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Climate Change Dynamics and the Operational Efficiency: Investigation of JSE-listed Manufacturing Companies in South Africa

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ABSTRACT

Climate change has become a concerning problem for the green environment which causes the planet to deteriorate. The changes in temperatures create major shifts in weather conditions which results in increase in surface temperatures, adding vast quantities of greenhouse gases to those naturally occurring in the atmosphere escalating in the greenhouse effect and global warming. The study desired to help manufacturing companies consider disclosing their information on how climate change and the economic transition will affect their businesses and how they will influence the wider environment and society. This disclosure motivates investors by informing them about climate solutions and how the company is building its resilience against climate impacts so that they can make informed investment decisions. The study composed data from 2005 to 2022 of JSE-listed manufacturing companies using Iress database. Econometric techniques such as the panel data dependence technique, pooled multivariate regression, Generalised Method of Moments (GMM), feasible generalized least squares and Pooled Fixed and Random effects have been used for the study. Apart from the methods which were highlighted, comprehensive conceptual issues relating to the sustainability of financial reporting were acknowledged and discussed. Findings from the results suggest that Inventory turnover ratio, waste management, industrial processes and supply chain disruptions had a positive impact on operational efficiency and the financial performance of the selected firms. This indicated that greenhouse gas emissions cause a decline in financial performance when the Inventory turnover ratio is used as a measurement.

Keywords: Climate Change, Sustainability, Operational Efficiency, Financial Performance, Financial Reporting
JEL Classifications: CGQ

1. INTRODUCTION

Climate change effects are becoming more and more apparent in floods and other climate-related challenges like fires, drought, and the loss of some species (Cianconi et al., 2020). Clayton (2020) states that climate change remains an important topic and will never be irrelevant. Therefore, companies should not be oblivious to this hot topic. Manufacturers should be aware of what type of material risks their business is exposed to, the area and the time scale. This is why manufacturing companies should provide more transparency on how climate change might impact the business financially and any business transactions. Inconsistency in financial reporting causes improper financial considerations for other users of the financial information provided. CDSB (2022) agrees that climate-related matters should be disclosed so that the information provided can be used to make relevant assessments by the users of financial statements over the short, medium, and long term.

The importance of South African manufacturing companies to the economy will be compromised as there will be inconsistent production, which can disrupt the entire supply chain (Axmadjonovich, 2023). According to Zhang et al. (2023), disruption may lead to delays in delivery times, shortages of raw materials or components, and increased costs, which can adversely affect relationships with suppliers and customers. In addition, the inconsistencies can lead to inventory management challenges, such as overstocking or understocking inventory. Consequently, overstocking ties up capital and warehouse space, while understocking can result in lost sales and dissatisfied customers. Flood-related claims of R245 million were received on April 14, 2022, and approximately R45 million of the claims were from residential, motor and commercial policies, while the remaining R200 million came from industrial policies covering plants, factories, equipment, and shipping and maritime policies (Maverick, 2022). Moreover, this was the biggest natural disaster that affected the insurance industry in South Africa since 2017 (Maverick, 2022). SA-News (2022) reported that Sihle Zikalala (South African Minister of Public Works and Infrastructure) highlighted that although the government has reprioritised R1 billion towards disaster relief interventions, the province needs more than R1.9 billion to complete the work.

Many manufacturers are preparing financial statements. However, what is missing is that they are not disclosing and making provisions for climate disasters. Hence, this study will assist in getting clarity as to whether this is true or not. The concealment of crucial information prevents investors from obtaining the most reliable reports, and they make decisions based on what is shown on face value, which, in most cases, there is an overstatement of figures in the financial statements. Reporting on climate change effects on the financial statements is motivated by risks that come with it (Gulluscio et al., 2020). Kaplan and Ramanna (2021) highlight that manufacturing organisations must disclose their Environmental, Social and Governance (ESG) problems and match them with their objectives rather than making general reports that are inaccurate, unreliable and cannot be verified. Some studies, like Schaltegger and Csutora (2012) and Chen et al. (2019) have focused on carbon accounting but have not addressed the issues of non-disclosure.

Climate change can have significant implications for the sustainability of financial reporting as it may increase risks and uncertainties. Furthermore, considering climate change in accounting can have several implications for the sustainability of manufacturing companies. For example, manufacturing companies need to account for the environmental costs associated with their operations. This includes measuring and reporting emissions, resource consumption (such as water and energy), and waste generation (Burritt et al., 2019). In addition, Lund et al. (2020) highlight that manufacturing companies rely on complex supply chains that can span multiple regions and countries. Climate change can impact the availability and cost of raw materials, transportation, and logistics, which in turn can affect production processes and profitability. This study intends to prevent these material implications and improve financial sustainability as non-disclosure can facilitate bad investment decisions and loss of assets. The application of climate accounting can improve financial strategies and the sustainability of manufacturing companies' financial reporting practices. That is why there is a need for this study to determine influence of climate change factors on the operational efficiency of JSE-listed manufacturing companies in South Africa.

The primary contributions of this study are diverse as follows:

1. As the sustainability of manufacturing companies are gradually becoming threatened, this research will help manufacturing companies develop sustainable business practices that not only mitigate environmental impacts but also contribute to long-term profitability and viability. The research findings in this field can be utilized by manufacturing companies to drive organizational learning and improvement by examining case studies and applying best practices.
2. This study provides a comprehensive observation which may be useful to those companies that wish to change their operational models. Consequently, the results of this study will bring awareness to stakeholders of manufacturing companies to comprehend climate accounting and the sustainability of financial reporting. This awareness can contribute to attracting environmentally conscious consumers and investors which can lead to increased market share for the manufacturers and profitability.
3. Lastly, the study contributed to theory by determining the theory underpinning this study, looking at different views of previous researchers and providing a lens for this study. Additionally, the study further unpacked climate accounting, sustainability theories and those that relate to financial reporting through the context of the manufacturing industry, which no studies to date have done in this area of focus, according to the knowledge of the researcher.

2. LITERATURE REVIEW

2.1. Climate Change Factors

Climate change is an intricate trend with myths and falsehoods circulating widely. This trend is influenced by numerous factors, both natural and anthropogenic. The impact of climate change is often cumulative, and the factors of climate change are usually interconnected. Therefore, a huge effort is required to address climate change issues which can include land use practices and adapting to current changes. Understanding these factors and their relations is crucial for developing strategies to mitigate and adapt to climate change.

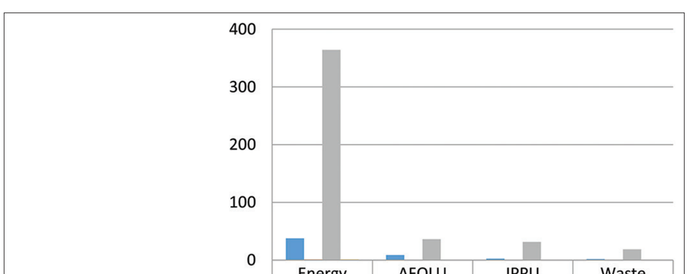
2.1.1. Greenhouse gas emissions (GHGs)

The high concentration of GHGs is the primary cause of climate change. The well-known GHGs among many are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Several manufacturing businesses utilise primary materials obtained from the agricultural sector to process their products into finished goods. According to Chataut et al. (2023), agriculture is responsible for approximately 12% of global anthropogenic GHG emissions. The amount of GHGs emitted through diverse activities, including organic and inorganic amendments, has risen as the population has grown (Guschow, 2021). Similarly, the atmospheric carbon dioxide (CO_2) concentration increased to as close as 100 parts per million. Notably, the contribution made by the manufacturing sector adds on top of prior contributions from other sectors. Therefore, GHGs will still continue to increase because of the connection to society's basic needs for food and energy. However, manufacturers can make substantial efforts to reduce the climate change driver such as gas emissions. As a result, a more sustainable environment can be created so that manufacturing companies are encouraged to report fairly.

Figure 1 shows the amount of GHG contribution from each industry globally and within South Africa. The data was extracted from Climate Watch (World Resources Institute)[1], International Energy Agency (IEA) and UNFCCC Data for the global results and South Africa's National GHG Inventory Reports (UNFCCC) for South Africa's data. The data on Figure 1 shows that there is a strong dominance of energy use in South Africa. It accounts for 81% of South Africa's emissions in comparison 75% globally. The global scale is still high but more moderate opposed to South Africa's. Energy consumption comes from the high carbon intensity which manufacturers highly use coal-fired electricity. For example; Eskom's fleet of aging coal power plants means the electricity grid is one of the most carbon-intensive in the world. This is why the electricity and heat sub-sector makes up a staggering 49% of the national total, whereas globally it is closer to 35%. While, the transport sub-sector makes up a 16% of the SA's total, whereas globally it is 10%. For the manufacturing and construction sub-sector makes up a 12% of the SA's total, whereas globally it is 8%. Lastly other sub-sector (inclusive of fugitive buildings) makes up a 12% of the SA's total, whereas globally it is 14%. Consequently, the world's largest single-point emitter uses coal to create synthetic fuels and chemicals used by the Sasol Secunda facility to convert coal to liquids. The emissions from this process are captured under "Energy" and "IPPU" which makes both these categories excessively high for South Africa. The illustrative shows that agriculture, forestry and land use sectors is the second largest carbon emitter. On a global scale, it contributes 17% which is mostly driven by deforestation (especially in the tropics), livestock (methane), and agricultural soils (nitrous oxide). On the other hand, the agriculture, forestry and land use sectors in South Africa is lesser which shows that is emits only 8%. However, this does not imply that this sector is more sustainable and maintains green practices but means that this sector has a smaller proportion of significant emissions than the energy sector. Figure 1 shows the outsized impact of industrial processes in South Africa is proportionally greater than the global average (7% vs. 5%). This is due to the dominance of the production of cement by the unique chemical processes at Sasol and emissions from the steel and ferroalloys (metals industry) in South Africa. Even though their emissions are processes related and not form the increased energy use by burning of fuel. Interestingly, waste contributes only 3% globally and 4% towards South Africa's emissions. So, with almost 0.75% of the global population, South Africa contributes almost 1% of total global GHG emissions. Therefore, it can be implied that it makes South Africa one of the top 20 absolute emitters globally. As a result, gives it one of the highest per capita emission rates, especially among developing nations. This shows that no single industry can resolve climate change issues on its own and solutions from different sectors are essential. However, there is a lot that manufacturing organisations can do to enforce sustainability in their etiquette. Manufacturers also need to understand that climate change factors need to be carefully studied, as this could potentially affect the organisation's financial performance and disregard the need to report on climate disclosures. Princiotta and Loughlin (2014) highlight that the climate change factors occur regularly and has been existent from the previous decade. Hence, to reduce the risks there will be a need to ameliorate the probable deleterious influences of climate change. Furthermore, ensuring that there is a global sustenance, a commitment from manufacturing businesses Is required to combat the impacts of climate change that sustainability is depending on (Abbass et al., 2022). Terent (2021) denotes that climate change factors are significant factors which determines the financial gains/losses of business. As a result, with climate change increasing each year, it indirectly adds to the environmentally oriented transformation of corporate management systems and technological modernization of production complexes. Henceforth, creating production trends and new competitiveness sources for the long run. In line with this is research by (Wang, 2017) who agree that investing in technology can positively affect the performance and sustainability of manufacturing companies significantly. So, this means that financial sustainability can be motivated by various factors. Therefore, integrating both operational and environmental measurement dimensions can naturally serve as a benchmark to measure the outcome of investment in technology.

1 climatewatchdata.org

Figure 1: Global VS South Africa GHG emissions (2024 estimates). Energy: Emissions from burning fuels for electricity, heat, transport, and manufacturing. AFOLU: Agriculture, Forestry, and Other Land Use (livestock, soils, deforestation). IPPU: Industrial Processes and Product Use (e.g., chemical reactions in cement/metals production). Waste: Emissions from landfills and wastewater

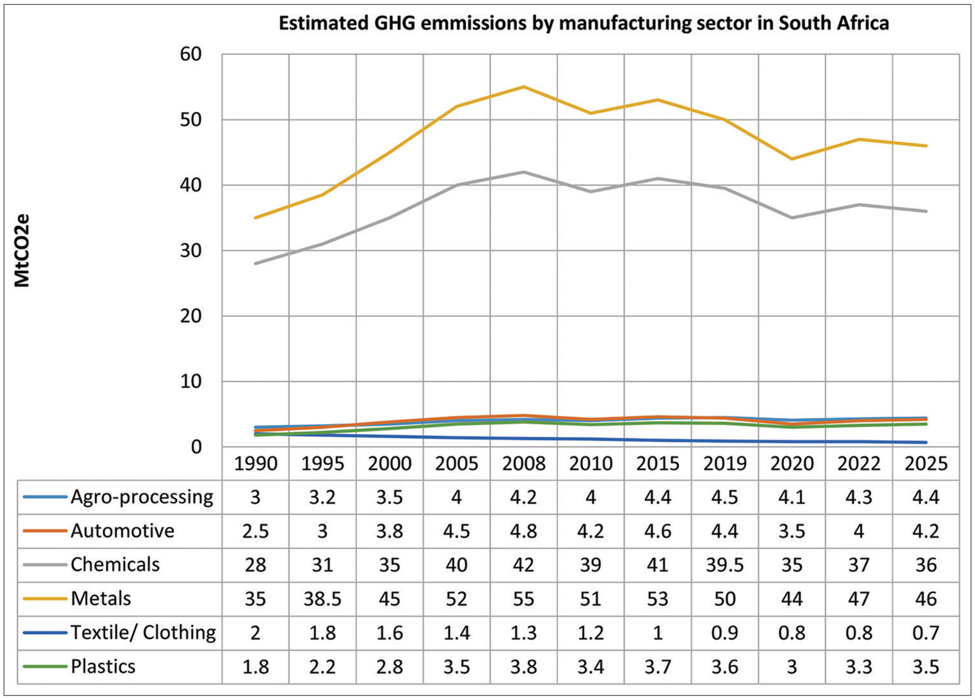


	Energy	AFOLU	IPPU	Waste
Global Emissions ($GtCO_2e$)	37.5	8.5	2.5	1.5
Global Share	75%	17%	5%	3%
South Africa Emissions ($MtCO_2e$)	364	36	31.5	18.5
South Africa Share	81%	8%	7%	4%

Source: Author's compilation (2025)

The graph in Figure 2 illustrates trends of historical data and future outlook of emissions from several sectors in the manufacturing context in South Africa which was extracted from the United Nations Framework Convention on Climate Change (UNFCCC). The metals industry is the largest emissions contributor which stems from huge consumption of electricity. From 1990 to 2022 the line on the graph starts high and grows robustly post-apartheid, peaking before the 2008 financial crisis. The sector is highly cyclical, so dips correspond with global commodity price downturns and domestic economic slowdowns before 2008 and between 2015 and 2016. Companies like ArcelorMittal South Africa and numerous ferroalloy producers are the primary contributors. Electricity shortages (load shedding) have also constrained production, inadvertently capping emissions

Figure 2: Greenhouse gas emissions across sectors



	1990	1995	2000	2005	2008	2010	2015	2019	2020	2022	2025
Agro-processing	3	3.2	3.5	4	4.2	4	4.4	4.5	4.1	4.3	4.4
Automotive	2.5	3	3.8	4.5	4.8	4.2	4.6	4.4	3.5	4	4.2
Chemicals	28	31	35	40	42	39	41	39.5	35	37	36
Metals	35	38.5	45	52	55	51	53	50	44	47	46
Textile/ Clothing	2	1.8	1.6	1.4	1.3	1.2	1	0.9	0.8	0.8	0.7
Plastics	1.8	2.2	2.8	3.5	3.8	3.4	3.7	3.6	3	3.3	3.5

Source: Author's compilation (2025)

at times. Currently, the emissions from the metal sector is projected to slightly decline. This implies that there is a combination of a weak domestic economy, high electricity costs, and the initial impacts of the carbon tax. On the other hand, the chemicals sector the second-largest emitter, dominated by Sasol. The processes are immensely carbon-intensive, releasing CO_2 directly from the chemical conversion of coal. Historically, just like the metals sector, chemical sector shows strong growth through the 1990s and 2000s as production capacity expanded. The line would be high and relatively stable compared to the more cyclical metals sector. It is less sensitive to short-term economic shocks but was impacted by the 2020 lockdown. In recent year, there is a slight downward trend that is projected. Sasol is under immense investor and regulatory pressure to decarbonize.

A significant drop in emissions would require a fundamental shift away from coal feedstock, which is a post 2025 goal. Automotive Sector shows significantly lower emissions than metals and chemicals. The primary reasons for these results stem from assembly lines, robotics, painting, and curing ovens. This is the largest source due to the grid's carbon intensity. In previous years, results show a steady growth, closely tracking the success of government support programs such as the Motor Industry Development Programme. It's a much smaller line than Metals/Chemicals. It shows drops during the 2008 crisis and 2020 pandemic, reflecting drops in vehicle production and sales. Projecting ahead, there is a slight recovery and growth are expected as the sector rebounds. Companies like, BMW, Mercedes-Benz are in the process of investing in producing electric and hybrid vehicles, but the primary manufacturing emissions profile will only change significantly as they invest in on-site renewable energy such as solar. Electricity seems to be the main driver for the plastics manufacturing sector, used to power injection moulding, extrusion, and blow moulding machinery. Some part of the production process requires heat from burning fossil fuels. However, the feedstock known as polymers embodies carbon but is not typically counted as an emission at this point on. In 1990 till 2022 there has been growth in this sector which is tied to consumer spending and the packaging industry. In the illustration, the line would show steady but uncertain growth. This is led by the economic cycles. Moreover, from 2025 onwards, it is observed that the trend is comparatively flat. Despite the demand for plastics remains, there's a counter-pressure from Extended Producer Responsibility (EPR) regulations and a global push for circular economy models. This encourages recycling and use of recycled content. As a result, it can be noted that this is less energy-intensive. For the agro-processing sector which include manufacturing companies like producing food, beverage and tobacco, breweries and wineries can release CO_2 during the fermentation stages. As a result, energy is used for boilers (steam), refrigeration, cooking, drying, and packaging. It is noted that in the past years, this sector was relatively stable and non-cyclical paralleled with the heavy industry.

The graph shows a low and slow movement, which is a sign that there is a steady growth aligned with population growth. Furthermore, it is less affected by economic downturns than automotive or metals. For projections of the current year and future years, it is anticipated that there will be a slight increase on the amount of emissions. This estimation stems from several manufacturing companies wanting to pursue energy efficiency and switching from coal to cleaner fuels (natural gas, biomass) or solar thermal for heating, which could temper emissions growth. Lastly, the textile sector is the only sector likely to show a long-term decline. This sector deals with dyeing and finishing which are particularly energy-intensive. Electricity is mostly used during this process. Hence, the South African textile industry has minimized significantly since the 1990s till 2022 due to intense competition from cheap imports from Asia. The line on the graph moves downwards over the three decades, making it the lowest line by the end of the period. Therefore, it is expected that this trend will continue with a slight decline as there are efforts to revive the local industry through master plans, large-scale, carbon-intensive growth is not anticipated in 2025. Consequently, as the years progress, the climate will be hugely influenced by the enormous greenhouse gases that occur if carbon footprints are not successfully reduced (Eskander and Fankhauser, 2020). So, it is crucial for the manufacturing industry to maintain sustainability for the purpose of reducing these gas emissions and ensuring a smooth financial reporting. Gupta et al. (2021) state that organizations are increasingly facing a burden to change manufacturing models from traditional to sustainable. The models aim to reinforce the necessity for evaluating their performance on sustainability issues. Cleaner production expenditures have been recognised by several manufacturing businesses as one of the burdens encountered and these costs are driven by inefficient processes and technologies that are not up to date. Consequently, this affects the financial performance of the organisation which leads to non-disclosure. Hence, fewer manufacturing companies are still not disclosing now and are unlikely to in the upcoming years, while climate change lingers as a concern. However, sustainable cleaner production can be incorporated into different eco-design strategies, like having a zero-waste programme, which may influence a circular economy.

2.1.2. Waste management as a climate change factor

Khan et al. (2022) define waste management as an image of culture generated by it and has an undesirable influence on human health as well as the environment. In addition, burning waste and decomposing organic waste in landfills are improper waste management practices by human beings in their companies. The population growth in South Africa is increasing considerably. StatSA[2] shows that the population of South Africa grew by 19.8 percentage points between 2011 and 2022, from 51,7 million persons in 2011 to 62 million persons in 2022. This record is the highest percentage change in population size since 1996. This is an indication that there is a need for manufacturing businesses to increase their production to accommodate the population growth. As a result, more pollution is caused by people and manufacturers, where waste management strategies are ineffective. Nguimkeu and Zeufack (2024) theorise that the manufacturing sector may be crucial for sustained growth in Africa. This implies that the direction of structural development is also relevant for productivity growth. On the other hand, Debnath et al. (2023) indicate that approximately 80% of the plastic waste in the ocean comes from terrestrial sites such as poorly maintained landfill sites, and is wind-swept by airflow and tides later on. Likewise, dumped plastic creates a global risk to ecological systems and public health due to poor decomposition, poor disposal systems, and unsustainable production. On the other hand, greenhouse gases, which contribute greatly to atmospheric pollution and climate change are Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). They are released into the air through various natural and human activities such as; respiration, where living organisms release CO_2 as a by-product of cellular respiration, decomposition, where organic matter decomposing in soil releases CO_2, the burning of fossil fuels like coal, oil, and natural gas combustion for energy and transportation, deforestation, where the reduction of forests limits CO_2 absorption by trees and burning organic matter for energy or land clearing. However, Gauci et al. (2024) argue that it is unclear whether CH_4 exchanges across terrestrial ecosystems and the atmosphere will be affected by warming and changes in precipitation patterns. Even though CO_2 is a common factor, CH_4 leads to a global warming contribution. Hence, uncontrolled wastage triggers the scarcity of raw materials due to ecosystem degradation and resource depletion can lead to higher production costs. Over and above, investors are likely to prioritise environmentally responsible companies.

Table 1 shows the total annual emissions from the waste sector in South Africa in 2024, projected to generate approximately 18.5 million tonnes of CO_2, equivalent to $MtCO_2e$. Therefore, the Waste Sector as a whole contributes approximately 4% of South Africa's total national greenhouse gas (GHG) emissions (UNCC, n.d). Meanwhile, the total sum of all greenhouse gas emissions from all sectors across the entire country is 450 $MtCO_2e$ (UNCC, n.d). In addition, 73% of these emissions come directly from solid waste disposal in landfills. The data in the table shows that the vast majority of the climate impact from waste is not from carbon dioxide (CO_2) but from methane (CH_4), a much more potent GHG

2.1.3. Industrial processes as a climate change factor

Industrial processes are a major contributor to climate change, accounting for a significant portion of global GHG emissions. According to Lin et al. (2011), global warming is caused by Industrial agriculture, which contributes a large total of agriculture-related GHG emissions. Furthermore, about 10-12% of global anthropogenic emissions are caused by the agricultural industry. One of the reasons for this contribution is the use of older technologies. Not having newer technologies or unproductive industrial procedures aggravates emissions. Therefore, new technologies are making it easier to identify emission sources to stop further damage with greater energy efficiency and lower-carbon alternatives. Ani et al. (2024) mention that Industrial activities that contribute to climate change are cement production, chemical manufacturing, and other industrial processes that release GHGs through fossil fuel combustion, chemical reactions, and other emissions. Due to these many productions, renewable energy usage is essential to minimise environmental diminution because there is an increase in demand for products hence the production capacity is increased which leads to increased risks of environmental pollution. So, addressing climate issues to strengthen the adoption of renewable energy is crucial in order to meet the country's objectives. More specifically, green finance can increase the development of renewable energy in the sector. Furthermore, when correct policy measures are applied, green finance is anticipated to lower CO_2 emissions by 12.4% and the consumption of fossil fuels by 26% (Behera et al., 2024). Conversely, there is a high possibility that this may be achievable by reducing the cost of capital for clean energy projects. On the other hand, urbanization and the environment have become the most talked-about topics due to the rising apprehension over pollutant emissions which contribute to climate change. Anser

2 Statistics South Africa | Census Dissemination (statssa.gov.za)

et al. (2024) agree that urbanization brings a huge impact towards societal changes. As a result, the change increases productivity, economic growth and enduring advancements in culture and education. It goes to show that, when CO_2 emissions are reduced, GDP also plays a cumulative role towards CO_2 emissions, and a decline in CO_2 emissions raises sustainable development. In other words, industrial processes should not be overlooked as they are crucial for efficient mass production to sustain the manufacturing company's financial well-being and streamline errors in production, which cause wastage that affects environmental health.

2.1.4. Increased energy costs as a climate change factor

Renewable energy sources like wind and solar power emit little to no greenhouse gases or pollutants. However, when substantial production is required, more electricity is generated, and manufacturing operations typically require significant energy inputs. Osman et al. (2023) state that the International Renewable Energy Agency (IRENA) predicts that by 2050, the energy consumed globally can come from 90% of renewable sources. The energy sources, such as fossil fuels or renewable energy, can have different carbon footprints and contribute to climate change. However, high energy consumption leads to increased GHG emissions, although the impact is dependent on how countries, societies and business organisations such as those involved in manufacturing respond to cost implications. Hence, mitigating GHG from predicted renewable energy is crucial to control its impact on climate change. Abbas et al. (2023) agree that electricity consumption is more polarized than traditional energy consumption. Interestingly, if the global population in 2050 progresses to approximately 9 billion and everyone consumes identical energy per capita, global energy consumption will be more than the 2050 prediction. According to Kirikkaleli and Adebayo (2021) increased energy costs are subjective towards how it responds to climate change. For example, a rise in prices encourages a shift in renewable energy like solar, which significantly has a lower carbon footprint. In addition, higher energy costs may prompt investments in energy-efficient technologies and behaviours, such as better insulation, energy-efficient appliances, or public transportation. These measures can decrease overall energy demand and emissions over the short and long term. Even though increased energy costs can become a catalyst for a greener environment, it can also trigger financial stress towards manufacturing organisations. Moreover, persistently high energy costs can contribute to inflation, slowing economic growth and undermining financial stability in the energy-importing region. An overview by Adebayo et al. (2023) highlights that renewable energy use has a positive influence on environmental quality. Consequently, companies reliant on energy-intensive processes face increased expenses, which could potentially reduce profitability and competitiveness. So, the need to control climate change and gain sustainable development makes the global renewable energy transition momentum stronger in instances of world environmental degradation. Table 2 shows the cost implications resulting from physical damages resulting from climate change.

According to Treasury (2025) the headline carbon tax rate for 2024 is R190 per tonne of CO_2e. While significant allowances currently reduce the effective rate, Eskom's annual emissions are 200 million tonnes. Even with a 95% allowance, this translates to a potential tax liability of R1.9 billion per year/. This is a figure set to increase sharply as allowances are phased out. The National

Table 1: Waste sector emissions in South Africa

Sources of emissions	Estimated emissions	Percentage of waste sector	Primary GHG's
Solid waste disposal (Landfills)	13.5 $MtCO_2e$	73	CH_4
Wastewater treatment and discharge	4.5 $MtCO_2e$	24	CH_4, N_2O
Incineration and open burning	0.5 $MtCO_2e$	3	CO_2, N_2O
Total	18.5 $MtCO_2e$	100	

Table 2: Direct costs from physical impacts

Climate driver	Impact on energy system	Statistical data/Cost indicator
Water scarcity	Eskom's coal fleet is predominantly cooled with fresh water. Lower rainfall and drought conditions reduce water availability, forcing plants to operate less efficiently or risk shutdowns.	1,400 litres of water is consumed to generate 1 MWh of electricity from a wet-cooled coal plant in South Africa[3]. Furthermore, Eskom's total water consumption is over 300 billion litres per year. Hence, during severe droughts as those experienced in 2015-2018, the risk to power stations like Kendal and Kriel was declared a national concern. Ultimately, this threatened a significant portion of the grid's capacity.
Extreme heat	Reduced Thermal Efficiency: Coal power plants are less efficient in high ambient temperatures. Grid Strain: Transformers and power lines have lower capacity and higher losses in extreme heat. Demand Spikes: Heatwaves drive up demand for air conditioning, pushing the grid to its limit.	Gabin (2024), states that 1°C increase in ambient temperature can reduce a power plant's efficiency by up to 0.5%. Additionally, during heatwaves, grid losses can increase by 2-4%. Therefore, the peak demand during a summer heatwave can be several thousand megawatts higher than on a normal day, increasing the likelihood of load shedding if supply is constrained.
Extreme weather (Floods and Storms)	Direct physical damage to critical infrastructure, including power stations, substations, and transmission or distribution lines, leading to costly repairs and extended outages.	The April 2022 floods in KwaZulu-Natal caused over R500 million in direct damages to eThekwini Municipality's electricity infrastructure alone[4]. Eskom reported significant damage to its substations and networks. These costs are ultimately recovered through tariffs or necessitate government bailouts, which are funded by the taxpayer.

Source: Author's compilation (2025)

3 Integrated results - Eskom

4 https://www.moneyweb.co.za/news/south-africa/kzn-floods-ethekwini-infrastructure

Treasury plans for the price to reach R560 per tonne by 2030. Through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), over R200 billion has been invested in the first several bid windows (energy, 2025). Moreover, the Integrated Resource Plan (IRP 2019) calls for 14,400 MW of new wind and 6,000 MW of new solar by 2030, this represents hundreds of billions of Rand in further investment. While the per-kWh cost of renewables is now cheaper than new coal, the capital outlay is significant. Eskom (2025) states that the Transmission Development Plan (TDP) estimates that over R350 billion is needed by 2033 to upgrade and expand the grid to accommodate new renewable energy. This includes building 14,000 km of new transmission lines. However, without this investment, a new and cheaper renewable power source cannot be connected to the grid. Consequently, this may prolong the reliance on expensive and failing coal. On the other hand, South Africa secured an initial R160 billion pledge from international partners for the Just Energy Transition Partnership (JETP) (commission, 2024). This funding is meant for investments in green industries like green hydrogen and electric vehicles, and ensuring a socially just transition. Hence, this is a direct cost that is associated with moving away from the fossil fuel based system.

2.1.5. Changing consumer preferences as a climate change factor

Consumers are increasingly concerned about the environmental impact of the products they purchase. As awareness of climate change grows, there is a shift towards sustainable and eco-friendly products. Manufacturing companies that fail to align with these changing consumer preferences may experience a decline in demand or face challenges in maintaining market share. Conversely, companies genuinely embracing sustainable practices can gain a competitive advantage and enhance their financial sustainability. Chen et al. (2021) agree that governments encourage the purchasing of eco-friendly products as they contribute to the sustainable development of the surroundings. Therefore, consumers need to prioritise eco-friendly products as companies are incentivized to manufacture goods with minimal carbon footprints. One of the substitute products chosen by consumers is electric vehicles over gasoline-powered vehicles simply leads to decreased greenhouse gas (GHG) emissions. Moreover, there is an increase in the selection of eco-friendly products by consumers because there is awareness and authoritative environmental guidelines. On the other hand, manufacturing businesses are subjected to carbon regulations, requiring recycling and reprocessing materials to encourage a circular economy through a closed-loop supply chain (Xu et al., 2023). That is why manufacturers produce eco-conscious brands that reduce emissions through the supply chain which consumers prefer resulting in ethical and sustainable brand pressures for manufacturing companies to adopt. At the same time, consumer preferences for recycling-friendly products advance waste management standards. So, the green industrial transformation encourages a resource-intensive economy with a high carbon emission, transforming it into a resource-efficient economy with low carbon emissions (Mehmood et al., 2024). While the aim is to reduce the causes of climate change by shifting consumer preferences to instil sustainability, the intention is to promote sustainable development and economic growth in the country. Hence, there is a need for sustainable expansion in which customer preference has a role in the enhancement of environmental quality to alleviate climate change by lowering carbon footprints.

2.1.6. Capital access as a climate change factor

Investors and financial institutions increasingly incorporate environmental, social, and governance (ESG) factors into their investment decisions. Manufacturing companies with strong sustainability performance and climate change mitigation strategies are more likely to attract investment capital and secure favourable financing terms (Digitemie and Ekemezie, 2024). Conversely, companies perceived as high-risk due to environmental liabilities or lack of sustainability may face difficulties accessing capital or may be subject to higher borrowing costs. Businesses can obtain access to capital in the following ways: firstly, debt capital – capital can be borrowed through a private or government institution, where they charge interest on the money. The interest charged depends on the capital type and the borrower's credit history. According to Bolton et al. (2023), climate change worsens conditions, as countries like Ukraine are experiencing the Russian invasion and face increased costs associated with mitigation and adaptation measures. Hence, climate change leads to a rise in economic unpredictability, and this may increase the hazard of debt suffering. Secondly, equity financing – innovative businesses often seek this type of financing. Entrepreneurs financed through equity may start using their funds and those of their family members when opening a business, but end up seeking other alternatives to equity seed capital. Manufacturers who adopt ESG as a vital driver in investment decision-making have lower debt financing (Zahid et al., 2023). So, capital structure has a big influence on the financial health of manufacturing companies. Thirdly, capital markets - stock and bonds are bought and sold by traders, which allows businesses to raise financial capital. According to Iyke (2024), clean energy investment lowers energy security risk. This is possible by providing more sustainable energy sources and reducing the dependence on imported energy. This shows that capital access contributes to climate change because it influences the availability and direction of investment toward industries, technologies, and infrastructure that either exacerbate or mitigate environmental impacts. Udeagha and Breitenbach (2023) state that not having sufficient capital reduces carbon energy which is created when renewable energy projects such as wind and solar are manufactured. As a result, capital must be redirected from carbon-intensive industries to sustainable solutions.

2.1.7. Supply chain disruptions as a climate change factor

Climate change can disrupt supply chains through extreme weather events, resource scarcity, or regulatory changes. Financial reporting should consider the potential impacts of climate-related supply chain risks on a company's operations, costs, and ability to meet customer demands (Diwan and Amarayil Sreeraman, 2024). During bad weather conditions like storms and floods, the supply chains are disrupted because of the changing weather patterns. Consequently, many South African businesses face the possible scarcity of critical materials and components due to the disruption. The unavailability of components required for production can make the manufacturing process come to a standstill creating backlogs and increasing lead time. Manufacturers need to understand how their business's supply chain could be impacted by the climate crisis and this is the most important segment of sustainability strategy. Ghadge et al. (2020) point out that climate risks towards the supply chain have a direct influence on food, mining and logistics sectors cascades into other interlinked global supply chain networks. Counterintuitively, supply chains and climate change are considered to mutually affect one another through GHG emissions resulting in natural disasters. Moreover, supply chain disruptions are responsible for the majority of downgrades of corporate credit ratings due to physical climate risks, making it precarious to recognize new conduct to gain a real competitive advantage. Costello (2020) agree that suppliers who are exposed to an exogenous decrease in financing from the bank, pass on the liquidity shock to their clients. As a result, two channels are affected which are; reduced accessible trade credit and a reduced supply of goods and service. On the other hand, Moretto and Caniato (2021) The COVID-19 outbreak impacted the world's population health and drastically affecting the economic activities in almost all countries. The pandemic not only affected the livelihood of humans and their normal activities, but it also put a major hit on supply chains across the globe. Many businesses sought alternatives which triggered climate risks to overcome shortages of stock and orders from users. The alternatives made used more power as certain products were in demand. As a result, the heat generated triggered risks to impact the climate. Hence, Supply Chain Finance (SCF) initiatives were made to cater for less privileged businesses, which were aimed at improving access to funding and the management of financial flows for the entire supply chain (Moretto and Caniato, 2021). Grasped from the empirical evidence were the factors that influence climate change, which could create disinterest in stakeholders such as investors as a result of non-disclosure of climate-related matters among listed manufacturing companies in South Africa.

2.1.8. Green contamination and operational efficiency in manufacturing companies

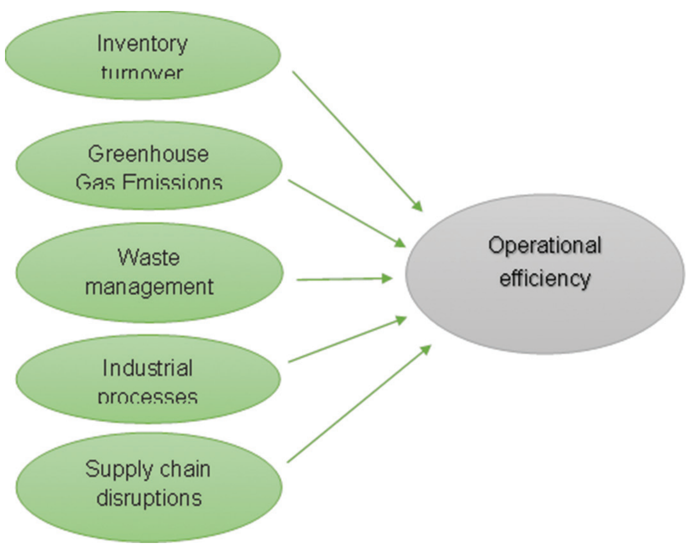
The matters concerning green surroundings are complex and dynamic making it challenging to envisage and directly trace the historical and three-dimensional changes in pollution. According to Liu et al. (2022), green contamination refers to the contamination of the natural environment due to human activities, leading to harmful effects on ecosystems, human health, and the planet as a whole. It occurs in various forms, including air, water, soil, noise, plastic, radioactive and thermal pollution. About 24% of worldwide diseases and 23% of human deaths are influenced by environmental factors (Xu et al., 2022). Therefore, green technology can positively influence the production company's operations, reducing pollution and improving living quality. Most manufacturing companies have strategic green goals to achieve and this is reflected by the quality and the type of products being manufactured. However, green contamination can also impact employees' attitudes and health which could affect their efficiency and productivity (Lin et al., 2021). Consequently, operational efficiency declines due to poor performance, workplace conflicts, and difficulties in attracting talent. Organizations that invest in eco-friendly practices and employee well-being can counteract these effects, ensuring a healthier, more productive workforce and a stronger business reputation. Aftab et al. (2023) State that before implementing green policies in manufacturing companies, they should study human behaviours in the work environment. This is a crucial element needed to ensure effective adoption and long-term success. As a result, helping to integrate contamination control measures into the manufacturing company's culture, making them a natural part of daily operations rather than a forced obligation. On the other hand, the influence of green contamination on business operations can be curbed by enforcing circular practices towards the economy (Khan et al., 2021). This is a practice of resource preservation which allows manufacturing companies to limit depending on recourses by reusing materials in their manufacturing processes. Chien et al. (2022) highlight that green contamination trading stimulates carbon emission reduction, leading to a decrease a labour efficiency. Although, the contamination can create cognitive impairment, physical discomfort of employees. Consequently, employees who are exposed to such contamination may choose to work fewer hours or adjust their work schedules to minimize exposure. However, green decontamination facilitates higher levels of operational efficiency (da Silva et al., 2021).

2.1.9. Management leadership and employee training on operational efficiency

According to Northouse (2025), effective leadership sets the tone for a company's culture, strategic direction, and operational performance. Strong leaders influence efficiency in variety of aspects such as aligning teams according to company's goals. With clear goals being set, manufacturing companies thrive in improving initiatives. This drive ensures that there are smooth operations within the organisation thus making informed decision and removing any bottlenecks. Vereb et al. (2025) indicate that a well-trained workforce ensures fewer errors, faster production, and consistent quality. Therefore, training improves efficiency through developing skills of employees so that they are updated with technical skills to operate machinery more effectively which can reduce idle time and product defects. Not only that, technology adaptability like IoT helps to smooth the training process and efficiently leverages new technology. (Njeru, 2022) found that there is a positive association concerning leadership and operational efficiency. The synergy between leadership and training creates a sustainable competitive advantage in the manufacturing industry. However, manufacturers operational performance is mostly enhanced through meeting targeted goals and maintaining effective systems that are reliable so that clients' expectations can be reached. Employees are regarded as asset in various companies. Sinha and Sengupta (2020) asserts that The working environment is ever changing, therefore investing in training activities could assist to speed up the workforce skills so that workers can adapt to the environmental change. Consequently, leadership focuses on the direction of the company, while the training aspect prepares employees with the skills to execute efficiently. Total quality management is another variable that has a progressive relationship with operational performance. Hence, strong management and skilled workers bring effectiveness of production, high-quality products, satisfied customers and increased revenue and profit. Top management commitment and leaders' involvement are the most important factors for the effectiveness of TQM practices. (Kebede Adem and Virdi, 2021).

Burawat (2019) emphasises that the absence of appropriate training activities can discourage value-add in manufacturing business processes which can lead to business discontinuity. It is crucial for manufacturing businesses to reshape their leadership style and incorporate their objectives to improve productivity and employee commitment. For that reason, to sustain training initiatives and learning, management support is essential so that manufacturing leaders can cultivate an environment impacted by climate change to be attractive to investors and be conducive workspace. This statement is agreeing to (Sinha and Sengupta, 2020) who elaborated that reshaping leadership style helps in disseminating the existing knowledge to guide future events and decision. Moreover, the literature covered existing knowledge related to this study's area of focus. However, there are limited studies with regards to climate change influence on operational efficiency in the south African manufacturing company's context. Furthermore, the methodology used in historic studies differ from the current study. Therefore, this study discourses these gaps by incorporating sustainability policies and a theoretical structure to accentuate the influence of climate change factors on the operational efficiency of JSE listed manufacturing companies.

2.2. Conceptual Framework



Source: Author's compilation (2025)

3. THEORETICAL REVIEW

3.1. The Legitimacy Theory

Legitimacy in the manufacturing environment is highly seen as a central aspect in terms of environmental interactions. What is more, some tasks (air and water pollution) in the manufacturing sector misuse the environment and create risks environmentally (Martin, 2018). As a result, the stakeholders are not impressed by these tasks as they pose a threat to the environment. To impress the stakeholders, manufacturing companies should have sustainable reports to prove to the stakeholders that the company's operations are genuine. As times change, so does the surrounding of the organizations. As a result of the change in times, expectations from stakeholders will be entirely different from historic times. Furthermore, the "change" brings out a shift in legitimacy (Moloi and Marwala, 2020). Manufacturers keep up with recent times and report using current information to support stakeholders in decrypting and decision-making processes. Deegan (2019) suggests that legitimacy is known to be a dichotomous variable for an organization that is unclear whether it is legitimate or illegitimate. Thus, manufacturers' legitimacy will depend on whether they conform to the outlooks of the community. So, this theory will continue to be used the most because of its institutionalization around the sustainability of financial reporting literature. Dumay et al. (2018) agree that this theory is the most used theory to date about sustainability. On the other hand, there is a lack of attention given to the roles of financial accountability in corporate reporting (Nishitani et al., 2021). The legitimating role cannot solve the social and environmental reality. So, voluntary reporting by manufacturing companies should not be underestimated as financial accountability and legitimating roles are not supposed to naturally collide with each other. On the contrary, another way for manufacturers to seek legitimacy is through the adoption of substantive legitimating management procedures for their operations (Crossley et al., 2021). Maintaining these substantive procedures will show how committed the organisation is. However, implementing these procedures is less meaningful to the organisation itself as it merely brings behavioural change but more in favour to hope for increased support from stakeholders. According to Silva (2021), the substantive legitimization procedures are insufficient if the companies goal is to achieve the Sustainable Development Goals (SDGs) by 2030. Companies have a moral obligation which comes from legitimacy that is owed to investors. Hence, manufacturers should prioritise their stakeholders by having moral legitimacy in their procedures because stakeholders are influential in sustainable development.

Based on this review, the following research hypothesis is suggested:

H_1: There is a significant relationship between climate change factors and operational efficiency.

4. RESEARCH METHODOLOGY

4.1. Research Method

Saud et al. (2020) highlight that using a panel estimation technique gives the variables used in a study a natural logarithm which smooths the data so that there is a more reliable estimation. On the other hand, panel data deals with omitted variable bias due to heterogeneity in the data (Rotimi and Ngalawa, 2017). In addition, panel data allows organisations to review how the variables are changing over time and how they could affect trends in future. Therefore, the benefits of using a panel design for this study are;

4.1.1. Panel unit root test

This is also known as the stationarity test that is used to depict the stationarity of panel data. As panel data is a combination of both time series and cross-sectional data, there is an indisputable need for a stationarity check to detect the presence of unit root in the variables and affirm the validity of the relationship between the variables. If panel data has a unit root, the data will move at random. The decision rule is that: if a critical value is less than the absolute value of statistics, there is the presence of stationarity in the observed data. This indicates that the null hypothesis is rejected.

For this study, the Augmented Dickey-Fuller (ADF) Fisher test, Levin, Lin and Chu (LLC) t-test, and Philips-Perron (PP) Fisher test are the types of unit root tests to be considered. Furthermore, to avoid spurious regression, it is important to check that the variables are well aligned. In addition to the unit-root test, the study will apply a stability test to assess the stability of the model. Yoo et al. (2022) highlight that the stability test reveals any structural breakage over time between the variables.

Ultimately, unit- root is written as $\Delta Q_{it} = \partial Q_{i,t-1} + \sum_{j=1}^{kw} \forall_i \Delta Q_{i,t-m} + \beta_i \gamma_{it} + \varepsilon_{it}$. From the equation, γ_{it} is the deterministic component, $\varepsilon_{it} \approx idd(0, \forall_i^2)$. The hypothesis is stated below.

$$H_0: \varphi = 0$$

$$H_1: \varphi < 0$$

The null hypothesis indicates that the *y* process has a unit root for each individual *i* while the alternate hypothesis indicates the data is stationary.

The ADF estimation is asserted below:

$$\Delta Q_{it} = \theta_i + \partial_i Q_{i,t-1} + \sum_{j=1}^{j=k_i} \forall_{ij} \Delta Q_{i,t-j} + \varepsilon_{it}$$

Therefore, the null and alternative hypothesis is asserted as:

$$H_0: \varphi_i = 0$$

$$H_1: \varphi_i < 0$$

4.1.2. Panel co-integration test estimation

This is a test used to detect the existence of long-run relationships amongst the variables examined in a model. Specifically, in this study, both Kao, Pedroni and Residual co-integration tests (Pedroni, 2004) will be conducted. These are Engle-granger-based but necessary for the analyses because they insist on the homogeneity of units in the dataset.

Detection of co-integration among variables is germane because;

- It reveals the existence of causal relationships even though it cannot show the direction of causality (Zafeiriou et al., 2022)
- It depicts an extended relationship among variables being analysed such that the linear combination between the variables becomes stationary even though they are not independently stationary.

The panel co-integration estimate is:

$$Q_{it} = \delta_{1i} + \delta_{2i}\beta_{it}^{c} + R_{it}\rho_{1i} + R_{it}\rho_{2i}\beta_{it}^{s} + \varepsilon_{it}$$

From the equation above, $R_{it} = R_{i,t-1} + \mu_{it}$, $i = 1 \ldots\ldots M$, $t = 1 \ldots\ldots W$.

δ_{1i} and δ_{2i} are unique constants, ρ_{1i} and ρ_{2i} are slope parameters, ε_{it} is the stationary disturbance term, Q_{it} and R_{it} are a unified process of order one for all *i*. Panel cointegration assumes that a deterministic trend does not exist.

The null and alternative hypothesis for "between dimension" and "within dimension" is written as:

Between dimension: $H_0: \forall_i = 1$

$H_1: \forall_i < 1$

Within dimension: $H_0: \forall_i = 1$

$H_1: \forall_i = \forall = 1$

Firstly, the Pedroni's panel co-integration tests statistic is written as:

$$l_{it} = \sigma_i + \sum_{k=1}^{j} \delta_{ik} d_{kit} + \varepsilon_{it}$$

i stands for the individuals, *t* stands for the time; σ_i is a coefficient that permits the individual-specific fixed effect; ε_{it} is the projected residual that portrays the divergence from the long-run correlation between the variables.

That is, $\varepsilon_{it} = \forall_i \varepsilon_{i(t-1)} + \gamma_{it}$

Secondly, the Kao ADF co-integration test's estimate is stated as:

$l_{it} = \sigma_i + \gamma d_{it}^{'} + \mu_{it}$. The estimated residual is μ_{it},

Where $\mu_{it} = \forall \mu_{i(t-1)} + \sum_{k=1}^{j} \zeta_{ik} \Delta\mu_{i(t-k)} + \gamma_{it}$

i are the companies that range from 1,………..*j*; *t* is the time (years).

γ represents the vector of the slope parameters; μ_{it} is the disturbance white noise error term.

σ_i is the constant term.

l_{it} is the integrated process of order one (1) for all individual *i* that is, $d_{it} \approx I(1) \forall i, \Rightarrow d_{it} = d_{i(t-1)} + \mu_{it}$,

$\{l_{it}, d_{it}\}$ are independent across all individuals.

$\theta_{it} = (u_{it}, \varepsilon_{it}^{'})^{'}$ is a linear process.

The long-run covariance matrix of $\{\theta_{it}\}$ is denoted by *π* which leads to:

$$\pi = \sum_{k=j}^{j} E(\theta_{ik}, \theta_{i0}^{'}) = \begin{pmatrix} \tau_u & \tau_{u\rho} \\ \tau_{\rho u} & \tau_\rho \end{pmatrix}$$

$$\sum = E(\pi_{i0}\pi_{i0}^{'}) = \begin{pmatrix} \Sigma_u & \Sigma_{u\rho} \\ \Sigma_{\rho u} & \Sigma_\rho \end{pmatrix}$$

The null and alternative hypothesis of no co-integration is applicable under the Kao test.

$$H_0: \partial = 1$$

$$H_1: \partial < 1$$

Following the null hypothesis that states there is no co-integration between the variables, the Kao ADF test statistic is written as;

$$ADF = \frac{\dfrac{t_{\hat{\partial}} + \sqrt{6a\hat{\rho}_v / 2\hat{\rho}_{0v}}}{2\hat{\rho}_{0v}} \approx A(0,1)}{\sqrt{\hat{\rho}_{0v}^2 \big/ 2\rho_v^2 + \left(3\hat{\rho}_v^2 / 10\hat{\rho}_{0v}^2\right)}}$$

Where, $\hat{\rho}_v^2 = \hat{\Sigma}_u - \hat{\Sigma}_{u\gamma} - \hat{\Sigma}_\gamma^{-1}$ and, $\hat{\rho}_{0v}^2 = \hat{\tau}_u - \hat{\tau}_{u\gamma} - \hat{\tau}_\gamma^{-1}$.

Johansen Fisher panel co-integration test has trace statistics and Maximum Eigen value of which both are based on the aggregates of the Probability values. Assuming ∂_i is the probability value for the individual (insurance company) i, under the null hypothesis H_0: $\partial_1 = 1$, tare t-statistics is given as: $-2\sum_{i=1}^{j} \log(\partial_i) \approx \chi_{2a}^2$. The test statistic ($\partial$trace) below will test the null hypothesis, H_0: $C \le u$ and alternative hypothesis H_1: $u = C$.

This is explicitly computed as: $\partial_{trace}(C) = -T\sum_{i+1}^{j} \ln(1-\hat{\partial}_i)$, where $\partial C + i.\partial p$ is the least value of Eigenvectors (j-C). The maximal Eigenvalue test ($\partial_{\max}$ with H_0: C cointegrating vectors against H_1: $C + 1$ cointegrating vector is given as; $\partial \widehat{\ln(}_{max}$.

4.2. Research Model

Investigate the impact of climate change factors on the operational efficiency of JSE-listed manufacturing companies in South Africa.

The model to be developed for the first objective is econometric, and panel data dependence techniques will be applied. The reason behind deciding to use this model is to forecast the impact of the independent variables on the organisation's financial reporting. The model adopted in this study is inspired by Oyetade et al. (2022) and Fatai Adedoyin et al. (2021). A static and dynamic model will be used so that there is sturdiness. Sun et al. (2020) have applied a basic and extended model to the examination of climate change risks on the financial performance of the mining industry. However, the model is basic and does not use the combination of the two models that are being used in this study. The significance of the dynamic model lies in its consideration of both financial performance and climate change factors, which are beneficial for forecasting purposes in the long run, rather than just in the current context. According to the researchers' understanding, this is the first study that will look at future predictions of operational efficiency and financial performance in the context of climate change for manufacturing companies within South Africa.

Model specification for the influence of Climate change factors (CCF) on Operational efficiency (OE).

$$OE_{it} = \partial_0 + \partial_1 GGE_{it} + \partial_2 WM_{it} + \partial_3 IP_{it} + \partial_4 SCD_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

$$ITR_{it} = \partial_0 + \partial_1 GGE_{it} + \partial_2 WM_{it} + \partial_3 IP_{it} + \partial_4 SCD_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

In addition, from the models above,

The pooled multivariate regression is the estimating technique for the static analysis.

Generally, the panel multi-variate regression model is stated as:

$$Q_{it} = \partial_0 + \pi R_{it}' + c_i + \varepsilon_{it}$$

Where,

$$\varepsilon_{it} = c_i + \lambda_{it}$$

This is a model for individual $i = 1,\ldots\ldots\ldots\ldots W$ which is observed for a period $t = 1,\ldots\ldots\ldots\ldots M$. Where Q_{it} is the dependent variable, R_{it}' is the G-dimensional row vector of time-varying explanatory variables and p_{it}' is the F - dimensional row vector of time-invariant explanatory variables without the constant. ∂_0 is the intercept, ∂_1-∂_4 are the estimated coefficients of the independent variables. π is the G-G-dimensional column vector of parameters and c_i is the individual-specific effect, while ε_{it} is the idiosyncratic error term.

The M observations for individual i are stated as follows.

$$Q_i = \begin{bmatrix} Q_{i1} \\ . \\ . \\ Q_{it} \\ . \\ . \\ Q_{iM} \end{bmatrix}_{M\,X\,1}, R_i = \begin{bmatrix} R_{i1}' \\ . \\ . \\ R_{it}' \\ . \\ . \\ R_{iM}' \end{bmatrix}_{M\,X\,G}, \varepsilon_i = \begin{bmatrix} \varepsilon_{i1} \\ . \\ . \\ \varepsilon_{it} \\ . \\ . \\ \varepsilon_{iM} \end{bmatrix}_{M\,X\,1}$$

WM observations for all individuals and periods are stated as:

$$Q = \begin{bmatrix} Q_{i1} \\ . \\ . \\ Q_{it} \\ . \\ . \\ Q_W \end{bmatrix}_{WM\,X\,1}, R = \begin{bmatrix} R_1 \\ . \\ . \\ R_i \\ . \\ . \\ R_W \end{bmatrix}_{WM\,X\,G}, \varepsilon = \begin{bmatrix} \varepsilon_1 \\ . \\ . \\ \varepsilon_i \\ . \\ . \\ \varepsilon_W \end{bmatrix}_{WM\,X\,1}$$

4.2.1. The dynamic analysis

A dynamic panel model will be used to quantify the factors influencing manufacturing companies' operational efficiency. The dynamic analysis will use the Generalised Method of Moments (GMM). GMM is used because;

i. It generates unbiased estimates of λ_t and α_i.
ii. The time-specific effect is shown by λ and α is the individual-specific effect. This solves endogeneity and bias in estimation because of the existence of a correlation between lagged figures of the dependent variables recorded as *it* and the error term as ε_{it}.
iii. The right instrument for lagged λ_{it-1}. This solves any inconsistencies and generates an unbiased predictor (not considering x_{it} and λ_t).
iv. It plays a role in determining a weighted matrix that can ensure the most efficient predictor (Khuong et al., 2022). According to (Jacquier et al., 2021), an orthogonal model means that all independent variables in that model are uncorrelated. If one or more independent variables are correlated, then that model is non-orthogonal.

Hansen (1982) posits that the Arellano-Bond estimation's first stage starts by transforming all the explanatory variables by using the generalized method of moments (GMM). The two-step system GMM is used to achieve the first objective in this study. Out of many other benefits of employing a system GMM estimator, it is pertinent to mention that the estimator is based on the non-linear moment conditions made available in the dynamic error component model. More so, there is a significant asymptotic efficiency benefit as stated by Blundell et al. (2011). Thus, to state the equation in the dynamic format for GMM to be applicable,

$$OE_{it} = \beta OE_{i(t-1)} + \delta GGE_{it-1} + \varphi WM_{it-1} + \emptyset IP_{it-1} + \vartheta SCD_{it-1} + \alpha_i + \lambda_t + \varepsilon_{it}$$

$$ITR_{it} = \beta ITR_{it-1} + \delta GGE_{it} + \varphi WM_{it} + \emptyset IP_{it} + \vartheta SCD_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

From the models above, β, δ, φ, $\emptyset$, ϑ are estimated coefficients of the independent variables.

The basic dynamic model is:

$$Q_{it} = \gamma Q_{i,t-1} + \beta R'_{it} + \varepsilon_{it}$$

$$\varepsilon_{it} = \alpha_i + \lambda_{it}$$

$$\epsilon(\alpha_i) = \epsilon(\lambda_{it}) = \epsilon(\alpha_i \lambda_{it}) = 0$$

Fixed effects, α_i and the idiosyncratic shocks, λ_{it} are the two orthogonal components embedded in the disturbance term, ε_{it}.

$$\Delta Q_{it} = (\gamma - 1) Q_{i(t-1)} + \beta R'_{it} + \varepsilon_{it}$$

The System GMM is preferred because the estimate is a combination of differences and level estimators as shown below.

$$\epsilon(Q_{i(t-n)} \text{-} \Delta\varepsilon_{it}) = 0$$

$$\epsilon(\varepsilon_{it} \Delta Q_{i(t-1)}) = 0$$

These can also be expressed as $\in \left(L'_{ni} V_i\right) = 0$ where $V_i = \begin{bmatrix} \varepsilon_i \\ \varepsilon_i \end{bmatrix}$

$$L_{ni} = \begin{bmatrix} L_{vi} & 0 \\ 0 & L^r_{hi} \end{bmatrix} = \begin{bmatrix} \Delta L_{vi} & 0 & 0 & \dots & 0 \\ 0 & \Delta Q_{i2} & 0 & \dots & 0 \\ 0 & 0 & \Delta Q_{i3} & \dots & 0 \\ . & . & . & \dots & 0 \\ 0 & 0 & 0 & \dots & \Delta Q_{i,T-1} \end{bmatrix}$$

Note that L_{vi} is the *(T-2) X* c_v matrix expressed as;

$$L_{vi} = \begin{bmatrix} Q_{i1} & 0 & 0 & \dots & 0 & \dots & 0 \\ 0 & Q_{i1} & Q_{i2} & \dots & 0 & \dots & 0 \\ . & . & . & \dots & . & \dots & . \\ 0 & 0 & 0 & \dots & Q_{i1} & \dots & Q_{iT-2} \end{bmatrix}$$

and L^r_{hi} is the non-redundant subset of L_{hi}.

$$\hat{\gamma}_n = \left(c'_{-1} L_c (L'_n L_n)^{-1} L'_n c_{-1}\right)^{-1} c'_{-1} L_n \left(L'_n L_n\right)^{-1} L'_n c$$

where, $n_i = \begin{bmatrix} \Delta Q_i \\ Q_i \end{bmatrix}$.

This is since;

$$c'_{-1} L_n \left(L'_n L_n\right)^{-1} L'_n c_{-1} = \Delta Q'_{-1} L_e \left(L'_e L_e\right)^{-1} L'_e \Delta Q_{-1} + Q'_{-1} L^r_h \left(L^{r'}_h L^r_h\right)^{-1}$$

$L^{r'}_h Q_{-1}$. Note that, $\hat{\gamma}_n = \delta \hat{\gamma}_e + (1-\delta) \hat{\gamma}^c_h$

4.2.2. Robustness tests

The first lag having zeroes for $\leq w$. The Arellano Bond test is based on $(1/M) \sum_i \hat{E}_i^{-1} \hat{E}_i$. Assuming errors are sufficiently uncorrelated across individuals, a central limit theorem assures that the statistic is asymptotically normally distributed as shown below.

$$\sqrt{M} \frac{1}{M} \sum_i \hat{E}_i^{-1} \hat{E}_i = \frac{1}{\sqrt{M}} \hat{E}^{-1} \hat{E}$$

The other test for the check for over-identification of instruments is the (Hansen, 1982) J test. This test is valid, and the instrument used will be tested. Further, to test for the predictive marginal mean, the predictive marginal test will be used.

4.3. Research Design

This study applies a positivist research paradigm. Therefore, the study will be using existing information from data sites to collect data (secondary data collection). The study relies on existing data on financial statements, which are published annually for the period spanning from 2005 to 2022. According to Lukey (2020), the UN Convention on Climate Change (UNCCC) started in 2004. Thereafter, the development of policies for climate change began in 2005, which was the year that the importance of climate accounting was drawn to companies. The reason for investigating all the listed manufacturing companies is to identify potential risks associated with supply chain disruptions, extreme weather events, and shifting consumer preferences. Mitigating these risks can encourage healthy competition and innovation within the manufacturing industry. Therefore, building trust with the investors as there will be transparency in the financial reporting. The manufacturing sector has a global impact, and its actions can significantly affect the environment and society. Thus, investigating these companies holds them accountable for their global responsibilities and encourages them to contribute to global sustainability goals. In addition, the study wants to assess how viable manufacturing companies will be in the long term as the world is facing climate change and resource constraints.

There are a lot of factors surrounding climate change which include some of which are not included in the study. Therefore, not all the listed manufacturing companies are impacted by the climate change factors that this study intends to investigate, such as Increased energy costs, changing consumer preferences, capital access, supply chain disruptions, greenhouse gas emissions, waste management, and industrial Processes. As a result, some manufacturing companies might fall out as they may not be a good sample to obtain information and use along with the study's climate change factors. In addition, manufacturing companies that are not listed on JSE including those that have been delisted (E.g., failure to comply with regulations) will be disregarded as they might not have financial data for the period that the study intends to investigate. This consideration has been made to avoid investigating only successful companies and leaving out non-surviving companies.

The reason for using these factors for this study is that they involve encouraging and supporting manufacturing companies to adopt sustainable practices, such as reducing emissions and minimizing their environmental impact. Thus, it plays a role in incentivizing and guiding manufacturing companies toward more responsible and climate-friendly practices to enhance their financial well-being. Some factors may be based on misinformation or misconceptions and incorporating them into decision-making can lead to inefficiencies and unnecessary costs for manufacturing organisations. It is essential to rely on reputable sources of information and scientific consensus when evaluating the impact of climate change on financial reporting sustainability and exclude factors that lack empirical evidence or are not pertinent to a specific industry or region.

5. ANALYSIS AND RESULTS

Table 3: Definition of variables for objective one

Variable type	Variable name	Variable code
Dependent variable	Operational Efficiency[5]	OE
Dependent variable	Inventory Turnover[6]	ITR
Independent variable	Greenhouse Gas Emissions[7]	GGE
Independent variable	Waste Management[8]	WM
Independent variable	Industrial Processes[9]	IP
Independent variable	Supply chain disruptions[10]	SCD

5 Ability of an organisation to reduce waste and still produce high-quality products.
6 Measures how efficiently a company uses its inventory
7 Emissions of gas into the atmosphere
8 Various ways to manage waste
9 Procedures used in manufacturing organisations
10 Event that creates a disruption in production or distribution of products

Investigate the impact of climate change factors on the operational efficiency of JSE-listed manufacturing companies in South Africa.

In Table 4, the descriptive analysis of results for the variables under consideration in this study is presented. The variables are OE, ITR, GGE, WM, IP and SCD. The mean of the performance variables such as OE and ITR for the period under consideration are 0.8783 and −1.6117. These were ranged from 0.0078 to 5.5728 and −2309.099 to 668.2817 respectively. The mean of the intellectual capital and liquidity variables such as GGE, WM, IP and SCD are 67.4181, 0.2615, 48.0149 and 214.4723. The range of values for these aforementioned independent variables are between 0.0000 to 99.9800, −0.9983 to 37.7665, 0.0000 to 84.0000 and 40.2800 to 3489.030 respectively. The rate at which OE, ITR, GGE, WM, IP and SCD deviated from their various mean are revealed to be 0.2283, 83.4716, 24.2003, 1.7512, 13.7483 and 286.4915 respectively. Thus, it can be emphasized that SCD has the highest rate of deviation from its respective mean, follows by ITR. However, OE is found with the smallest deviation from its mean.

From the skewness result, it was revealed that OE, WM and SCD are positively with skewness coefficient of 6.7467, 15.3691 and 7.7377 respectively. Thus, the variables are skewed to the right of the means. It is also showed that ITR, GGE and IP are negatively skewed with skewness coefficient of −21.561, −0.7054 and −0.3383 showing skewness to the left of the mean. The kurtosis results revealed that OE, ITR, WM, IP and SCD are leptokurtic with kurtosis coefficient index greater than 3. While the kurtosis of GGE is observed to be platykurtic with the kurtosis coefficient index <3. The Jarque-Bera values with the associated $P < 0.05$ indicated that the financial performance, intellectual capital and liquidity variables consisting of OE, ITR, GGE, WM, IP and SCD are from normally distributed population datasets.

In Table 5, the correlation coefficients result showing the degree of relationship among the explanatory variables under consideration in this study, including OE, ITR, GGE, WM, IP and SCD, are presented. From Table 3, it is revealed that OE positively correlated with GGE, WM and IP with the correlation coefficient of 0.0419, 0.0165 and 0.0756, respectively. It is also revealed that OE has a negative correlation with SCD, with a correlation coefficient value of −0.0418, respectively. Also, it is found that ITR positively correlated with GGE, WM, IP and SCD with the correlation coefficient of 0.0039, 0.0033, 0.0212 and 0.0022, respectively. GGE is positively correlated with IP with a correlation coefficient of 0.1406, but negatively correlated with the WM and SCD with correlation coefficients of −0.0085 and −0.0164. The results show that WM is negatively correlated with IP and SCD with correlation coefficients of −0.0272 and −0.0155, respectively. However, it is found that the correlation between STD and LTD was negative with a correlation coefficient value of −0.033, while the correlation between IP and SCD is positive with a correlation coefficient value of 0.0131. Thus, the low or weak correlation between the variables under study revealed the absence of a multicollinearity problem in establishing a linear and dynamic linear relationship among the variables and, as such, established the independence of the explanatory variables under investigation. It must be noted that the data set for this study consists of variables that include

Table 4: Descriptive analysis of results

	OE	ITR	GGE	WM	IP	SCD
Mean	0.8783	−1.6117	67.4181	0.2615	48.0149	214.4723
Median	0.8910	0.7§332	71.3300	0.1110	48.0000	151.7200
Maximum	5.5728	668.2817	99.9800	37.7665	84.0000	3489.030
Minimum	0.0078	−2309.099	0.0000	−0.9983	0.0000	40.2800
Standard Deviation	0.2283	83.4716	24.2003	1.7512	13.7483	286.4915
Skewness	6.7467	−21.5614	−0.7054	15.3691	−0.3383	7.7377
Kurtosis	134.3689	566.8211	2.6447	299.5891	3.2809	78.2913
Jarque-Bera	1071824.	19664863	130.1910	5467963.	33.0029	363112.7
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	1295.607	−2378.890	99509.24	386.0448	70822.03	316346.6
Sum Sq. Dev.	76.8761	10277086	863845.7	4523.559	278609.2	1.21E+08
Observations	1475	1476	1476	1476	1475	1475

Source: Researcher's Computation (2025)

Table 5: Correlation analysis results

Variables	OE	ITR	GGE	WM	IP	SCD
OE	1.0000	0.0026	0.0419	0.0165	0.0756	−0.0418
ITR	0.0026	1.0000	0.0039	0.0033	0.0212	0.0022
GGE	0.0419	0.0039	1.0000	−0.0085	0.1406	−0.0164
WM	0.0165	0.0033	−0.0085	1.0000	−0.0272	−0.0155
IP	0.0756	0.0212	0.1406	−0.0272	1.0000	0.0131
SCD	−0.0418	0.0022	−0.0164	−0.0155	0.0131	1.0000

Source: Researcher's Computation (2025)

cross-section and time series, and as such, a need to examine the stationarity among the variables. Hence, in Table 6, the stationary results are presented.

In Table 6, the results of the stationarity or the unit root test are presented to examine the short-run relationship among the variables considered in this study. This test is carried out using Levin, Lin and Chu t* to test for the group unit root or stationarity, while Im, Pesaran and Shin W-Stat, ADF - Fisher Chi-square and PP - Fisher Chi-square are used to test for the individual variable's stationarity or unit root. From the results presented in Table 7, it is found that in absolute terms that OE, ITR, GGE, WM, IP and SCD across all the group of 82 cross section with Levin, Lin and Chu t* statistics of 28.5104 ($P < 0.05$), 26.5157 ($P < 0.05$), 29.6733 ($P < 0.05$), 25.7654 ($P < 0.05$), 27.5041 ($P < 0.05$). and 15.5886 ($P < 0.05$) respectively revealed that the financial performance and climate change factors or variables under consideration were stationary at the level.

However, for the individual cross-section, the ADF-Fisher Chi-square and PP-Fisher Chi-square Statistic are used to test for the unit root of the financial performance variables and the climatic change factors under consideration. Thus, from Table 3, OE, ITR, GGE, WM, IP and SCD with the value 953.268 ($P < 0.05$), 830.549 ($P < 0.05$), 929.145 ($P < 0.05$), 914.853 ($P < 0.05$), 841.709 ($P < 0.05$) and 458.984 ($P < 0.05$) for ADF-Fisher Chi-Square and 1792.95 ($P < 0.05$), 983.690 ($P < 0.05$), 1160.94 ($P < 0.05$), 1567.79 ($P < 0.05$), 1068.82 ($P < 0.05$) and 364.097 ($P < 0.05$) respectively for PP-Fisher Chi-Square Statistic show that the financial performance and climate change factors or variables under consideration are stationary at level. Evidently, it can be emphasized that all the financial performance and climate change factors or variables under consideration are stationary and, as such, establish the short-run equilibrium relationship among the variables. Based on this result, this study examines the long-run equilibrium relationship among the variables, and the results are presented in Table 7.

In Table 7, the test for cointegration using the Pedroni and Kao residual test is presented. The test was carried out using the Group PP-Statistic, Group ADF-Statistic for the Pedroni residual test and ADF for the Kao residual test. In the results presented in Table 8, it is found that in an absolute term, Group PP-Statistic value of 26.8520 and 21.6132 ($P < 0.05$) and Group ADF-Statistic value of 19.4140 and 17.9865 ($P < 0.05$) from the Pedroni residual test revealed the existence of cointegration among the financial performance variables (OE and ITR) and climatic change factors (GGE, WM, IP and SCD) for each of the firms under consideration. Also, the Kao residual test with ADF Statistic values of 21.3533 and 6.1630 with associated ($P < 0.05$) further revealed cointegration among the financial performance variables (OE and ITR) and climatic change factors (GGE, WM, IP and SCD) used for the fitted models. Thus, it can be emphasized based on this that there is a long-run equilibrium relationship and stability among the variables for the fitted models under investigation.

In Table 8, the dynamic panel generalized method of moment (GMM) result for investigating climatic change measured by OE, GGE, WM, IP and SCD and their relationship or impact on financial performance (OE) is presented. Thus, in this study, the dynamic panel two-step system GMM is chosen based on the rule of thumb which shows that the estimated coefficient value of −0.1351 for OE (−1) using the difference panel GMM is less than the estimated coefficient value of −0.0957 obtained for OE (−1) using the dynamic fixed effect panel model. Thus, from the results presented in Table 6, the fitted dynamic panel two-step system GMM showed that GGE WM and IP had a positive impact on the OE of the selected firms. The result further revealed that GGE, WM and IP have a contributory impact on financial performance measured by OE of the selected firms were 0.0003%, 0.0020% and 0.0007%, respectively. Also, from the result, OE (-1) and SCD negatively contributed to the OE as a measure of the financial performance of the selected firms under consideration. The result further indicated that the OE (−1) and SCD caused a decline in the financial performance measured using the OE of the selected firms to the turn of 0.0842% and 0.00003% respectively.

Table 6: Stationarity or unit root test

Variables	Levin, Lin and Chu t*		Im Pesaran and Shin W-Stat		ADF-Fisher Chi-square		PP-Fisher Chi-square	
	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
OE (0)	−28.5104	0.0000	−26.8392	0.0000	953.268	0.0000	1792.95	0.0000
ITR (0)	−26.5157	0.0000	−23.1454	0.0000	830.549	0.0000	983.690	0.0000
GGE (0)	−29.6733	0.0000	−27.1066	0.0000	929.145	0.0000	1160.94	0.0000
WM (0)	−25.7654	0.0000	−25.6871	0.0000	914.853	0.0000	1567.79	0.0000
IP (0)	−27.5041	0.0000	−24.7436	0.0000	841.709	0.0000	1068.82	0.0000
SCD (0)	−15.5886	0.0000	−12.2130	0.0000	458.984	0.0000	364.097	0.0000

Source: Source: Researcher's Computation (2025)

Table 7: Panel cointegration test (Pedroni and Kao residual cointegration test)

Pedroni residual test	Cointegration OE, GGE, WM, IP and SCD		Cointegration ITR, GGE, WM, IP and SCD	
	Statistic	P-value	Statistic	P-value
Panel v-statistic	−1.4836	0.9310	−8.6384	1.0000
Panel rho−statistic	−1.8527	0.0320	1.6245	0.9479
Panel PP-statistic	−17.8146	0.0000	−10.5085	0.0000
Panel ADF-statistic	−17.0293	0.0000	−10.4896	0.0000
Group rho-statistic	2.7339	0.9969	2.4492	0.9928
Group PP-statistic	−26.8520	0.0000	−21.6132	0.0000
Group ADF-statistic	−19.4140	0.0000	−17.9865	0.0000
Kao residual test				
ADF	−21.3533	0.0000	6.1630	0.0000
Residual variance	0.0949		13464.25	
HAC variance	0.0295		1066.68	

Null Hypothesis: No cointegration and Trend assumption: No deterministic trend
Source: Researcher's Computation (2025)

The probability values with (P < 0.05) revealed that the estimated parameters were statistically significant in determining the financial performance (OE) of the firms under consideration. Also, from the result presented in Table 5, it was found that the number of instruments (82) is equal to the number of groups or cross-sectional (82) used for the estimated parameters of the fitted dynamic panel two-step system GMM model, which indicated the unbiasedness of the fitted model. Also, the Sargan statistic value of 72.25 with Chi P < 0.05 showed that the over-identifying restriction is rejected because the fitted model was not weakened by many instruments, even if it was not robust, and as such implies that the result obtained does not have any evidence against the validity of the instrument. Hence, the appropriateness and reliability of the dynamic panel two-step system GMM in examining the relation between financial performance (OE), climatic accounting and sustainability captured by GGE WM IP and SCD of the selected firms for this study. The Arellano-Bond test using AR (2) statistic value (1.0400) with P > 0.05 indicated the absence of serial correlation in the result obtained using the dynamic two-step system panel GMM model.

In Table 9, the dynamic panel generalized method of moment (GMM) result for investigating climatic change measured by ITR GGE WM IP and SCD and their relationship or impact on financial performance (ITR) is presented. Thus, in this study, dynamic first difference panel GMM is chosen based on the rule of thumb which shows that the estimated coefficient value of 0.0537 for ITR (−1) using the first difference panel GMM is greater than the estimated coefficient value of 0.0282 obtained for ITR (−1) using the dynamic fixed effect panel model. Thus, from the results presented in Table 6, the fitted dynamic first difference panel GMM showed that ITR (−1) WM, IP and SCD had a positive impact on the OE of the selected firms. The result further revealed that ITR (−1) WM, IP and SCD contributory impact on financial performance measured by ITR of the selected firms were 0.0537%, 0.2227%, 0.2261% and 0.0013%, respectively. Also, from the result, GGE negatively contributed to the ITR as a measure of the financial performance of the selected firms under consideration. The result further indicated that the GGE caused a decline in the financial performance measured using the ITR of the selected firms to the turn of 0.0009% respectively.

The probability values with (P < 0.05) revealed that the estimated parameters were statistically significant in determining the financial performance (ITR) of the firms under consideration. Also, from the result presented in Table 9, it was found that the number of instruments (84) is greater than the number of group or cross-sectional (82) used for the estimated parameters of the fitted first difference panel GMM model thus, indicating the unbiasedness of the fitted model. Also, the Sargan/Hansen J statistic value of 80.3587 with P > 0.05 showed the insignificance of over-identifying restriction and as such the model is not rejected because the fitted model was robust and was not weakened by many instruments. Hence, it can be emphasized that the results were obtained using valid instruments. Hence, the appropriateness and reliability of the first difference panel GMM model in assessing the relation between financial performance (ITR), climatic accounting and sustainability captured by GGE WM IP and SCD of the selected firms under consideration in this study. The Arellano-Bond test using AR (1) statistic value (0.0332) with P > 0.05 indicated the absence of serial correlation in the result obtained using the first difference panel GMM model.

6. DISCUSSION OF RESULTS, IMPLICATION OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

6.1. Discussion of Results

This research investigated climate change factors and the operational efficiency of manufacturing companies' financial reporting in KwaZulu-Natal, South Africa. The study used data collected from data sources of a certain period from the past. Data collected assisted in capturing the variables of each objective to determine the connection of the variables being tested. Several tests were made, guided by models which generated a report indicating whether a relationship exists among the constructs. This research is vital to policymakers in the manufacturing industry

Table 8: Dynamic panel GMM (OE, GGE, WM, IP and SCD)

Variable	Pooled effect panel model		Fixed effect panel model		First differences panel GMM model		Panel system GMM model	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
C	0.7495	0.0000	0.9110	0.0000	-	-	21.1300	0.000
OE (-1)	0.0729	0.0047	−0.0957	0.0003	−0.1351	0.0000	−0.0842	0.0210
GGE	0.0003	0.2216	−3.88E-05	0.8786	−0.0001	0.0000	0.0003	0.0460
WM	0.0015	0.6557	0.0015	0.6288	0.0018	0.0000	0.0020	0,2020
IP	0.0010	0.0211	0.0012	0.0046	0.0011	0.0000	0.0007	0.1340
SCD	−3.46E-05	0.0930	−3.20E-05	0.1200	−2.48E-05	0.0000	−0.00003	0.2840
R-squared	0.0137		0.1767					
Adjusted R-squared	0.0101		0.1224					
F-statistic	3.8568	0.0017	3.2561	0.0000			4075.42	0.0000
Instrument Rank					82			
J-statistic					79.2182	0.4087		
Sargan							72.25	0.0000
Hansen							42.59	0.1480
Arellano-Bond Serial Correlation Test								
AR (1)							−2.3600	0.0180
AR (2)							1.0400	0.3000

Source: Researcher's Computation (2025)

Table 9: Dynamic panel GMM (ITR, GGE, WM, IP and SCD)

Variable	Pooled effect panel model		Fixed effect panel model		First differences panel GMM model	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
C	−8.4404	0.3894	−4.6184	0.4370	-	-
ITR (−1)	0.0856	0.1216	0.0282	0.5495	0.0537	0.0000
GGE	0.0126	0.8982	−0.0358	0.6645	−0.0009	0.7325
WM	0.1714	0.2666	0.0725	0.2927	0.2227	0.0000
IP	0.1213	0.2501	0.1090	0.3117	0.2261	0.0000
SCD	0.0004	0.8928	0.0002	0.9182	0.0013	0.0000
R-squared	0.0078		0.0596			
Adjusted R-squared	0.0042		−0.0022			
F-statistic	2.1829	0.0537	0.9630	0.5759		
Instrument Rank					84	
J-statistic					80.3587	0.4362
Sargan						
Hansen						
Arellano-Bond serial correlation test						
AR (1)	−0.0332		−9328566.5578		280936908.9056	0.9735
AR (2)	NA		−713355.7955		NA	NA

Source: Researcher's Computation, 2025

in South Africa. The study has found factors influencing climate change important to consider, not only when making business decisions but also when including climate-related matters in financial reports. Therefore, manufacturing companies should not overlook the critical information required for disclosure in their reporting, as this can be a reflection of deviating from disclosing material information to deceive or overstate financial statement items. From an analyst's point of view, few reports consist of matters pertaining to climate change by manufacturing companies. Instead, the majority of analyst reports are focused on business industries that have differential values considered to be material. Consequently, the findings of this study match the perspective of analysts prioritizing industries that are compliant in disclosing crucial climate-related data that can influence users of that information when making decisions. However, manufacturing companies are gradually becoming motivated to disclose their climate information. It may not have been compulsory to disclose in the past, but with the drastic changes in climate in recent years, it is a compelling need to be transparent on such information that could be a risk to the organisation or the investor. Overall, the study seeks to establish ways that the study's variables could trigger issues of climate change factors so that implications can be drawn to inform policy to enhance the financial reporting sustainability.

6.2. Implication of Findings

The sustaining conclusion drawn from this study on the policy implications was that the standard setters and the ability to emphasise climate-related financial disclosures on manufacturing companies, so that there can be a sustainable business that is cautious of matters concerning human well-being and the planet at large. An environmentally cautious company attracts investors who seek transparency in the company's financial reporting, which will include climate disclosures to assist them in their decision-making. Based on the variables tested in chapter four, it is evident that no matter which variables are being tested against the sustainability of financial reporting, they will influence the policies straightaway. The policy implications go further to employees of the company, that renewable energy is key to reducing the tension of employees being insecure about their jobs if sudden changes to the company's goals are made to achieve sustainability protocols. As a result, employees must adjust to the shift in the strategic policies made so that the operational efficiency is not compromised. Furthermore, the economy strongly relies on major contributors such as the manufacturing industry. So, financial analysts must be able to access transparent financial statements to be able to weigh the stock market position the company has. Non-disclosure can hinder or damage ties between investors and manufacturing companies. Therefore, it is vital to maintain the sustainability policies to remain competitive. This backs up the literature that climate accounting plays a role in sustainability, so that the company's reports are fairly presented in a manner that will attract investors to boost the South African economy. Standard setters and other policy makers can find this study's implications useful with the aim of solving the issues, and future research can unpack how these implications can be resolved.

6.3. Recommendations

a) Since the study relied purely on statistical data, a different approach to the method used to collect and analyse data can be used. Moreover, the study investigated manufacturing companies listed on the JSE for a period of 17 years (2005-2022). Therefore, further study can assess the financial reporting after this period.
b) The results of the research study apply to listed manufacturing companies in South Africa, making the information ungeneralizable with other manufacturing companies besides South Africa. Every country has its own conservative guidelines; thus, the impact of climate change may vary from one region to the next. So, future research may consider replicating this study using the data from another stock exchange.
c) Increased energy costs result in product costs increasing as more energy is required to manufacture a product. Hence, using the models adopted in this study would reduce the cost to produce, lower the transportation disruption consequences. Not using the correct methods to forecast for climate-related matters could increase the possibility of a decline in target profits for the manufacturers, thus reducing their financial performance, which will affect their reporting transparency.

7. CONCLUSION

This research investigated the influence of climate change factors on operational efficiency of listed manufacturing companies in South Africa. According to Ngepah et al. (2024), the manufacturing industry in South Africa has been placed in one of the top centres. Not only that, but it also adds value towards the expansion of the economy. Therefore, one can say that this sector is a catalyst for advancement and plays a major role in the gross domestic product (GDP) of South Africa. In addition, this sector managed to generate 13% of the economy's GDP which is about R3 trillion in value. This expansion not only boosts the economy positively but creates more job opportunities for the South Africa citizens. Even though manufacturing sector plays a vital role in the economy, there is a grey area on the transparency and fairness in their reporting, particularly concerning material disclosure of climate change matters. Incorporating environmental considerations into decision-making ensures long-term well-being for individuals, businesses and the planet, encompassing practices such as resource efficiency, waste reduction, and community engagement. This research has investigated the effects of climate change factors on operational efficiency, hoping this investigation would provide solutions to the inquiry.

The GMM estimation model used to address the first objective of the study, estimating the impact of operational efficiency and inventory turnover ratio using factor variables, showed that factors such as greenhouse gas emissions, waste management, industrial processes, and supply chain disruptions positively influence operational efficiency in the selected firms. Hence, the adaptation of the climate accounting approach acts as a decision-making tool for the company to apply environmental management practices in the manufacturing industry. With such evidence, the company is capable of enhancing its financial performance by increasing the efficiency of its operations, which can be achieved by implementing climate accounting and adopting sustainable practices within the company. To the researcher's knowledge, this is a new principle designed using the listed manufacturing companies' data in the South African framework. So, the results found in this study contribute immensely to the literature in the area of focus. In addition, adopting sustainable practices comes with benefits such as economic and ecological benefits for the manufacturing sector, as the factors influencing climate change would be minimized or mitigated. South Africa's manufacturing industry is a significant part of the economy, contributing 13% to GDP and employing a substantial portion of the formal workforce, with key sectors including agro processing, automotive, chemicals, and textiles. This is quite impressive that this industry has made huge efforts to lower the unemployment rate in South Africa, which is currently sitting at a rate of 31.9% for the second successive quarter in quarter four of 2024[11]. Moreover, the number of unemployed individuals decreased by 20 thousand to 7.991 million.

Most studies agree that climate change factors are likely to affect the financial performance of an organisation. Although operational efficiency is required for the context policy to improve sustainable practices, it will depend on the level of climate change and the level of risks associated with the changes to be able to determine strength. Emissions and their impact have been addressed by researchers in the past to understand their carbon footprint.

REFERENCES

Abbas, J., Wang, L., Ben Belgacem, S., Pawar, P.S., Najam, H., Abbas, J. (2023), Investment in renewable energy and electricity output: Role of green finance, environmental tax, and geopolitical risk: Empirical evidence from China. Energy, 269, 126683.

Abbass, K., Qasim, M.Z., Song, H., Murshed, M., Mahmood, H.,

11 https://tradingeconomics.com/south-africa/unemployment-rate#:~:text=Over%20a%20Year-,South%20Africa's%20unemployment%20rate%20fell%20for%20the%20second%20successive%20quarter,20%20thousand%20to%207.991%20million.

Younis, I. (2022), A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environmental Science and Pollution Research, 29(28), 42539-42559.

Adebayo, T.S., Kartal, M.T., Ağa, M., Al-Faryan, M.A.S. (2023), Role of country risks and renewable energy consumption on environmental quality: Evidence from MINT countries. Journal of Environmental Management, 327, 116884.

Aftab, J., Abid, N., Cucari, N., Savastano, M. (2023), Green human resource management and environmental performance: The role of green innovation and environmental strategy in a developing country. Business Strategy and the Environment, 32(4), 1782-1798.

Ani, E.C., Olajiga, O.K., Sikhakane, Z.Q., Olatunde, T.M. (2024), Renewable energy integration for water supply: A comparative review of African and US initiatives. Engineering Science and Technology Journal, 5(3), 1086-1096.

Anser, M.K., Khan, K.A., Umar, M., Awosusi, A.A., Shamansurova, Z. (2024), Formulating sustainable development policy for a developed nation: Exploring the role of renewable energy, natural gas efficiency and oil efficiency towards decarbonization. International Journal of Sustainable Development and World Ecology, 31(3), 247-263.

Axmadjonovich, Q.S. (2023), Increasing the efficiency of use of production investments in industrial enterprises. Asia Pacific Journal of Marketing and Management Review, 12(6), 15-21.

Behera, B., Behera, P., Sethi, N. (2024), Decoupling the role of renewable energy, green finance and political stability in achieving the sustainable development goal 13: Empirical insight from emerging economies. Sustainable Development, 32(1), 119-137.

Blundell, R., Bond, S., Windmeijer, F. (2011), Estimation in Dynamic Panel Data Models: Improving on the Performance of the Standard GMM Estimator. London: Institute for Fiscal Studies (IFS).

Bolton, P., Buchheit, L., Gulati, M., Panizza, U., Di Mauro, B.W., Zettelmeyer, J. (2023), On debt and climate. Oxford Open Economics, 2, 307-316.

Burawat, P. (2019), The relationships among transformational leadership, sustainable leadership, lean manufacturing and sustainability performance in Thai SMEs manufacturing industry. International Journal of Quality and Reliability Management, 36(6), 1014-1036.

Burritt, R.L., Herzig, C., Schaltegger, S., Viere, T. (2019), Diffusion of environmental management accounting for cleaner production: Evidence from some case studies. Journal of Cleaner Production, 224, 479-491.

CDSB. (2022), Basis for Conclusions on IFRS S2 Climate-Related Disclosures. IFRS Foundation. Available from: https://www.ifrs.org/content/dam/ifrs/project/climate-related-disclosures/issb-exposure-draft-2022-2-basis-for-conclusions-climate-related-disclosures.pdf

Chataut, G., Bhatta, B., Joshi, D., Subedi, K., Kafle, K. (2023), Greenhouse gases emission from agricultural soil: A review. Journal of Agriculture and Food Research, 11, 100533.

Chen, G., Shan, Y., Hu, Y., Tong, K., Wiedmann, T., Ramaswami, A., Guan, D., Shi, L., Wang, Y. (2019), Review on city-level carbon accounting. Environmental Science and Technology, 53(10), 5545-5558.

Chen, S., Qiu, H, Xiao, H., He, W., Mou, J., Siponen, M. (2021), Consumption behavior of eco-friendly products and applications of ICT innovation. Journal of Cleaner Production, 287, 125436.

Chien, F., Zhang, Y., Sadiq, M., Hsu, C.C. (2022), RETRACTED ARTICLE: Financing for energy efficiency solutions to mitigate opportunity cost of coal consumption: An empirical analysis of Chinese industries. Environmental Science and Pollution Research, 29(2), 2448-2465.

Cianconi, P., Betrò, S., Janiri, L. (2020), The impact of climate change on mental health: A systematic descriptive review. Frontiers in Psychiatry, 11, 74.

Clayton, S. (2020), Climate anxiety: Psychological responses to climate change. Journal of Anxiety Disorders, 74, 102263.

Commission, P. C. (2024). PCC recommendations report. Available from: https://www.climatecommission.org.za/

Costello, A.M. (2020), Credit market disruptions and liquidity spillover effects in the supply chain. Journal of Political Economy, 128(9), 3434-3468.

Crossley, R.M., Elmagrhi, M.H., Ntim, C.G. (2021), Sustainability and legitimacy theory: The case of sustainable social and environmental practices of small and medium-sized enterprises. Business Strategy and the Environment, 30(8), 3740-3762.

Da Silva, P.C., De Oliveira Neto, G.C., Correia, J.M.F., Tucci, H.N.P. (2021), Evaluation of economic, environmental and operational performance of the adoption of cleaner production: Survey in large textile industries. Journal of Cleaner Production, 278, 123855.

Debnath, B., Bari, A.B.M.M., Ali, S.M., Ahmed, T., Ali, I., Kabir, G. (2023), Modelling the barriers to sustainable waste management in the plastic-manufacturing industry: An emerging economy perspective. Sustainability Analytics and Modeling, 3, 100017.

Deegan, C.M. (2019), Legitimacy theory: Despite its enduring popularity and contribution, time is right for a necessary makeover. Accounting, Auditing and Accountability Journal, 32, 2307-2329.

Department Electricity and Energy Republic of South Africa. (2025), IPP Projects. Available from: https://www.ipp-projects.co.za

Digitemie, W.N., Ekemezie, I.O. (2024), Assessing the role of climate finance in supporting developing nations: A comprehensive review. Finance and Accounting Research Journal, 6(3), 408-420.

Diwan, H., Amarayil Sreeraman, B. (2024), From financial reporting to ESG reporting: A bibliometric analysis of the evolution in corporate sustainability disclosures. Environment, Development and Sustainability, 26(6), 13769-13805.

Dumay, J., La Torre, M., Farneti, F. (2018), Developing trust through stewardship: Implications for intellectual capital, integrated reporting, and the EU Directive 2014/95/EU. Journal of Intellectual Capital, 20(1), 11-39.

Eskander, S.M.S.U., Fankhauser, S. (2020), Reduction in greenhouse gas emissions from national climate legislation. Nature Climate Change, 10(8), 750-756.

Eskom. (2025), Demand Management Programme. Available from: https://www.eskom.co.za

Fatai Adedoyin, F., Agboola, P.O., Ozturk, I., Bekun, F.V., and Agboola, M.O. (2021), Environmental consequences of economic complexities in the EU amidst a booming tourism industry: Accounting for the role of brexit and other crisis events. Journal of Cleaner Production, 305, 127117.

Gabin, M. (2024), Reducing the Carbon Footprint of the University of Cape Town: An Energy Systems Approach. Available from: https://hdl.handle.net/11427/40298

Gauci, V., Pangala, S.R., Shenkin, A., Barba, J., Bastviken, D., Figueiredo, V., Gomez, C., Enrich-Prast, A., Sayer, E., Stauffer, T. (2024), Global atmospheric methane uptake by upland tree woody surfaces. Nature, 631(8022), 796-800.

Ghadge, A., Wurtmann, H., Seuring, S. (2020), Managing climate change risks in global supply chains: A review and research agenda. International Journal of Production Research, 58(1), 44-64.

Gulluscio, C., Puntillo, P., Luciani, V., Huisingh, D. (2020), Climate change accounting and reporting: A systematic literature review. Sustainability, 12(13), 5455.

Gupta, H., Kumar, A., Wasan, P. (2021), Industry 4.0, cleaner production and circular economy: An integrative framework for evaluating ethical and sustainable business performance of manufacturing organizations. Journal of Cleaner Production, 295, 126253.

Guschow. (2021), Climate Transparency Report. Available from: https://www.climate-transparency.org/wp-content/uploads/2021/10/ct2021southafrica.pdf

Hansen, L.P. (1982), Large sample properties of generalized method of moments estimators. Econometrica: Journal of the Econometric Society, 50, 1029-1054.
Iyke, B.N. (2024), Climate change, energy security risk, and clean energy investment. Energy Economics, 129, 107225.
Jacquier, P., Abdedou, A., Delmas, V., Soulaïmani, A. (2021), Non-intrusive reduced-order modeling using uncertainty-aware deep neural networks and proper orthogonal decomposition: Application to flood modeling. Journal of Computational Physics, 424, 109854.
Kaplan, R.S., Ramanna, K. (2021), Accounting for Climate Change. Business Management. Available from: https://hbr.org/2021/11/accounting-for-climate-change
Kebede Adem, M., Virdi, S.S. (2021), The effect of TQM practices on operational performance: An empirical analysis of ISO 9001: 2008 certified manufacturing organizations in Ethiopia. The TQM Journal, 33(2), 407-440.
Khan, A.R., Razzaq, A., Zhang, Y., Miller, S. (2021), Retracted: Industry 4.0 and circular economy practices: A new era business strategies for environmental sustainability. Business Strategy and the Environment, 30(8), 4001-4014.
Khan, S., Anjum, R., Raza, S.T., Ahmed Bazai, N., Ihtisham, M. (2022), Technologies for municipal solid waste management: Current status, challenges, and future perspectives. Chemosphere, 288, 132403.
Khuong, N.V., Rahman, A.A.A., Meero, A., Anh, L.H.T., Liem, N.T., Thuy, C.T.M., Ly, H.T.N. (2022), The impact of corporate social responsibility disclosure and accounting comparability on earnings persistence. Sustainability, 14(5), 2752.
Kirikkaleli, D., Adebayo, T.S. (2021), Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. Sustainable Development, 29(4), 583-594.
Lin, B., Chappell, M., Vandermeer, J., Smith, G., Quintero, E., Bezner-Kerr, R., Griffith, D., Ketcham, S., Latta, S., McMichael, P., McGuire, K., Nigh, R., Rocheleau, D., Soluri, J., Perfecto, I. (2011), Effects of industrial agriculture on climate change and the mitigation potential of small-scale agro-ecological farms. CABI Reviews, 2011, 1-18.
Lin, Y., Huang, R., Yao, X. (2021), Air pollution and environmental information disclosure: An empirical study based on heavy polluting industries. Journal of Cleaner Production, 278, 124313.
Liu, X., Lu, D., Zhang, A., Liu, Q., Jiang, G. (2022), Data-driven machine learning in environmental pollution: Gains and problems. Environmental Science and Technology, 56(4), 2124-2133.
Lukey, P. (2020), The South African national climate change response policy: An evidence-based policy-making case study. Department of Environment, Forestry and Fisheries, Pretoria, 1, 2.
Lund, S., Manyika, J., Woetzel, J., Barriball, E., Krishnan, M. (2020), Risk, Resilience, and Rebalancing in Global Value Chains. USA: McKinsey Global Institute.
Martin, H.D. (2018), Demystifying the link between institutional theory and stakeholder theory in sustainability reporting. Economics, Management and Sustainability, 3(2), 6-19.
Maverick, D. (2022), SA Insurance Industry Drowning in Claims after KZN Flash Floods, Covid-19 and July Riots. Available from: https://www.dailymaverick.co.za/article/2022-04-24-sa-insurance-industry-drowning-in-claims-after-kzn-flash-floods-covid-19-and-july-riots
Mehmood, S., Zaman, K., Khan, S., Ali, Z., Khan, H.U.R. (2024), The role of green industrial transformation in mitigating carbon emissions: Exploring the channels of technological innovation and environmental regulation. Energy and Built Environment, 5(3), 464-479.
Moloi, T., Marwala, T. (2020), The legitimacy theory and the legitimacy gap. In: Artificial Intelligence in Economics and Finance Theories. Germany: Springer. p103-113.
Moretto, A., Caniato, F. (2021), Can supply chain finance help mitigate the financial disruption brought by Covid-19? Journal of Purchasing and Supply Management, 27(4), 100713.
Ngepah, N., Saba, C.S., Kajewole, D.O. (2024), The impact of industry 4.0 on South Africa’s manufacturing sector. Journal of Open Innovation: Technology, Market, and Complexity, 10(1), 100226.
Nguimkeu, P., Zeufack, A. (2024), Manufacturing in structural change in Africa. World Development, 177, 106542.
Nishitani, K., Unerman, J., Kokubu, K. (2021), Motivations for voluntary corporate adoption of integrated reporting: A novel context for comparing voluntary disclosure and legitimacy theory. Journal of Cleaner Production, 322, 129027.
Njeru, C. (2022), Effect of Leadership on Operational Efficiency of Non-governmental Organizations in Nairobi County. Kenya: Kenya University of Nairobi.
Northouse, P.G. (2025), Leadership: Theory and Practice. United States: Sage Publications.
Osman, A.I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., Rooney, D.W., Yap, P.S. (2023), Cost, environmental impact, and resilience of renewable energy under a changing climate: A review. Environmental Chemistry Letters, 21(2), 741-764.
Oyetade, D., Obalade, A.A., and Muzindutsi, P.F. (2022), The impact of changes in basel capital requirements on the resilience of African commercial banks. Scientific Annals of Economics and Business, 69(1), 111-132.
Pedroni, P. (2004), Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric theory, 20(3), 597-625.
Presidential Climate Commission. (2024), PCC Recommendations Report. Available from: https://www.climatecommission.org.za
Princiotta, F.T., Loughlin, D.H. (2014), Global climate change: The quantifiable sustainability challenge. Journal of the Air and Waste Management Association, 64(9), 979-994.
Rotimi, M.E., Ngalawa, H. (2017), Oil price shocks and economic performance in Africa’s oil exporting countries. Acta Universitatis Danubius. Œconomica, 13(5), 169-188.
SA-News. (2022), KZN Flood Victims to Get Temporary Accommodation by Weekend Available from: https://reliefweb.int/report/south-africa/kzn-flood-victims-get-temporary-accommodation-weekend
Saud, S., Chen, S., Haseeb, A., Sumayya, G., (2020), The role of financial development and globalization in the environment: Accounting ecological footprint indicators for selected one-belt-one-road initiative countries. Journal of Cleaner Production, 250, 119518.
Schaltegger, S., Csutora, M. (2012), Carbon accounting for sustainability and management. Status quo and challenges. Journal of Cleaner Production, 36, 1-16.
Silva, S. (2021), Corporate contributions to the Sustainable Development Goals: An empirical analysis informed by legitimacy theory. Journal of Cleaner Production, 292, 125962.
Sinha, S., Sengupta, K. (2020), Role of leadership in enhancing the effectiveness of training practices: Case of Indian information technology sector organizations. Paradigm, 24(2), 208-225.
Terent, N.E. (2021), Climate change as a factor in the development of companies: Corporate strategies and guidelines for state industrial policy. Studies on Russian Economic Development, 32(5), 485-491.
Treasury, N. (2025), Carbon Tax. South Africa. Available from: https://www.treasury.gov.za
Udeagha, M.C., Breitenbach, M.C. (2023), The role of financial development in climate change mitigation: Fresh policy insights from South Africa. Biophysical Economics and Sustainability, 8(1), 1.
United Nations Climate Change. (n.d). UN Climate Change. Available dfrom: https://unfccc.int
Vereb, D., Krajcsák, Z., Kozák, A. (2025), The importance of positive employee experience and its development through using predictive analytics. Journal of Modelling in Management, 20(1), 51-69.

Wang, D.D. (2017), Do United States manufacturing companies benefit from climate change mitigation technologies? Journal of Cleaner Production, 161, 821-830.
Xu, H., Jia, Y., Sun, Z., Su, J., Liu, Q.S., Zhou, Q., Jiang, G. (2022), Environmental pollution, a hidden culprit for health issues. Eco-Environment and Health, 1(1), 31-45.
Xu, Z., Pokharel, S., Elomri, A. (2023), An eco-friendly closed-loop supply chain facing demand and carbon price uncertainty. Annals of Operations Research, 320(2), 1041-1067.
Yoo, J.M., Shin, H., Chung, D.Y., Sung, Y.E. (2022), Carbon shell on active nanocatalyst for stable electrocatalysis. Accounts of Chemical Research, 55(9), 1278-1289.
Zafeiriou, E., Azam, M., Garefalakis, A. (2022), Exploring environmental-economic performance linkages in EU agriculture: Evidence from a panel cointegration framework. Management of Environmental Quality: An International Journal, 34(2), 469-491.
Zahid, R.M.A., Saleem, A., Maqsood, U.S. (2023), ESG performance, capital financing decisions, and audit quality: Empirical evidence from Chinese state-owned enterprises. Environmental Science and Pollution Research, 30(15), 44086-44099.
Zhang, W., Xu, N., Li, C., Cui, X., Zhang, H., Chen, W. (2023), Impact of digital input on enterprise green productivity: Micro evidence from the Chinese manufacturing industry. Journal of Cleaner Production, 414, 137272.