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A CONCEPTUAL FRAMEWORK OF GREEN MANUFACTURING STRATEGIES FOR GREENHOUSE GAS EMISSIONS REDUCTION IN MALAYSIAN MANUFACTURING INDUSTRY

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ABSTRACT

Green manufacturing is a practice that aims to reduce waste and pollution throughout the manufacturing process. The research scope covers how the implementation of green manufacturing practices helps manufacturing companies to reduce GHG emissions. The main objective of the study is to determine the relationship between green manufacturing practices and GHG emissions and how knowledge, costs, regulations and technology moderate the relationship between green manufacturing practices and GHG emissions in Malaysia. This paper reviews the existing literature on the topic and proposes a conceptual framework of green manufacturing practices for Malaysian manufacturing industry context. This study intends to provide insights into green manufacturing and as well as to fill the research gaps in how green manufacturing helps in reducing GHG emissions.

Keywords: Green manufacturing strategies, greenhouse gas emissions, manufacturing industry

INTRODUCTION

Environmental issues such as greenhouse gas emissions, pollution, deforestation and global warming are a major concern in Malaysia. In order to overcome these environmental issues, the Malaysian government urges manufacturing companies to implement green manufacturing practices. In recent years, green manufacturing has been addressed by various researchers in different kinds of fields. Most of the previous studies of green manufacturing focused on the drivers (Luo et al., 2018; Seth et al., 2018; Singh et al., 2016; Ghazilla et al., 2015; Jian, 2013), barriers (Karuppiah et al., 2020; Ghazilla et al., 2015), applications (Leong et al., 2019a) and impacts of green manufacturing in different sectors such as automotive and manufacturing (Leong et al., 2019a; Abdul-Rashid et al., 2017). Other than that, the previous researchers have also highlighted the practical, empirical and theoretical gaps in green manufacturing in Malaysia. However, the research on the reduction of GHG emissions with the implementation of green manufacturing practices in Malaysia has yet to receive much attention from the researcher. Hence, more research is needed to help the manufacturing industries in Malaysia understand the strategies that can be used to reduce GHG emissions through the implementation of green manufacturing practices.

Generally, manufacturing is listed as one of the important economic sectors of Malaysia (Malaysian Investment Development Authority (MIDA), 2022). Malaysia manufacturing grew moderately by 3.9% on the Gross Domestics Products (GDP) in the fourth quarter of 2022 led by electrical, electronic and optical products, transport equipment, other manufacturing and repair. (Department of Statistics Malaysia, 2023).

In 2015, the Federation of Malaysian Manufacturers (FMM) aimed to have over 100 manufacturing companies adopt green manufacturing practices by 2020 (Federation of Malaysian Manufacturers, 2015). The number of companies registered with MyHijau Mark is increasing from 2015 to 2023. MyHijau Mark is an initiative by the government to encourage Malaysians to source and purchase green products and services. In Malaysia, there are 792 companies and 15,022 products and services registered with MyHijau Mark as of 31st December 2023 (MyHijau, 2024). Besides, Malaysia encourages manufacturing companies to go green by introducing various initiatives such as Energy Management Gold Standard (EMGS), ISO 14001 Certification, MyHIJAU SME & Entrepreneur Development Programme and other green certification schemes (Prime Minister's Office of Malaysia, 2019).

Malaysia has pledged to bring down the greenhouse gas emission (GHG) intensity of GDP by 45% by 2030 corresponding to the emissions intensity of GDP in 2005 (The Star, 2021). Malaysia ranks 56th in the climate change performance index as of 2023 (Climate Change Performance Index (CCPI), 2024).

Table 1

Summary of GHG Inventory for 2019

Sector	GHG Emission/Removal (Gg CO_2 eq.)
Energy	259,326.11
IPPU	32,853.80
AFOLU-Agriculture1	9,921.71
AFOLU-LULUCF2	-214,714.54
Waste	28,256.59
Total (Excluding LULUCF)	330,358.21
Total (Including LULUCF)	115,643.68

According to the Malaysia's Fourth Biennial Update Report, the total of GHG emissions excluding land use, land-use change, and forestry (LULUCF) was 330,358.21 Gg CO_2 eq. in 2019 (UNFCCC, 2022). This issue triggers public concern as the number of emissions is high. According to Khoo (2019), the main causes of GHG emissions in Malaysia are energy consumption, transportation and waste. The data from Malaysia's Fourth Biennial Update Report supported the previous research by mentioning that energy, transport and manufacturing and construction sector as the top three contributor to the GHG emissions in Malaysia in 2019.

Table 2

Summary Total GHG Emissions for Sector in 2019.

Sector	Sub-sector	Gg CO_2 eq. (Gg)	Percentage (%)
	GWP		
Energy	Energy Industries	131,735.68	50.80
	Manufacturing Ind. & Construct.	33,578.18	12.95
	Transport	64,973.10	25.05
	Other Sectors	6,064.92	2.34
	Non-Specified	492.59	0.19
	Fugitive Emission from Fuels	22,481.62	867
	Total	**259,326.11**	**100**
IPPU	Mineral Industry	10,085.03	30.70
	Chemical Industry	5760.43	17.53
	Metal Industry	13,081.31	39.82
	Electronics Industry	2,790.46	8.49
	Product Uses as Substitutes for Ozone Depleting Substances	929.77	2.83
	Other Product Manufacture and Use	206.80	0.63
	Total	**32,853.80**	**100**
Waste	Solid Waste Disposal Sites	11,681.20	41.34
	Biological Treatment of Solid Waste	0.41	0.00
	Waste Incineration	44.51	0.16
	Open Burning of Waste	2.78	0.01
	Domestic Wastewater Treatment and Discharge	2,065.22	7.31
	Industrial Waste Treatment and Discharge	14,462.46	51.18
	Total	**28256.58**	**100**

According to UNFCCC (2022), the GHG emissions of energy sector was 259,326.11 Gg CO_2 eq., & it increased by 27.95% in 2019 compared to 2005 based year emissions. The emissions from the energy industries contributed as the highest sub-category with emissions of 131,735.68 Gg CO_2 eq. (50.80%) followed by transport sector with emissions of 64,973.10 Gg CO_2 eq. (25.05%) and manufacturing and construction sector with emissions of 33,578.18 Gg CO_2 eq. (12.95%). The total emissions of IPPU in 2019 was 32,853.80 Gg CO_2 eq., & the GHG emissions had increased by 118% compared to 2005 based year emissions due to the increase emissions from metal industry. The most GHG emissions was contributed from metal industry with 13,081.31 Gg CO_2 eq. (39.82%). It is followed by mineral industry with 10,085.03 Gg CO_2 eq. (30.70%), electronics industry with 2,790.46 Gg CO_2 eq. (8.49%), product uses as substitutes for ozone depleting substances with 929.77 Gg CO_2 eq. (2.83%) and other product manufacture and use with 206.80 Gg CO_2 eq. (0.63%). On the other hand, the total emissions by waste sector was 28,256.58 Gg CO_2 eq., & it increased 28.43% in 2019 compared to base year 2005. The main contributor was industrial wastewater treatment and discharge with 14,462.46 Gg CO_2 eq. (51.18%) followed by solid water disposal sites with 11,681.20 Gg CO_2 eq. (41.34%) and domestic wastewater treatment and discharge with 2,065.22 Gg CO_2 eq. (7.31%).

As this study focus on manufacturing companies in Malaysia, the analysis will delve deeper into the data related to energy, IPPU and waste. However, the discussion will not extend to the agriculture and LULUCF sectors. Hence, a study is needed to identify how green manufacturing strategies can help manufacturing companies reduce their GHG emissions. This paper proposes a conceptual framework to understand the moderating impact of knowledge, costs, regulations and technology on the relationship between green manufacturing practices on greenhouse gas emissions.

LITERATURE REVIEW

In this research, systematic literature review (SLR) was used to identify, review and analyse the existing literature from various databases and sources which includes SCOPUS and Google Scholar. The keywords were used for the search ("green manufacturing" or "eco manufacturing" or "green production" or "sustainable production") and ("greenhouse gas emissions" or "carbon footprint"). Initially, a total of 3,748 literatures was found and a screening process was undertaken to select the relevant literature that mainly focused on green manufacturing strategies and GHG emissions which resulting in the exclusion of irrelevant and duplicate articles. Finally, only 42 articles were included in the analysis of literature review in this study.

Manufacturing Sector and Greenhouse Gas Emissions in Malaysia

Manufacturing sector is one of the main contributors to the economy of Malaysia. According to the data from Department of Statistics Malaysia, Malaysia's manufacturing sector contributes 23.6% of Malaysia's GDP in 2020 (Department of Statistics Malaysia, 2021). The sub-sectors within manufacturing sector in Malaysia include food, beverages and tobacco; textile, wearing apparel, leather and footwear; wood, furniture, paper products and printing; petroleum, chemical, rubber and plastic; non-metallic mineral products, basic metal and fabricated metal products; electrical and electronics products; transport equipment and other manufactures. According to the Monthly Manufacturing Statistics Malaysia, there were 2.37 million persons engaged in the manufacturing sector amounting to RM8.2 billion in February 2024 (Department of Statistics Malaysia, 2024). An increase of 0.6 percent can be seen in the employees that engaged in manufacturing as compared to 2.35 million persons in February 2023. The sales value of the manufacturing sector in February 2024 was RM146.2 billion and grew 0.7 per cent as compared to the previous month. (Department of Statistics Malaysia, 2024).

According to MyHijau Mark and Directory, the manufacturing sector has traditionally played an important role in transforming raw materials from diverse sources into innovative products. There has been an increased demand for materials and goods with the rising living standards and population growth. The industry has evolved into highly complex structures that convert raw materials into finished products in order to meet the market demand. The evolution requires the utilization of natural resources such as fossil fuels, metals, water and minerals at higher energy intensities to achieve the necessary production volumes. Consequently, it will lead to more waste and emissions being released into the environment along with the depletion of natural resources (MyHijau Mark and Directory, 2022).

The effects of climate change are very notable to many cities worldwide. The cases for the greenhouse gas emissions, pollution, deforestation and global warming in Malaysia have increased rapidly over the past few decades. Besides that, water scarcity is evidence of the effects of climate change. In addition, heatwaves and flooding are threats to Malaysia every year. Yusliza et al. (2019) mentioned that the influence of the manufacturing sectors towards the environment is indeed a concern as it is the main contributor to environment degradation.

Greenhouse gas is gases that trap heat in the atmosphere, causing infrared radiation to be absorbed, which is then automatically release thermal radiation back into the atmosphere (Olanrewaju & Mbohwa, 2018). According to UNFCCC (2020), GHG include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and F-gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). CFCs are gases that are created due to human activities and not naturally exist in the atmosphere, while gases such as CO_2, CH_4 and N_2O are naturally existed in the atmosphere and it will continue to increase due to human activities (Rana et al., 2015). According to the Third Biennial Update Report, manufacturing and construction industries were the third largest contributor among the major sources of emissions (UNFCCC, 2020). Currently, Malaysia contributes 0.7% to global GHGs emissions (Twelfth Malaysia Plan 2021-2025). Hence, it is unavoidable for the manufacturing companies to create emissions and wastes during the production.

Impact of GHG Emissions

The release of GHG in the atmosphere will likely cause global warming issues and impact on a variety of aspects of climate such as sea levels, precipitation, air and ocean temperatures. According to Jamaica Climate Change Youth Council (2021), global warming occurs when the human population increases and so does the burning of fossil fuels. The burning of fossil fuels will lead to the release of GHG emissions in the atmosphere and hence increase the temperature. As a result, climate changes such as flooding, melting of ice caps and glaciers, hurricanes and drought happen (Mith, 2019). According to Solum (2022), toxic gases such as carbon dioxide and methane are released into the air due to the burning of fossil fuels by the manufacturing companies due to its operating activities. Solum (2022) also mentioned that the released of toxic gas to the atmosphere will affect the temperature of the planet as the carbon dioxide and methane absorbed the radiation from the sun.

Besides that, GHG emissions also caused the rise of sea levels. The global sea levels are rising year by year as the sea temperature is increasing and the melting of ice caps and glaciers. According to National Geographic Society (2022), the rise of sea levels is occurring at a faster rate and it is predicted to increase in the upcoming years.

The GHG emissions also has an impact on marine's life. Conserve Energy Future (2022) mentioned that most industries require a lot of water for the operating activities and the waters are mixed with heavy metals, harmful chemicals and radioactive waste during the process. These chemicals and radioactive wastes are dumped into open oceans or rivers. As a result, the level of alkalinity in the sea is affected and fishes are forced to come to the surface for the oxygen.

In addition, the ecosystem is damaged due to the release of GHG. According to National Geographic Society (2022), flora and fauna are affected by climate change. As the temperature rises, the wildlife lose their habitats and are forced to find new habitats. The mangrove forests are affected as the soil erosion happens due to the rise of sea water that invades the coastal areas. Besides that, industrial accidents such as leakage of radioactive, oil spills and fire caused the animals to lose their habitats (Conserve Energy Future, 2022). Consequently, animals and plants started to go extinct due to the extreme weather.

Last but not least, GHG emissions have a negative impact on human health. As the atmosphere was full of GHG, extreme heat and pollution are occurring. Poor air quality increases the chances of respiratory problems such as asthma and difficulty to breathe. According to United States Environmental Protection Agency (2022), extreme weather also increases the risk of heat related illness. The warmer temperature in the atmosphere will increase the spread of diseases and pandemics such as malaria and dengue. Solum

(2022) mentioned that human being will suffer damage of lung, pancreas, heart and brain due to the absorption of the toxic gases. For example, air pollution not only suppressing the lung's normal growth rate but as well as speeds up the decline of lung function**.**

Initiatives to Reduce GHG Emissions in Malaysia

The reduction of GHG emissions allowed living things to have a healthier environment. Therefore, the initiatives done by the government are classified based on sectors.

In 2016, National Energy Efficiency Action Plan (NEEAP) was introduced to enhance the implementation of energy efficiency by targeting residential, commercial and industrial sectors. The goal for this initiative is to conserve electricity and decrease the growth in electricity demand (Prime Minister Office, 2019). NEEAP aims to conserve 52,233 GWh of electricity in a ten years' period from 2016 to 2025 which is equal to a decrease of 8.0 percent in electricity demand at the end of the plan. The initiatives under NEEAP are five star rated appliances, minimum energy performance standards (MEPS), energy audits and energy management in buildings and industries and energy efficient building design. The promotion of five star rated appliances successfully avoided 31. 04 Gg CO_2 eq for refrigerator and 330.51 Gg CO_2 eq for air conditioner. The use of energy efficient lighting and promotion of high efficient electric motors under the Minimum Energy Performance Standards (MEPS) Programme avoided 0.53 Gg CO_2 eq and 038 Gg CO_2 eq respectively. The energy audits and energy management in commercial buildings and industries under the Energy Audit Conditional Grant (EACG) were the highest contribution in energy savings with the avoidance of 80.76 Gg CO_2 (UNFCCC, 2020). According to the NEAAP, the conservation of electricity will result in a decrease in peak demand and the necessity to construct new power plants in the future. In simpler terms, the success of NEEAP will enhance the electricity load profile through improved management of peak loads in the power system (Prime Minister Office, 2019).

Green Building Rating Scheme aims to encourage the utilization of the resources, especially energy and water, which can reduce GHG emissions. In the Eleventh Malaysia Plan, the new government building will utilize the green attributes, green designs and green building materials in accordance with the standards such as Green Performance Assessment System (Green PASS) green ratings by the Construction Industry Development Board (CIDB) and Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST). Therefore, the organizations will be encouraged to earn Green Building Index (GBI) or green renewable energy for private buildings. By achieving points in these targeted area, the building will likely become environmental friendly than those that do not address the issues (Green Building Index, 2024).

According to GBI ratings, an estimated amount of 143.47 Gg CO_2 eq of emissions reduction were achieved with the implementation of green building. There are two initiatives taken by the government in the waste sector. The initiatives are waste paper recycling and biogas recovery from palm oil mill effluent. A target of 22% recycling was set by National Solid Waste Management Policy 2006 and the Eleventh Malaysia Plan for 2020. According to the UNFCCC (2020), an increase of recycling rate of materials from 17% in 2015 to 21% in 2017 can be seen in the survey conducted by Solid Waste and Public Cleansing Management Corporation (SWCorp). Therefore, the initiative resulted in the emissions reduction of f 3,937.76 Gg CO_2 eq in 2016 (UNFCCC, 2020).

On the other hand, the government launched the Entry Point Project on Developing Biogas Facilities at Palm Oil Mills in 2010 as part of its Economic Transformation Program after realizing the economic potential of biogas from palm oil mill effluents (POME). This program's goal was to ensure that every

palm oil mill was equipped with biogas entrapment facilities. Therefore, all new mills and existing mills are compulsory to apply for expansion to install biogas trapping or methane avoidance facilities starting 1 January 2014 (UNFCCC, 2020). According to Malaysia's Third Biennial Update Report, 104 of 454 palm oil mills were completely equipped with biogas capture facilities (UNFCCC, 2020). This initiative led to a reduction of 2,377.84 Gg CO_2 eq in 2016.

Material substitution and utilizing recycled materials are one of the initiatives to reduce GHG emissions for industrial processes and product use sector. Materials substitution using different raw materials has been implemented in the cement, iron and steel industries in order to improve sustainability and reduce emissions. For cement industries, fly ash and granulated blast furnaces were used as a substitution material in order to reduce the amount of clinker in cement. While iron and steel industries reduce the emissions by using recyclable materials such as scrap as one of the main raw materials. The utilization of raw materials helps to minimize the consumption of raw material by minimizing the extraction and the use of iron ore (UNFCCC, 2020).

The government had done various initiatives to reduce GHG emissions. The existing initiatives create a friendly and conducive environment which promotes more mitigation actions to be carried out. Green Technology Tax Incentives was introduced by the government with the goal to strengthen the implementation of green technology in Malaysia. Green Technology Tax Incentives consists of Green Income Tax Exemption (GITE) which qualify green service providers and Green Investment Tax Allowances (GITA) which qualify green assets and projects (UNFCCC, 2020). The eligible applicants for this scheme are companies that are investing in green technology, taking part in green technology projects and green technology service providers. According to UNFCCC (2020), MyHIJAU is a green recognition scheme which lists the certified products and services that fulfil local and international environmental standards. The eligible applicants for GITA are local companies that are investing in green technology and it is listed under the MyHIJAU Directory and companies that take part in green technology projects for their own consumption or business. On the other hand, the eligible applicants for GITE are green technology provider companies that are listed in MyHIJAU Directory.

Green Manufacturing

Green manufacturing is a concept that began in the late 1980s in Germany and it covers the entire lifecycle of the product (Matthew, 2020; Sezen & Cankaya, 2013). Green manufacturing is also known as sustainable production, green production, environmentally conscious manufacturing, clean manufacturing and eco manufacturing (Mittal, 2017). These terms were used by different researchers and the term 'green manufacturing' was defined in a variety of ways by the previous researcher.

According to Matthew (2020), green manufacturing is about making a product with a modern manufacturing process that will generate less pollution to the environment. Cheong et al. (2019) stated that green manufacturing helps in reducing the environmental impacts and enhances ecological efficiency by eliminating environmental wastes. Khan et al. (2020) suggest that green manufacturing includes several aspects such as green product design, usage of environmentally friendly materials, minimizing packaging in environmentally friendly ways, distribution and reuse after the end of product life. Basically, the definition of green manufacturing that was defined by the previous researchers are almost similar to each other as the term shares similar aims and goals which is an eco-friendly process to eliminate wastes and preserve the environment. In short, green manufacturing is a manufacturing process which is used to convert raw material to final product with the concept of eliminating wastes, reducing the pollution and minimizing the negative impacts towards the environment.

Green Manufacturing Strategies

The past decade has seen the rapid development of green manufacturing globally. Manufacturers are aware that it is important to keep the environment safe at every production phase. Manufacturers need to consider green strategies to improve the sustainability of the production activities. The existing literature shows that several green manufacturing strategies have been implemented by manufacturing companies. According to Logesh and Balaji (2020), green manufacturing consists of green process planning, green supply chain, green purchasing, green productivity, green disposal, green design, design for environment and green technology. On the other hand, Qi et al. (2017) and Ghazilla et al. (2015) stated that the strategies consist of green design, green procurement, green manufacturing, green packaging and distribution, end of product life and remanufacture. To sum up, the strategies are slightly different for the existing literature.

Green process planning is one of the strategies of green manufacturing. Liu et al. (2020) mentioned that process planning is used to reduce cost by analysing and planning the process flow, machine and tools required for the production. Besides that, the process planning helps the companies to reduce energy consumption of the machine and the carbon emissions from the production. On the other hand, Leong et al. (2019b) stated that green planning processes focus on the usage of the green technology in order to reduce the environment impacts by minimizing the usage of raw materials, reducing generated wastes and conserving energy.

Next, green supply chain. Green supply chain is a strategy used by companies to include the environmental feature into the decision making in every production stage (Seow & Hamid, 2017). The green supply chain management was often viewed as the representative of the environmental-friendly image in connection with the product design, manufacturing production and technologies (Seow & Hamid, 2017). Seow and Hamid (2017) also mentioned that green supply chain is defined as the entire chain of relationships that exists between the manufacturers, suppliers, consumers and as well as the recovery process.

Logesh and Balaji (2020), Qi et al. (2017) and Ghazilla et al. (2015) mentioned that green purchasing, also known as green procurement, is also a green manufacturing strategy. Yee et al. (2021) mentioned that green purchasing is a purchasing initiative used by the companies to cooperate with the suppliers by purchasing the products or materials that meet with the companies' environmental goals. Besides that, Yee *et al.* (2021) mentioned that the capabilities and practice of green purchasing contribute to enhancing sustainability related to financial and economic performance such as increase in productivity, sales and reducing costs.

The existing literature also points out that green productivity is one of the strategies (Perera & Amarena, 2021; Logesh & Balaji, 2020; Leong et al., 2019b). According to Christian and Sahroni (2020), green productivity is a strategy that can provide positive changes in socioeconomic fields by enhancing productivity and environmental performance. Leong et al. (2019b) mentioned that the green productivity is used to reduce generated wastes. The negative environmental impacts of the company's activities can be reduced with green productivity by using the combination of the suitable application of techniques, tools, technology and environmental management (Christian & Sahroni, 2020). Besides, the companies can increase the business performances with the improvement of the product quality, reuse materials, reduce waste, and eliminate pollution (Perera & Amarena, 2021).

In addition, green disposal is also one of the green manufacturing strategies (Logesh & Balaji, 2020; Matthew, 2020; Sahar et al., 2020). According to Matthew (2020), green disposal is used to minimize electronic waste in the environment by reusing, replacing, retaining, disposing and upgrading outdated

machines and technology. Sahar et al. (2020) mentioned that disassembly and remanufacturing is included in green disposal. Disassembly can reuse, reduce, recycle and reproduce the materials to minimize landfill wastes. On the other hand, remanufacturing is a process that creates new products which makes use of the discarded parts from the dismantling of existing products.

The literature shows that green design is also a green strategy used by the companies (Logesh & Balaji, 2020; Matthew, 2020; Leong et al., 2019b; Qi et al., 2017; Ghazilla et al., 2015). According to Matthew (2020) and Leong et al. (2019b), green design which is also known as eco-design focuses on creating goods that are free of wastes and environmentally-friendly to use. Dahmani et al. (2021) mentioned that green design methods, tools, and environmental design tools such as design for environment (DfEs) and life cycle design are used to support the product design phase. According to Leong et al. (2019b), design for environment (DfEs) is part of the process design as DfEs identify and design a product depending on its impact to the environment throughout the product life cycle. Besides, Life Cycle Assessment (LCA) is important in the starting design stage as it reduces the generated wastes and identifies the environmental impact of the product throughout the product life cycle which starts from the selection of the materials until the disposal (Dahmani et al., 2021; Leong et al., 2019b).

The existing literature also points out that green innovation is one of the strategies (Yusliza et al., 2020; Leong et al., 2019b; Seth et al., 2018; Seow & Hamid, 2017). Green innovation is defined as a manufacturing approach that introduces new eco-friendly products or processes with the aims of reducing environmental impacts and increasing competitiveness (Leong et al., 2019b; Seow & Hamid, 2017). On the other hand, Seth et al. (2018) mentioned that green innovations that include the use of eco-friendly processes and recycled goods have a lot of potential for improvement in the business.

Last but not least, green technology. The adoption of green technology which includes the implementation of new or improved techniques, processes and systems helps to reduce harmful impact of the business activities to the environment as well as human activities (Yacob et al., 2018). According to Xian et al. (2017), green technology is used to reduce the consumption of natural resources and energy, minimize the generated wastes and recycle leftover materials. Similarly, Seth et al. (2018) and Eshikumo and Odock et al. (2017) pointed out that green technology can reduce the environmental impact and increase the economy by optimizing the process and reducing energy consumption.

Barriers and Drivers of Green Manufacturing Implementation

Table 1 features a list of barriers and drivers of green manufacturing implementation and were categorised based on four dimensions which were policy, social, organisational and technology. The barriers and drivers of green manufacturing practices include regulation, incentive, supply chain pressure, customer demand, employee, top management commitment, green technology and innovation.

Table 3

Barriers and Drivers of Green Manufacturing Practices

Dimension	Categories	Barriers	Drivers	Sources
Policy	Regulation	Weak regulation, lack of awareness, lack of guideline	Pressure from government, stricter regulation and legislation	Karuppiah et al. (2020); Cheong et al. (2019); Leong et al. (2019a); Seth et al. (2018); Luo et al. (2018); Mittal (2017); Singh et al. (2016); Ghazilla et al. (2015)
	Incentive	Lack of financial resources, investment, foreign direct investment and subsidies	Tax incentive, subsidies	Karuppiah et al. (2020); Leong et al (2019a); Luo et al. (2018); Mittal (2017); Ghazilla et al. (2015)
Social	Supply chain pressure	Absence of green disposal system, lack of systematic implementation method	Use recycled materials in manufacturing process	Karuppiah et al. (2020); Leong et al (2019a); Luo et al. (2018); Mittal (2017)
	Customer demand	Customer demand for environmental friendly products, lack of customer interest on green	Customer demand on environmental friendly products and customer awareness on green initiatives	Karuppiah et al. (2020); Foo et al. (2019); Cheong et al. (2019); Leong et al. (2019a); Seth et al. (2018); Luo et al. (2018); Mittal (2017)
Organizational	Employee	Lack of competent employee, low employee commitment, lack of environment knowledge, inadequate training	Employee demand firm to implement green manufacturing practices and training for their health and safety	Karuppiah et al. (2020); Leong et al (2019a); Luo et al. (2018); Yacob et al. (2018); Mittal (2017); Hassan et al. (2015); Singh et al. (2016); Ghazilla et al. (2015)
	Top management commitment	Poor organization style or structure	High commitment from management and stakeholder	Karuppiah et al. (2020); Cheong et al. (2019); Leong et al. (2019a); Luo et al. (2018); Mittal (2017); Mittal (2017); Ghazilla et al. (2015)
Technology	Green technology	Technology risk, low implementation of green technology	Improve carbon footprint, reduce energy consumption	Cheong et al. (2019); Leong et al. (2019b); Hassan et al. (2015); Ghazilla et al. (2015)
	Innovation	Lack of research and development (R&D)	Reduce emissions, energy saving, reuse or recycle resources	Karuppiah et al. (2020); Seth et al. (2018); Mittal (2017); Ghazilla et al. (2015)

The adoption of green manufacturing is influenced by a variety of factors and as well as its drivers. Regulation acts as both a hindrance and a driver for companies to adopt green manufacturing practices. On one hand, Karuppiah et al. (2020) highlighted that the lack of guidelines and resource persons in the field limits companies' ability to adopt green practices. Additionally, Leong et al. (2019a) and Mittal (2017) pointed out that companies often lack awareness of the benefits of green practices due to inadequate information. Conversely, several studies (Cheong et al., 2019; Leong et al., 2019a; Seth et al., 2018; Luo et al., 2018; Mittal, 2017) emphasize the role of regulations as a driver for implementing green manufacturing practices. Leong et al. (2019a) emphasized the importance of government regulations in

encouraging and supporting manufacturing companies to adopt green practices. Foo et al. (2019) argued for tighter regulations to minimize environmental impact, while Mittal (2017) stated that legislation can drive companies to enhance their corporate social responsibility. Luo et al. (2018) highlighted the combined impact of market pressure and environmental regulations in driving companies to adopt green practices. Additionally, Foo et al. (2019) suggested that companies can achieve green manufacturing through waste reduction, recycling, pollution prevention, and ISO 14000 certification.

The financial status of a company serves as both a barrier and a driver for green manufacturing practices. On one hand, Leong et al. (2019a) highlighted how insufficient financial resources hinder the successful implementation of green practices. Companies often need to invest in new technology and restructure production processes, leading to increased costs. For instance, investments in new technology and changes to production floors require significant financial resources. Additionally, Karuppiah et al. (2020) noted that inadequate subsidies from the government can discourage companies from adopting green practices, as green initiatives often require higher investments. Conversely, government incentives play a crucial role in motivating companies to adopt green manufacturing practices. Leong et al. (2019a) mentioned that the Malaysian government offers tax incentives, such as investment tax allowances, to manufacturing companies. These incentives aim to encourage companies to invest in green practices by providing funding and incentives for green projects. Moreover, various financial incentives, such as investment subsidies, tax exemptions, rebates, green premiums, soft loans, awards, and grants, are provided to motivate manufacturing companies to adopt green practices (Luo et al., 2018; Mittal, 2017; Ghazilla et al., 2015).

According to Luo et al. (2018) and Mittal (2017), supply chain pressure plays a significant role in motivating companies to engage in green manufacturing practices. Implementing measures such as the 3Rs (Reduce, Reuse, and Recycle) in production can help companies contribute to environmental protection. However, as identified by Karuppiah et al. (2020) and Leong et al. (2019a), poor supply chain management and the lack of a systematic implementation method pose barriers to adopting green practices. Companies face challenges in meeting the demands of the supply chain, which hinders their ability to implement sustainable practices effectively.

Both customer demand and lack of awareness act as significant factors influencing the adoption of green practices. On one hand, customer demand for green products is a crucial driver in implementing green manufacturing practices (Foo et al., 2019; Cheong et al., 2019; Leong et al., 2019a; Seth et al., 2018; Luo et al., 2018; Mittal, 2017). Customers are increasingly aware of environmental degradation and are requesting eco-friendly products, thereby pressuring manufacturing companies to produce such products (Foo et al., 2019; Seth, 2018; Luo et al., 2018). Mittal (2017) emphasizes the role of customers as important stakeholders in shaping companies' social responsibility. However, customer demand can also act as a hindrance when there is a lack of awareness about the importance of green products (Karuppiah et al., 2020). In developing countries, the awareness of green products is relatively low compared to developed countries (Karuppiah et al., 2020). Additionally, customers in developing countries may prioritize price over environmental concerns, opting for lower-priced products (Mittal et al., 2017). This indicates that despite the demand for green products, customer awareness and price sensitivity can pose challenges for companies looking to adopt green practices.

Employee involvement plays a dual role in the implementation of green manufacturing practices. On one hand, employees act as drivers for companies to adopt such practices by demanding their implementation in order to reduce occupational health and safety hazards (Luo et al., 2018; Yacob et al., 2018). Employees are keen to see their companies adopt green practices for the betterment of their working environment and overall well-being. However, employees also pose significant barriers to the implementation of green manufacturing practices (Karuppiah et al., 2020; Leong et al., 2019a; Mittal, 2017; Hassan et al., 2015;

Ghazilla et al., 2015). The lack of skilled and qualified employees is a major obstacle (Karuppiah et al., 2020), along with a dearth of expertise and communication gaps within companies (Leong et al., 2019a; Mittal, 2017). This scarcity of competent employees and inadequate training may discourage companies from adopting green practices (Mittal, 2017), leading to low employee involvement and job dissatisfaction (Hassan et al., 2015). Additionally, employees may find it difficult to access relevant information on green practices, further hindering the company's progress (Ghazilla et al., 2015). Thus, while employees are instrumental in driving the adoption of green practices, their lack of skills, expertise, and involvement can present significant challenges for companies.

The commitment of top management is paramount in driving the adoption of green practices within a company. Studies have shown that the lack of top management commitment can hinder the adoption of green manufacturing practices (Karuppiah et al., 2020; Leong et al., 2019a; Mittal, 2017; Ghazilla et al., 2015). Unstructured organizations and a lack of management commitment can lead to confusion in knowledge flow and a disregard for the importance of green practices (Karuppiah et al., 2020; Mittal, 2017; Ghazilla et al., 2015). Additionally, fear of failure among top management can result in low involvement in green practices (Leong et al., 2019a). Conversely, research also emphasizes the importance of top management commitment in the implementation of green manufacturing practices (Cheong et al., 2019; Leong et al., 2019a; Luo et al., 2018; Mittal, 2017). Top management acts as the final decision-maker in companies, and their involvement is crucial for green initiatives (Cheong et al., 2019; Luo et al., 2018; Mittal, 2017). Training and education programs for top management are needed to increase their understanding and support for the implementation of green manufacturing (Leong et al., 2019a).

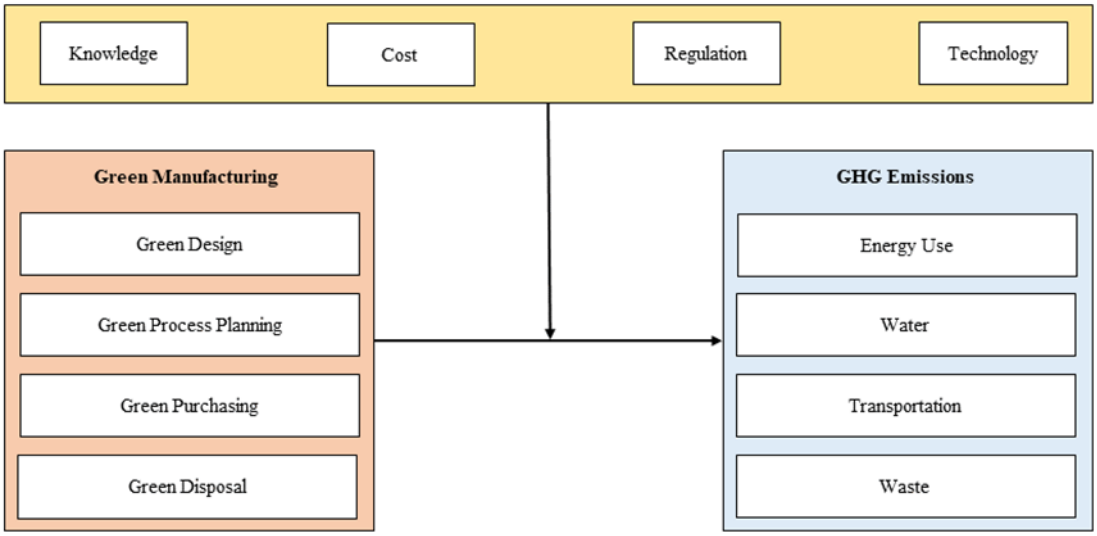
Technology and innovation play a significant role in both facilitating and hindering the implementation of green manufacturing practices. On one hand, some manufacturing companies face challenges due to outdated and low-efficiency technology (Leong et al., 2019b). The high implementation costs, particularly for small and medium-sized enterprises (SMEs), make it difficult for them to invest in new technology and design products according to environmental standards (Singh et al., 2016; Mittal, 2017). Mittal (2017) highlighted technical difficulties, as green production projects require high investments with slow returns. Additionally, the lack of new technology, resources, and processes hinders companies' ability to fully support green practices (Ghazilla et al., 2015). Inadequate innovation and research and development further impede the implementation of green manufacturing practices (Karuppiah et al., 2020; Ghazilla et al., 2015). On the other hand, technology and innovation serve as drivers for companies to adopt green manufacturing practices. The implementation of green practices can lead to efficient production flows as technology advances (Cheong et al., 2019). Advancements in technology not only reduce operational costs and environmental pollution but also contribute to extensive economic growth (Leong et al., 2019a). Moreover, green innovation enables companies to improve products and processes (Seth et al., 2018). Therefore, while technology and innovation pose challenges for some companies, they also offer opportunities for implementing and enhancing green manufacturing practices.

Conceptual Framework and Hypothesis Development

According to Twelfth Malaysia Plan (2021-2025), manufacturing companies are required to adopt the environment, social and governance (ESG). The adoption of ESG by the manufacturing sectors will promote low carbon and climate resilient economy. Therefore, knowledge, costs and regulation are set as the moderator on the relationship between green manufacturing practice and GHG emissions. Figure 1 shows the relationship between green manufacturing strategies and GHG emissions in Malaysia with the moderating effects of knowledge, costs, regulation and technology. Besides, hypotheses were developed from the proposed conceptual framework. In this research, there are four hypotheses constructed based on

the conceptual framework. These hypotheses were made in order to identify how green manufacturing practices help in reducing greenhouse gas emissions (GHG).

Figure 1
Conceptual Framework



Knowledge serves as a crucial moderator in the relationship between green manufacturing practices and GHG emissions reduction across various dimensions. According to Matthew (2020) and Leong *et al.* (2019b), green design which is also known as eco-design focuses on creating goods that are free of waste and environmentally-friendly to use. Khaleeli et al. (2021) defined environmental knowledge and awareness as an individual's level of understanding of environmental problems and concerns as well as the degree to which they are supporting the solutions to these problems. Khaleeli et al. (2021) also revealed that environmental knowledge may influence an individual's attitudes and intentions to behave sustainably in both of its forms, namely the actual or objective knowledge. Therefore, employees with a deep understanding of green design concepts are more likely to implement eco-friendly products and manufacturing processes, resulting in reduced energy use and GHG emissions. Similarly, the process planning helps the companies to reduce the energy consumption of the machine and the carbon emissions from the production, thus positively impacting emissions reduction. Besides that, Yee et al. (2021) mentioned that green purchasing is a purchasing initiative used by companies to cooperate with suppliers by purchasing products or materials that meet the companies' environmental goals. Hence, it can reduce the emissions associated with transportation and production. According to Matthew (2020), green disposal is used to minimize electronic waste in the environment by reusing, replacing, retaining, disposing and upgrading outdated machines and technology. Disassembly can reuse, reduce, recycle and reproduce the materials to minimize landfill waste. Based on the discussion, this paper proposes the following hypotheses:

Hypothesis 1: Knowledge moderate positively the relationship between green manufacturing and GHG emissions.

Cost plays a significant role as a moderator in the relationship between green manufacturing practices and GHG emissions reduction. Environmental costs are defined as the cost that is needed to be paid by the companies in order to minimize the consumption of the raw materials and environment pollution in the manufacturing process (Li et al., 2022). According to Grudzien et al. (2018), the environmental costs that

the companies are going to spend on are the cost for the ongoing maintenance and installation of equipment, investments costs on both the facilities and employees, and costs of nonconformities such as costs of removal of potential emergency situations and administrative fines for not adhering to current legal requirements. In green design, high initial costs of eco-friendly materials and technologies can often deter companies from investing in sustainable design practices. Leong et al (2019a) mentioned that the advancement in technology not only reduced operation costs and environmental pollution but also led to extensive growth in the economy. Liu et al. (2020) mentioned that process planning is used to reduce cost by analyzing and planning the process flow, machine and tools required for production. However, Ghazilla et al. (2015) mentioned that the manufacturing companies had difficulty obtaining financial support as the green manufacturing practices needed a higher cost to be implemented. According to Hlavacek et al. (2023), green purchasing can help reduce the pollution, reduce energy use and water, conserve natural resources, reduce environmental costs, transportation, disposal, and reduce waste. Hazaea et al. (2022) stated that the cost of green products is normally higher than non-green products. Foo et al. (2021) mentioned that the primary goal of green purchasing is to focus on the overall costs including recycling content, reusing and eliminating waste activities for cost-saving programs. Sahar et al. (2020) mentioned that disassembly and remanufacturing is included in green disposal. Disassembly can reuse, reduce, recycle and reproduce the materials to minimize landfill wastes. Based on the discussion, this paper proposes the following hypotheses:

Hypothesis 2: Cost moderate positively the relationship between green manufacturing and GHG emissions.

Regulatory frameworks serve as important moderators in the relationship between green manufacturing practices and GHG emissions reduction. Leong et al. (2019a) mentioned that the regulation set by the government plays an important role in encouraging and supporting the manufacturing companies to implement green manufacturing practice. Foo et al. (2019) mentioned that companies need to comply with environmental regulation to avoid legal penalties and fine from the government. Adbaidainy (2021) mentioned that the stricter the regulation, the higher the motivation for a company to implement green manufacturing practice. Similarly, Foo et al. (2019) also stated that the government should tighten the regulations to minimize the environmental impact. On the other hand, Mittal (2017) revealed that legislation is an important driver for companies to enhance their corporate social responsibility. Luo et al. (2018) pointed out the market pressure and environmental regulation have a stronger impact for the companies to adopt the green practice. Foo et al. (2019) mentioned that the main driver of green purchasing is regulatory pressure as the companies are forced to follow the regulation in order to provide a consistent supply of green inputs to produce green products. According to Qu et al. (2020), companies need to conduct internal environmental management evaluation of suppliers and ensure that they comply with environmental management standards. Hence, it can reduce the emissions associated with transportation and production. Sustainable waste management strategies such as reducing waste generation, improving waste collection and disposal methods and promoting recycling and composting can help to reduce emissions (Perkumiene et al., 2023). Based on the discussion, this paper proposes the following hypotheses:

Hypothesis 3: Regulation moderate positively the relationship between green manufacturing and GHG emissions.

Technology serves as a key moderator in the relationship between green manufacturing practices and GHG emissions reduction by providing innovative solutions to environmental challenges. Cheong et al. (2019) mentioned that the implementation of green manufacturing practice can help the companies to have efficient production flow as the shift of technology occurred. Leong et al (2019a) mentioned that the

advancement in technology not only reduced operation costs and environment pollution but also led to an extensive growth in the economy. Normally, SMEs are short of resources to invest in new technology and design the products according to the provided environmental standards and guidelines (Mittal, 2017). According to Fernando and Wah (2016), manufacturing company that has purchased green technology from green suppliers delivers benefits to customer and society. Besides that, green technology allows companies to incorporate green processes into production, therefore reduce the environmental impact of industrial activities (Javaid et al., 2022). Based on the discussion, this paper proposes the following hypotheses:

Hypothesis 4: Technology moderate positively the relationship between green manufacturing and GHG emissions.

CONCLUSION

This study offers insights on how green manufacturing practices for greenhouse gas emissions reduction in Malaysian manufacturing industry. This study brings additional clarity to knowledge, cost, regulation and technology in the reduction of GHG emissions. The existing literature shows that green manufacturing strategies consist of green disposal, green supply chain, green purchasing, green productivity, green disposal, green design, design for environment and green technology. Besides that, the researcher further elaborates on the benefits, barriers and drivers of implementing green manufacturing strategies. A conceptual framework was developed to identify the relationship between green manufacturing strategies and the reduction in GHG emissions. Hypotheses were made to test the relationship between the independent variables and dependent variables. This study has attempted to fill this theoretical gap by further investigating the relationship between green manufacturing practices and GHG emissions. Hence, this study has deepened insights into the impact of knowledge, cost, regulation and technology on the relationship between green manufacturing practices and GHG emissions.

However, there is still a limitation found in this study as this study did not directly investigate other elements such as incentives, supply chain pressure, customer demand top management commitment and innovation in the policy, social, organizational and technology dimension. It will alter the focus of this study's aim and scope. Therefore, it is left to the future study. With reference to this study's scope, the focus has been on green manufacturing practices (green design, green process planning, green purchasing and green disposal), the moderator (knowledge, cost, regulation and technology) and GHG emissions (energy use, water, transportation and waste). Future researchers may try other green manufacturing strategies (green supply chain, green productivity, green innovation and green technology).

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REFERENCES

Abdul-Rashid, S.H., Sakundarini, N., Ghazilla, R.A.R., & Thurasamy, R. (2017). The impact of sustainable manufacturing practices on sustainability performance: Empirical evidence from Malaysia. *International Journal of Operations and Production Management*, *37*(2), 182-204.

Adbaidainya, I. (2021). Evaluation of green manufacturing implementation on regulation, costs, and knowledge. *Jurnal Ekonomi dan Bisnis Airlangga*, *31*(1), 64-73.

Chiet, C.W., Ching, N.T., Huat, S.L., Fathi, M., & Tzuu, T.J. (2019). The integration of lean and green manufacturing for Malaysian manufacturers: a literature review to explore the synergies between lean and green model. In *IOP Conference Series: Earth and Environmental Science* (Vol. 268, No. 1, p. 012066). IOP Publishing.

Christian, Y., & Sahroni, T.R. (2020). February. Green productivity methodology for furniture industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 426, No. 1, p. 012159). IOP Publishing.

Climate Change Performance Index (CCPI) (2024). *CCPI Rank*. Retrieved from https://ccpi.org/country/mys/

Conserve Energy Future (2022). *What is Waste Management and Various Methods of Waste Disposal?* Retrieved from https://www.conserve-energy-future.com/waste-management-and-waste-disposal-methods.php

Dahmani, N., Belhadi, A., Benhida, K., Elfezazi, S., Touriki, F.E., & Azougagh, Y. (2022). Integrating lean design and eco-design to improve product design: From literature review to an operational framework. *Energy and Environment*, *33*(1), 189-219.

Department of Statistics Malaysia (2024). *Monthly Manufacturing Statistics, Malaysia, March 2024*. Retrieved from https://www.dosm.gov.my/portal-main/release-content/monthly-manufacturing-statistics-malaysia-march-2024

Department of Statistics Malaysia (2023). *Malaysia Economic Performance Fourth Quarter 2022*. Retrieved from https://v1.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=100&bul_id=RkhsOGEwclM4T1UxZ1Vmb0pwL1JlQT09&menu_id=TE5CRUZCblh4ZTZMODZIbmk2aWRRQT09

Department of Statistics Malaysia (2021). Index of Industrial Production, Malaysia December 2021. Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=90&bul_id=U2l2dkJMZzc1cTBPdS9Yand3QkthQT09&menu_id=SjgwNXdiM0JlT3Q2TDBlWXdKdUVldz09

Eshikumo, S.M., & Odock, S.O. (2017). Green manufacturing and operational performance of a firm: Case of cement manufacturing in Kenya. *International Journal of Business and Social Science*, *8*(4), 106-120.

Federation of Malaysian Manufacturers (2015). GBI Targets 100 Green Rated Factories by 2020. Retrieved from https://www.fmm.org.my/FMM_In_The_News-@-GBI_targets_100_green_rated_factories_by_2020.aspx

Fernando, Y., Wah, W.X., & Shaharudin, M.S. (2016). Does a firm's innovation category matter in practising eco-innovation? Evidence from the lens of Malaysia companies practicing green technology. *Journal of Manufacturing Technology Management*, *27*(2), 208-233.

Foo, M.Y., Kanapathy, K., Zailani, S., & Shaharudin, M.R. (2019). Green purchasing capabilities, practices and institutional pressure. *Management of environmental quality: An international journal*, *30*(5), 1171-1189.

Ghazilla, R.A.R., Sakundarini, N., Abdul-Rashid, S.H., Ayub, N.S., Olugu, E.U., & Musa, S.N. (2015). Drivers and barriers analysis for green manufacturing practices in Malaysian SMEs: A preliminary findings. *Procedia CIRP*, *26*, 658-663.

Green Building Index (2024). *The GBI Rating System*. Retrieved from https://www.greenbuildingindex.org/how-gbi-works/gbi-rating-system/

Grudzien, L., Osinski, F., & Jasarevic, S. (2018). Analysis of the environmental costs in manufacturing companies in the SME sector in Poland. In *Advances in Manufacturing* (301-310). Springer International Publishing.

Hassan, M.G., Nordin, N., & Ashari, H. (2015). Sustainable manufacturing practices implementation in Malaysia industries. *Jurnal Teknologi*, *44*(4), 49-56.

Hazaea, S.A., Al-Matari, E.M., Zedan, K., Khatib, S.F., Zhu, J., & Al Amosh, H. (2022). Green purchasing: Past, present and future. *Sustainability*, *14*(9), 5008.

Hlaváček, M., Čábelková, I., Brož, D., Smutka, L., & Prochazka, P. (2023). Examining green purchasing. The role of environmental concerns, perceptions on climate change, preferences for EU integration, and media exposure. *Frontiers in Environmental Science*, *11*.

Jamaica Climate Change Youth Council (2021). *The Greenhouse Effect: Advantages and disadvantages*. Retrieved from https://ourfootprintja.org/2021/03/02/greenhouse-effect-the-advantages-and-disadvantages/

Javaid, M., Haleem, A., Singh, R.P., Khan, S., & Suman, R. (2022). Sustainability 4.0 and its applications in the field of manufacturing. *Internet of Things and Cyber-Physical Systems*, *2*, 82-90.

Jian, C.Y., 2013, January. The role of green manufacturing in reducing carbon dioxide emissions. In *2013 Fifth International Conference on Measuring Technology and Mechatronics Automation* (pp. 1223-1226). IEEE.

Karuppiah, K., Sankaranarayanan, B., Ali, S.M., Chowdhury, P., & Paul, S.K., 2020. An integrated approach to modelling the barriers in implementing green manufacturing practices in SMEs. *Journal of cleaner production*, *265*, 121737.

Khaleeli, M., Pradeep, S., & Krishnadas, L., 2021. The effects of environmental knowledge and green products awareness on green management and sustainable performance: Evidence from manufacturing sector in UAE. *Management Science Letters*, *11*(3), 757-762.

Khan, S.A.R., Yu, Z., Belhadi, A., & Mardani, A., 2020. Investigating the effects of renewable energy on international trade and environmental quality. *Journal of Environmental Management*, *272*, p.111089.

Leong, W.D., Lam, H.L., Ng, W.P.Q., Lim, C.H., Tan, C.P., & Ponnambalam, S.G. (2019a). Lean and green manufacturing—A review on its applications and impacts. *Process integration and optimization for sustainability*, *3*, 5-23.

Leong, W.D., Teng, S.Y., How, B.S., Ngan, S.L., Lam, H.L., Tan, C.P., & Ponnambalam, S.G. (2019b). Adaptive analytical approach to lean and green operations. *Journal of Cleaner Production*, *235*, 190-209.

Li, X., Ma, C., & Lv, Y. (2022). Environmental cost control of manufacturing enterprises via machine learning under data warehouse. *Sustainability*, *14*(18), 11571.

Liu, Q., Liu, J., Dong, Z., Zhan, M., Mei, Z., Ying, B., & Shao, X. (2021). Integrated optimization of process planning and scheduling for reducing carbon emissions. *Journal of Industrial and Management Optimization*, *17*(3), 1025-1055.

Logesh, B., & Balaji, M. (2021). Experimental investigations to deploy green manufacturing through reduction of waste using lean tools in electrical components manufacturing company. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *8*(2), 365-374.

Luo, Y., Jie, X., Li, X., & Yao, L. (2018). Ranking Chinese SMEs green manufacturing drivers using a novel hybrid multi-criterion decision-making model. *Sustainability*, *10*(8), 2661.

Sadiku, M.N. (2020). *Emerging green technologies*. CRC Press.

Mittal, V.K. (2017). Perspectives on green manufacturing. *Advanced Manufacturing Technologies: Modern Machining, Advanced Joining, Sustainable Manufacturing,* 213-236.

Mith, M. (2019). *Advantages or disadvantages of the greenhouse effect*. Retrieved from https://medium.com/@mariamith22/what-are-the-advantages-or-disadvantages-of-the-greenhouse-effect-ba6feb97169d

MyHijau (2024). *MyHijau Mark Registration (Green Products & Services).* Retrieved from https://www.myhijau.my/statistics/

MyHijau (2022). *Green practices guideline for manufacturing sector*. Retrieved from https://www.myhijau.my/ebook/pdf/mgtc.pdf

National Geographic Society (2022). *Causes and effects of climate change*. Retrieved from https://education.nationalgeographic.org/resource/climate-change

Olanrewaju, O.A., & Mbohwa, C. (2018). The need for Greenhouse Gas analyses in industrial sectors. In *Environmental Carbon Footprints* (pp.1-18). Butterworth-Heinemann.

Perera, R.A.S.A., & Amarasena, S. (2021). Contribution of green productivity to the success of business performance: A literature review. *International Journal of Innovative Research and Publications*, *1*(2), 6-16.

Perkumienė, D., Atalay, A., Safaa, L., & Grigienė, J. (2023). Sustainable waste management for clean and safe environments in the recreation and tourism sector: a case study of Lithuania, Turkey and Morocco. *Recycling*, *8*(4), 56.

Prime Minister's Office of Malaysia (2019). *Green Technology Master Plan Malaysia (GTMP 2017-2030)*. Retrieved from https://www.pmo.gov.my/2019/07/green-technology-master-plan-malaysia/?highlight=green%20technology%20master%20plan

Qi, A.N., Sin, T.C., Fathullah, M., & Lee, C.C. (2017). September. The impact of fit manufacturing on green manufacturing: A review. In *AIP Conference Proceedings* (Vol. 1885, No. 1). AIP Publishing.

Qu, G., Zhang, Z., Qu, W., & Xu, Z. (2020). Green supplier selection based on green practices evaluated using fuzzy approaches of TOPSIS and ELECTRE with a case study in a Chinese internet company. *International Journal of Environmental Research and Public Health*, *17*(9), 3268.

Rana, S., Pichandi, S., Karunamoorthy, S., Bhattacharyya, A., Parveen, S., & Fangueiro, R. (2015). 7 carbon footprint of textile. *Handbook of sustainable apparel production*, p.141.

Sahar, D.P., Afifudin, M.T., & Indah, A.B.R. (2020). October. Review of green supply chain management in manufacturing: A case study. In *IOP Conference Series: Earth and Environmental Science* (Vol. 575, No. 1, p. 012239). IOP Publishing.

Seth, D., Rehman, M.A.A., & Shrivastava, R.L. (2018). Green manufacturing drivers and their relationships for small and medium (SME) and large industries. *Journal of Cleaner Production*, *198*, 1381-1405.

Seow, C.N., & Hamid, N.A.A. (2017). June. Green manufacturing performance measure for automobile manufacturers. In *2017 International Conference on Industrial Engineering, Management Science*

and Application (ICIMSA) (pp. 1-5). IEEE.

Sezen, B., & Cankaya, S.Y. (2013). Effects of green manufacturing and eco-innovation on sustainability performance. *Procedia-Social and Behavioural Sciences*, *99*, 154-163.

Singh, S., Olugu, E.U., & Musa, S.N. (2016). Development of sustainable manufacturing performance evaluation expert system for small and medium enterprises. *Procedia CIRP*, *40*, 608-613.

Solum (2022). *What are the Ways to Make Factories Eco-friendly?* Retrieved from https://www.solumesl.com/en/insights/how-can-factories-become-good-for-the-environment

The Stars (2021). *Malaysia plans to reduce greenhouse gas emission by 45%*. Retrieved from https://www.thestar.com.my/news/nation/2021/10/11/pm-malaysia-plans-to-reduce-greenhouse-gas-emission-by-45

United Nations Framework Convention on Climate Change (2020). *Malaysia, biennial update report (BUR), BUR 3*. Retrieved from https://unfccc.int/documents/267685

United Nations Framework Convention on Climate Change (2022). *Malaysia, biennial update report (BUR), BUR 4*. Retrieved from https://unfccc.int/documents/624776

United States Environmental Protection Agency (2022). *Overview of greenhouse gases*. Retrieved from epa.gov/ghgemissions/overview-greenhouse-gases

Xian, C.Y., Sin, T.C., Liyana, M.R.N., Awang, A., & Fathullah, M. (2017). Green perspective in food industry production line design: A review. In *AIP Conference Proceedings* (Vol. 1885, No. 1). AIP Publishing.

Yacob, P., Wong, L.S., & Khor, S.C. (2019). An empirical investigation of green initiatives and environmental sustainability for manufacturing SMEs. *Journal of Manufacturing Technology Management*, *30*(1), 2-25.

Yee, F.M., Shaharudin, M.R., Ma, G., Zailani, S.H.M., & Kanapathy, K. (2021). Green purchasing capabilities and practices towards Firm's triple bottom line in Malaysia. *Journal of Cleaner Production*, *307*, p.127268.

Yusliza, M.Y., Yong, J.Y., Tanveer, M.I., Ramayah, T., Faezah, J.N., & Muhammad, Z. (2020). A structural model of the impact of green intellectual capital on sustainable performance. *Journal of Cleaner Production*, *249*, p.119334.