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An Assessment of Environmental Related Key Performance Indicators of the Chemical Industries

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Abstract. One of the most critical issues faced by chemical industries is reducing the environmental impact caused due to pollution, which has resulted in global warming and health issues. Most chemical industries monitor and use Key Performance Indicators (KPIs) to control pollution, which is currently done by using various KPI's that are dependent on the product they are producing. Therefore, a study is conducted using a systematic literature review (SLR) focused on articles published between 2000 and 2022 to identify and categorize various KPIs that manufacturers have used to reduce their respective pollution. The results were divided into four main categories - air, water, land, and other pollution. The results demonstrated that ethylene manufacturing industries are the major contributor to air pollution. The mining, gas, and oil industries significantly resulted in water pollution. The land and groundwater pollution were mainly due to mining industries. The other pollution was mainly due to activities such as maintenance and performance of equipment and quality of raw materials.

Keywords. KPIs, Environmental Impact, Chemical Companies, Chemical industries

1. Introduction

Industrialization promotes rapid economic growth, and manufacturers are ever increasing their investment for sustainable development. Nevertheless, manufacturing consumes massive amount of fossil fuel, significantly increasing year on year, producing substantial greenhouse emission and air pollution, impacting the environment [1]. Energy consumption data shows that 2.24 billion metric tonnes of CO_2 were emitted in 2000 increasing to 6.44 billion metric tonnes by 2014 [2].

Furthermore, much of the energy consumed by manufacturing is wasted due to misuse or old machinery [3], which demonstrates why equipment selection is critical. Yet, old machines may have an attractive return on investments and fulfill their purpose, meaning they continue to be used despite having a high consumption of energy and emissions of CO_2 compared with new technology. For instance, if modern machines are adopted, the chemical and petrochemical sector's performance may improve [4].

In this context, manufacturers are now increasing their investment in enhancing their production activities by reducing CO2 emissions. It is due to deep concern about the issues of global warming and climate change and increased awareness of air pollution caused by increasing industrialization [5]. As a result, there has been considerable

pressure on the industrial sectors to make more significant efforts to protect the environment. Manufacturing industries are thus attempting to overcome these challenges [6]. This study investigates KPIs that chemical companies use to monitor their environmental impact. The systematic literature review aggregates statistical measurements from multiple data to compile a complete, informed picture of the latest research and identify current gaps in our knowledge [7].

2. Methodology

This study focuses on three related subtopics: Key performance indicators, environmental impact, and chemical companies. When selecting the articles to review, at least one of the aforementioned keywords had to be directly or indirectly involved. This became the criterion for selecting research articles under PRISMA 2020 [7]. The sources used to collect those articles were Scopus, ProQuest, Elsevier, Cranfield library, Scholar, and IEEE Xplore. When searching for relevant publications, we screened for the keywords: petrochemical industry, KPIs (in chemical engineering), and environmental impact.

We identified 58 published articles relevant to the theme of studying the KPIs that companies monitor to reduce their environmental footprint. The strategy for our search followed three stages: first, we searched different databases by analyzing the titles, abstracts, and index terms of articles. In the second stage, we reviewed all identified keywords and index terms across all included databases. In the third stage, we used the reference lists of the leading articles to search for additional studies. All studies included in this review met the inclusion criterion

In the steps taken to determine the studies included in our review, firstly, we identified 659 articles through database searching. Those articles were then filtered, and after removing the duplicates and those that were ineligible, 337 were left. We then screened the results and reduced them to 58 studies to include. The processes described are illustrated in Figure 1.

3. Result and Discussion

The data we collected, as illustrated in the graph, there was a steady rise in global CO_2 emissions from 25.1 to 31.86 billion metric tonnes between 2000 and 2008 (see Figure 2). The increasing concentration in the air was caused by human activities, primarily by burning fossil fuel [8]. Traditional fuels such as gas, coal, and oil contribute to global emissions since CO_2 is a by-product of burning hydrocarbons. The rising CO_2 emissions between 2000 and 2008 were also a result of the growth, development, and industrialization [9]. Particularly, the industries established during this period used traditional fuels as their primary sources of energy.

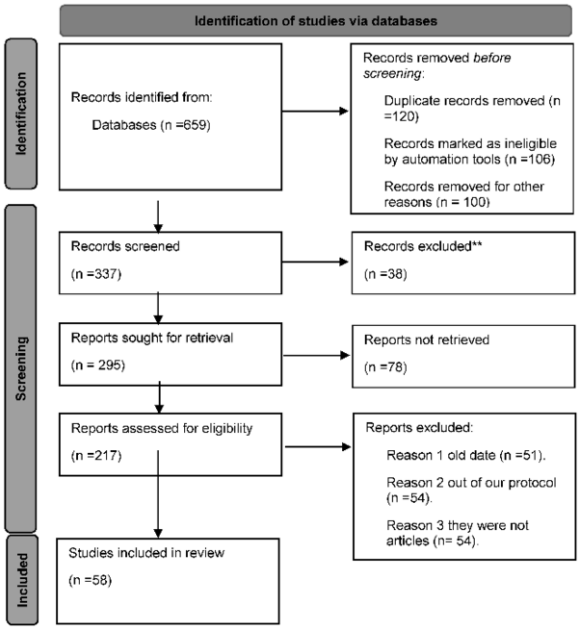

Figure 1. Flow diagram of the processes.

However, between 2008 and 2009, slower economic growth, reduced annual global emissions from 31.86 to 31.31 billion metric tonnes in the major industrial countries. These nations included those in the European Union (EU), Asia, and North America; their combined downturn reduced global CO_2 emissions [8]. At the same time, in the EU countries, reliance on coal-based electricity for their industries was curtailed as they began to use renewables such as wind and biomass. Nevertheless, the reduced CO_2 emissions were short-lived as the annual global rates increased to 33.35 billion metric tonnes in 2010, reaching 35.69 billion metric tonnes by 2014. A similar decreasing trend was also observed between 2014 and 2017 because of slow economic growth and the adoption of renewable energy sources. However, global CO_2 emissions increased to 37.9 billion metric tonnes in 2019.

An article by [9] indicated that global CO_2 emissions dropped by 2.6 billion metric tonnes in 2020. The decrease was primarily due to the lockdown imposed during the onset of the COVID-19 pandemic. During this period, most countries implemented measures to stop the spread of coronavirus by restricting people's movements, hence reducing the need for transportation [9]. Similarly, the pandemic affected the production of goods; thus, there was slow demand and use of fossil fuels in the industries. Therefore, a fall in energy demand reduced global CO_2 emissions, especially in industrial countries such as China and India [10]. Nevertheless, increased global CO_2 emissions were seen in 2021 due to the rebound after-effects of the COVID-19 pandemic. In order to revitalize the economy, especially in certain industries, meant increased demand for fossil fuels than in the previous years.

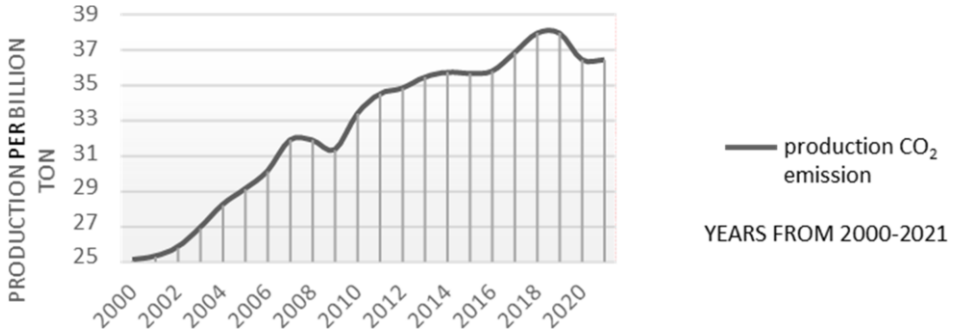

Figure 2. Rate of CO_2 emission in atmosphere from 2000-2021.

Global CO_2 emissions are expected to rise further if companies do not minimize their CO_2 emissions by tracking KPIs [11]. The dependent variable in this study is how much CO_2 is produced by petrochemical manufacturing industries. We expected to find a significant positive correlation between energy consumption and CO_2 output from specific manufacturing processes within these industries and the data collected confirmed that this is the case. Higher energy consumption leads to an increased in the output of CO_2.

Furthermore, our data showed a significant positive correlation between the quality of raw materials used for the manufacturing processes and the efficiency of older or low-quality machines. The data shows that older machines requiring higher maintenance levels produced increased CO_2 compared to newer and more efficient technology. We also expected there to be anegative correlation between the quality of raw materials and CO_2 output, which means using better quality materials may significantly reduce pollution and so represent an opportunity to make a significant positive environmental impact. Though high-quality materials may be more expensive, their reduced negative environmental impact could mean companies are not penalized in the long term and thus save money.

The findings of our review highlighted how all pollution by chemical/petrochemical companies of air, land, and water is predicted to sooner or later affect humans and animals. The current situation is a source of global concern about climate change, and specifically, warming due to such emissions. The data shows that emissions to the air are by far the most significant issue, representing over three-quarters (78%) of the total emissions from petrochemical industries (see Figure 3). These emissions comprise several elements, which are collectively known as greenhouse gases: carbon dioxide (CO_2), Nitrous Oxide (N_2O), Ozone (O_3), Sulphur Hexafluoride (SF_6), Perfluorochemicals (PFCs), Hydrofluorocarbons (HFCs), and Methane (CH_4). CO_2 emissions are of specific concern due to the massive amount of CO_2 already in the air. At the same time, there are also the issues of acid rain and smog containing Sulphur dioxide (SO_2), Nitrogen Oxides (NOx), Ammonia (NH_3), and Carbon Monoxide (CO).

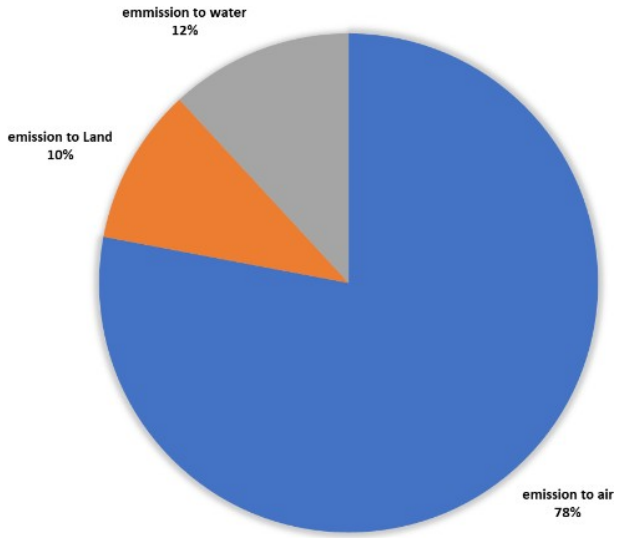

Figure 3. The percentage of emissions to air, water and land by chemical companies.

This study found a significant positive correlation between the petrochemical and chemical industries' energy consumption and the resultant CO_2 output. As energy consumption increases, so will CO_2 emissions. Here, the dependent variable is the quantity, i.e., how much CO_2 is produced. We expected a positive correlation, and this was found to be the case. We noted from the data that there might also be a relationship between the quality of material and maintenance, not just energy (see Figure 4).

There is a significant correlation between the energy consumption and CO_2 output, and it is perhaps also necessary to look at the quality of the raw materials used and the standard of the equipment/its maintenance, to assess a company's performance and determine which of these leads to an increase in its energy consumption.

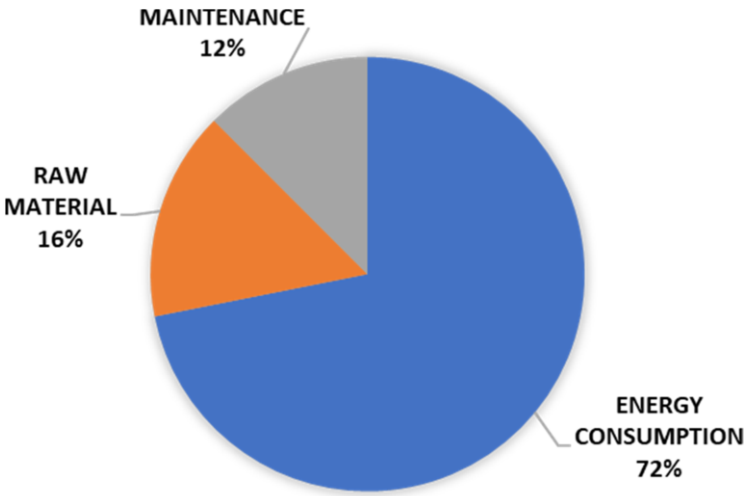

Figure 4. Proportions of articles that mention different subtopics.

4. Conclusion

This review aimed to determine the KPIs adopted by the chemical/petrochemical industries that impact the environment. The quality of the raw materials and the standard of machine's were the main contributors to the amount of CO_2 generated. Accordingly, both factors should be considered by companies and governments seeking to reduce CO_2 emissions. The present study represents an attempt to highlight these issues, and further research examining the quality of the materials used by chemical companies will help to reduce the sector's energy consumption. Moreover, this, research should shed light on the equipment producing significant CO_2 emissions that could be replaced with new, less-polluting equipment. However, the current results require corroboration in future research to determine whether they are robust and generalizable, Nevertheless, this study provides clear support for investment in new equipment and high-quality raw materials that could be useful for reducing the environmental impact of the industry.

References

[1] Z. Sun, D. Wei, L. Wang, and L. Li, "Simulation-based production scheduling with optimization of electricity consumption and cost in smart manufacturing systems," in *2015 IEEE International Conference on Automation Science and Engineering (CASE)*, Aug. 2015, vol. 2015-Octob, pp. 992–997. doi: 10.1109/CoASE.2015.7294228.

[2] R. Xu and B. Lin, "Why are there large regional differences in CO2 emissions? Evidence from China's manufacturing industry," *Journal of Cleaner Production*, vol. 140, pp. 1330–1343, Jan. 2017, doi: 10.1016/j.jclepro.2016.10.019.

[3] W. Al-Subaiei, E. Al-Herz, W. Al-Marri, R. Al-otaibi, H. Ashyan, and H. Jaber, "Industry 4.0 Smart Predictive Maintenance in the Oil Industry to Enable Near- Zero Downtime in Operations," 2021. doi: http://www.ieomsociety.org/singapore2021/papers/1234.pdf.

[4] O. Taylan, D. Kaya, and A. Demirbas, "An integrated multi attribute decision model for energy efficiency processes in petrochemical industry applying fuzzy set theory," *Energy Conversion and Management*, vol. 117, pp. 501–512, Jun. 2016, doi:10.1016/j.enconman.2016.03.048.

[5] A. Lamjahdi, H. Bouloiz, and M. Gallab, "Overall performance indicators for sustainability assessment and management in mining industry," in *2021 International Conference on Optimization and Applications, ICOA 2021*, May 2021, pp. 0–5. doi:10.1109/ICOA51614.2021.9442635.

[6] C. Y. Yuan and D. A. Dornfeld, "Reducing the environmental footprint and economic costs of automotive manufacturing through an alternative energy supply," *Transactions of the North American Manufacturing Research Institution of SME*, vol. 37, pp. 427–434, 2009.

[7] M. J. Page *et al.*, "Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement," *Journal of Clinical Epidemiology*, vol. 134, pp. 103–112, 2021, doi: 10.1016/j.jclinepi.2021.02.003.

[8] J. G. J. Olivier and J. A. H. W. Peters, "No growth in total global CO 2 emissions in 2009," 2010. [Online]. Available: www.pbl.nl/en.

[9] C. le Quéré *et al.*, "Fossil CO2 emissions in the post-COVID-19 era," *Nature Climate Change*, vol. 11, no. 3, pp. 197–199, Mar. 2021, doi: 10.1038/s41558-021-01001-0.

[10] N. Hausfather, "Feeling the structures of Québec's 2012 student strike at Concordia University: The place of emotions, emotional styles, and emotional reflexivity," *Emotion, Space and Society*, vol. 40, p. 100809, Aug. 2021, doi: 10.1016/J.EMOSPA.2021.100809.

[11] S. Jagtap, G. Garcia-Garcia, and S. Rahimifard, "Optimisation of the resource efficiency of food manufacturing via the Internet of Things," *Computers in Industry*, 127, p.103397, 2021, doi: 10.1016/j.compind.2021.103397.