Application and impact of tribology in energy-an overview

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Abstract. The use and effects of tribology in the field of energy are the subjects of this term paper. By calculating how energy use, economic output, and pollutants are all impacted by friction and wear, it discusses how tribology can be used to reduce the amount of unnecessary energy used by mechanisms, which is important in reducing the number of emissions produced by different industries. In turn, this enables industries including transportation, energy, mining, and paper production to reduce their overall energy use and emissions. Additionally, since the effect of friction cannot be directly estimated in the mining industry since it is less developed, we analyze the effect of wear in the mining industry by computing the friction loss as a component of the overall energy consumption looking at the downtime in materials, the overall number of mines in the world, the quantity of energy used the mining and the equipment's life expectancy. This report also discusses current developments in novel materials, lubricants, and design modifications that have the potential to cut energy losses by 18–40%, primarily due to friction and wear. Up to 8.7% of the world's total energy use and 1.4% of GDP might be saved (GNP).

Keywords: Tribology, energy, application, friction, wear

1. Introduction

Global energy consumption has significantly expanded since the start of the industrial revolution and is currently at 400 exajoules (EJ) each year. Much of the energy produced now is still based on fossil fuels, as it was in those early years, which, it must be said, has had a very negative effect on our environment. Today, just vehicles utilize about 30% of all energy produced, and of that, many machines' moving parts still lose around one-third to friction and wear. To lower the amount of unneeded energy used by mechanisms and, consequently, the amounts of emissions produced by different sectors, the science of tribology is being applied. For many years, tribology information has been employed by scientists to comprehend the roles of wear and friction between two surfaces that come into

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1.1 Role of Tribology in energy efficiency

Given how much energy is lost through friction in mechanical components nowadays, tribology is extremely crucial. We must reduce the quantity of lost energy if we want to utilize less of it. In sliding contacts, significant energy is lost owing to friction. Therefore, a greener and more sustainable future depends on developing ways to reduce friction and wear using innovative tribology technology.

In the following years, there will likely be an increase in global energy use, placing pressure on the environment and resources. At the same time, friction wastes a significant quantity of energy; for instance, seven quads of energy are lost yearly due to friction in passenger cars worldwide. Further waste is produced when contacting materials wear out since it takes a lot of energy to replace them and wear-induced failures can have high financial, environmental, and safety impacts. In addition, a lot of the difficulties that new energy-efficient technologies, like wind turbines, face are tribological in nature. As a result, tribology is crucial to solving some of the world's most pressing problems about energy efficiency and the effects that energy use has on the economy and society.

Wear and friction issues can reduce a machine's efficiency and increase its energy usage. [1] presented their research on the consequences of friction on worldwide energy output, business, and the environment in the transportation and industrial sectors in 2015. They arrived at the result that reducing friction requires 20% of the power generated globally. Therefore, reducing friction and wear can result in significant energy and financial savings, as well as lower CO_2 emissions. One of the primary study areas of actual tribology is the development of novel lubricants that can accomplish these objectives without harming the environment.
People have been extracting substantial materials from the crust of the earth for long periods using a variety of techniques. These techniques consist of strip mining, quarrying, excavation, and open-pit mining. Advanced mining operations go much further than such substances to just provide raw resources that enhance the security and life quality of individuals in the current industrialized civilization, even though a large percentage of cultural mining operations concentrated on trying to dig for iron, silver, gold, tin, copper, lead, coal, and diamonds Even though there is much wide range of options and types of mines across the globe, ranging from small top mines to huge manufacturing deep mines which extract ores

from several km below the earth's surface, all mines function utilizing the same basic mining processes.

There are various steps in mining, such as Loading, Excavation, Breaking, Transport, and Hauling. The fragment size is reduced during mineral exploration, and many beneficiation methods are used to remove gangue minerals to produce products of higher grade (e.g. flotation and gravity separation). Mining is a very energy-intensive activity because of all the aforementioned steps. In reality, it's estimated that the mining and mineral industries use between 4 and 7 percent of the total energy produced worldwide. A significant portion of energy consumption in mines is related to friction and wear losses, in addition to the necessity for high energy-consuming procedures such as rock breaking, crushing, loading, hauling, transportation, pumping, and ventilation maintenance in underground mines.

In a highly advanced contemporary society, manufacturing, power generation, and transportation are essential industrial operations. To move both humans and all types of work in a variety of shapes, they make use of a wide range of mechanical systems and machinery. These systems contain numerous mechanical parts and, consequently, interacting areas. Such machines' ability to operate smoothly, consistently, and over an extended period depends heavily on how effectively wear and friction are managed across all of their multiple interacting surfaces. Since 1966, the field of science and technology known as tribology has focused on understanding and controlling the frictional, wearing, and lubricating of these interacting surfaces when they are in action [2]. Wearing malfunctions had enormous negative economic repercussions on Britain's production & society in the middle of the 20th century, which served as the primary impetus for the establishment of the new science of tribology. During the same period, numerous innovative technological solutions that could be employed to lessen friction and wear had been devised, but they had not yet been widely used. According to Jost's research, large-scale utilization of newer, more cutting-edge tribological innovations might result in yearly savings of 515 million UK pounds, or 1.36% of the country's GNP at the time. The analysis specifically stated that such savings might be made within ten years, which was crucial. After receiving 1.25 million pounds in 10 years from the British government towards the advancement and application of tribology in research, education, and industry, the savings were expected to be 200 million pounds per year [3]. Other analogous studies that were conducted after the Jost study indicated similar potential savings in China (2%-7%, 1986), the Us (0.79%-0.84%, 1977, 1981), Germany (0.5%, 1976), and Japanese (2.6% of the GNP in 1970). Big differences between the expected savings are likely caused by variations in each country's level of industrialization and industrial infrastructure, as well as by the year that calculations were done and the calculating method that was employed. Since the time of the Jost report, there has been a significant advancement in our understanding of the basic mechanisms underlying tribological phenomena and the creation of a wide range of other technological innovations, such as better design, advanced materials, interface techniques, and lubricants, that can significantly reduce friction and enhance wear protection. Additionally, the expanded information derived from the aforementioned international tribological investigations has been applied in higher education and industry. However, due to an expanding global population, rising energy demands, and restrictions on the use of fossil fuels because of environmental concerns, our civilization is currently facing new difficulties. These days, it has become crucial to limit the use of fossil energy, which will combat climate change to ensure the sustainability of global society. End-use energy efficiency is anticipated to have the greatest impact (38%) and tribology could make a significant contribution in this area, new feature design with sensor systems, the latest innovative alternatives like fresh surface treatments, surface technology (including surface modifications, adjustments, and texture mapping), fresh petroleum products and preservatives (including nanoparticles and solid lubricants), new bioengineering, nanotech, and integrated computation methods, and so on [4]. The notion of

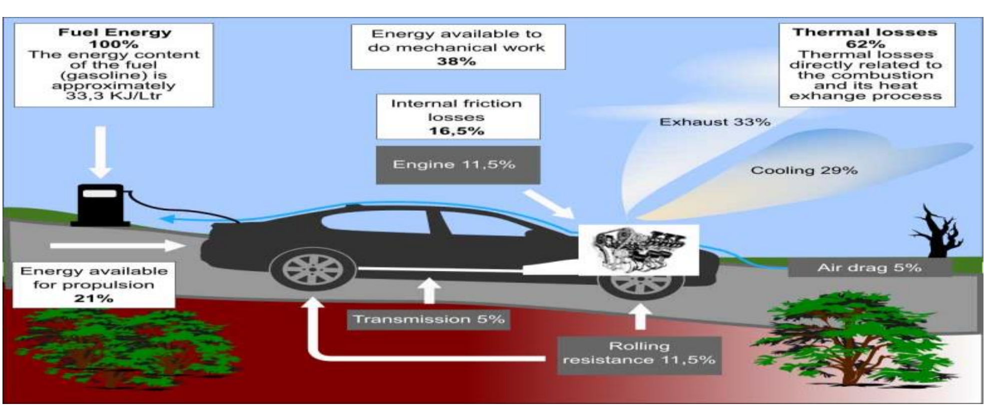
"eco-friendly tribology," was newly established and is defined as the tribe components of ecosystem functions, bioeffects, and environmental effects, is concerned with the effects of contact pressure on global energy demand in passenger vehicles, lorries, buses, and paper machines as well as the effects from both wear and friction in the mining industry [5].
Using data from major energy-consuming sectors of transportation, paper production, mining, and the energy industry, we will assess how wearing and resistance affect the amount of energy used globally, the cost to society, and greenhouse gas emissions. We will then calculate the potential savings that could be realized by utilizing new tribological solutions that have emerged in the last few years. Based on information from the previous case studies as well as information from other publications, this is accomplished.

1.2 Energy usage worldwide and the effect of friction and wear reduction in energy efficiency.

Each year, the human race uses enormous amounts of energy. Some energy sources can be used immediately; for example, burning coal or natural gas to heat a home. However, energy sources are more frequently employed to create electricity, which has a nearly infinite number of uses. These include residential heating and cooling, food preparation, and powering a wide range of contemporary technologies, such as satellites, computers, cell phones, and medical equipment.
A 2017 study by Holmberg et al, discovered that as a result of expanding societal needs and a variety of commercial activities, there has been an upward trend in the demand for energy globally since the turn of the century. The ultimate power consumption increased globally by 2.3% in 2013 to over 9300 Mtoe, with the global energy demand doubled over the preceding 40 years (equivalent to 390 EJ). Even while new renewable energy sources are constantly being created, non-renewable fossil fuels, over 80% of the world's energy is still provided by petroleum, coal, and gas. The biggest contributors to greenhouse gas emissions are these fossil fuels. 2012 saw an additional 1.4% rise in the energy consumption of CO_2-generating energy sources [6].
All types of mining, including quarrying, underground excavation, strip mining, open-pit mining, and the processing of solid minerals taken from the crust of the earth, are included. For countless years, digging has served as an essential part of human activity. since it offers the raw materials needed to improve safety and both improved living standards and helped create the modern industrial world. the uncovering of coals, diamonds, lead, tin, gold, silver, copper, and other metals has been among our collection of experiences' most significant mining operations for a very long time [6].
Total energy consumption must be calculated by combining data on the consumption of several energy sources, including but not limited to electricity consumption by nation, oil consumption by nation, gasoline consumption by nation, and coal consumption by nation. When nations are compared, the variations in population size reflect the overall energy use. This implies that the relationship between energy use and population density is inverse.
Energy is a very important resource for the industry. They require a lot of energy, which must be provided given the plants and machinery in use. Due to industries' comparatively higher energy needs than households, industrialization is a significant factor in energy consumption. Energy demands have been rising steadily since before independence in Nigeria, where the majority of power is produced through hydroelectricity. However, it's crucial to remember that demand and supply are woefully out of balance. This has caused consumers to hunt for alternative sources of energy, with many resorting to solar energy or petroleum product generators. The need for energy has increased significantly since before independence due to the introduction of new and improved technology, but the supply has not significantly improved because power generation has been neglected by numerous government

administrations. As a result, the power grid has been continuously collapsing. There have been numerous economic downturns. This has had a significant impact on energy consumption going back to before independence because many companies have been financially handicapped by the high cost of generating power on their own due to inflation and a lack of supply. The economy continues to decline as a result. This has indirect effects on both the population and demand since, during recessions, foreign investors pack up and go because they can no longer operate at full capacity due to the high cost of living. Companies like Nestle and GSK have disbanded over time. This has also discouraged potential investors from making investments in Nigeria, which hurts Internal Generated Revenue (IGR). A portion of the population is now unemployed due to the crippled industrial sector. These harm both the (GNP) and (GDP). The terrible economic situation has also hurt consumers in general (GNP).
The purchasing power of the population of a country has a significant impact on the standard of living of every financial class within that nation. Due to inflation, Nigeria is currently experiencing an economic muddle that is actively eradicating the middle class. However, there is a severe mismatch between the supply and demand of energy, which has resulted in scarcity. Because scarcity frequently raises the price of general commodities, this has had an impact on the nation's electricity pricing. forcing people to use less energy because it is too expensive.

1.3 Effect of Friction and wear reduction on energy efficiency
A machine becomes less efficient when there is friction. For a machine with friction, the quantity of friction must be multiplied by the ideal input force or effort to produce the desired output force. As a result, the force's mechanical advantage will be reduced. The number of times a machine can handle additional force is referred to as its mechanical advantage (MA). Efficiency is determined by how much friction and other variables detract from a machine's theoretical maximum work output. A machine with no friction would have 100% efficiency. Friction creates heat, which is energy that should be converted into motion. Heat is produced as a result of the energy loss.
When two surfaces move or spin against one another, whether or not they are lubricated, friction occurs. Normal places for this to happen include camshafts, valve stems, bearings, and transmission, as well as the interface between piston and cylinder walls. Despite substantial study in many areas, the creation of new materials, enhanced lubrication, and enhanced design, still necessitate a significant amount of energy to minimize friction.
Rubbing provides a beneficial role in the slowing process. You can consider any object as a vehicle, such as a bicycle, and if you were the one in control, you would apply the brakes to slow down or stop the bicycle. When you press the brake, the braking system will initiate



contact with the turning wheel. The wheel will travel less quickly or even not at all due to friction.

Figure 1: Energy losses in an internal combustion machine [7].

Considering the diagram above, Mechanical power makes up 38% of the fuel's energy after thermal losses. 38% of these; The transmission uses 5%, while the engine uses 11.5 percent of this to overcome friction.
The remaining fuel energy for propulsion is 21.5 percent, 11.5 percent for rolling resistance reduction, and 10 percent for air drag reduction and vehicle acceleration. Whenever the brake pedal is pressed to slow the vehicle down, the energy utilized to propel it is wasted [7]. Hysteresis losses account for the majority of the rolling resistance, which is 15.5%. When the brakes are applied to slow down the car, it loses the power that was needed to move.
V-belts are used in several industrial applications to transfer power from one machine to another. However, a V belt cannot do this without friction between the machines.
When you ride a bike on the road, you can also feel it because we can't even ride bikes without friction. If you picture yourself riding a bicycle on a muddy road during a rainy season, the bike will swerve because the friction of the road will be reduced. Friction hence has many useful uses in both engineering and daily life.
Wear is mechanically induced damage to a surface that results in the result of the surfaces and material or materials' relative velocity in contact with it, causing the material to gradually be lost. A fluid, additional surface, or hard, large granules in a fluid or suspension, like a lubricant, are examples of interacting substances. Wear, like friction, can be helpful or harmful. Cutting, grinding, polishing, and machining are a few examples of procedures that result in regulated and productive wear. However, because wear results in components degrading or even failing, it is a very costly problem in the majority of technological applications. It is frequently not as severe or sudden as a fracture when it comes to safety. Wear can be measured (correlated) by using mass or amount of material lost per unit of sliding distance. The two main ways to represent it are the constant wear coefficient (K) and the tool wear (wear capacity per unit-imposed amount of load/unit sliding distance).
Lubrication will lower friction, which will lower losses and boost efficiency. Friction causes machines to warm up and slacken. Excessive use slows down and wears down parts, which has a negative effect initially on efficiency. Additionally, metals expand as a result of the heat produced by friction. Friction is the enemy of ideal mechanical effectiveness. Mechanical friction losses can be decreased by changing sliding metal contacts to rolling contacts, lightening the load on moving parts, tightening tolerances during production to improve the fit of pistons with bores, and improving lubrication between sliding or rolling parts.

2. Frictions and wear's action on energy usage, financial setbacks, and pollution

2.1 Transportation

13113 million tonnes of oil equivalent, or 549 EJ, were produced as energy globally in 2011 (Total Primary Energy Supply, TPES)[1]. This left 373 EJ for the world's final energy consumption after power stations, burners, energy transportation inefficiencies, and the energy sector each accounted for one-third of its consumption. itself (Total Final Consumption TFC). In addition to households and services (35%) and other energy consumers like industry (29%), transportation (27%), and industry (29%), this portion was also utilized for raw materials (9%) and non-energy purposes (such as households). By a factor of 152 EJ, oil accounts for 41% of the world's energy supply.

Since the start of the industrial revolution, CO_2, the main greenhouse gas, has been gradually rising in the atmosphere. In 2011, it reached a level of 31,600 Mt. [1] 23% of this (7200 Mt) was produced by global transportation, with road transport accounting for the lion's share of this. Road traffic accounted for 71.7% of all Carbon dioxide emissions in Europe related to transportation in 2009; marine transportation contributed 14.6%; aviation contributed 12.3%; and rail transportation produced 0.8%. 63% of the total oil used globally is used for transportation. The remaining portion is utilized by a business producing raw resources as well as other uses. Road traffic consumes the most energy (73% of all energy used in the transportation industry), followed by rail (3%) traffic, then marine (10%), and aviation (10%) (Global, 2011). However, ships (75%) and trains (13%), followed by automobiles (12%), and airplanes (0.3%), transport the vast bulk of the globe's freight [8].

Friction uses between 25 and 30 percent of the energy used in the transportation sector. But recent tribological research and inventions have produced ground-breaking technologies where contact has been reduced even by 50percentage to 90 percent less than the average amount seen in modern automobiles. Holmberg et al [9] studies for large trucks show the power loss from resistance could be cut by 37% if the world's vehicles all adopted the most cutting-edge tribological solutions now used in modern commercial heavy vehicles. This factor would be lowered by 60% if the top tribological products now in use in research laboratories were utilized, then by 68 percent if such new products predicted for usage in 2025 were used. It would take a lot of work and money to install the most cutting-edge commercial solutions available today in every truck and bus, which is not economically viable. Nevertheless, it would be plausible to predict that massively focused study, innovation, and implementation efforts on innovative tribological solutions, which result in a 14% decrease in fuel consumption, may attain within 4 to 8 years, this amount will drop to 50 percent. It was concluded that long-term fuel consumption decreases of 37% were feasible. Because there are fewer heavy-duty vehicles in the worldwide fleet, fewer people own them, and they are more organized than users of transport vehicles have assumed that modifications to lessen losses due to friction will be simpler to implement and will, thus, have a greater immediate impact. Heavy-duty vehicle penetration into the global fleet market is predicted to take 4 to 8 years, as opposed to five to ten years for passenger vehicles.

2.2 Paper production

The power required to eliminate friction in a paper machine, a sophisticated factory output machine, was determined by Holmberg et al. in another study [10]. In 2012, 8525 paper machines were running throughout the world, and they required 101,400 GWh of electricity to reduce friction. In this study, the worldwide the typical paper device and its normal operating conditions worldwide were defined using the same methods as above for vehicles. This device underwent a thorough analysis. A maximum of 30% of the overall energy required by the machine is represented by electrical energy. The remainder is made up of 67% process heating steam energy and 3% manufacturing fuels. 9.2% of the total energy used by the paper machine and 32% of the electrical energy are consumed as a result of direct friction losses. This was utilized in the following ways: 48% in water-lubricated sliding contacts at textiles (23%), HD contacts (9%), water-lubricated sliding connections at doctor blades (2%), and sealing boundaries lubrication seal contacts (18%). In the near term (about 10 years), using slashing technology for friction reduction might decrease losses due to friction in paper machinery by 11%, and in the long run (around 23.6%), according to predictions. A total of 10.6 million tonnes of CO_2 would be emitted globally as a result, with short-term economic savings of €2 billion, long-term savings of €4 billion, efficiency gains of €78,000 GWh, and a €22.7 billion Carbon dioxide pollution control. There are several potential strategies for reducing resistance to motion in paper machines, such as the implementation of low-resistance and incredibly resilient coating materials, exterior advanced technologies with surface texture, lowered as well as whittled down lubricating oils but also fluids, novel substances, materials science in seals, doctor blades, and textile materials, along with creative designs.

2.3 Mining industry

During a study, the power needed to reduce resistance and the financial implication of aging in the mining sector were looked at. The mining business is technically far less developed internationally than the paper industry, as well as the interaction especially in the case of a material breakup, in sliding interactions and crushing, are quite severe [1]. An unadjusted tribological analysis of power losses in mining would not be very reflective because wear plays a significant role in energy usage in the mining industry. Contrary to friction, wear cannot be described by a single general term, making the wear problem more difficult. Measures such as the use of friction coefficient and wearing factor are common in many wear circumstances, including abrasive, destructive, anytime the moveable counterpart is deplorable and erosive decay is mentioned. But not all wear scenarios allow for their use. As a result, there are many different methods for describing wear in the available literature, which would include wear rate, volume, depth, and size of the worn grooves, etc. [11,12]
This method is outside the purview of the study and present state of practice since it requires relevant data that is not currently available in a unified form to calculate the energy parameters associated with wear. Due to this, a different strategy has been employed, and that is to estimate the costs associated with these energy factors. Since we now have useful data from the sector, this is simpler. Following the maintenance share of the turnover by keeping an eye on the expenses for replacement parts, maintenance labor, and downtime is a standard practice in the industry. This is frequently carried out for both individual machines and entire systems. Costs associated with production loss due to wear failure during downtime are also calculated. As a result, all categories of wear problems as defined in an industrial environment are taken into account in the computations.
To meet the standards of the U.S. mining industry, 32% electricity, 34% diesel,10%coal, 2% gasoline, and 22% natural gas are used. Typically, 42% of the energy used was for material handling, 39% was for processing, and 19% was for extraction. Material handling uses diesel fuel 87 percent of the time (US DOE 2002, US DOE 2007). Individual mining equipment's and equipment's typical energy consumption breakdown is provided (US DOE, 2002).

2.3.1 Mining energy consumption analysis

Breakdown of worldwide mining units' average energy uses the estimations below are made as computations' input data:
-The mineral mining sector uses 12 EJ/an of energy globally.
- There are 150,000 mines and quarries in all. (This figure accounts for rock excavation)
- While the remaining quarries and mines are smaller, 5,000 of them are large industrial mines;
- 9,6 EJ/a, or 80 percent of such energy utilized in the mining sector, is used by the 5,000 big industrial miners.
- Most industrial mines are surface-based, with about 15% of them being underground.
1,700 significant mineral processing facilities, based on the estimation that there are 2-4 times as many mines and facilities worldwide;

The 5,000 major industrial mines are thought to consume 80% of all the power used in mining, which may seem excessive considering the small total number of mines. Here, it is taken for granted that the overall number of mines globally also includes those that are no longer operational and a sizable number that is only sometimes used, depending on the price on the market, or only used briefly. When comparing our estimate to the average annual energy consumption, taking into account the energy used to extract each tonne of ore and the recovery rate from a Canadian mining study [13], 30 to 50 percent of the energy needed in mining is generally spent in mineral processing. Approximately 19–4–5 times more energy is used in underground mining than in surface mining (20–50 kW/t compared to 5–10 kW/t) [13-22]. According to a different estimate, underground mining uses 180 kWh/t of energy on average compared to kWh/t for ground extraction is 25 [23] In the US, surface mining produces 10 times more ore and coal than deep mining [22] It is determined that while the annual mining output of surface mines is approximately seven times greater than that of underground mines, the energy intensity of surface mines is approximately seven times lower. This indicates that the yearly energy consumption of both top extraction and subterranean mining is nearly equal. We reach the following conclusion on the distribution of energy in mining: - Surface mining uses 30% of the energy, or 3.6 EJ, whereas mineral processing uses 40% or 4.8 EJ. Additionally, we determine that the 5000 big industrial mines worldwide annually use the following amount of energy:

- 4250 surface mines produce 2.88EJ,
- 750 underground mines produce 2.88EJ, and
- 1700 processing companies produce 3.84EJ.

Given the typical global mining units we previously mentioned, we can now estimate the typical annual power consumption of the huge industrial operations that make them up.

- The average global surface coal mine produces 5,80 TJ/a (0.19 TWh/a), the average global ferrous iron processing facility produces 4,260 TJ/a (0.63 TWh/a) and the average global underground copper mine produces 4,840 TJ/a (1,07 TWh/a),

Information from the was used to produce the allocation of power used for mining activities [13-15, 18-20 24-26].

Mine 1990	Number of mines	Total energy	Friction		Wear replacment parts		Maintene labour	Downtime spare equipment		prod loss	Wear total	total	Total friction and wear	
Parameter			energy	cost	energy	cost	cost	energy	cost	cost	energy	cost	energy	cost
Unit		TJ	TJ	kEuro	TJ	kEuro	kEuro	TJ	kEuro	kEuro	TJ	kEuro	TJ	kEuro
Calc step	2	1	3	4	6	5	7	11	8,9,10	11,12	13	13	13	13
GA underground	750	3638	1614	29046	469	13408	13408	32	646	3352	502	30815	2115	59861
Crushing wear CAW		534	160	2886		5772			250					
Abr impact wear AIW		683	218	3932		3932			102					
Lubricated wear LW		2421	1235	22228		3705			295					
GA surface mine	4250	671	290	5227	83	2383	2383	5	103	596	89	5464	379	10691
Crushing wear CAW		43	13	231		461			20					
Abr impact wear AIW		227	73	1307		1307			34					
Lubricated wear LW		402	205	3689		615			49					
GA processing plant	1700	2259	742	13348	477	13632	13632	20	405	3408	497	31076	1239	44424
Crushing wear CAW		226	68	1220		2440			106					
Abr impact wear AIW		1911	611	11005		11005			285					
Lubricated wear LW		122	62	1123		187			15					

Figure 2: The average worldwide underground mining, surface mine, and mineral processing unit's energy loss and wear-related costs [1]

https://doi.org/10.1051/e3sconf/202339101081

Mine 1990	Friction		Wear replacment		Maintene	Downtime			Wear		Total friction and	
			parts		labour	spare equipment		prod loss	total	total	wear	
Parameter	energy	cost	energy	cost	cost	energy	cost	cost	energy	cost	energy	cost
Unit	PJ	MEuro	PJ	MEuro	MEuro	PJ	MEuro	MEuro	PJ	kEuro	PJ	MEuro
Underground mining	1513	27230	440	12570	12570	30	606	3143	470	28889	1983	56119
Surface mining	1543	27766	443	12659	12659	27	545	3165	470	29028	2013	56794
Mineral processing	1576	28364	1014	28967	28967	43	861	7242	1057	66037	2633	94402
	4631	83361	1897	54197	54197	101	2012	13549	1997	123954	6629	207315

Figure 3: Worldwide, underground mining, surface mining, and mineral processing all experience energy loss and wear-related expenses [1]

3. Friction and wear-reducing means and technology

3.1 Bearing

A bearing is part of a machine that reduces friction between moving parts and restricts relative motion to only that motion that is desired. The design of the bearing may, for example, allow the moving part to move freely in either a linear or free rotation around a fixed axis. Managing the normal force vectors operating on the moving elements may likewise be used to prevent motion [27]. To facilitate the intended motion, the majority of bearings minimize friction. According to what kind of function, the motions permitted, or the orientations in which forces are delivered to the parts, bearings can be categorized into a variety of subcategories. In general, bearings avoid unwanted metal-to-metal contact between two parts in motion. This prevents wear and tear on the parts by reducing heat and friction output. Additionally, energy consumption is reduced since low-friction rolling replaces sliding action.

Plain Bearing

A plain bearing is the most basic form of bearing since it only has a surface and no moving parts. In the railroading sector, it is likewise referred to as a solid bearing or slide bearing, or sliding contact bearing. In general, plain bearings are the most affordable kind of bearing. They also have a great load-carrying capability, are lightweight, and are compact [27]. Depending on where it is used, it is typically constructed of cast iron, bronze, graphite, steel, or hard plastic. Sleeve bearings are the most prevalent type of plain bearing (Figure 4).

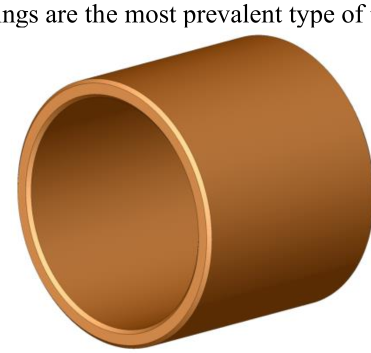


Figure 4: A simple sleeve plain bearing [27].

Rolling element bearing

It is a bearing that bears loads by sandwiching moving parts, like balls or rollers, between two concentric rings with grooves referred to as races. It is sometimes referred to as a roller bearing. Races' corresponding relative mobility results in comparatively little sliding and rolling resistance of the rolling elements. The advantage of rolling-element bearings is that they provide a fair balance between cost, carrying capacity, size, weight, toughness, precision, friction, and other factors. A ball bearing is the most common kind of roller element bearing [27]. Other types of rollers include gear rollers, tapered rollers, needle rollers, and spherical rollers (Figure 5).

Figure 5: A ball bearing [27].

Fluid bearing

A thin, quickly moving layer of pressurized gas or liquid is formed between the bearing surfaces in fluid bearings to sustain the load. Fluid bearings (Figure 6) are less susceptible to resistance, wear, and disturbance than many other types of bearings while there is no connection between the moving components and no sliding friction as a result. As a result, some fluid bearings may experience almost no wear when operated properly. There are several general categories of bearings, including hydrostatic and hydrodynamic bearings. Pumps are used to apply external pressure to the fluid in hydrostatic bearings, which are frequently formed of oil, water, or air [27]. With the help of the high speed of the journal, the part of the shaft that rests on the fluid, hydrodynamic bearings pressurize the fluid in a wedge between the faces.

Figure 6: A fluid bearing (Velling, 2020).

Magnetic bearing

A particular kind of bearing called a magnetic bearing relies on magnetic levitation to support loads. Without any physical contact, magnetic bearings support the moving parts. For example, they can levitate a rotating shaft and permit relative motion with negligibly wearable mechanical parts and very little friction. Magnetic bearings, which have no absolute speed limit, are capable of supporting the highest speeds. Magnetic bearings (Figure 7) have the advantages of operating in a vacuum and without lubrication, as well as extremely low and predictable friction. Magnetic bearings are being used in a growing number of industrial components, including compressors, turbines, pumps, motors, and generators.

Figure 7: A magnetic bearing [27].

Flexure bearing

One specific type of flexure used when one or more angular degrees of freedom must be flexible is called a "flexure bearing". Flexure bearings frequently make up supplementary mechanisms. In circumstances requiring angular compliance, flexure bearings serve a similar purpose to traditional bearings or hinges. However, because they have virtually no friction, flexures don't need to be lubricated. Flexure bearings (Figure 8) have the benefit of being more affordable and simpler than the majority of other bearings. Additionally, they are frequently compact, light, frictionless, and simpler to repair without specialized tools. Flexure bearings have some limitations, one of which is that they can occasionally be too small for bearings that carry heavy loads

Figure 8: A flexure bearing [27].

Composite bearing

A composite bearing(Figure 9) is a bearing formed from a mixture of materials, such as an upgrade with fiber, and it may also contain lubricants and other components that reduce friction. Several applications, including those requiring wear- or high-temperature resistance, can have composite bearings specifically made to fit their needs. The composite bearing's backing might affect how much it weighs. You can use a steel or alloy backing for applying the PTFE liner. Filler compounds allow for the optimization of several composite bearing characteristics, including creep resistance, wear resistance, and electrical conductivity.

Figure 9: A composite bearing [27].

3.2 Lubrication

Lubrication is the application of a thin lubricant coating between surfaces in contact to lessen friction wear and tear and permit the smooth operation of components in touch [28]. An element known as a lubricant lessens wear and tear on moving surfaces by reducing friction.

Grease is made by mixing thickeners with oil, which is commonly mineral oil (such as lithium-based soaps). Lubricants like graphite, molybdenum disulfide, and other materials may be mixed with additional particles. Grease's ability to combine effectively with oil's lubricants adds stickiness and makes it possible for the lubricants to adhere to surfaces[29]. Grease can also operate as a barrier, shielding surfaces from all contaminants with the potential to damage them. Grease is also used as a barrier or to protect surfaces from various contaminants. For instance, various oils and greases were available in a variety of consistencies. Due to its excessive thickness and sticky nature, grease has drawbacks that can quickly result in resistance in fast-moving machines. Various kinds of grease are calcium grease, Lithium grease, sodium grease, etc. Uses include linkages, gears, and chains.
Oils are these thin liquids composed of long polymer chains as well as certain other components. These include degreasers, which stop the formation of deposits, corrosion inhibitors, which stop corrosion, and anti-oxidants, which stop the oil from oxidizing. They are fairly tough to remove from between the surfaces of the thick chains, but you may use oil to create a slippery barrier there [29]. Oils' weights are determined by their viscosities. Lower values indicate a more fluid flow. Uses include maintaining tools for bearings, hinges, and blade sharpening. When you wish to lubricate anything without using grease, you use oil. If the lubrication that the little elements are without upsetting you is what you need

3.3 Nanotribology

In the branch of tribology known as Nano-tribology, atomic interactions, and quantum effects play a crucial role in the investigation of nanoscale phenomena including resistance, wearing, adherence, and lubricating. The main objective of this subject is to describe the features and modify surfaces for scientific and technological purposes. By altering the nanoscale topology of surfaces, it is possible to achieve super lubrication and super adhesion, which can be used to reduce or intensify friction more so than macroscopic lubrication and adhesion. Critical friction and wear issues can be eliminated by coating moving parts with super-lubricant coatings because micro- and Nano-mechanical devices have an extremely high surface volume ratio. However, Nano-tribological methods offer a solution to circumvent adhesion issues in those circumstances.

Surface Force Apparatus

SFA, or the Surface Forces Apparatus, is a device used to measure physical surface-to-surface interactions, such as van der Waals contacts, capillary forces, and adhesion, in fluids and vapers. Since the first of this kind of device was described in 1969, many different iterations of this tool have been developed.

Super lubricity at an Atomic Scale

Super lubricity is a tribological condition that occasionally manifests at material connections at the nanoscale and is frictionless. If two surfaces that are interacting have distinct surface lattice patterns, friction at the nanoscale is usually anisotropic, which means that each atom is susceptible to a variable amount of force from each direction. There may be essentially little friction in this situation as a result of the forces canceling each other out.

Thermo lubricity at an Atomic Scale

Thermal influences on lubricity at the atomic level could no longer be dismissed as insignificant with the development of AFM and FFM. Due to heat stimulation, the tip could occasionally hop forward and backward on the slide [30]. The tip takes a while to move between some of relatively low power points and heat motion can end up causing it to make a lot of spontaneous forward and backward jumps, so the lateral force required to make the edge follow the slow support motion is small. As a result, the friction force decreases significantly when the sliding velocity is low. The phrase "thermal lubricity" was first used to describe this circumstance.

4. Results and discussion

Examining tribology's use and effects in the energy sector is the main goal of scholars studying this subject. The majority of research to date has focused on how wear and friction affect energy use, using data from all over the world, but primarily from the United Kingdom and the United States. We have not only looked at Nigeria's energy consumption and how the nation's supply and demand for energy are out of balance in this study but also the United Kingdom and the United States as case studies. In addition, we've included tips for lowering friction and wear, which would considerably boost energy efficiency.
Each year, the human race uses enormous amounts of energy. Coal, natural gas, and oil are non-renewable fossil fuels that still make up more than 80% of all energy. The energy demand has doubled globally over the past 40 years, and in 2013, the final energy consumption of the entire planet climbed by 2.3%. Energy is a highly important resource for the industry. They require a lot of energy, which must be provided given the plants and machinery in use.
Due to inflation, Nigeria is currently experiencing an economic muddle that is actively eradicating the middle class. Since the foreign investors have left, this has indirect effects on both the population and demand. The number of times a machine can handle additional force is referred to as its mechanical advantage (MA). A machine with no friction would have 100% efficiency. When two surfaces slide or spin against one another, friction is created. Even though new materials, better lubrication, and improved designs have been created, friction removal still requires a significant amount of energy. Numerous useful applications of friction can be found in both engineering and daily life.

Cutting, grinding, polishing, and machining are a few examples of processes that result in controlled and productive wear. Because it results in components degrading or failing, wears is a very costly problem in the majority of technological applications.

With oil making up 41% of the global energy supply, the ultimate energy consumption after furnaces, power plants, energy transportation inefficiencies, and the power sector is 373 EJ. The transportation sector uses 73% of its energy for road traffic, 75% for ships, and 3% for aviation. About 25 to 30 percent of all energy usage is accounted for by friction energy consumption. If the top tribological treatments utilized in research labs were used, this factor might be reduced by 60%. The authors concluded that a feasible long-term fuel consumption decrease of 37% [9].

In a separate research, Holmberg et al. figured out how much energy a paper machine needs to overcome friction, a sophisticated industrial production equipment. In 2012, 101,400 GWh of electricity was needed to minimize friction in the world's 8525 paper mills. Electrical energy accounts for no more than 30% of the total energy required by the paper machine, which is used in very small amounts. In the short term (about 10 years), friction losses in paper machines may be reduced by 11%, and over the following 25 years, they may be reduced by 23.6%. Furthermore, to meet its energy requirements, the mining sector in the United States uses 32% electricity, 22% natural gas, 34% diesel, 2% gasoline, and 10% coal. Material handling has the following statistics, 39% for processing, and 19% for extraction, and the average energy usage was 42%. 12 EJ/a is the industry's total annual energy use. Large industrial mines make up about 85% of surface mines and just 15% of underground mines. In the US, deep mining yields 10 times as much coal and minerals than surface mining. Surface mining uses 25 kWh/t of energy, but deep mining uses 19–4–5 times as much energy (or 5–10 kW/t). Regarding the three mining units with the global average (GA), friction and wear losses were computed by [6]. Costs for power, diesel fuel, and maintenance total 0.7 euros per liter, 0.06 euros per kilowatt-hour, and 6 euros per hour, respectively. One GJ of power will set you back 16.7 Euros, according to the table above. The following estimates take into account the worldwide average energy price of 1 GJ = 18 € or 1 TJ. The data from [6] are employed to figure out the losses due to friction for each mining operation as a section of the overall power consumption for the sample case study. The costs of downtime for the mining equipment are used to determine the amount of energy needed to create the replacement machinery. The three criticality levels for mining equipment are estimated to be similarly distributed, and expenses associated with output loss are anticipated to account for 25% of overall maintenance costs.

To save energy and increase efficiency, we also go through how to lessen friction and wear. We discuss bearings, lubricants, and Nanotribology in particular.

An apparatus component known as a bearing limit relative motion and lowers friction between moving elements. Direct metal-to-metal contact between two components in relative motion is mostly avoided by bearings. By doing this, friction, heat production, and eventually part wear and tear are avoided. The kind of operation, the permissible motions, or the orientations of the loads (forces) applied to the components, bearings can be widely categorized. The simplest form of bearing is a plain bearing, also known as a sliding contact bearing or slide bearing. It only has a bearing surface, no rolling parts, and nothing else. The benefit of rolling element bearings is that they offer a good balance between price, dimensions, weight, carrying capacity, robustness, friction, and other elements. Gear rollers, tapered rollers, needle rollers, spherical rollers, ball bearings, and fluid bearings are a few examples of roller element bearings. A small layer of quickly moving, pressured liquid or gas supports the load in a fluid bearing, which is located between the bearing surfaces. If used properly, some fluid bearings can have almost no wear. A magnetic bearing is a type of bearing that uses magnetic levitation to sustain a load. Ordinary ball bearings would have had a shorter lifespan or made more noise and vibration in applications involving high loads,

high speeds, or great accuracy. There is no sliding friction since there is no contact between the moving pieces. Compressors, turbines, pumps, motors, and generators are just a few examples of industrial machinery that increasingly uses magnetic bearings. In comparison to most other bearings, flexure bearings have the benefit of being straightforward and affordable. Additionally, they frequently have low friction, are compact and lightweight, and are simpler to repair without specialized tools. The term "composite bearing" refers to a bearing manufactured from a mix of components, including friction-reducing lubricants and chemicals and materials like a resin bonded with fiber. It may be adapted to fit the needs of various applications, such as those needing wear- or high-temperature resistance.
Applying a thin coating of a substance known as a lubricant between surfaces in contact is the process or technique known as lubrication. Grease is made by mixing thickeners with oil, which is commonly mineral oil (such as lithium-based soaps). Long polymer chains with various additional ingredients make up oils. The many forms of grease include sodium grease, lithium grease, and calcium grease. A lubricant is a material that lessens wear and tear on surfaces that are moving relative to one another. Specific kinds of lubricants, including silicon, molybdenum, graphite, and PTFE, are used in dry lubricant applications. The molecular structure of these particles makes them exceedingly slippery, which also helps these surfaces' surfaces move more easily against one another. It is used to remove rust from locks, nuts, and other objects that are stuck. For long-lasting lubrication, penetrating oils are not designed, on the other hand.
In the branch of tribology known as Nano-tribology, atomic interactions, and quantum effects play a key role in the study of lubrication, friction, wear, adhesion, and other phenomena. A device used for determining the physical forces that occur between surfaces, such as capillary, adhesion forces in liquids and vapor, and van der Waals interactions, is known as the Surface Force Apparatus (SFA). With the invention of AFM and FFM thermal influences on lubricity at the atomic scale could no longer be dismissed as minor. At the nanoscale, friction is usually anisotropic: individual atoms are susceptible to varying forces originating from different directions if two surfaces interacting have distinct surface lattice patterns.

5. Conclusion

In conclusion, we were able to discuss how wear and friction impact energy consumption worldwide by looking at specific sectors which include the transportation, paper production, and mining industries.
By looking at these sectors we were able to determine how wear and friction affect their energy output and also how much energy can be saved by employing tribological solutions. We were also able to estimate how emissions would be reduced by employing tribological solutions

Acknowledgment

The Authors acknowledged the financial support by the founder of Afe Babalola University in this research

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