



## Cleaner production: A brief review on definitions, trends and the importance in environment protection

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### Abstract

There are several environmental issues caused by economic growth and urbanization, such as soil degradation, water scarcity, deforestation, and biodiversity extinction. To solve these environmental problem issues, cleaner production (CP) had presented as account to reduce waste generation, energy usage and environmental pollution. CP concept was accepted and applied on many industrial sectors. Based on the current trend, CP is shifting to tackle global environmental problems by focusing on reducing carbon emission and resources consumption. In this paper, implementation of CP was presented such as waste and pollutants reduction, process and products efficiency improvements, and risk reduction towards human and environment. Overall, CP is an effective tool not only in environmental protection, but also in company management as it can increase the profit gains, reduce resources consumption, reduce pollutants emission and protects the safety of staff and workers.

Keywords :

Cleaner production, environmental pollution, environmental protection

## 1 Introduction

In the modern era of 21<sup>st</sup> century, the earth is currently facing serious environmental issues such as soil degradation, water scarcity, and deforestation. Based on current humans' activities and demand, it needs an equivalent of 1.5 earths to sustain the population (Fund, 2019). Currently, there are 9 key concerns in global environmental challenges including ozone depletion, freshwater availability, marine fishery collapses, marine dead zones, deforestation, biodiversity destruction, climate change and continued growth of human population (Erisman et al., 2013). Blind persuasion of economic growth and urbanization is one of the main factors causes environmental pollution and triggered some of the global environmental problems such as global warming (Liang et al., 2009). The rapid industrialization has also increased the usage of primary energy and resources, while producing large quantity of industrial waste which causes severe pollutions.

From year 2011 to 2015, China's total industrial output had a 20.52% increase, however the pollutants emission such as wastewater, gas and solid waste also increase significantly due to inefficient pollution control (Cao et al., 2019). As one of the largest iron and steel production country, 50.2% of world iron and steel is produced from China in 2015, and this made steel division energy intensive as well as main source of greenhouse gasses (GHG) emission (Wang et al., 2007).

Bank (2018) stated that the world would generate 2.59 billion tons of solid waste annually by year 2030 and 3.40 tons annually by year 2050. This data did not include generated wastewater and gas. Hence it is important to reduce waste generation in order to solve various environmental problems. Cleaner production in industry can be accounted to reduce waste generation, energy usage and environmental pollution. Based on the 12 principles of Green Engineering and Green Chemistry, some of the principle's accounts for cleaner production and products such as designing safer chemicals, inherent rather than circumstantial, maximize mass, energy, space and time efficiency and more (Hadibarata, 2019). Therefore, this article reviews the cleaner production regarding major trends and highlights solutions to several challenges for future sustainable production.

## 2 Definition for cleaner production

Several scholars and associations had defined the meanings of cleaner production. According to Nagesha (2018), cleaner production is a preventative way to reduce the bad effects of products and production towards the environment. United Nations Environment Program (UNEP) describes cleaner production as "the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risk to human and the environment" in year 1989 when establishing the Cleaner Production Program. Organization for Economic Cooperation and Development (OCED) defines cleaner technology as a technology that uses natural resources in most effective approach in all stages of their lives, where products are reduced or non-harmful to environment. The products shall be easy to recover and recycle, while minimum energy is used for production. European Commission also stated

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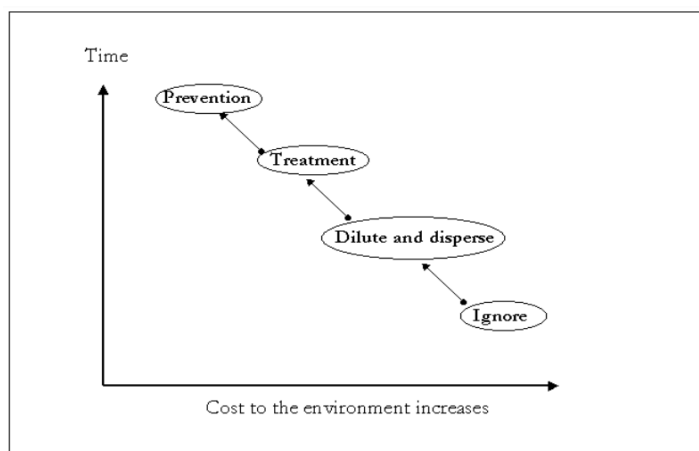
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that cleaner production shall take in the account of technologies and processes. In Green Engineering concepts, cleaner production consists of production processes, products and services. For production processes, raw materials and energy shall be conserve while eliminate the uses of toxic raw materials and reduce the quantity and toxicity of waste and products. Strategy focused on products include lowering the impacts of products from raw material extraction to product disposal. Environmental concerns shall be included in designing and delivering services.

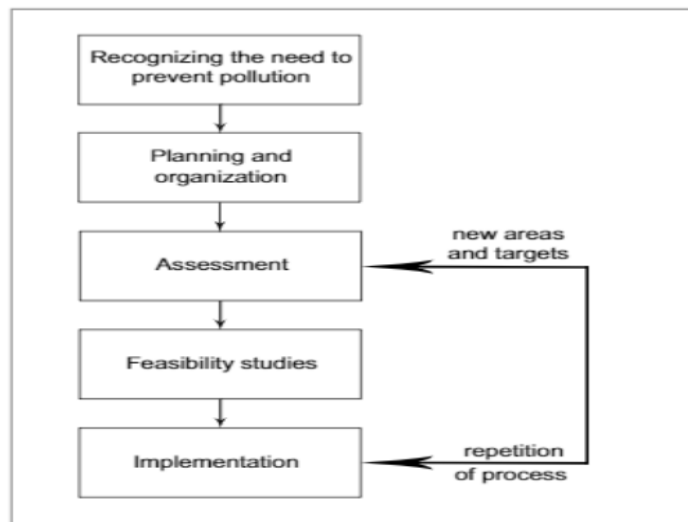
UNEP and United Nations Industrial Development Organization (UNIDO) pointed out 4 responses of industries towards pollution. The first one will be industry ignoring all the consequences causes to the environment, lead to maximum damage to the environment. Secondly, the pollution is “diluted” as it become less harmful towards human and environment. The next stage is treating pollution through the so-called end-of-pipe approach. The last approach is preventing pollution and waste generation at the source, which only start to implement in recent years (UNIDO, 2004). Figure 1 shows the trends of treating pollution.



**Figure 1** Response of business towards environment pollution (UNIDO, 2004)

The beginning of cleaner production approach is discovered by an American company called 3M. A 3P program, meaning of “Pollutions Prevention Pay” is initiated by the company during year 1975. Based on the program, the waste material produced during manufacture processes is regarded as the wrong input of materials, while employees were encouraged to come out with new ideas that could reduce waste produce, while increase production efficiency. Employees who submitted an option which accepted by the company will be rewarded and this implementation already helped the company to reduce waste production as well as production cost. By the implementation of this approach, 3M company able to get the attention from various bodies and was awarded with the World Environment Center’s First Annual Gold Medal for International Corporate Environmental Achievements (Royston, 1979). Around the same time, the effort for pollution prevention was done by the Dupont Company. A manual for pollution prevention was created for their plant managers to engage in pollution prevention. The manual was then taken in by USA Environment Protection Agency (US/EPA) and was published as the Waste Minimization Opportunity Assessment Manual in year 1988 and cleaner production was accepted in USA as an effective and viable ways to treat environmental problems (Dieleman, 2007). A PRISMA project was conducted in year 1989 by 2 of the Netherlands Universities as well as the Dutch Organization of Technology Assessment. The aim of the project is to develop a set of tools to facilitate industry, consultant and the governments to adopt the 3P approach, by a project demonstration to justify the usefulness of US/EPA Manual. The project came up with an improved version of the manual and various publication had describing the usage of the manual (Dieleman and Hoo, 1993). UNEP then consider the result of PRISMA and applied it in a cleaner production program a year later. Both

UNEP and UNIDO has been spreading the concept and methodology of cleaner production to the world since year 1992, while UNEP had set up several national cleaner production centers in various countries such as China, India, Vietnam and more. Hence, around end of 1980’s and early of 1990’s, cleaner production has been recognized through the world as various projects and development showed positive results by applying Cleaner Production concept and was accepted and applied on many industrial sectors (Dieleman, 2007). Figure 2 shows different phases for Cleaner Production application in a project based on the US/EPA manual.



**Figure 2** Cleaner Production project hierarchy based on US/EPA manual (Dieleman and Hoo, 1993)

### 3 Concept evolution in cleaner production

Since the development of cleaner production concept by UNEP in 1992, the vision of cleaner production has changed through the years. The change included the scope, content as well as the sectors which applying the approach. New methods and a wider approach are needed in order to target different aspect of sustainable development in various sectors such as eco-tourism, health-care services and products, agriculture activities and smart cities rather than just industry production (Hens et al., 2018). In year 1998, UNEP stated cleaner production as the continuous application of an integrated, preventative strategy applied to processes, products and services in pursuit of economic, social health, safety and environmental benefits during the International Declaration on Cleaner Production (UNEP, 1998). The differences between the both definitions are that the newer concept take into the account of social economic and safety context. Yaacoub and Fresner (2007) stated that cleaner production is a preventive, company-specific environmental protection initiative. It focuses on waste minimization and emission as well as maximize product output. This concept, however, only focus on industrial activities. In 2017, European Commission defines the cleaner technologies as technologies that extract and uses natural resources in the most efficient way in all stages; and the product generated should reduce or have no harmful components; while minimize releases to the surroundings during fabrication and product usage; and products can be easily recovered and recycled as far as possible; while only needed small amount of energy input (EC, 2017). In around 20 years’ time of evolution, there were more attention give towards the efficiency of resources used, sustainability in terms of social dimension, as well as economic dimension while focus on production cost reduction, business profit and production efficiency while the main concept is still target in environmental aspect. Hence, the most

modern concept for cleaner production could be a business strategy which bond to the 3 pillars of sustainable development, which is environmental, social and economic context (Hens et al., 2018).

## 4 Trends of cleaner production in different countries

The trends of global cleaner production are studied by Cong and Shi (2019) by using over 1380 journal articles published in Journal of Cleaner Production from year 2002 to year 2017 across 29 countries. It is found that resources endowments and country's development level is one of the main reasons that affects the characteristic of cleaner production in each country. Those 29 countries were divided into 3 groups, which are developed, emerging and less-developed countries. Absolute quantity of articles and the reveal comparative advantages (RCA) is used to define the representative industry of the country, while absolute quantity is to determine heated concern and RCA is used for characteristic comparison between countries. Based on studies, developed countries mainly specialized in chemical products, automotive, plastics and rubbers as well as animals and agriculture products while African countries focus on metal industries. In G7 (developed) countries, the top industries with most attention paid were, manufacturing of motor vehicles, trailers and semitrailers, transport equipment, food products, wood products except for furniture, electronic devices, rubber and plastics as well as chemicals product. United State (US) and United Kingdom (UK) both focus on cleaner production of chemical products, Germany in metals and motor vehicles, Italy in non-metallic and mineral products such as eco-friendly fiber and ceramics tiles, while Japan in focus on CO<sub>2</sub> emission in metals and chemicals manufacturing. In emerging countries such as Brazil, China, Russia, India, South Africa and Turkey, the main focus in on manufacture of tobacco products, wood products other than furniture, basic pharmaceutical products and preparations, beverage and mining of metal ores. In China, cleaner production is suggested to widely cover all the industries while most of the industries is present in their research papers. Brazil is focus on chemical and non-metallic minerals product manufacturing while Turkey in textiles industries. Russia and South Africa's trends is not obvious due to lack of data collected. In less-developed countries such as Africa region, cleaner production is not very common as only 17 out of 50 plus countries in Africa published studies on cleaner production. Egypt and South Africa are both leading countries in cleaner production implementation, while Ghana is the first who paid attention to it in Africa. In the region, the main focus is on manufacture of non-metallic mineral products, food products and mineral ore mining. In terms of evolution in cleaner production, China and US has been chosen as leading countries based on the number of publications in the field, while both countries also consider as world's largest economy bodies. The categories of publications in China is one of the most diverse, represented cleaner production is given huge focus in the country. Over years, China's changes the focus on chemicals production towards non-metallic product manufacturing, basic metals, machinery equipment as well as energy generation. Chinese researchers focused on the performance, sustainability, innovation and barriers in their researches at first, while later shift towards CO<sub>2</sub> emission, carbon footprints and energy consumption due to climate change. As for US, the coverage for cleaner production in industries also consider very wide, while the trends change from chemical production, basic metals manufacture, and motor vehicles to machinery and equipment production. The coverage of focus was almost same as China, but wider as bio-fuels and biomass, corporate social-responsibility and consumption was mentioned. In the beginning, US scholars focus on re-manufacturing and supply chain rather than just general concept mentioned before. However, recent researches still change to en-

ergy efficiency and carbon emission (Cong and Shi, 2019).

## 5 Reasons to adopt and implement

Many of the scholars had stated the benefits and reasons to adopt cleaner production. Other than reduce impacts towards the environment, cleaner production also helps to reduce company's operating cost as well as increase profit gains and protect the safety of workers. Through the cleaner production processes, many of the unwanted production cost were able to cutoff or minimized such as waste handling and discharge cost, raw materials input, insurance premium and potential risk by using harmful chemicals. Besides that, others indirect positive impacts could be improved company's image, improve company's performance and increase their competitiveness with other companies. In a broader view, cleaner production could be one of the solutions towards global environmental challenges such as water pollution, ozone depletion and resources depletion (El Haggag, 2010).

As one of the main reasons to implement cleaner production, pollutants and waste can be significantly reduced. Many studies had shown that clean production reduce the pollutants generation through productive operation, while the reduction in greenhouse gasses emission and others residue are one of the most generalized benefits through cleaner production. Fore and Mbohwa (2010) stated that one of the aims in cleaner production is to reduce waste generation especially schedule waste as well as pollutants. The ideal process based on cleaner production is to perform recycle process for waste generation without pollution emission through the whole lifecycle of production process and products, while zero waste dispose is set as the ultimate goals. In a case study of cleaner production application in Brazil wooden furniture factory, many of the unwanted waste can be reduced while there is increase in profits. The company reuse the thicker rigid plastic tape from raw materials' packing and turn them into product packaging. The company save the production of packing material, which is 2383 kg of rigid plastic tape and 11 kg of tape waste annually, while 2890 kg of thicker rigid plastic waste from raw materials packaging was no longer wasted. Besides that, wood waste is also being reduced by replacing new thinner blades in multilayer machine. The company saved equivalent to US\$ 45542.00 per year due to the reduction in wooden board consumption and rigid plastic tapes. Other than that, waste such as mud, chemical reagents and greenhouse gasses emission is also been reduced. The company reduced yearly solid waste generation by 23% and also decreased annual effluent emission by 93% (Massote and Santi, 2013). In a case study of brewery, by applying the cleaner production operation, a total of 21% reduction in greenhouse gasses emission is observed due to the reduction in energy consumption and generation. Besides that, there is 11% reduction is wastewater discharge to the environment causes by the diminishing of water used to clean the kettle (Rivera et al., 2009).

In this part, the focus is on the uses of production resources such as energy, water and other materials. It is one of the main reasons of cleaner production application that agreed and researched by many scholars (Matos et al., 2018). This benefit is highly related towards the main methodology in cleaner production as the productivity and process efficiency is often increase by reducing the levels of residues, pollutants and emissions that needed to be treat. (Ozturk et al., 2016) found that most industrial processes often required huge amount of energy and raw materials, while many unwanted byproducts and waste is generated due to inefficiency of processes and productions. For example, in a textile industry, resources usage such as energy and water could be intensive due to complexity of production processes and large chemical usage in dyeing and bleaching stages (Kocabas et al., 2009, Verma et al., 2012). The main environmental concerns from the textile industry could be high discharge of wastewaters that contains much pollutants such as chelating agents, dispersing agents, heavy metals,

dyes and pigments, which have a high amount of chemical oxygen demand (COD) (Dasgupta et al., 2015). Hence, it is important to lower the input utilization for single unit production, while a big difference could appear in a large-scale production. In the concept of green engineering, outward pull rather than inward push is related as the focus in on the product increases and processes without additional input of raw materials. By gaining high efficiency in production processes, the uses of energy and resources can be reduced, and this could be a way to solve natural resources depletion problem.

In a case study dairy milk production, it is found that water is one of the main consumptions. Livestock sector producing 3.2 million liters of milk yearly and contributes around 2% to Itapetinga's Gross Domestic Product (GDP), a municipality in state of Bahia, North-East region of Brazil. Water is needed in dairy production as for cattle's daily consumption, as well as other production uses such as cleaning milking installations and equipment, ensure the cleanliness of the farming surroundings. Cow milk is made up of around 87% of water, hence more water consumption is needed for lactating cows than other animals for milk production. Water consumption can be reduced to around 75% by using buckets rather than using water hose, while up to 100% in washing milking parlor by using scraping and dry washing instead of water hose. Several techniques can be implemented in milking industry to lower the water consumption such as using pressurized water for cleaning, dry-cleaning and using foaming system (Willers et al., 2014).

When it comes to jewelry production industry, metal finishing operations are one of the major sources of environmental pollution (Hamid and Idris, 1996). Gold-plated jewelry industry in Brazil is one of the main country's income source, while it generates US\$ 92 million by exporting jewelry products in year 2006, which increased 26% compare to year 2005. Most of the producing companies is in Sao Paulo, which is around 200 companies over 560 around the country. The case study example is based on a gold-plated jewelry industry located in Sao Paulo, while this company producing around 600kg of products each month. By applying cleaner production management system, ratio of wastepaper generation to the mass of pieces produced is dropped by 47% in weight, due to the recycling of cardboard boxes from material supplier. Water consumption in the industry also drop by 35%, by controlling the rinsing tank manually by line staff and only opened when certain turbidity is reach. Besides that, the electric consumption is drop by 18% by turning off the heat bath for 90 minutes and 3 times per day without affecting the whole processes. Another 18% drop in energy uses is due to usage of polyvinyl chloride (PVC) balls to reduce water evaporation and heat losses. Hence, a total 36% drop in energy consumption is measured by applying cleaner production (Giannetti et al., 2008).

Risk reduction is one of the benefits gain when a company comply with cleaner production methodology. Risk reduction observed through cleaner production were mainly in 3 states, they are occupational, human and environmental. Occupational risk is referred to the danger that may occur during work time and within the working environment. Human risk refers to the human health affection by hazardous material exposure as well as internal and external contamination. While environmental risk is the risk of pollution faced by organization when hazardous waste release and

gases emission to the environment, and causing environmental impacts (Matos et al., 2018). Based on Armenti et al. (2011), Cleaner Production-Pollution Prevention (CPPP) is one of the choices in modern environmental development, which also considered as primary prevention of the public health sense as this management system is capable of prevent possible harmful chemicals uses in industrial processes by adopting new technologies. Their case study stated that CPPP had positive impacts towards workers' safety and health other than waste reduction and cost savings. End-of-pipe controls shall shift towards CPPP as it is one of the strategies to promote the preventions of injuries, illness and fatalities in working environment due to a safer environment provided by reducing hazardous waste and pollutants as well as the uses of harmful chemicals. The end-of pipe technologies are often observed with an external environmental risk changes towards an internal occupational health risk while hazardous waste and pollutants is confine in the production process; and vice versa, will causes environmental pollution when waste is release to the environment. While going through cleaner production approach, both cases can be ceased as the main objective of the preventive approach is to identify and eliminating possible hazardous waste at the source of production (Matos et al., 2018). The shift towards CPPP would be a solution in adverse environmental and public health issues related to industrial activities.

## 6 Conclusion

In conclusion, cleaner production should be implemented in various industries as it is one of the key factors to solve or reduce the environmental problems, we are currently facing such as global warming and water pollution. Based on the current trend, cleaner production is shifting to tackle global environmental problems by focus on reducing carbon emission and resources consumption. Despite all the benefits, there are still barriers that slow down the development of cleaner production such as individuals refuse to change the already existed methods and practices. While some concern that the cost of implementing cleaner production requires more cost and preexisting processes. Besides that, individuals may lack of pathways and knowledge to apply cleaner production in their production line. Hence, public education and researches shall be carried out in order to solve the current barriers by raising public's awareness and introducing new methods and pathways for cleaner production.

## Declaration of competing interest

The authors declare no known competing interests that could have influenced the work reported in this paper.

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