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DEPLOYMENT OF CLEANER PRODUCTION METHODOLOGY TO LOWER THE CARBON FOOTPRINT IN THE MANUFACTURE OF HEALTHCARE PRODUCTS

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ABSTRACT

Some organizations in South Africa focus on traditional end-of-pipe technologies in favour of Cleaner Production (CP) technologies. The case study that manufactures healthcare products was using a lot of energy, water, raw materials, which ultimately led to waste and greenhouse gas emissions like CO_2. With the goal of lowering CO_2 emissions from the manufacturing processes, a CP strategy was used to investigate the healthcare product manufacturing facility. The research framework was characterised by premise selection, cleaner production audit, carbon footprint estimation, as well as generation, evaluation and implementation of CP options. An energy, raw material, and resource consumption and waste assessment was carried out through a CP audit and the product's carbon emission was found to be 323 kg CO_2 per 1000 litres of healthcare product. This study identified 20 cleaner production options to lower the carbon footprint. The implementation of CP options, which primarily focused on design modifications, enhanced operational efficiency, and improved waste management reduced the carbon footprint of healthcare products by approximately 82065 kg of CO_2 annually. It was noted that the transition to cleaner production methodologies requires initial investments and a commitment to change management. However, the long-term benefits, including cost savings, regulatory compliance, improved corporate image, and environmental stewardship, far outweigh the initial challenges.

Keywords: Cleaner Production, Carbon footprint, GHG emissions.

INTRODUCTION

Over the past 20 years, the global beauty market, which includes cosmetics, toiletries, and healthcare products, has grown at an average annual rate of 4.5% (Bhadmus, 2023). Annual growth rates have ranged from 3% to 5.5%. This demonstrates the healthcare market's steady and ongoing growth. Several well-known producers of healthcare products that produce a range of healthcare products, which are separated into categories such as toiletries, makeup, fragrances, and skin and hair care, are growing rapidly. When it comes to sustainability, the healthcare sector tackles environmental impact in a variety of ways, with operational effectiveness, sourcing of raw materials, developing green chemicals, and sustainable manufacturing techniques, waste management, environmentally friendly formulation, environmentally friendly packaging, energy sources, and water and carbon management (Sahota, 2014). Making production as efficient as feasible is crucial in the fight to use fewer resources and produce less waste.

The manufacturing facility for healthcare products has some long-term sustainability goals, one of which is to use only renewable energy sources, which could lower CO_2 emissions. The healthcare product manufacturing sector takes some control measures to ensure that no manufacturing waste ends up in landfills. Waste from landfills can result from the massive amount of packaging materials used in the production of healthcare products, including plastic bottles, pouches, caps, pumps, shippers, and shrink wrap. Each producer has taken the initiative to work toward reducing, recycling, and reusing packaging materials. GHGs have a big impact on the environment and human health and owing to the increased greenhouse gas emissions from the production of healthcare items, it is vital to investigate and determine the potential carbon footprint contributions (Lenzen et al., 2020). The substantial greenhouse gas emissions from the production of healthcare goods cause climate change and global warming.

By using a cleaner production technique, the research project is aimed to lower the carbon footprint at the facility that manufactures healthcare products. The objectives of this study are:

- To conduct a cleaner production audit to ascertain the present state of the facility used to manufacture healthcare items;
- To calculate the carbon footprint produced at the chosen production facility for healthcare products;
- To implement CP options to lower the carbon footprint in the manufacture of healthcare products.

LITERATURE REVIEW

Production Processes for Healthcare Products

Healthcare goods are made with a variety of chemicals, including surfactants, oils, fats, perfumes, emollients, cleaning agents, and mineral oils. The activities that comprise the procurement of bulk intermediates, products, mixing, grinding, heating, cooling, filing, and packing materials, as well as bulk intermediates and products, are all part of the manufacturing process in the healthcare production facilities (Asif & Usmani, 2024). The distribution, release, storage, and quality monitoring of the completed goods are also included. With more automation and mechanization, operating technologies are improving. The method of producing liquid products involves batch mixing and continuous blending. Water, energy, electricity, raw materials, and packaging materials are the main resources needed in the day-to-day production of healthcare items. In healthcare goods, water serves as the main ingredient, dissolving components like conditioning and cleansing agents.

Process water, which is utilised in the creation of personal care products, is monitored in accordance with Good Manufacturing Practices as outlined in ISO 22716, an international standard on GMPs, as well as FDA Guidance on Cosmetic Manufacturing Practice Guidelines. High levels of energy, water, electricity, chemicals, and raw material consumption are used in the manufacturing sector, which releases waste and greenhouse gases into the atmosphere that have a negative impact on both human health and the environment. Many processes in the operation process, including the extraction of raw materials, mixing, filing, packaging, heating process, IT, and lighting, demand a significant quantity of electricity.

Farias et al. (2021) highlighted that cleaning products are indispensable nowadays, with personal and environmental hygiene perceived as vital for all societies globally. Additionally, the need to reduce usage of products that are harmful to human health and the environment prompted the search for detergents that are derived from chemically synthesised from natural green surfactants or components of biological (plant or microbiological) origin. It was noted that the identification of healthcare items in the environment should be a major responsibility of the healthcare industries (Sherman et al. 2020). Once used, bottles, pouches, tubes, and other healthcare container packaging materials are thrown away and end up in landfills, where they can take years to decompose. To lessen their negative effects on the environment, the healthcare sectors are aiming for eco-friendly packaging and green formulation.

The existence of medical supplies in aquatic environments at amounts that could have a negative impact on the environment has recently come to the attention of more people (Abou-Elwafa et al. 2017). According to a study, tricarbon (TCC) and triclosan (TCS), which are known as antimicrobial compounds, were found in the algae samples (Coogen et al., 2017). Despite being found in freshwater environments at extremely low concentrations, PCP and its metabolites are physiologically active and can affect aquatic organisms that are not intended targets more severely.

Global Warming

The increase in atmospheric GHG levels is the cause of global warming. The greenhouse effect will be exacerbated by the following gases: CO2, N2O, CH4, and fluorinated gases (EPA, 2017). The primary human-caused source of greenhouse gas emissions is CO2 emissions. Earth's temperature will probably rise gradually as a result of global warming (Ghommem, Hajj, & Puri, 2012). The concentration of GHG in the atmosphere will rise as a result of increased emissions. The amount of energy absorbed by the GHG is determined by the Global Warming Potential (GWP), which was developed. A higher GWP GHG will significantly contribute to global warming. The quantity of energy absorbed by the GHG is determined by the Global Warming Potential (GWP), which was created. A higher GWP GHG will significantly contribute to global warming. Parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt) will be used to measure the concentrations of greenhouse gases.

Global development has accelerated throughout time, improving living standards but also having serious detrimental consequences on the environment (Georgiadis et al., 2006). Growing amounts of greenhouse gases (GHGs) have caused South Africa, a developing country, to quickly transition from an agricultural to an industrialized economy with (GHG) emissions being increasingly released from automobiles, industry, and power plants (Zaid et al., 2015). In South Africa, the primary sources of CO2 emissions are transportation, residential and industrial activities, as well as the production of energy. The goal of the South African government is to cut greenhouse gas emissions by 40% by 2030. To prevent environmental damage, a number of steps have been implemented.

Carbon Footprint

According to Ramli and Munisamy (2015), one of the main sources of emissions that seriously harm the environment, such as SO2, NOX, and CO2, is the industrial sector. Carbon footprints are measured in tons of carbon dioxide equivalent and comprise all greenhouse gas emissions, including carbon dioxide, nitrous oxide, hydrofluorocarbons, methane, perfluorocarbon, and sulfur hexafluoride (Wrobel-Jedrejewska et al., 2016). Assessing one's carbon footprint is one of the many initiatives that some are considering to slow down global climate change. According to Laurent et al. (2010), carbon footprint is utilised as an environmental performance indicator in products in the current state of our understanding of the consequences of climate change.

One of the main causes of the rise in CO_2 emissions from fuel and energy use has been industrial development. According to Hosseini et al. (2013), the main sources of greenhouse gas emissions in manufacturing are energy use, fuel burning during production, and fuel consumption during logistical activities. By 2035, energy may be significantly improved, its reliance on fossil fuels reduced, and carbon dioxide emissions avoided through the widespread use of currently available renewable energy sources and energy efficiency (Gan et al., 2013). Energy efficiency strategies are essential for both minimizing negative social and environmental effects and promoting sustainable economic development, as the growing demand for energy consumption has contributed to the increase in CO_2 emissions (Sabori et al., 2012). The amount of CO_2 or CO_2 equivalent gases that eventually contribute to global warming and climate change will decrease as a direct result of the reduction in carbon emissions (Fernando and Hor, 2017). The two types of carbon emissions sources in industry are on-site carbon emissions from internal operations and indirect carbon emissions from resource usage at external locations from firm premises.

Numerous techniques and instruments for CO_2 emission and GHG emissions mitigation have been implemented as a result of the enormous growth in the economic, social, and environmental effects of CO_2 and GHG (Fais, Sabio, and Strachan, 2016). Companies do have certain restrictions, such as a weak long-term policy framework for reducing carbon dioxide emissions (Okereke, 2007). As a result, a significant amount of trash and emissions are produced, mostly in the form of CO_2 from the production process, which has an adverse effect on the environment and public health. The primary sources of CO_2 emissions include energy use and various operations such as drying, heating, cooling, and chilling (Rahim & Abdul Raman, 2017). According to a recent study, the use of thermal or electrical energy during life cycle operations has a bigger influence on the environment (Laurent, Olsen & Hauschild, 2010).

Cleaner Production Approaches for Lowering Carbon Dioxide Emissions

According to Khan et al. (2014), a sustainable option to slowing the rise in CO_2 emissions will be provided by process integration, which is a strategic approach to managing CO_2 emissions. The consumption rate of fuel, electricity, water, solid waste, and waste water generation is used to quantify CO_2 emissions in the fruit juice production industry. According to research, electricity accounts for 88% of total emissions in the plant. (Rahim & Raman, 2015). One of the suggested CP choices was the effective functioning of the refrigeration system, which involves increasing the air conditioning system. It has helped reduce CO_2 emissions and save electricity, both directly and indirectly.

In addition, Wrobel-Jedrezejweska et al. (2016) found that the primary source of CO_2 emissions during the fruit paste technology manufacturing process is the refrigerated storage of raw materials and semi-finished items, accounting for 77% of total emissions. Reducing capacity, maximizing the utilization of cooling spaces, and rationalizing storage chambers are crucial steps in optimizing the process to reduce greenhouse gas emissions. The emission reduction plan will concentrate on areas of higher priority, like packaging, in light of the study that was done. Water, energy, raw materials, and vast amounts of chemicals are used in the production of plastic resin from recycled plastic. The production process produces a huge amount of CO_2, which leads to the generation of vast amounts of waste and emissions that have an adverse effect on the environment and public health. According to Rahim and Raman (2017), the primary sources of CO_2 emissions include power use and various operations such as heating, cooling, chilling, and drying. A number of CP options have been implemented at the factory to lower CO_2 emissions, such as installing LED energy-efficient lightbulbs for the lighting system, raising the temperature in the air conditioning system, and optimizing the temperature during the heating and extrusion processes.

RESEARCH METHODOLOGY

Figure 1 shows the framework that was adopted for the study. A suitable facility for producing healthcare products has been selected for the study since it has an established operation and an effective record-keeping system. The management gave their prior consent for this research to be conducted. This facility produces a wide range of medical supplies for the industry, such as bandages, roll plasters for wounds, and stiff strapping tapes for people with strained joints, like sports. The plant employs roughly 150 people and runs around the clock. About 75 batches, or 500 tons of healthcare products are produced weekly on the premises. A CP audit was undertaken to develop cleaner production plan that is technically, economically and environmentally feasible, and elicit the reasons for high energy consumption, high material consumption, and pollution. CP audits are recognised as management tools that include a systematic, documented, continuous, objective, and participatory procedure to evaluate the performance of current or proposed production systems. They also identify and implement appropriate management actions and policies (DOE, 2007).

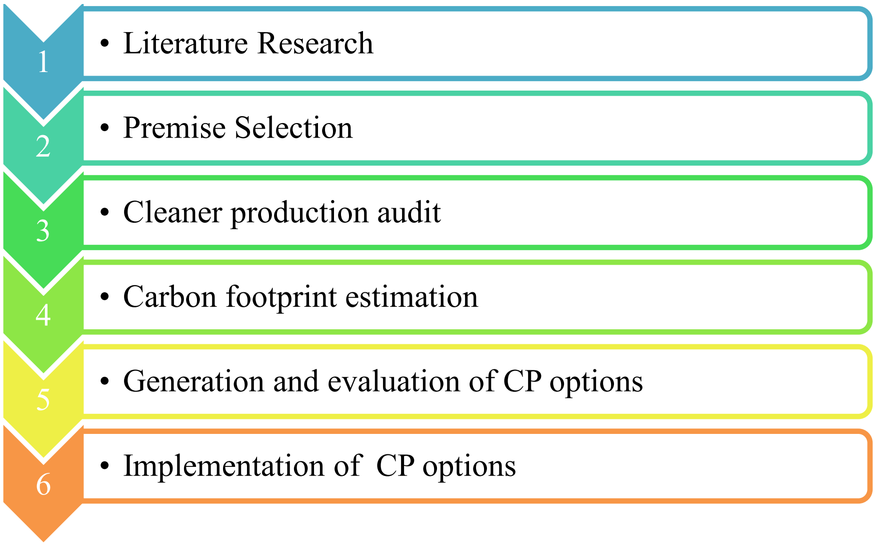

Fig. 1 Research framework

The plant's cleaner production audit was carried out on-site by observation and a walk-through inspection (Gemba Walk). During the audit, interviews with the maintenance team, supervisor, facilities, and machine operator were conducted to gain an understanding of the operation and process flow. The primary goal of the audit is to gather both quantitative and qualitative data regarding the operation procedures, waste production, and resource usage. The data collected comprises the amount of raw materials used, the amount of water and power used, the amount of fuel used, the amount of waste water created, the amount of solid waste, the amount of hazardous waste, and the amount of CO_2 emissions per unit of healthcare product produced (kg CO_2/litre) at the location. The workflow in each process, as well as the material and utility inventory records, were reviewed in order to gather further data.

Cleaner production options were generated and evaluated for technical, economic and environmental feasibility to increase production efficiency and lower the carbon footprint produced on the premises based on the audit findings and analysis. Viable CP options were thereafter selected for implementation and it was also imperative to monitor performance and sustain cleaner production activities.

RESULTS AND INTERPRETATION OF FINDINGS

Preliminary Assessment

The purpose of the preliminary assessment was to collect fundamental information from the premises, such as the plant's operating hours, the total number of items produced, the number of employees, the unit operations involved, and the types of processes involved. The preliminary assessment of the plant focused on material balance of sources of CO_2 emissions, electricity and water consumption, raw material consumption and chemicals, fuel consumption and production of waste. To familiarize oneself with the locations of operating sites, including production, raw material storage, warehousing, administration, and wastewater treatment plant (WWTP), the facilities and management team provided the plant's site layout. Figure 2 displays a process flowchart for the Input – Output analysis results.

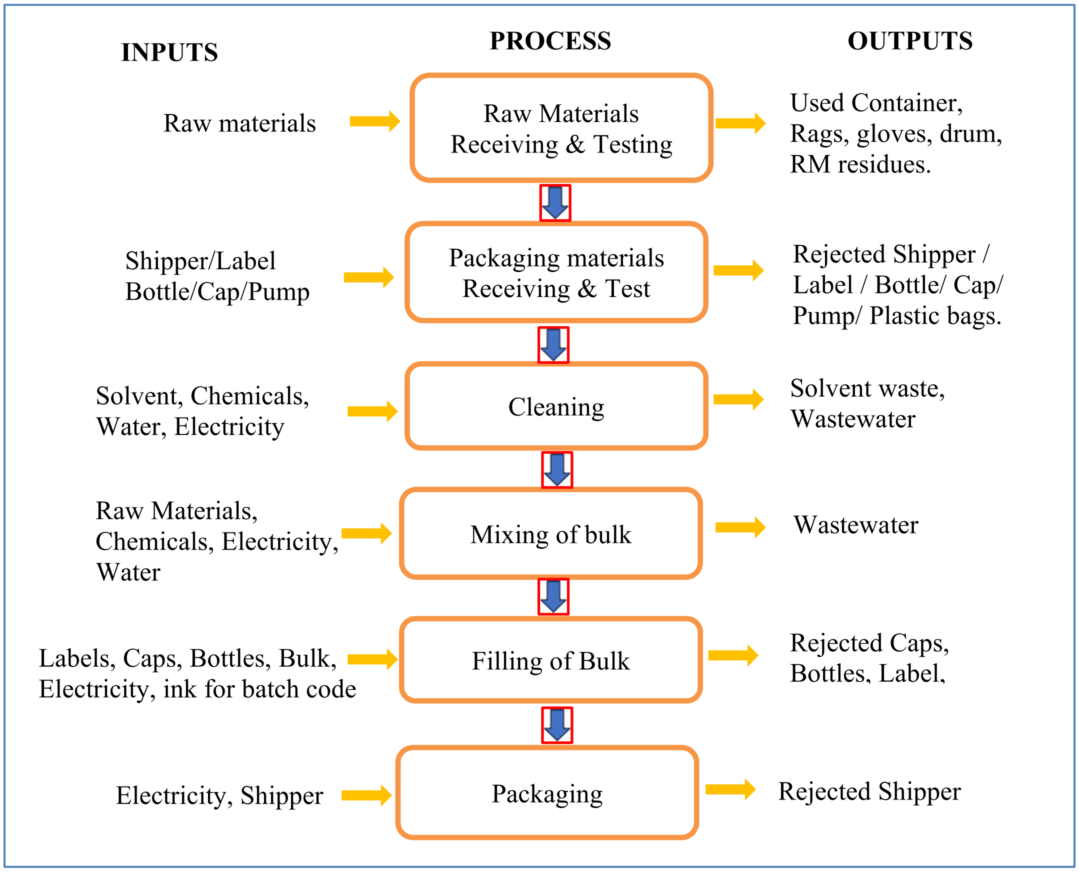

Fig. 2 Input – Output analysis results

Performing a material balance in the manufacture of healthcare products is crucial for ensuring efficient use of materials, minimizing waste, and achieving regulatory compliance. By systematically accounting for all inputs, outputs, and losses, manufacturers can optimize their processes, reduce environmental impact, and improve overall sustainability. The key components of material balance include the raw materials that are required for the production of healthcare products, such as active ingredients, excipients, solvents, and packaging materials. The inputs include all materials and energy sources that enter the manufacturing process and these encompasses raw materials, water, energy such as electricity and steam, as well as auxiliary chemicals. The processes involve the various stages of manufacturing, such as mixing, reaction, separation, purification, and packaging. The outputs are the finished healthcare products, waste materials, emissions, and any by-products. It is also worth noting that losses can occur due to inefficiencies in the process, evaporation, leaks, spills, and material handling. Identifying and minimizing these losses is crucial for improving process efficiency. Table 1 shows the material balance for the inputs and outputs that cause CO_2 emissions from the plant.

Table 1. Material balance of sources of CO_2 emissions

Inputs	Outputs
Coal: 10,000 kg/day (assuming 70% carbon content, 1% sulphur)	25,666.67 kg of CO_2 200 kg of SO_2 20 kg of NO_x 1,500 kg of ash
Limestone: 2,000 kg/day	1120 kg of CaO 880 kg of CO_2
Natural gas: 5,000 m^3/day	9857.25 kg of CO_2/day 12.5 kg of NO_x/day 0.75 kg of CO 35.85 kg of CH_4 (unburned)
Water (For processing): 15,000 litres /day	Solid waste: 5000 kg/day Wastewater: 10,000 litres/day

Electricity Consumption

The premise uses a total of 689155 kWh per month. The primary unit involved in the operation was recognized with the appropriate energy rating in the audit findings. The electrical consumption of the main unit operations is displayed in Table 2 with the following shows the main unit's electrical consumption during operation, along with the energy rating and daily operating hours:

Table 2. Electrical consumption of main operations

Type	Operating hours/month	Monthly consumption (kWh)
270kW Air Compressor	312	8×10^4
5kW Machine	576	3.1×10^4
1.2kW Lights	576	6.9×10^2
37.5kW Air Conditioners	576	2.1×10^4
18.5kW Motor pump	576	1.0×10^4
50 kW Boiler	312	1.56×10^4

Water Consumption

The audit's findings demonstrate the necessity of water in the production of medical supplies. In the process, water is employed as the primary ingredient and for cleaning. A total of 7083 kg of process water is required for the mass glue manufacturing process to create 10 tons of finished product. In addition, non-process water is necessary for the operation's sanitization and cleaning procedures, which include cleaning the prices and the in-process areas. The filter, mixing tank, and storage tank also require some periodic cleaning. The procedure of cleaning involves cleaning several components such as the floor, hose, and pumps. Each month, the cleaning and sanitisation procedure uses roughly 2778 m^3 of water. The amount of water consumed in the premises for domestic usage is around 853 m^3. The water use on the premises is summarized in Table 3.

Table 3. Monthly water consumption

Process	**Water consumption/month (m^3)**
Process Water	1417
Non-Process water (CIP)	2778
Non-process water (Domestic)	253
Total	5048

Raw Material Consumption and Chemicals

A vast quantity of raw materials is utilised in the process of making healthcare products. The audit findings indicate that in order to manufacture 10 tons of adhesive mass, 2917 kg of raw material are needed. The results of the audit indicate that 598 tons of raw material are used in production per month. Additionally, it was noted that during operation, 15 tons of raw material were missing. In order to determine the raw material losses during the audit, the receiving, compounding, packing, and storage areas were assessed. Large drums and bags containing the raw components are delivered to the compounding area. To combine, these unprocessed ingredients are weighed and added to the mixing tank. It was noted that the raw materials were lost as a result of handling, contamination, storage, and transportation. It was discovered during the audit that the raw material containers for the two different batches were not properly separated and were instead stacked on the same pallet. Eventually, this will cause the raw materials to become contaminated and be recorded as waste. In addition, it is discovered that the analytical and microbiology laboratories utilise 30 litres of chemicals each month.

Fuel Consumption

Natural gas was utilised by the factory to power its heating and mixing operations. The monthly record of natural gas purchases was used to quantify the natural gas, with the total cost of the gas being converted into mmbtu of natural gas. Natural gas served as the plant's fuel source for operation. The monthly consumption of natural gas was 3045 mmbtu. Moreover, steam was utilised to heat the mixture during the operation. About 1170 tonnes of steam is needed for the operation of the plant.

Production of Waste

Wastewater, hazardous waste, and solid waste are the three categories into which the waste generated in the manufacturing facility can be separated. The monthly trash production is quantified in Table 4. According to the audit's findings, roughly 1237 kg of solid trash are produced monthly overall. The packaging materials that make up the solid wastes include labels, bottles, pouches, shippers, and rejected caps. The audit's findings indicate that the machine's setting is when the most rejected pouches occur. Hazardous materials and emissions are defined by the US Environmental Protection Agency (EPA) as poisonous (toxic), combustible, corrosive, or chemically reactive at concentrations higher than designated safety limits. This classification applies to liquid, solid, and gaseous waste products as well as emissions.

Table 4. Monthly production of waste

Types of Waste	**Quantity per month**
Solid Waste	1237 kg
Waste Water	3777m^3
Hazardous Waste	5500 kg

Typical sources of production waste included the following:

- Chemical waste, such as raw material leftovers from industrial tanks and drums;
- Waste solvent from cleaning equipment;
- The shipper's ink, which was used to print the batch code on the bottles;
- Tested using packing materials;
- Lab-tested finished goods;
- Off-spec items (finished goods and packaging materials);
- Used materials that came into contact with chemicals, like gloves and rags;
- Spilled bulk raw materials during operation and transit;
- Remaining supplier packaging, including paper, plastic bags, plastic bins, and plastic drums.

In addition, 3777 m^3 of waste water are produced by the business each month. This wastewater is produced by the machinery and equipment's cleaning and sanitization processes, as well as domestic wastewater and water from leaks and overflows that occur during operation. The COD value of the wastewater released was 62 mg/litre.

Quantification of carbon footprint

Carbon footprint quantification was done to calculate the amount of carbon dioxide emitted for the generation of waste water, solid waste, fuel, electricity, and water. Carbon dioxide Emission Factor (CEF) values shown in Table 5 were used to compute the estimates for the total carbon emission footprints of the energy sources. Roughly 650 tonnes of CO_2 emissions were released from the site each month, or 323 kg of CO_2 every 1000 litres of healthcare products produced.

Table 5. CEF Values for resources and waste (Rahim & Raman, 2017)

Resources and waste	CEF Value	Unit
Natural Gas	53.06	Kg CO_2/mmbtu
Electricity	0.70	KgCO_2/kWh
Water	0.32	kgCO_2/m
Solid Waste	3.7	kgCO_2/kg
Wastewater	1	kgCO_2/ kg COD removed
Steam	0.61	kgCO_2/kg

Power
The monthly average for electricity use is = 689155 kWh
The estimated CFP = 689155 x 0.70 $kgCO_2/kWh$ = 4.8×10^5 kg CO_2.
Water
Average water consumption per month = 5048 m^3 of water
Estimated CFP = 5048 $m^3 \times 0.32$ $kgCO_2/m^3$ = 1.6×10^3 $kgCO_2$.
Natural gas
The natural gas used (3045 mmbtu per month) = 3045 mmbtu x 53.06 kg CO_2/mmbtu
= 1.6×10^5 kg CO_2
Solid Waste
Solid Waste Generated (1237 kg per month) = 1237kg x 3.7 kg CO_2/kg
= 4.5×10^3 kg CO_2
Wastewater
Using an emission factor of 0.7 kg CO_2/m^3 from a monthly volume of 3777 m^3 of wastewater:
Total CO_2 Emissions = 3777 $m^3 \times 0.7$ kg CO_2/m^3 = 2643.9 kg CO_2

Generation of Cleaner Production Options

It was noted that the transition to cleaner production methodologies requires initial investments and a commitment to change management. However, the long-term benefits, including cost savings, regulatory compliance, improved corporate image, and environmental stewardship, far outweigh the initial challenges. CP solutions have been developed to increase production efficiency and lower the carbon footprint produced on the premises based on the audit findings and analysis.

Cleaner Production options for Lowering Electricity Use

The main source of CO_2 emission for the plant is electricity. The motor, pump, chiller, air conditioner, boiler, lighting, and air compressor use the majority of the electricity. The workable CP solutions have been developed to lower the building's electricity usage and CO_2 emissions. To properly manage energy in the premises, management should be a key player in ongoing improvement. An energy evaluation should be created and kept up to date by management. To keep an eye on energy performance, an energy performance indicator needs to be identified.
CP Option 1: Zones for lighting control

Energy-saving techniques ought to be used for the lighting solutions. One can build up lighting control zones according to functional areas. When workers enter and exit the office and reception area, the occupancy sensor and timer should be installed in those areas. It is also possible to change the office layout to include a day lighting system that allows electric lights to be turned off. With this option, monthly electricity use can be reduced by 10% and CO_2 emissions by 48 kg and 69 kWh, respectively.

CP Option 2: LED lamp with energy efficiency
LED lamps, which are more energy-efficient and have higher luminous efficacy, are used; their range is 901m/W to 1041m/W. The most energy-efficient choice is this one, according to

Muhammad Asif et al. 2013) The energy consumption of the 49 existing lamps is reduced by 12% as compared to the 605k Wh/month that these LED lamps will consume. A monthly decrease of 60 kg of CO will result with this CP option. The following is the payback period calculation for installing LED lamps:

Investment Cost = R4400
Annual saving. = R1589

$$\text{Payback period} = \frac{Investment\ Cost}{Annual\ Saving} = \frac{R4400}{R1589} = 2\ years\ and\ 10\ months$$

CP option 3 (Light turned off)

Good practices can be put into effect to ensure efficient energy management. Make sure to turn out the lights for the hour-long break. As there are no initial costs involved, this can be put into practice right now. With this CP option, monthly electricity use can be reduced by 29 kWh, resulting in a monthly savings of 20 kg of CO_2.

CP option 4 (Air compressor without oil)

Compressed air is essential for the production process and it was clear from the audit finding analysis that there are two distinct types of air compressors, one for oil injection and the other for oil free operation. The manufacturing now uses an outdated air compressor with worn-out parts. The ageing air compressor's maintenance costs are rising. By purchasing a new, oil-free compressor, the factory may drastically lower its annual CO_2 emissions and operating costs. To prevent contamination, the coarse and fine dust filters in the oil-free air compressor remove dust from compressed air. One of the parts of the air compressor used to remove oily impurities is the oil coalescing filter. The components of the oil-free compressor include the air compressor, cooling tower, condensed water, oil coalescing filter, air dryer, flow meter, dew point meter, compressor controller and dust filter. The whole estimated cost for installing each compressor unit is included in the investment cost.

The yearly savings cover system service, energy savings, and maintenance. Installing an oil- free compressor might result in a monthly energy consumption reduction of 52857 kWh, or 37000 kg CO_2. The following is the payback period calculation for installing a new air compressor:

Investment Cost = R 1 562 000
Annual saving = R340 640

$$\text{Payback period} = \frac{Investment\ Cost}{Annual\ Saving} = \frac{R1\ 562\ 000}{R340\ 640} = 4\ years\ and\ 7\ months$$

CP option 5: Compressor inverter installation

By installing an inverter unit in the compressor, the flow rate may be adjusted and power consumption can be decreased. The fruit juice production plant has adopted this CP option, allowing for a 10% reduction in energy consumption (Rahim & Raman, 2017). By installing an inverter, one can lower monthly energy use by 8424 kWh, or 5897 kg of CO_2. The following is the payback period calculation for installing a new air invertor for an air compressor:

Investment Cost = R 28 948
Annual saving = R 22 138

$$\text{Payback period} = \frac{Investment\ Cost}{Annual\ Saving} = \frac{R28\ 948}{R22\ 138} = 1\ year\ and\ 4\ months$$

CP option 6: Disabling the air compressor

When taking a one-hour break, the air compressor must be shut off. This may result in a monthly reduction of 4536 kg of CO_2 by lowering energy use by 6480 kWh.

CP option 7: Switched off air conditioner

The study's recommended CP choices were concentrated on effective air conditioning system control. The plant should adopt some of the recommended CP choices as best practices.

Turning off the air conditioner in the office for almost an hour is one of the CP options that is recommended. Good practice can be used by opening the window to keep adequate ventilation in the space rather of utilising air conditioners. Turning off the air conditioning in the vacant space is also advised. Savings on electricity are achieved without requiring any investment. In addition, confirm that the temperature is adjusted correctly in the designated region. According to Abdul Kader (2014), an increase in temperature of 1°C has the potential to save electricity use by around 6%. Thus, it was recommended in this analysis that the plant raise the temperature of the air conditioning system from 18 °C to 20 °C, which would save 12% of the electricity use without requiring any more funding. A monthly reduction of 2592 kWh in power use could result in a monthly reduction of 1814 kg CO_2 emissions.

Cleaner Production options for Lowering Water Use

The most important ingredient in the manufacturing process is water. According to the quantification of carbon footprint, water contributes 1615 kg of CO_2. The workable CP option and recommended best practices for manufacturing water conservation. The use of water and carbon impact will decrease with the use of CP alternatives.

CP option 8: Water Sense Installation Aerators with limited flow

Install low flow plumbing fixtures in the sinks and toilets. This is going to regulate how much water we use to flush the toilets. To control the water flow, trigger hose nozzles, flow restrictors, and tap aerators must be added. The EPA (2017) describes the Water Sense low flow aerators as water-saving faucets that can be used in kitchens and toilets. In a month, this flow aerator can save up to 220 litres per tap, according to the water corporation's analysis. Therefore, installing a flow aerator may result in a monthly reduction of 7 kg of CO_2. The following illustrates the payback period calculation for installing a 100 litre air water sense flow aerator:

Investment Cost = R15000
Annual saving = R 601

$$\text{Payback period} = \frac{Investment\ Cost}{Annual\ Saving} = \frac{R15\ 000}{R\ 601} = 2\ years\ and\ 6\ months$$

CP option 9: Tank Jet 360 Installation

The high-efficiency cleaning apparatus uses pre-existing hoses and high-pressure sprayers at low volume and high efficiency. The spray ball device in the tanks must be constructed to cover the whole surface area. Tanks up to 30 metres in diameter can be cleaned using the Tank Jet 360 tank cleaner. According to Spraying System Co., the Tank Jet reduces waste by 50% and offers high-impact cleaning outcomes in a short cycle time. The water bill and CO_2 emissions will drop by

RM3167 and 445 kg CO_2, respectively, using this CP option. The Tank Jet 360 tank cleaner can be shown in Figure 3.

Fig. 3 TankJet 360 tank cleaner

The following computation displays the payback period for installing the Tank Jet 360 tank cleaner:

Investment Cost = R40 000
Annual saving = R38 004

$$\text{Payback period} = \frac{Investment\ Cost}{Annual\ Saving} = \frac{R40\ 000}{R38\ 004} = 1\ year\ and\ 1\ months$$

CP option 10: Cleaning and sanitization process optimisation

To maximise the operation's cleaning and sanitization process, it is important to streamline the cleaning procedure and use less water during the sanitization step. This CP option may result in a 50% reduction in the amount of water used for operations, which is equal to a 445 kg CO_2 emission reduction.

CP Option 11: Reusing Water

It is possible to reuse the water used for rinsing throughout the cleaning procedure. The rinse water can be used for the pre-rinse of the subsequent cleaning cycle. Recycled water will also be used for the first spill and floor cleanup.

The plant uses 15 000 litres of water per day, a 20% reduction due to water reuse would save:

Water Savings =15 000 litres/day × 0.2 = 3000 litres/day

The plant also discharges 10 000 litres of wastewater per day, a 20% reduction due to water reuse would save:

Wastewater Reduction = 10 000 litres /day × 0.2 = 2000 litres/day

Hence total water savings would cascade to 5000 litres per day or 33% of daily water usage. Implementing water reuse systems not only leads to significant water savings but also reduces operational costs and enhances sustainability practices within the personal healthcare product manufacturing sector.

CP Option 12: Gathering Rainwater

Rainwater collection is one of the CP Options that ought to be suggested to provide a consistent supply of water for domestic usage. A rainwater harvesting system in conjunction with rainwater reuse will efficiently provide clean water for domestic consumption on a regular basis.

Water Collected = Catchment Area (sqm) × Rainfall (mm) × Efficiency of catchment area
Water Collected (litres) = 500 sqm × 800 mm × 0.8
Water Collected (litres) = 320 000 litres/year

Since the water used by the plant for processing is 15,000 litres /day or an average of 3.9 million litres per year, water savings from the rainwater harvesting is about 8.2%.

CP Selections Cutting Down on Natural Gas Usage

CP option 13: Furnaces insulation

The CP option will be used to lower the amount of natural gas used in the heating system for industrial processes. In order to maintain low temperatures outside, the furnace must have adequate insulation to reduce heat loss. This CP option will allow for a 5% reduction in energy use.

CP option 14: Heating equipment running at maximum capacity

To heat water, air, and the material beforehand, recover heat from the exhaust or flue gas. In addition, effective operating procedures must be followed in order to guarantee that the heating apparatus runs at maximum capacity and reduce cycle delays.

Cleaner Production options for Lowering Chemical Optimization and Raw Materials

CP option 15: Avoid using dangerous substances

Remove some dangerous substances from the cleaning process. Decrease the proportion of solvents, such IPA, that are utilised in the lab and cleaning procedures.

CP option 16: Utilising essential natural elements

The selection of ingredients and raw materials for formulations must be continuously improved. For the product to be safe and have a minimal impact on the environment, formulations should include essential natural elements.

CP option 17: Raw material segregation and storage

The CP option recommended setting up a specific area for raw material segregation and storage. Make that the raw materials on the pallet correspond to a single batch. At the compounding area, the raw materials should be properly segregated. This is to stop raw resources from becoming contaminated and becoming garbage.

Cleaner Production options for Waste Management

CP option 18: Introduce composite testing material

This will be recommended. Redesign the process for testing the goods and bulk. The laboratory generates the majority of the waste on the property because a lot of products are disposed of there after testing. Therefore, the introduction of the composite testing method will decrease the amount of bulk testing.

CP option 19. Reuse of packaging material

As a result, the location will produce less solid trash. It is possible to lower the carbon footprint by 10%, or 459 kg.

CP option 20: Machine setting improvement

To reduce the quantity of pouches rejected, the production line's machine settings should be improved. This will guarantee a 50% decrease in packing material rejections. As a result, the carbon footprint is reduced by 2290 kg CO_2, and no investment is required.

Implementation of Cleaner Production options

Based on the audit findings and carbon footprint analysis has shown electricity consumption been identified as the major entity that needs to take into concern to reduce the CO_2 emission. Table 6 shows a summary of implemented CP options for lowering electricity use. Based on the potential CP options identified in the healthcare products manufacturing premise, CP options without any cost of investment had to be implement immediately. The CP options with shorter payback period were chosen implemented once the financial is available. The implementation of suggested CP options will reduce the CO_2 emissions by 44839kg CO_2. The CP options recommended for reducing the electricity consumption are listed as below:

Table 6. Summary of implemented CP options for lowering electricity use

Number	**CP option**	**Reduction in electricity consumption (kWh/month)**	**Kg CO_2**	**Payback period**
1	Installation of occupancy sensor and timer in lighting area	69	48	Immediate
2	Switching off lights during one-hour break	29	20	Immediate
3	Increase air conditioning temperature from 18°C to 20°C	2592	1814	Immediate
4	Installation of oil-free air compressor	52827	37000	4 years 7 months
5	Installation of inverter on air compressor	8424	5897	1 year 4 months
6	Installation of LED lamp	86	60	2 years 10 months

Natural gas usage is the second-highest source of CO_2 emissions after electricity in the facility used to manufacture healthcare items. The primary option to lower the premise's natural gas usage has been determined to be the CP option, which comes with no implementation costs. By putting the recommended CP alternatives into practice, CO_2 emissions will be decreased by 32314 kg CO_2. In addition to natural gas and electricity, there are other CP choices that may be used right once to save water consumption without incurring any implementation costs. By putting the recommended CP alternatives into practice, CO_2 emissions will be decreased by 452 kg CO_2. In this instance, the cleaning and sanitization process optimisation and installation of minimal household equipment will take precedence.

Implementing CP solutions to reduce solid waste at no cost will need to happen right away. The suggested CP alternatives will result in a 3667 kg CO_2 reduction in CO_2 emissions. Regarding wastewater, a 30% reduction in CO_2 emissions was anticipated from using improved treatment technology leading to 793.17 kg CO_2 reduction from 2643.9 kg CO_2. Based on the implementation of recommended CP options, it was possible to reduce the carbon footprint emission in healthcare product manufacturing premise. Figure 4 shows a summary of contributions to CO_2 emission reduction by the sources after CP implementation, totaling 82065 kg CO_2.

It is imperative that the adopted CP alternatives be routinely monitored to make sure the primary goal is met without the need for interventions or loss. It was advised to take appropriate pictures or videos of the CP implementation during the monitoring phase for training and documentation purposes. In addition, ongoing input from both customers and employees is necessary to better understand the success of CP implementation.

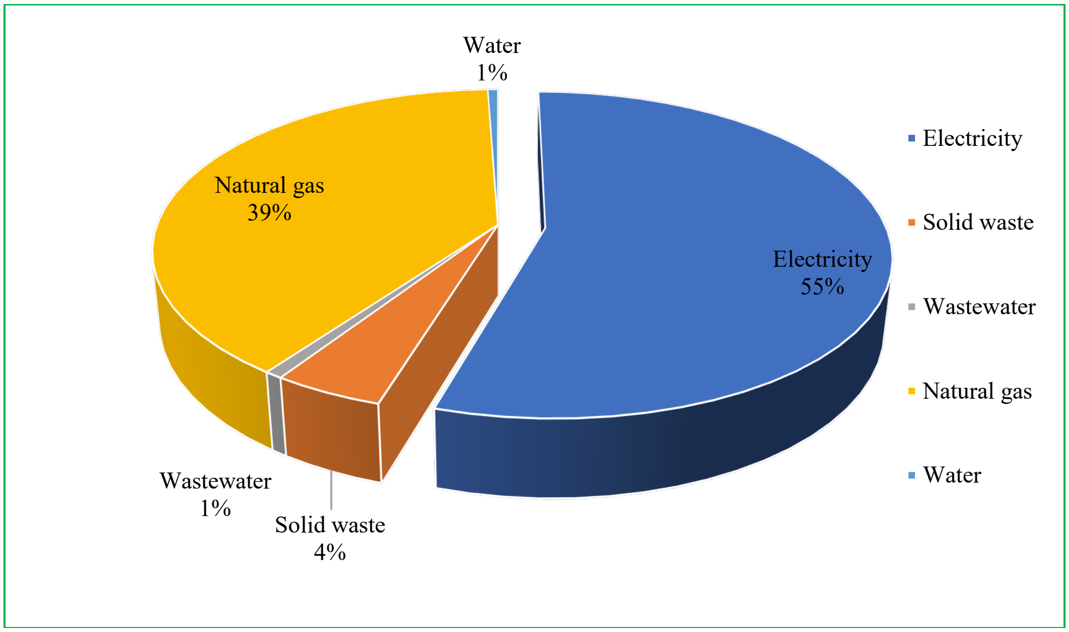

Fig. 4 Summary of CO_2 emission reduction according to sources after CP implementation

CONCLUSION

The deployment of cleaner production methodologies in the manufacture of healthcare products demonstrates significant potential for reducing the carbon footprint of the industry. By integrating sustainable practices, optimizing resource use, and adopting advanced technologies, healthcare product manufacturers can achieve substantial environmental benefits while maintaining product quality and safety. The analysis revealed that a cleaner production strategy is technically, ecologically, and financially possible. As a result, the CP method found increases overall operating efficiency in the facility used to manufacture health items in addition to reducing carbon dioxide. By embracing sustainable practices, manufacturers cannot only reduce their carbon footprint but also contribute to the global effort in combating climate change. The successful implementation of these methodologies will require collaboration among stakeholders, continuous innovation, and a dedicated approach to environmental responsibility.

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