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ENERGY ANALYSIS OF PULP MILL

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ABSTRACT

The pulp and paper industry annually produces over 300 million tons of paper products used across society in print media, packaging, tissue, and hygiene. Transforming wood into useful products involves energy- and resource-intensive processing to separate cellulose fibers from wood components, including hemicellulose, lignin, and extractives. The industrial sector is the largest user of energy in many parts of the world. The pulp and paper industry accounted for 6% of total global industrial energy consumption, being the fourth largest energy consumer worldwide. Pulp and paper production, an energy-intensive process, is among the main light industries contributing to energy saving and pollution emission reduction. Pulp and paper mills are highly complex and integrate many different process areas including wood preparation, pulping, chemical recovery, bleaching, and papermaking to convert wood to the final product. Processing options and the type of wood processed are often determined by the final product. With the rise in environmental awareness due to the lobbying by environmental organizations and with increased government regulation there is now a trend towards sustainability in the pulp and paper industry. Sustainable pulp and paper manufacturing requires a holistic view of the manufacturing process. During the last decade, there have been revolutionary technical developments in pulping, bleaching and chemical recovery technology. These developments have made it possible to further reduce loads in effluents and airborne emissions. Thus, there has been strong progress towards minimum-impact mills in the pulp and paper industry. The minimum-impact mill is a holistic manufacturing concept that encompasses environmental management systems, compliance with environmental laws and regulations and manufacturing technologies. This study aims to highlight the pulping processes for Pulp Mill A, energy use and loss analysis, and energy-saving opportunities identified during the case study. The main objective of the case study was to help identify areas where energy is being lost and recommend possible energy-saving suggestions that can be incorporated into real-world operations.

Keywords: Pulp & Paper Industry, Energy Conservation, Carbon Dioxide Emission

1. INTRODUCTION

The pulp and paper industry annually produces over 300 million tons of paper products used across society in print media, packaging, tissue, and hygiene. Transforming wood into useful products involves energy- and resource-intensive processing to separate cellulose fibers from wood components, including hemicellulose, lignin, and extractives. The main raw material of paper is composed of annual plants such as wood, jute, hemp and reed, and with the development of today's industry, wastepaper raw materials are combined with cellulose, wood pulp and old paper pulp intermediates (Oktay & Şahiner, 2007). Global demand for market paper climbed from 42.8 million metric tons in 2005 to over 58.9 million metric tons in 2018 (Narciso et al., 2020). By 2023, this figure is predicted to have climbed to approximately 66 million metric tons. According to 2019 data, North America accounts for 33% of worldwide pulp production, followed by Europe with 26% of the world's pulp output (Bhat et al., 2019). The World Bank estimated the worldwide paper and pulp market to be worth 348.43 billion US dollars in 2019 and predicted it to expand at a compound annual growth rate (CAGR) of 0.8 percent through 2027, reaching a total value of more than 370 billion US dollars (Talebjedi et al., 2021). This industry produces various paper products, including papers for wrapping and packaging, newsprint, printing, and writing (Sharma al., 2020).

Paper is a consumable that is used almost everywhere in daily life, and it is also an intermediate good used in the fields of printing, packaging and health. Especially with the spread of e-commerce, advances in the logic industry and increasing environmental awareness, the importance of paper in the packaging industry has gradually increased. Analysis of the paper production in some world countries and the production of paper in factories, the ranking is as follows; Spain (Xativa) 1150, France (Herault) 1189, Italy (Fabriano) 1260, Germany (Nuremberg) 1389, Switzerland (Marry) 1400, Belgium 1407, Netherlands (Gennep) 1428. England (Hertfordshire) 1488, Sweden (Motala) 1532, Denmark 1540, Russia (Moscow) 1690 USA (Germanstown, Pa.) 1690 Aytaç and Korkmaz, M. (2022), South Africa (Johannesburg), Walker (2013), Riverbed Technology (2011). Analyzing the countries with pulp foreign trade surplus in GTIP (2011-2015) in Table 1, it is observed that Canada, the USA and Brazil rank in the first three places while South Africa is ranked eighth, Aytaç and Korkmaz, (2022).

Table 1 First 20 countries with pulp foreign trade surplus in GTIP (2011-2015) Source: TURKSTAT

Country	Balance of Trade - Thousand $				
	2011	2012	2013	2014	2015
1. Canada	7.236.411	6.431.510	6.532.185	6,463,980	5.956.479
2. USA	5.926.238	5.809.899	5.186.376	5.214.636	5.299.295
3. Brazil	4.627.242	4.366.746	4.849.313	4.950.889	5.264.693
4. Chile	2.744.569	2,494,641	2.764.575	2.847.890	2.540.357
5. Sweden	2.271.909	2.041.574	2.665.904	2.728.112	2.440.334
6. Finland	1.553.900	1.403.318	1.796.749	1.866.438	1.738.423
7. Russia	1.244.737	1.077.996	971.590	1.044.998	1.017.969
8. South Africa	897.278	625.302	607.402	711.712	648.637
9. Portugal	666.508	612.960	622.652	583,423	621.033
10. New Zealand	519.235	465.134	501.203	531.155	480,792
11. Indonesia	-242.959	-4.492	112.652	-28.017	445.446
12. Czech Rep.	286,200	227.755	251.405	225.755	211.855
13. Norway	340.867	327.491	289,932	286.154	210.403
14. Hong Kong	263,165	232.404	201.999	171.359	159,983
15. Singapore	142,097	-44.845	111.376	152.064	100,588
16. Belgium	140,931	109.748	42.603	9,437	78.379
17. Estonia	101.498	88.214	80.892	94.814	74,905
18. Slovakia	-.27.452	46.204	27.528	37.508	56.661
19. Bulgaria	52.693	39.130	45.307	50.309	47.139
20. Free Zones	8.561	2.396	3.606	7.301	47.035

Description of the Pulp and Paper Manufacturing Process: The manufacturing of paper or paperboard can be divided into six main process areas, which are discussed further in the sections below: (1) wood preparation; (2) pulping; (3) bleaching; (4) chemical recovery; (5) pulp drying (non-integrated mills only); and (6) papermaking. Figure 1 below presents a flow diagram of the pulp and paper manufacturing process. Some pulp and paper mills may also include converting operations (e.g., coating, box making, etc.); however, these operations are usually performed at separate facilities.

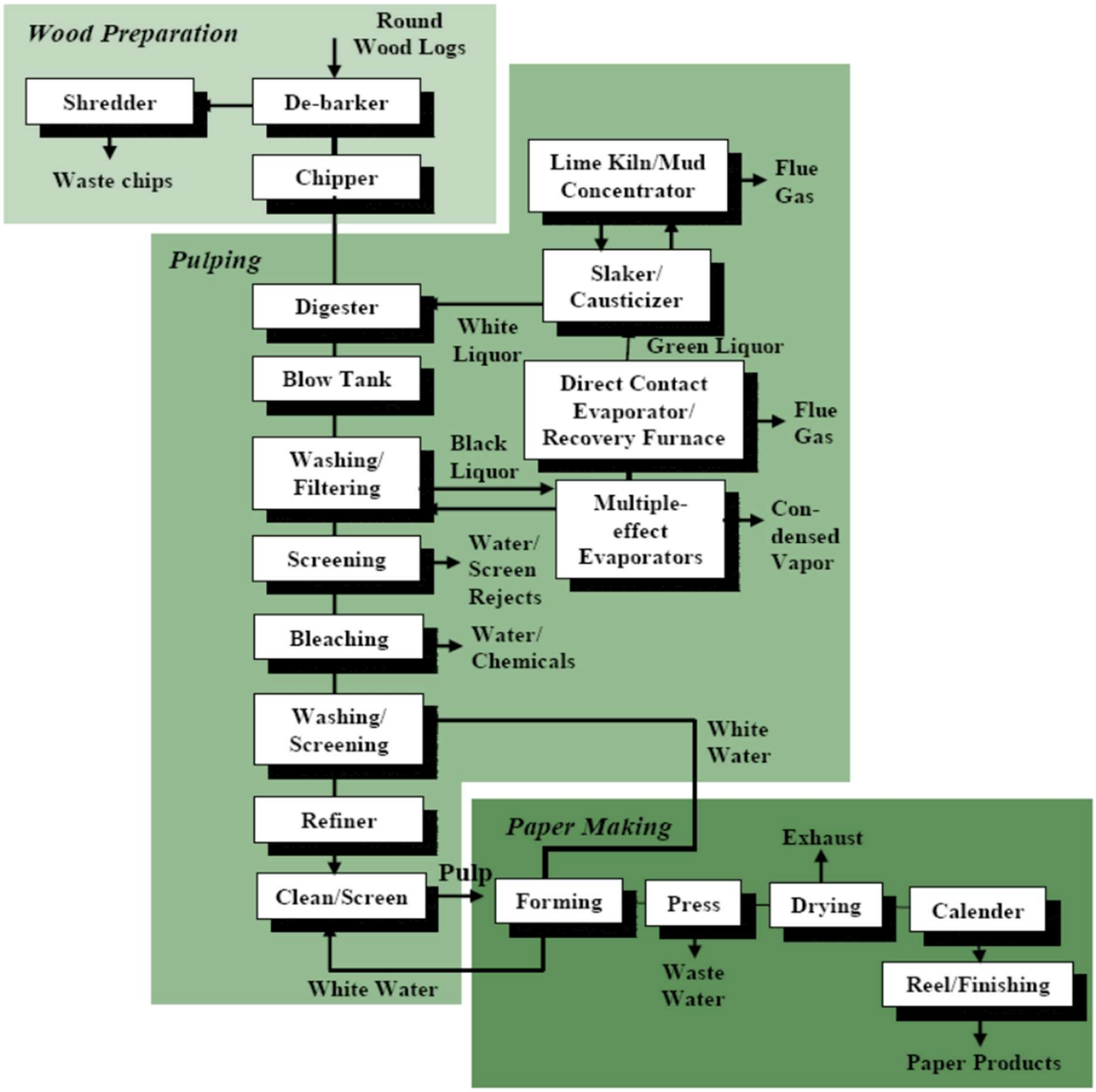

Figure 1. Flow Diagram of the Pulp and Paper Manufacturing Process (Staudt 2010)

Addressing the production process of paper, it is seen that it is produced in different textures and contents according to the place of use and feature (Bajpai,2015). The basic structure of paper production is wood-based, agricultural product-based and wastepaper-based production differentiation. Due to the differences in production methodologies, the production quality and content of paper also change.

There are an estimated 386 pulp and/or paper manufacturing facilities in the in the U.S., including:

• 120 mills that carry out chemical wood pulping (kraft, sulfite, soda, or semi-chemical),
• 47 mills that carry out mechanical, groundwood, secondary fiber, and non-wood pulping,
• 102 mills that perform bleaching, and

• 369 mills that manufacture paper or paperboard products. (EPA 2010b)

In South Africa, Pulp, Paper, and Paperboard Mills companies is estimated at 766. South Africa is a major player in key pulp and paper segments in regional and global markets. The country is one of the world's largest producers of dissolving wood pulp and is the largest producer of pulp, paper and paper products on the African continent. Sappi's story is a tale of how a traditional pulp and paper company has evolved to remain relevant and thrive in a rapidly changing world. It began during the historic moment when South African Pulp and Paper Industries Limited was established on 17 December 1936. Sappi and started manufacturing paper from straw at our first mill east of Johannesburg. Today, Sappi is a global diversified Woodfibre company focused on providing dissolving pulp, packaging and speciality papers, graphic papers, as well as biomaterials and biochemicals to customers in more than 150 countries. Other than Graphic paper, best known for use in offices and in glossy magazines, Sappi also is the world leader in the production of dissolving pulp for use in the manufacture of viscose staple fiber (VSF). Sappi is a force to be reckoned with in the global packaging and specialty paper market (ranging from labels to flexible packaging, silicone base paper, liner applications, grease-proof paper and the use of release paper as a cast in the production of synthetic leather). Some integrated pulp and paper mills perform multiple operations (e.g., chemical pulping, bleaching, and papermaking; pulping and unbleached papermaking; etc.). Nonintegrated mills may perform either pulping (with or without bleaching), or papermaking (with or without bleaching). Further descriptions of the Pulp and Paper Manufacturing Process are provided in the works of (ECR 2005, EPA 2001a, EPA 2008, EPA 2002).

This study aims to highlight the pulping processes for Pulp Mill A, energy use and loss analysis, and energy-saving opportunities identified during the case study. The main objective of the case study was to help identify areas where energy is being lost and recommend possible energy-saving suggestions that can be incorporated into real-world operations. The paper answers the following questions:

- Where is the energy used in a typical P & P mill?
- Where is energy lost in a typical P & P mill?
- Which technical opportunities are available for energy savings in P & P mills and where do they lie?

2. Case Study of Energy Consumption and Loss Analysis

2.1 Audit Approach

The energy audit was characterized by a walk-through survey to understand the pulp mill processes and to understand the equipment that is used in the mill. During that initial survey, preliminary identification of the energy conservation opportunities was done. Many of energy conservation opportunities were identified and a qualitative screening analysis was performed to identify energy efficiency opportunities that had significant energy saving potential, which warranted further study. Focusing on those opportunities that had better energy saving potential was done afterwards. During the data analysis all data collected were cross-checked and where necessary engineering judgment was applied. The level of engineering detail varied according to each energy efficiency opportunity identified, with less detail required on simple inexpensive energy efficiency measures and more detail on capital-intensive retrofitting measures.

2.2 Plant Description

The mill under study is situated 50 km south of the port of Durban in South Africa. It has become one of the largest mills of its sort in the world. Today it is the single largest manufacturer of chemical cellulose with a capacity to produce approximately 800 000 tons of pulp per year, most of which is sold to Europe, America and Asia. It is also renowned for being the first company to produce high-grade dissolving pulp from Eucalyptus trees. The process flow diagram is shown in Figure 2.

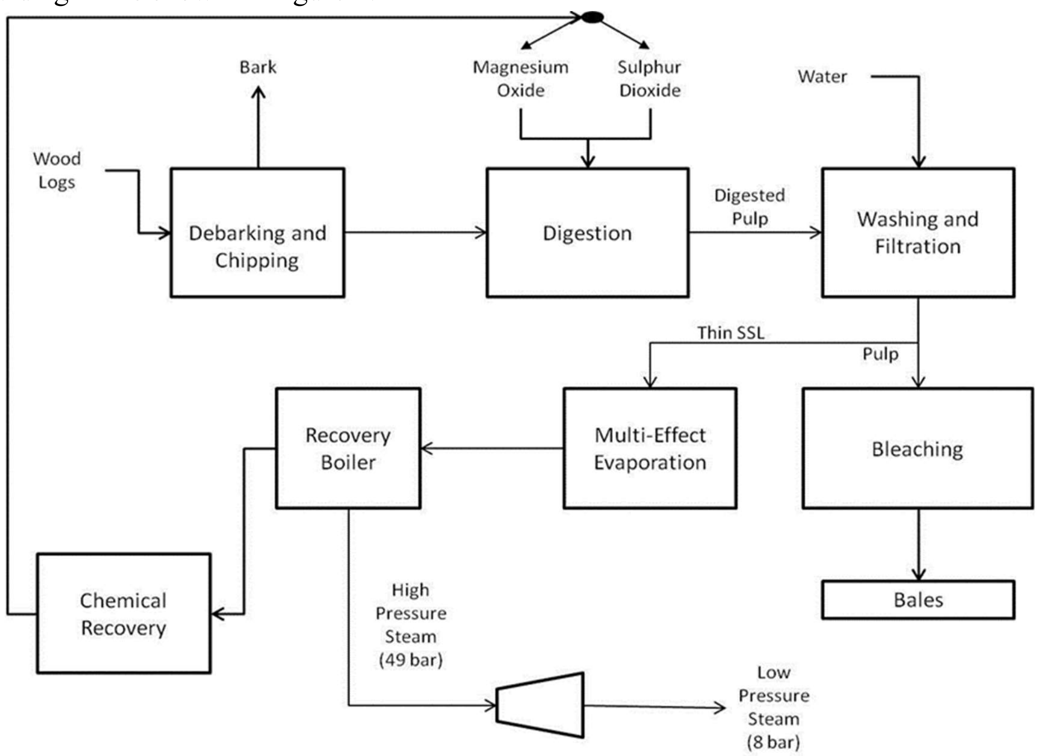

Figure 2: Process flow diagram for Pulp Mill A

As can be seen in Figure 2, wood is first debarked and then chipped. The wood chips are mixed with water and enter the digester to remove the hemicellulose and lignin through solubilization. The solubilization occurs at a temperature of approximately 160 °C with sulfur dioxide in combination with either magnesium oxide (Mg-O) or calcium oxide (Ca-O). Currently, the facility has three digestion lines, two of which use magnesium oxide as the solubilization agent while the third utilizes calcium oxide. The digester product slurry is then washed and separated into the pulp, which is bleached and rolled into sheets, and diluted SSL, which contains lignosulphonates (water-soluble lignin), sugars and organic acids and phenolic compounds. The SSL from the magnesium oxide lines is processed for the recovery of energy (steam and power) and pulping chemicals. The SSL is concentrated in a multi-effect evaporator before the combustion of the resulting syrup in a recovery boiler, which recovers magnesium oxide and sulfur dioxide for the digestion process The energy generated from the combustion of SSL is often not sufficient to satisfy the energy demands of the mill itself, and an additional fuel source such as bark, field biomass residues (collected and processed into hog fuel) or coal is needed. The spent SSL from the calcium oxide digestion at Pulp Mill A is split into two streams, one of which is sent to a neighboring lignosulphonates recovery plant, and the second is discharged as effluent.

3. Findings from Observations

3.1 Instrumentation

It was noted during the audit that the mill is not well instrumented. Inadequate instruments are hindering smooth production and energy consumption monitoring. This might be attributed to the original design of the mill hence more detailed survey is needed to find ways of improving pulp mill instrumentation, that is, valves, transmitters' controllers and actuators availability at strategic measuring points.

3.2 Management and Organization

The audit identified that the engineering department does not have energy management textbooks. No energy-related technical information documentation is available at the mill and this affects the smooth flow of activities since no engineer can perform at their best without adequate technical referencing. The recommended corrective measure will be to purchase energy-related textbooks for use by the engineering department staff.

It was also noted that most engineering personnel have narrowly defined responsibilities. This works well if the primary focus of keeping production equipment operating at a peak is to be achieved but makes them lack in general energy management skills. Competent energy experts should have an integrated outlook of the mill to accomplish their job well. Over specialization in an energy professional can result in energy efficiency opportunities being missed. By periodically rotating positions the staff can develop a better background and a more comprehensive and integrated outlook of the plant.

Energy scenario for Mill A

Energy Scenario for Mill A. The energy scenario for Mill A is summarized in Table 2.

Financial year	**Production**	**Specific electricity consumption kWh/t paper**	**Specific steam consumption/t production**	**Specific coal consumption t/t of production**
2013-2014	53 767	1 027.92	6.08	13 789
2014-2015	51 692	1 008.51	6.17	14 325

Table 2: Energy scenario for Mill A

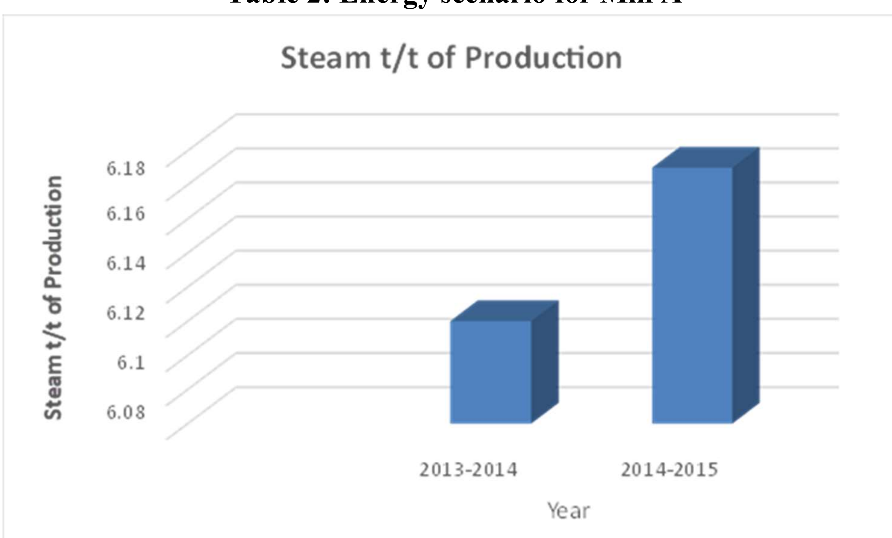

Figure 3: Specific steam consumption trend per ton of production

The steam production trend shows that the steam production per ton of production is increasing significantly (Figure 3).

The electricity consumption trend for Pulp Mill A shows a decreasing trend (Figure 4). This might be as result of some energy conservation measures being taken by the pulp mill in the period under scrutiny. This consumption however is far more than the best practice figure for sulphite pulp processing of 406 kWh/ton of production meaning the mill is wasting millions of Rands on electricity (see benchmarking in section 4.1).

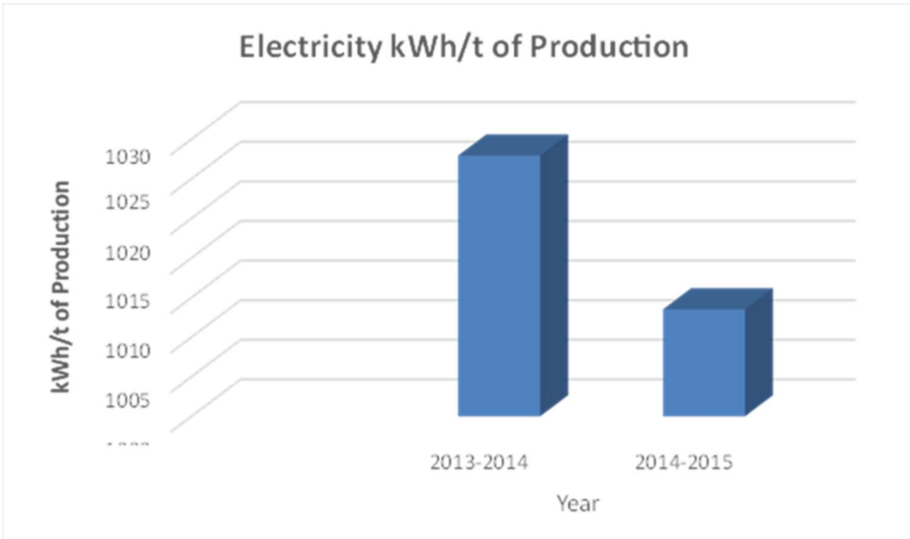

Figure 4: Specific electricity consumption per ton of production

The coal consumption trend for Pulp Mill A from 2013 to 2015 is shown in Figure 5. It is clear from the figure that specific coal consumption was increasing per ton of pulp produced. This might be an indication that there is energy efficiency improvement potential within the coal-fired generation units.

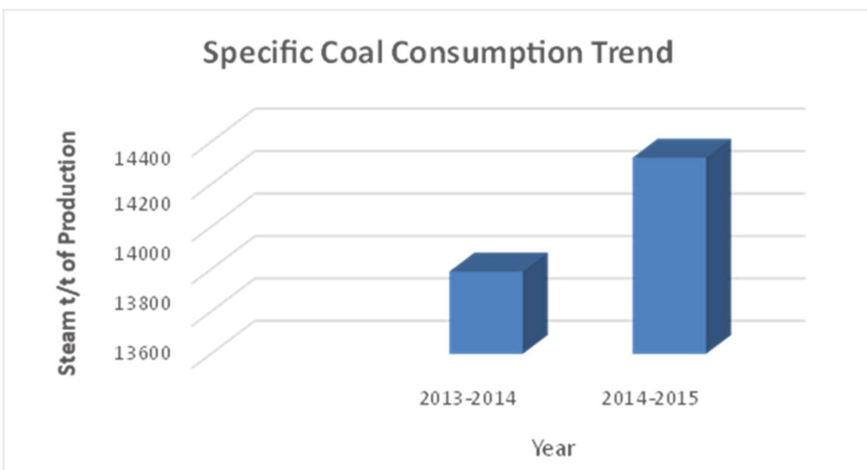

Figure 5: Specific coal consumption trend

Benchmarking Comparison

Benchmarking is fundamental for comparative analysis. It is usually undertaken to compare the production costs of various mills, mill uptime, energy consumption profiles or other critical energy parameters. Benchmarking is always conducted against mills of a similar type producing essentially the same product. The gap analysis will reveal the difference between mills of the same age and design criteria. Benchmarking should be the first step a mill should undertake to get a clear picture of its operations. Benchmarking enables mill management to get a relative performance comparison of their mill with similar mills or models that represent norms of best practice performance. Further, benchmarking is also useful in energy efficiency studies in providing the necessary direction in search of energy efficiency opportunities. However, for it to be relevant, section-wise benchmarking must be carried out, and energy type. e.g. steam, and electricity quantified and compared accordingly.

The specific electricity consumption of Mill A for 2014 is 1 027 kWh/Ton of pulp. It is evident from Table 3 that Pulp Mill A's electricity consumption is higher compared to the norms set by best practice. Pulp Mill A consumes 152% more electricity compared to the norms set by best practice. To improve the specific consumption of electricity there must be continuous effort to find energy conservation opportunities and to implement those opportunities and optimization of the process.

A plant-wide breakdown of specific equipment can be done to get a clear picture of the electricity consumption pattern.

Table 3: Specific energy consumption of best practice (BP) and Pulp Mill A

Specific consumption	Sulphite pulp	Grade	Index
	BP value	Mill A	MILL A / BP
Electricity (kWh/t of production)	406	1027	2.52
Steam (t/t of production)	8.01	6.08	0.75

Analysis of Mill A Energy Losses Methodology

Step 1: Questionnaire

A questionnaire was designed and handed out to retrieve the data required to analyze the pulp mill energy profile. Information required was on energy inputs into the plant boundary, black liquor used, electricity sales and sectional equipment energy consumption. The questionnaires were well answered and all the data required was captured. Complete data that was available was for the year 2014.

Step 2: Total Energy Supply, 513 082 GJ/M

Energy supply is the sum of fuel consumption, purchased electricity, steam, biomass, and black liquor or by-product fuels. After analyzing the data obtained for 2014, the energy supply was 24 145 511 kWh/M transforming to 86 924 GJ/M of electricity, 13 789 tons/M of coal equivalent to 382 782.64 GJ/M, 159 tons/M of High Fuel Oil (HFO) equivalent to 6 758 GJ/M, 3 449.67 tons/M of Sulphur representing 32 185 GJ/M, 75 117 litres/M of diesel equivalent to 2 961 GJ/M, 3 886 litres/M of petrol equivalent to 147 GJ/M and 51.94 $m3$/M of LPG equivalent to 1 325 GJ/M. This means 513 082 GJ/M of energy went into the mill in 2014 as shown in Table 4.

Table 4: Energy supply for 2014

Energy source	Units/M	Figures for 2014	Conversion factors	Converting to GJ/M	%
Coal	Tons	13789	27.76	382 782	74.6
Electricity	kWh	24 145 511	0.0036	86 924	16.94
Sulphur	Tons	3 450	9.328	32 185	6.27
HFO	Tons	159	42.5	6 758	1.32
Diesel	Litres	75 117	0.88x44.8/1000	2 961	0.58

Petrol	Litres	3 886	0.8 X 27.3	147	0.03
LPG	M^3	51.94	25.5	1 325	0.26
Total				**513 082**	**100**

Step 3: Central Energy Generation/ Utilities 1 281 098 GJ/M

This value includes energy supply plus the black liquor that came from mill, represented by renewable energy on the flow diagram. (Figure 6). Onsite power generated refers to the energy that was produced onsite by a coal fired system or from recovery of black liquor.

(513 082 GJ/M) + (768 016 GJ/M) = 1 281 098 GJ/M

Renewable energy to boiler was composed of black liquor which was about 246 414 GJ/M from MGO1 and 521 602 GJ/M from MGO2 giving a total of 768 016 GJ/M. Steam plant energy was composed of 100 464 tons/M from coal fired boilers, 217 968 tons/M from recovery boilers and 8 420 tons/M from Sulphur boilers making a total of 326 852 tons/M of steam equivalent to 882 500 GJ/M.

1. **Loss in Boilers and Electricity, 194 400 GJ/M**

This is quantified by first determining the total energy that was supplied to boilers and then subtracting onsite generation, steam plant energy and electricity sales figures from it.

(Fuel to Boilers) – (Steam Plant Energy) – (Power Generated) – (Electricity sales)

(1 189 742 GJ/M) – (882 500 GJ/M) – (112 042 GJ/M) – (800 GJ/M) = 194 400 GJ/M.

2. **Direct fuel Supply, 4 432 GJ/M**

(Central Energy Generation) – (Steam Plant Energy) – (Power Generation) – (Utility Power Plant) – (Losses to Boilers) – (Electricity Sales).

(1 281 098 GJ/M) – (882 500 GJ/M) - (112 042 GJ/M) – (86 924 GJ/M) – (194 400 GJ/M) – (800 GJ) = 4 432 GJ/M.

3. **Step 4: Energy Distribution, 1 086 098 GJ/M**

This quantifies energy that was supplied to the system processes. It is quantified by taking off losses in boiler and electricity generation from the Central Energy Generation figure.

(Central Energy Generation) – (Losses in boilers and electricity generation) – (Electricity sales).

(1 281 098 GJ/M) – (194 400 GJ/M) – (800 GJ/M) = 1 086 098 GJ/M.

4. **Distribution Losses, 270 852 GJ/M**

These losses occur in energy distribution channels like valves, steam traps, pipes and electrical transmission lines. The losses are quantified based on some rough estimates based on P & P industry operation experience. The losses range from 5% to 40% although in this report a figure of 30% for steam distribution, 3% for fuel transmission and 3% for electricity transmission is used in the calculations. Take note that losses in steam pipes and straps have been reported to be as high as 20% to 40% (Hooper and Gillette, 2002). Calculations of Distribution Losses are as follows:

Steam Pipes: (Steam Plant Energy) x 30% (882 500) *0.3 = 264 750 GJ/M
Fuel Pipes: (Direct Fuel Supply) *3% (4 432) *0.03 = 133 GJ/M
Electricity Lines: (Utility Power + Power Generation) *3% (198 966) *0.03 = 5 969 GJ/M
Total Transmission Losses 264 750 GJ/M + 133 GJ+ 5 969 GJ/M = 270 852 GJ/M.

Step 5: Energy Conversion, 815 446 GJ/M

This value is quantified by subtracting distribution losses, energy to facilities and export energy from energy distribution. It represents the energy that goes into process systems, including process heating, motor-driven equipment and process equipment.
(Energy Distribution) – (Distribution Losses) – (Non-Process Energy/ Facilities) (1 086 698 GJ/M) – (27 082 GJ/M) – (400 GJ/M) = 815 446 GJ/M.
Total energy conversion equipment losses = process heating losses + cooling system losses + electrochemical losses + other losses.
(62 643 GJ/M) + (31 862 GJ/M) + (5 831 GJ/M) + (1 554 GJ/M) = 102 890 GJ/M
Total machine drive losses = pump losses + fan losses + compressed air losses + refrigeration + other drive losses (see Table 7-4).
(18 592 GJ/M) + (9 013 GJ/M) + (29 216 GJ/M) + (125 GJ/M) + (2 345GJ) + (1 475) + (500 GJ/M) = 62 265 GJ/M
Total equipment losses = total energy conversion losses + total machine drive losses 102 890 GJ/M + 62 265 GJ/M = 163 155 GJ/M

Table 5: Other energy conversion losses

Other energy conversion losses	Energy use	System loss	Energy loss	Assumption based on operation experience
Process heating	417 617	0.15	62 643	(15% rough estimate)
Electrochemicalsystem	31 816	0.15	31 862	(15% rough estimate)
Cooling systems	58 312	0.1	5 831	(15% rough estimate)
Onsite transport	3 108	0.5	1 554	(50% assuming gasoline and diesel engines)

Table 6: Analysis of machine drive losses

Machine drives	Energy Use GJ/M	System loss	Energy loss GJ/M
Pumps	46 480	40%	18 592
Fans	22 533	40%	9 013
Compressed air	36 520	80%	29 216
Refrigeration	2 500	5%	125
Material handling	46 890	5%	2 345
Material processing	16 386	90%	1 475
Others	10 000	5%	500
Total losses	181 309		61 65

Step 6: Process Energy Use, 622 291 GJ/M

The process energy use is estimated by subtracting energy losses due to equipment inefficiency from the energy conversion system to the process energy use system.
Process Energy Use = energy conversion – total equipment losses = 622 291 GJ/M. From the above analysis identification of areas where energy was being lost and areas with potential energy-saving opportunities were noted (Figure 6).

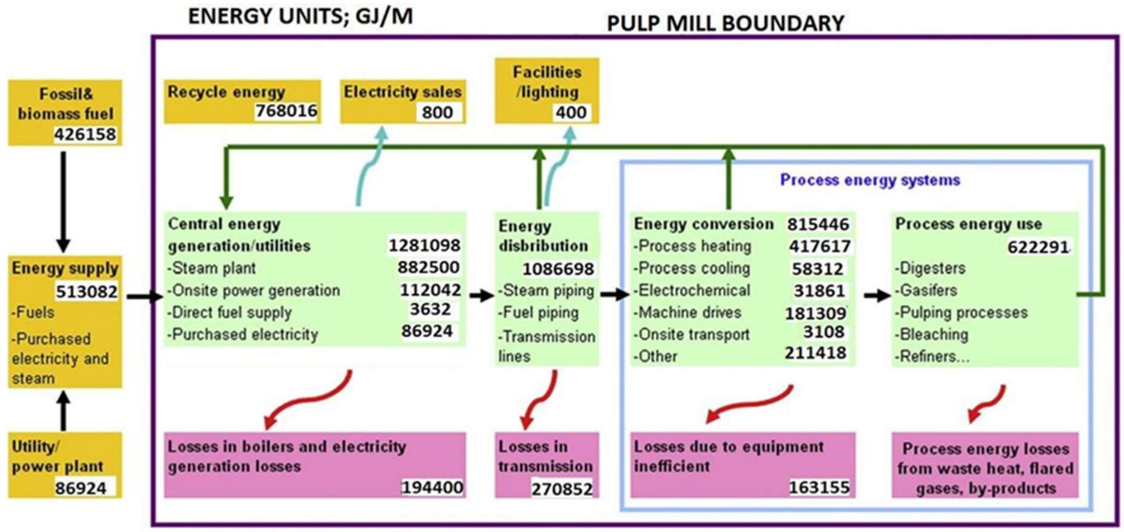

Figure 6: Pulp Mill A, energy flow profile for 2014

Energy use and loss profile was analyzed earlier in this paper. Primary energy which includes purchased fuels and electricity, renewable fuels and energy losses associated with onsite power generation and energy supply streams are analyzed.

Energy Loss Analysis

The energy use and loss of Mill A were analyzed in this section and the analysis and results are described below. Primary energy which includes purchased coal, purchased electricity, HFO, sulfur, diesel petrol and LPG provided a perspective on the total energy use associated with P & P production. The primary energy inputs are shown in Figure 7.

According to Figure 7, almost 75% of energy used is contributed by coal purchased for boilers, with purchased fuel following 17% (approximate). Sulfur purchased for the liquor plant occupies the third spot with a contribution of about 6% (approximate). Diesel, petrol, and low-pressure gas contribute very small energy supply percentages with a combined percentage of 1%. (approximate).

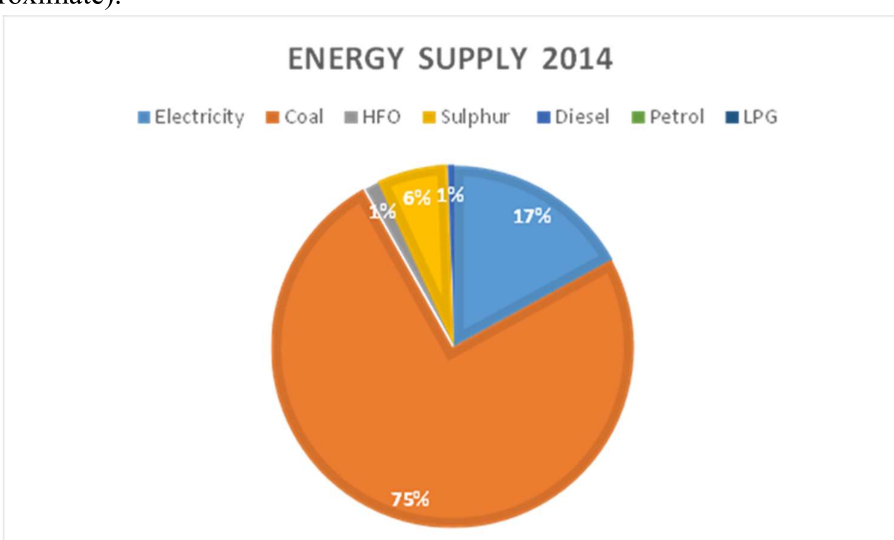

Figure 7: Energy Supply Percentages

Energy use distribution profile

According to the energy flow methodology described in the section under Energy Scenario for Mill A, the primary energy use is listed in Table 7. The primary energy use shows that boiler and electricity generation accounted for a significant portion of primary energy supplied to Pulp Mill A.

According to Table 7, 15% of the primary supply is lost in the boiler and electricity generation. Almost 70% is converted to steam plant energy. Onsite generation contributed only 9% of the primary energy supplied in 2014 showing that the mill generates most of its electrical energy requirements.

Table 7: Primary energy use

Mill Area	Energy use in GJ/M	%
Electricity sales	800	0.06%
Steam plant energy	882 500	68.89%
Onsite power generation	112 024	8.74%
Direct fuel supply	4 432	0.35%
Purchased electricity	86 924	6.79%
Losses in boiler and generation	194 400	15.17%
Central energy generation	1 281 080	100.00%

According to Table 7, purchased electricity contributed only 7% of the energy supply to the mill, this shows that Pulp Mill A is generating most of its electricity needs. The remainder was contributed by fossil fuel supplies.

A closer look at Central Energy Generation shows that boiler and generation losses accounted for almost 15% of the total energy in the system. A greater portion of 69% was used to generate steam. Onsite power generation accounted for only 9% of the actual energy in the system as shown in Figure 8.

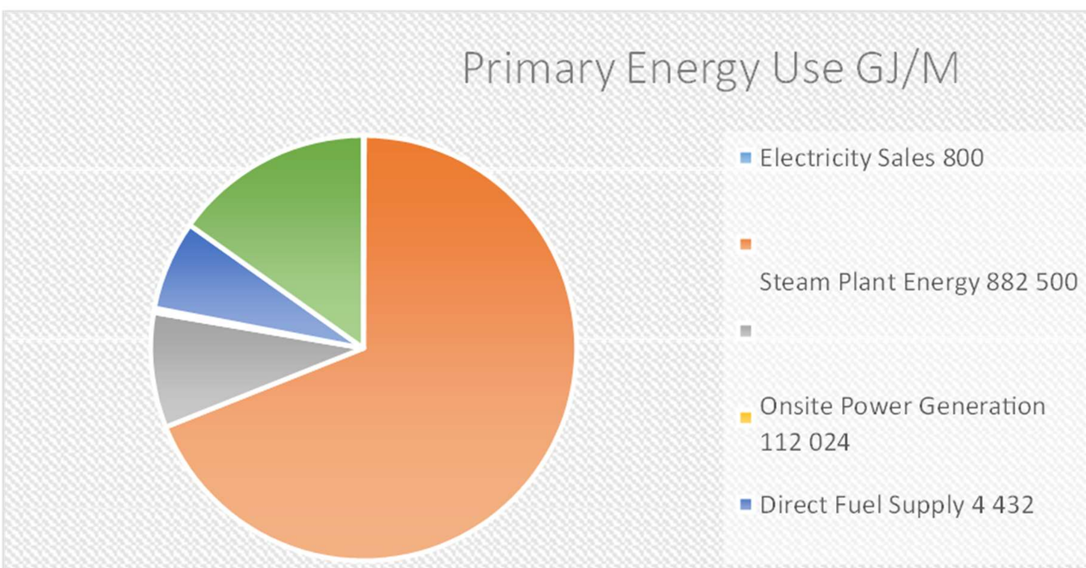

Figure 8: Primary energy use distribution for Pulp Mill A

Analysis of energy losses

Analysis of the energy losses as described in Table 8 reveals that most energy losses occur in energy distribution channels. This is followed by equipment inefficiency energy losses and lastly boiler and generation losses. The total energy losses amounted to 629 207 GJ/M. As determined from energy flow analysis, the general energy flow and losses are illustrated in Figure 9. Energy distribution losses accounted for an energy loss of 43%, boiler and generation losses of 31 %, and Equipment inefficiency of 26 %.

Table 8: Onsite energy loss profile

Mill Area	Energy LossesGJ/M	%
Boiler and generation losses	194 400	0.31
Energy distribution losses	270 852	0.43
Equipment inefficiency losses	163 155	0.26
Total losses	**629 207**	**100**

As shown in Table 8, almost half of the losses occur in distribution of energy. Most of the losses are caused by inefficient stream traps, energy transfer losses and energy leaks.

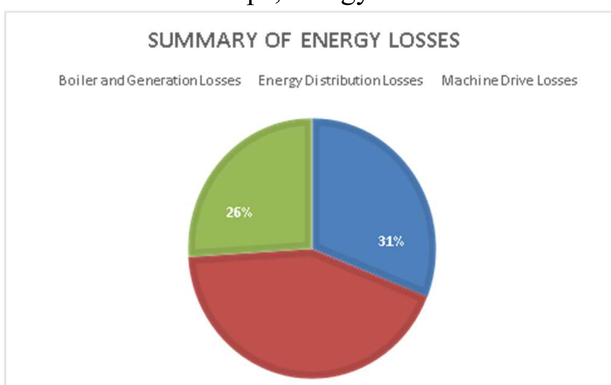

Figure 9: Analysis of energy losses

Energy Conservation Opportunities

1) Boilers and electricity power generation losses: Use heat stored in wet scrubbers to pre-heat boiler feed water and stop pre-heating boiler feed water using low-pressure steam when turbines are not being used. Increase electricity production by decreasing low-pressure steam network operating pressure. Other conservation measures such as aiming to reduce excess oxygen level to 4% to 6% at the coal-fired boilers and installation of a flash tank at the coal-fired boilers blowdown and inject that steam into the low-pressure network are also recommended. Review the blowdown strategy on coal-fired boilers and try to reduce it.

2) Losses in energy distribution channels: Repair leaking steam pipes and broken steam traps on site. Manage steam venting better, by either using steam pipes, deaerator tanks, or demineralized water tanks as steam accumulators/sinks. Energy consumption and production costs would be reduced by insulating steam pipes properly.

a) Install a small heat exchanger to extract heat from the deaerator vent and use it to pre-heat feed to the deaerator.

b) Steam traps: regular steam trap testing weekly to monthly for high pressure (above 10 bars), monthly to quarterly for medium (2 bars to 10 bars) and annually for pressures below 2 bars are recommended.

c) Start using distillation columns to produce methanol from foul condensate.

3) Equipment inefficiency:

a) Dryer: Heat recovery from the dryer since is the highest energy consumer in the pulp mill.

b) Fan, pump and motor: Installation of VFDs on motors, properly sized motors, avoidance of throttling valves, properly sized pumps and pipes and trim impellers.

c) Air compressor system: Turning off unnecessary compressed air, air inlet temperature reduction and pressure drop minimization are recommended corrective measures.

4) Energy Saving Evaluation

Based on the data derived from the energy survey, several energy conservation measures were identified. To screen and finalize those that had significant saving potential to the mill utility (electricity and water), consumption and cost baseline for 2014 were used. The figures below provide an impetus for discovering energy conservation opportunities. Tables 9 and 10 show the consumption figures and costs for the year 2014.

Table 9: Summary of utilities consumption figures for 2014

Consumption	Unit	Quantity
Coal	t/t of production	1.75
Steam	t/t of production	6.08
Water	M^3/t of production	124
Power	kWh/t of production	1027.92

Table 10: Summary of utilities costs

Consumption	Unit	Rands
Steam	T	112
Water	M^3	2
Power	kWh	1.25

The criteria used to evaluate the cost-effectiveness of the savings was the payback method. The payback method was preferred because it shows the number of years it will take a measure to pay for itself using the stream of savings. It is also very prevalent and easy to calculate. According to the energy loss analysis, the opportunities identified are shown in Table 11.

Table 11: Evaluation of Saving Potential

Mill area	Saving justification	Energy reduction GJ/M	Investment cost Rands	Cost of saving	Payback period (months)
1) Use heat stored in a wet scrubber to pre-heat boiler feed water	Savings generated by reduced use ofcoal	13 024	70 000	420 000	2.4
2) Aim to reduce excess oxygen level to 4% to 6% at the coal-fired boilers. Currently, boilers operate at 8% to 12% excess oxygen to avoid problems with overheating grate shafts. E.g., install water-cooled shafts	Savings generated by reduced use ofcoal	23 154	93 000	550 000	2.0

3) Ensure monetization of excess black liquor. Currently, when there is too much black liquor to burn it immediately, it is sent to wastewater. Install storage tanks, so that it can be burned later	Increased blackliquor for steam production	571	13 000	22 000	7.1
4) Upgrading of screening/cleaning and bleaching equipment	N/A	64 614	82 000	430 000	2.3
TOTALS		**175 722**	**258 000**	**1 422 000**	**13.8**

Other Identified Energy Efficiency Opportunities

Substitution of V-belts with Flat Belts in Chipper Drives

During the energy audit, it was noted that v-belt-driven electric motors are being used at Pulp Mill A for chipper drives. V-belts have a major disadvantage in that the system results in continuous absorption of useful power adding to unnecessary operation costs for the mill. It is therefore recommended to replace v-belts with flat belts in chipper drives. Flat belts are recommended in that they are more efficient due to the increased gripping method. Furthermore, v-belts wedging action causes significant energy losses due to its engagement with the pulley as it is pulled in and out. Flat belts save energy as they require less energy to go around a pulley, as opposed to v-belts which result in significant wear due to different pitch-circle diameters. The energy saving of this measure would result in about 5% to 15% savings (Table 12).

Table 12: Operation data for chipper with potential energy saving at Mill A

Equipment	Load in Kw	Operating hours a year	Annual power consumption	Annual savings (5% of consumption)	Annual savings in Rands
Chipper 1	350	8 500	2 975 000	148 750	185 937.5
Chipper 2	350	8 500	2 975 000	148 750	185 937.5
Chipper A	630	8 500	5 355 000	267 750	334 687.5
Chipper B	630	8 500	5 355 000	267 750	334 687.5
Total savings					**1 041 250**

Investment, savings and payback of the energy conservation opportunity are shown in Table 13.

Table 13: Investment savings and payback in Rands

Category	Amount (Rands)
Cost of savings per annum (A)	1 041 250
Investment amount (B)	1 120 000
Payback (B/A X 12) months	13

Installation of VFD on Recycle Pump to Tower 3

During the survey, it was noted that the recycle pump was throttled by 75% at its discharge end. This pump is driven by a 90 kW motor, and the current drawn by the motor was found to be 125 amps (80 kW). It is hereby recommended to install a VFD to this motor. Installation of a VFD will result in proper regulation of the speed of the motor hence power reduction drawn by this system. This energy-saving measure will result in the reduction of power consumption by almost 30% of the installed capacity rating and this will save 30 kW per hour.

Table 14: Investment savings and payback in Rands

Category	Amount (Rands)
Cost of savings (A) (30kW X 8500 X 1.25/kWh)	318 750
Investment amount (B)	53 445
Payback (B/A X 12) months	2.01

Boiler 4 FD Fan Change of Material Design

Boiler 4 FD Fan has a designed motor rating of 160 kW running on a V-belt. During the audit, it was noted that the running load was 90 kW. The fan blades were also discovered to be made from cast iron which is heavy resulting in high torque being experienced in the driving system. It is therefore advised to replace the existing cast iron fan blades with fiber-reinforced plastic ones. Fiber-reinforced plastic blades are versatile and easy to manufacture and condition to meet different fan designs. In addition, fiber-reinforced blades do not corrode easily as compared to cast iron ones and hence have a longer life span. Considering the operating parameters of the fan, power savings of 20% to 40% can be achieved. Using a figure of 20% energy consumption reduction, a power saving of about 18 kWh will be observed. By changing the existing boiler fan with a fiber-reinforced one 15 300 kWh will be saved with an investment of R45 000 Table 15 below, considering 8 500 hours of operation per year.

Table 15: Investment savings and payback in Rands

Category	Amount
Cost savings per annum (A) (15 300 kWh X X1.25/kWh)	R191 250
Investment amount (B)	R45 000
Payback (B/A X 12) months	2.82

Chlorine Plant Hot Water Pump Replacement

During the energy audit, it was observed that two hot water pumps are being driven by 37 kW motors running continuously at the cooling tower of the chlorine dioxide plant. Instead of using two pumps, one pump can be sufficient for the requirements of the system if it is an energy-efficient pump with a motor rating of 55 kW. It was observed that now the two pumps are drawing 34.7 kW of power each. This energy-saving measure would result in significant energy savings as shown in Table 16. An amount of 118 800 kWh power per annum can be saved if the two motors are replaced by one 55 kW motor.

Table 16: Energy consumption and saving potential of cooling tower pumps in the chlorine plant

Description	Power kW
Power consumption of existing pumps (34.5 kW x 4 say 70 kW)	70
Estimated power consumption of proposed pumps (considering full capacity)	55
Amount of power saving	15

The investment saving and payback of energy conservation opportunity is shown in Table 17.

Table 17: Investment saving and payback in Rands

Category	Amount
Cost of saving (A) (15 X 8500 X 1.25/kWh	R159 375
Investment (B)	R62 745
Payback (B/A X12) months	4.7

Therefore, it is recommended to replace the existing pumps with a new one which will result in an energy saving of R159 375 per annum.

Vacuum Pumps Replacement with New Energy Efficient in the Chlorine Dioxide Plant

During the energy audit, it was observed that a vacuum was provided for the drum filter of brine sludge at the chlorine dioxide plant. Against design suction of 510 mm Hg, the vacuum was found to be developing only 400 mm Hg despite the chloride plant requiring 500 mm Hg. This is resulting in poor filtration of brine sludge. Therefore, it is recommended to replace the existing pump with an energy-efficient one with different specifications as shown in Table 16.

Table 18: Specifications of vacuum pumps

Description	Existing pump	Proposed vacuum pump
Capacity	860	900
Suction vacuum pump (mm Hg)	610	700
Motor rating (kW)	45	30
Running load (kW)	36	24

This measure will result in the mill saving 12 kW per hour resulting in a saving of R60 000 per annum considering 12 hours of operation for 330 days of operation per annum. In addition, filtration of the brine will improve significantly.

Investment, savings, and payback of the energy conservation opportunity are shown in Table 17.

Table 19: Investment saving and payback in Rands.

Category	Amount
Cost of saving (A)(800 X 8500 XR1.25/kWh)	R51 000
Investment	R34 450
Payback (B/A X12) months	7.4

Installation of a Metallic Gate for Easy Movement of Wood in the Water Channel

It was noted that wood logs are transported to chipper belt conveyors through a diverted water channel. Near each conveyor, the water channel bifurcates for feeding each chipper. The log flow to each chipper is controlled by adjusting the jack ladder operating speed. The logs then move onto the five splitters that separate the logs, so that they approach the chipper one by one. Belt conveyors move the logs toward the chippers. During loading at Chipper 3, the water channel is blocked by a sheet, but due to the diversion of water, both channel logs do not move freely and get jammed at this point resulting in idle running of chippers. Installation of a moving guide gate will result in free movement of the logs. The proposed gate in the flumes of the chippers in Pulp Mill A is shown in Figure 10.

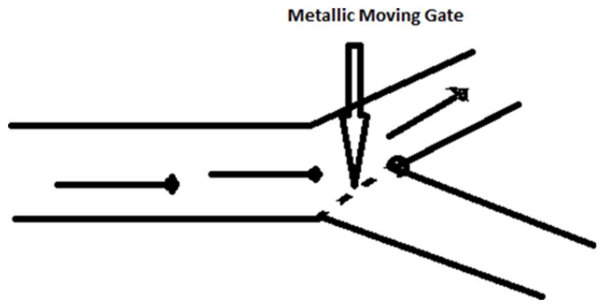

Figure 10: Metallic movable Gate

Fixing the metallic plate will result in the unidirectional flow of water in the channel. As a result, there will be no interruption in the movement of wood logs in the water channel which will result in the reduction of idle running hours of chippers. Investment savings and payback of the energy conservation opportunity are shown in Table 20.

Table 20: Investment savings and payback in Rands

Category	Amount
Cost of saving (A)(400 X 330 X 1.25/kWh	R185 625
Investment (B)	R75 000
Payback (B/A X12) months	4.8

By adopting this measure and fixing a guide gate in the water channel, the running hours of chippers may be reduced to 32 hours as opposed to the existing 35 hours resulting in an energy saving of 450 kWh per day amounting to R185 625 per annum considering 330 days of operation in the year with an investment of R75 000 only with a payback of 4.8 months.

Summary of Energy Conservation Opportunities

The cost savings and investment of energy conservation opportunities are summarized in Table 21. An amount of R3 429 250 can be saved per annum by investing R1 718 640. By implementing energy-saving proposals the mill can significantly reduce the consumption of electricity and steam.

Table 21: Summary of the cost savings and investment opportunities

Total Savings per annum	Investment Amount
R3 429 250	R1 718 640

Other Unquantified Identified Projects

- Repair leaking steam pipes and broken steam traps on site. Properly maintaining steam traps. Saving justification: steam saved.
- Insulate steam pipes properly. Uninsulated pipes lead to radiative losses and higher steam consumption. Saving justification: steam saved.
- Form an interdepartmental group that will work on increasing condensate recovery. Currently, only 30% of the condensate is recovered, e.g., ensure infrastructure is in place to recover condensate saving justification. Save on energy contained in condensate.
- Manage steam venting better, by either using steam pipes, deaerator tanks, or demineralized water tanks as steam accumulators/sinks. Currently on average 6 tons/hr. of steam is vented due to rapid swings in steam demand. Aim to be able to absorb these steam swings in the steam network or use cold water tanks as steam sinks to lose no energy. Energy saving justification: reduced use of coal.

- Start using a distillation column to produce methanol from foul condensate. A distillation column is already installed on site, but not used. It can produce methanol that can be burned in recovery boilers.
- Switch off one aerator. Demand for condensate recovery is 300 tons/hr while installed capacity was noted to be 450 tons/hr. Each aerator has 2 ton/hr condensate lost due to plume venting. Running with one less aerator and rotating them weekly to avoid corrosion will yield significant savings in low-pressure steam and reduced coal usage.

Summary

The findings have revealed that energy losses are indeed occurring in the plant, and there are possible savings that can be achieved by following some structured processes as outlined above. In this limited period of one year, a total of energy savings worth over 3 million Rands were identified and could be retrofitted into existing processes without affecting production output. Identifying energy losses and taking steps to eliminate these energy losses has economic and environmental benefits.

Conclusions and Recommendations

This work has analyzed the energy consumption of a major energy-consuming pulp mill and the factors that influence energy efficiency adoption by the P & P industry using the pulp mill as a case study. The main objective of the research was to identify areas of energy losses in pulping processes and from the results a total of 629 207 GJ/M of energy losses were experienced by the mill in the trading year 2014-2015. These losses occurred in energy distribution channels, boilers and electricity generation units and due to equipment inefficiency. The energy loss profile was then used to identify energy-saving measures that can be taken to reduce the energy losses without affecting the pulping processes. A total of 10 projects were identified and their savings and investment were quantified. To identify the losses an energy audit was carried out on a pulp mill. The data collected from the audit was used to formulate the energy flow profile of the pulp mill. The energy flow profile helps to identify energy losses occurring inside a system boundary such as a pulp mill. Some of the recommended corrective measures that were suggested for boiler and generation energy losses included the use of heat stored in wet scrubbers to pre-heat boiler feed water, reduction of pre-heating boiler feed water using low-pressure steam when turbines are not being used and increasing electricity production by reducing low-pressure steam network operating pressure.

Measures suggested to reduce electricity distribution losses include repairing leaking steam pipes and broken steam traps on site, and proper management of steam venting by either using steam pipes, deaerator tanks, or demineralized water tanks as steam accumulators/sinks. Suggestions to curb equipment energy losses include installation of VFD on electric motors, and proper sizing of pumps and its piping system. The main aim of this study was to identify areas where energy is being lost during P & P production at Mill A. The research study managed to achieve this and has recommended corrective measures that are practical and feasible.

An investigation into factors influencing energy efficiency adoption found that there are many barriers to energy efficiency adoption by the P & P industry. Major barriers identified by the research were “energy costs are sufficiently important” and the slow rate of return of investment in energy efficiency projects. Other noted barriers were capital availability, staff shortage for energy projects and uncertainty regarding the future of pulp mills. Key drivers to energy efficiency that were unveiled are government policy and corporate support. The understanding of barriers to energy efficiency adoption allows a better understanding of factors affecting industry and this initiates a more detailed analysis which will enhance efforts to reduce energy consumption and greenhouse gas emissions.

Recommendations

- Traditional housekeeping management was identified as an important way for the mill to save energy, specifically active programs to monitor and prevent motors being left open and repairing steam leaks and compressed air leaks.
- Present instrumentation at the mill should be repaired, particularly automatic steam controls and steam and electricity flow meters should be installed, particularly steam. Instrumentation maintenance programs should begin. The plant must have the necessary skills to repair and maintain the instrumentation.
- The procurement team must include energy efficiency criteria in their ordering of equipment. This must be accompanied by additional training for procurement personnel on energy efficiency; this can be accomplished easily if external vendors are allowed to undertake some lectures on their products. This should also occur for contractors to verify their level of knowledge in terms of energy efficiency.
- Production and energy data are being reported at different time intervals, they need to be correlated to gain a clear picture of production vs energy ratio.
- For management to gain more ideas, employees must be requested to send their ideas for energy saving to a central location where they will be screened and captured. This will also instill confidence in employees as they will feel valued.

After studying barriers and drivers to energy efficiency adoption, the overall recommendations for industry and government suggested by this research are for the government to put aside funding for energy efficiency initiatives and energy auditing, more senior management involvement in energy efficiency initiatives, and more energy efficiency awareness for organizations so that all employees become aware. The researcher also recommends sector-specific energy surveys so that every organization best understands its energy profile pattern.

The research concludes that pulp mill energy efficiency analysis can significantly help a P & P plant to improve its energy efficiency and reduce its CO2 emissions with knowledge of areas of energy losses.

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