rogers, J.G., Cooper, S.J., Norman, J.B., 2018. Uses of industrial energy benchmarking with reference to the pulp and paper industries. Renew. Sustain. Energy Rev. doi:10.1016/j.rser.2018.06.019.

Saygin, D., Worrell, E., Patel, M.K., Gielen, D.J., 2011. Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. Energy doi:10.1016/j.energy.2011.08.025.

Shahbír, I., Mirzaeian, M., 2017. Carbon emissions reduction potentials in pulp and paper mills by applying cogeneration technologies. Energy Procedia doi:10.1016/j.egypro.2017.03.1075.

Shahbír, I., Mirzaeian, M., Mooney, J., Anvari, F., 2016. Energy efficiency improvement potentials of pulp and paper sector through energy benchmarking and cogeneration. In: Proceedings of the 29th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems, ECO.

Suhr, M., Klein, G., Koutr, I., Rodrigo Gonzalo, M., Giner Santos, G., Roudier, S., Degado Sancho, L., 2015. Best available techniques (BAT) - reference document on best available techniques in the pulp and paper industry. JRC Science and Policy Reports.

Szabó, L., Soria, A., Forström, J., Kerinen, J.T., Hytinen, E., 2009. A world model of the pulp and paper industry: demand, energy consumption and emission scenarios to 2030. Environ. Sci. Policy doi:10.1016/j.envsci.2009.01.011.

The World Bank, 2022.

US Department of Energy, 2015. Bandwidth study on energy use and potential energy saving opportunities in U.S. Pulp and Paper Manufacturing.

US Department of Energy, 2004. Improving steam systems performance: a sourcebook for industry.

US Energy Information Administration (EIA), 2019. U.S. energy information administration - EIA - independent statistics and analysis. Color. State Profile Energy Estim. URL https://www.eia.gov/todayinenergy/detail.php?id=41435 (accessed 6.16.22).

Wohlfarth, R., Kohan, A.L., 2021. Boiler Operator’s Guide, 5th ed. McGraw-Hill Education.