TRADE & INDUSTRIAL POLICY STRATEGIES

INDUSTRY STUDY

Sustainability Report: Electronics Industry

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TIPS industry studies aim to provide a comprehensive overview of key trends in leading industries in South Africa. For each industry covered, working papers will be published on basic economic trends, including value added, employment, investment and market structure; trade by major product and country; impact on the environment as well as threats and opportunities arising from the climate crisis; and the implications of emerging technologies. The studies aim to provide background for policymakers and researchers, and to strengthen our understanding of current challenges and opportunities in each industry as a basis for a more strategic response.

This industry study explores the carbon intensity across the electronics value chain, covering emissions from raw material extraction, manufacturing processes, and end-use applications, as well as circularity, recycling, and other greenhouse gas emissions. It also discusses sustainable technology solutions and the policy environment in South Africa.

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ABBREVIATIONS

BFRs	Brominated Flame Retardants
CO2	Carbon dioxide
DFFE	Department of Forestry, Fisheries and the Environment
EPR	Extended Producer Responsibility Regulations
FCs	Fluorinated Compounds
F-GHGs	Fluorinated Greenhouse Gases
GHGs	Greenhouse Gases
GWP	Global Warming Potential
HPC	High-performance Computing
ICT	Information and Communication Technology
ICA	International Copper Association
PCBs	Printed Circuit Boards
PPA	Power Purchase Agreement
WEEE	Waste Electronic and Electrical Equipment
WHO	World Health Organization

INTRODUCTION

Products from the electronics manufacturing value chain are essential to modern economies. The electronics industry faces challenges in its transition in transforming into a more sustainable industry as greenhouse gas (GHG) emissions are present throughout the supply chain, including mining raw materials, manufacturing, and assembling electronic components. Carbon dioxide emissions, for example, are produced during the manufacturing process of electronic devices, where primary materials and chemicals are used as raw materials/inputs, and fossil-based energy is frequently employed, resulting in high carbon emissions. Other pollutants released during the production of electronics include sulphur hexafluoride and perfluorocarbons. Companies within the value chain also face challenges in analysing the carbon footprint, particularly the emissions linked to the hardware they purchase and sell.

The global awareness of the electronics industry's environmental impact has prompted electronic manufacturers to transform to more sustainable materials, energy-efficient sources, and technologies to lessen their environmental impact. Governments throughout the world have implemented policy efforts, notably the Circular Economy and Extended Producer Responsibility (EPR) regulations, to promote the reduction of emissions and the appropriate disposal and recycling of electronic waste. In South Africa, the Waste Electronic and Electrical Equipment (WEEE) EPR Regulations went into force in 2021. These regulations seek to promote appropriate disposal and recycling of electronic waste, so contributing to a healthier environment for future generations.

In this study, the electronics industry encompasses the production of electronic components, circuit boards, and devices, which are crucial for a wide range of applications across sectors such as consumer electronics, telecommunication equipment, medical devices and instruments, and the automotive industry, among others. The first paper of this series, *Industry Study: Electronics Industry,* presents a comprehensive value chain analysis of the electronics industry, providing a detailed examination of its structure, key players, and market dynamics. The first section explores the carbon intensity across the electronics value chain, covering emissions from raw material extraction, manufacturing processes, and end-use applications, as well as circularity, recycling, and other greenhouse gas emissions in the industry. It also discusses sustainable technology solutions. Section two focuses on the policy environment in South Africa, analysing key regulations and initiatives from other countries aimed at reducing emissions. The final section concludes.

1. CARBON INTENSITY OF THE VALUE CHAIN

Electronics manufacturing, along with the toxic compounds found in modern devices, has a negative impact on the environment. In the electronics industry, key contributors to carbon emissions include the electricity mix, energy-intensive processes, globalised supply chains, short product lifecycles, and high demand for new products.

In South Africa, electronics manufacturing and assembly facilities rely on a coal-heavy electricity supply, leading to higher emissions per kilowatt-hour (kWh) compared to using renewable energy sources. Energy-intensive processes, such as those involved in printed circuit board (PCB) assembly, use high-temperature reflow ovens to create reliable solder joints. These processes require precision equipment that often operates continuously in large-scale operations, thus consuming significant amounts of energy. In addition, the global supply chains in the electronics industry often involve suppliers spread across different continents. This necessitates long-distance transportation and extensive logistics networks, both of which contribute to carbon emissions. Furthermore, the disposal of electronic products at the end of their life cycle generates substantial waste that pollutes the environment. The rapid innovation cycles in consumer electronics, such as smartphones and laptops, encourage frequent device replacement, driving increased manufacturing and resource extraction. While emissions data for the electronics industry in South Africa are not specifically estimated due to a lack of data (DFFE, 2022), the following sections will explore the carbon emissions associated with each stage of the electronics value chain at both global and, where possible, domestic levels.

1.1. Inputs/raw materials emissions

The extraction and processing of raw materials, as well as the use of hazardous chemicals, all contribute significantly to GHG emissions during the manufacturing of electronic devices. Various materials are utilised as inputs in electronics production, including metals such as copper, ferrous metal, and aluminium, emitting carbon dioxide during their extraction, processing, and manufacturing stages. According to the International Copper Association, copper production contributes around 0.2% of global greenhouse gas emissions and refined copper production emitted 4.6 tonnes of carbon dioxide equivalent (tCO2e) per metric tonne of copper in 2018. Other materials, such as plastics, are critical inputs in the production of electronic devices; nevertheless, the fabrication of plastic components for electronics is highly energy-intensive, and polymers alone create carbon emissions. Domestically, electronic manufacturers do source polymers locally, where in 2023, about 6% of virgin polymer was consumed by the electrics and electronics sector (Plastics SA, 2024). However, the local electronics industry relies heavily on plastic imports.

Furthermore, traditional silicon-based components are damaging to the environment due to waste generated during processing, and the potentially harmful effects of the materials used in production. Domestically, companies are involved in processing silicon-based components using traditional and innovative methods, even though using traditional methods to produce silicon-based materials is unsustainable as they rely on carbon-rich processes which are highly energy-intensive (Furgal and Lenora, 2020).

1.2. Manufacturing processes

In the manufacturing of electronic products, significant amounts of energy are used, primarily relying on fossil fuels, which leads to increased carbon dioxide emissions. In South Africa, coal-generated energy accounts for 82% of the energy supply (DMRE, 2023). Local electronic manufacturers produce products that are highly energy-intensive in their production and assembly processes. Consequently, the reliance on non-renewable energy sources, particularly coal-fired electricity, contributes to indirect carbon emissions in the country.

The manufacturing of PCBs greatly contributes to greenhouse gas emissions due to energy-intensive processes and the materials used. High-temperature reflow ovens, essential for soldering components onto the boards, consume a significant amount of energy, often sourced from coal-based electricity. Moreover, the reliance on unsustainable materials like lead-based solder and the disposal of hazardous chemicals, such as non-eco-friendly cleaning agents, pose environmental and health risks, particularly when PCBs are not disposed of properly. In South Africa, some local companies still use lead-based solder for older products that require compliance with older standards.

The use of brominated flame retardants (BFRs) in electronic components raises significant environmental and health concerns. Local manufacturers incorporate these substances into various electronic products for fire safety. However, BFRs can pose risks during soldering or in the event of a fire, as harmful substances may be released into the environment, threatening human health and contributing to pollution (Ezema Ike-Eze et al., 2023). In addition, manufacturing products from virgin materials have a greater climate impact compared to using recycled materials.

The production of semiconductors also contributes to a significant carbon footprint. Semiconductor fabrication requires large amounts of electricity and specialised process gases, which are potent GHGs. The manufacturing steps that involve high heat or vacuum processes consume substantial energy. These energy-intensive processes include photolithography, etching, and chemical vapor deposition. In 2021, the global semiconductor industry was estimated to produce 76.5 million tons of CO_2 equivalent emissions. This total included 30.6 million tons attributed to Scope 1 emissions and 45.9 million tons from Scope 2 emissions (Pelcat, 2023). In South Africa, domestic semiconductor production is limited, with a primary focus on design and specialised applications. The country heavily relies on imports of semiconductor components, including advanced chips for electronics manufacturing. As a result, the carbon emissions associated with semiconductor production are embedded in the imported chips, effectively outsourcing these emissions to countries with major semiconductor manufacturing hubs, such as China, Taiwan, the United States (US), and South Korea.

1.3. Downstream/end-uses

The carbon footprint of the Information and Communication Technology (ICT) sector includes emissions from devices such as computers, servers, and mobile phones. The Implications for Climate Action 2024 Report by the World Bank and the International Telecommunication Union estimates that the ICT industry emitted a total of 567 million tons of CO_2 equivalent in 2022, making up 1.7% of global emissions. The report indicates that most of these emissions (63%) come from embedded emissions (related to manufacturing) and the use of ICT products. Additionally, telecommunications contributed 23% of the emissions, while colocation, cloud, and content data centres contributed 13%.

Energy-intensive data centres have emerged as a new source of increased electricity use. The power used by servers and other equipment results in carbon dioxide emissions (Uddin et al., 2015). According to Gupta et al. (2020), the primary sources of carbon emissions in data centres include natural gas and diesel (Scope 1), energy consumption (Scope 2), and the manufacturing of buildings and server hardware (Scope 3). In South Africa, large commercial data centres are estimated to use about 12-20MW of power (TechCentral, 2024). The number of data centres has increased significantly in recent years, driven by new facilities being established by information and technology companies. Similarly, activities such as computer programming, data processing, and cloud computing consume substantial amounts of electricity, contributing to their carbon footprint (Huang et al., 2009; Silva et al., 2024). This energy consumption is primarily driven by the infrastructure that supports these operations, including data centres, cloud services, and high-performance computing (HPC) facilities. Additionally, the substantial electricity demand of HPC systems, driven by their intensive computing power, supporting equipment, and cooling resources, makes them substantial energy consumers and contributors to climate change (Silva et al., 2024).

In South Africa, several foreign direct investments in data centres have included commitments to renewable energy (see Table 1). For example, DPA Southern Africa entered into a 20-year power purchase agreement (PPA) with African Data Centres, under which DPA SA will supply 12MW of renewable solar energy to Africa Data Centres' facilities in South Africa. Similarly, Hisense plans to implement a solar energy system to meet the power needs at its Atlantis facility. Econet Energy has also installed solar photovoltaic panels at the Liquid Telecom campus and data facilities in Midrand. Furthermore, in 2022, Teraco announced an investment of R1.1 billion to build a data centre in Gauteng and generate electricity for its sites across the country.

Table 1: Data centres and renewable energy investments

INVESTOR FIRMS	PROJECT NAME	DOMESTIC GEOGRAPHIC LOCATION	INVESTOR COUNTRY
Teraco	Teraco data centre and power generation infrastructure	Not reported	Multiple
Teraco	Teraco CT2	Cape Town	United States
Econet Global	Econet Energy (Distributed Power Africa) Solar PV installations	Multiple locations	Mauritius
Cassava Technologies	Cassava Technologies South African Investment Conference commitment	Cape Town, Johannesburg	United Kingdom
DPA Southern Africa (Joint venture between Distributed Power Africa and EDF Renewables	Africa Data Centre solar PV power plant	Bloemfontein	Multiple
Amazon/Sola Group	Amazon renewable energy project (Sola Group)	Not reported	United States
Hisense	Hisense solar power investment	Atlantis	China
Oracle Corporation	Oracle Headquarters	Woodmead	United States

Source: TIPS FDI Trackers.

1.4. Circularity and recycling

The disposal of electronic products at the end of their life cycle generates a considerable amount of waste (e-waste), some of which is hazardous. Electrical and electronic products are abandoned as they break or become obsolete (WHO, 2024). South Africa creates around 6.2 kilograms of e-waste per capita per year, with 12% recycled (WasteAid, 2024). According to Singh and Ogunseitan (2022), global embodied greenhouse gas (GHG emissions from some e-waste generated by ICT equipment will reach 852 MMT of carbon dioxide per year by 2030. According to the World Health Organization (WHO), mobile phones, laptops, household appliances, and medical equipment are some of the most common items found in e-waste streams. Therefore, throwing away these electronic devices has a negative effect on the environment. Recycling e-waste, for instance, through unsound methods such as dumping, burning, shredding and landfilling exposes people to dangerous chemicals including lead (neurotoxicants) and mercury, which pollute the air and water, thereby harming both the environment and human health.

1.5. Other emissions and pollutants

The electronics sector emits greenhouse gases such as nitrous oxide and fluorinated compounds. Fluorinated greenhouse gases (F-GHGs) are produced by various electrical devices that include liquid crystal display (LCD) panels. These gases are primarily emitted during the manufacturing process of flat panel displays, most often LCD panels, used in televisions, computer monitors, and other display products (US EPA, 2016). Each time these are produced, potent F-GHGs are released into the atmosphere. Other GHG emissions related to electronics manufacturing include perfluorocarbons and sulphur hexafluoride, both linked to the electronics industry. As a result, the electronics industry's carbon footprint extends beyond production.

1.6.Technological options

Sustainable electronics manufacturing offers many opportunities to enhance efficiency, reduce waste, and improve cost-effectiveness. This section focuses on the technical aspects of electronics manufacturing, highlighting the use of environmentally friendly materials and components, as well as energy-efficient production techniques. By using recycled materials and components, manufacturers can minimise their carbon footprint associated with new material extraction and processing. Furthermore, investing in energy-efficient technologies and processes can lead to significant reductions in emissions.

1.6.1. Sustainable technology options in the electronics value chain

Inputs

- Metals such as copper, gold, and aluminium can be recovered from electronic waste, which helps decrease the demand for virgin materials and the emissions associated with their extraction. Plastics can be sourced from post-consumer recycled resins or bio-based alternatives. In addition, input suppliers can enhance energy inputs by using renewable energy sources and low-carbon processes in mining or refining. Utilising recycled components and materials can further lower the carbon footprint by minimising the need for new material extraction and processing.

Enhancing efficiency in product design

- Focus on reducing the weight of components and minimising reliance on rare or high-impact materials, for example, replacing cobalt or heavy rare earth elements with more sustainable and cost-effective alternatives. Additionally, adopting modular design principles enables the replacement of individual sub-components rather than entire devices, reducing waste and extending product lifespans.

Manufacturing and assembly

- **Energy efficiency:** Upgrading to energy-efficient equipment, such as motors, compressors, and Heating, Ventilation, and Air Conditioning (HVAC) systems, is crucial. Implementing smart control systems and optimising production lines can also help reduce waste and conserve energy. In PCB assembly, technologies such as surface mount technology machines use less power, which helps lower the carbon footprint of the assembly process. In addition, transitioning to renewable energy sources is vital for reducing emissions in electronics assembly and data centres. For example, energy sources such as solar photovoltaic systems and wind power have short installation lead times, which helps decrease reliance on fossil fuels.
- **Transition to renewable energy** by acquiring sustainable electricity through PPAs or installing on-site solar and wind systems, while also working with grid operators and local governments to enhance renewable capacity.
- **Process gas management:** Utilising abatement technologies to capture harmful process gases before their release, focusing on high global-warming-potential (GWP) gases and replacing them with lower-GWP alternatives whenever possible.
- **Sustainable materials and eco-friendly practices** are crucial for reducing environmental impact. For example, lead-free soldering uses solder that does not contain lead, replacing the traditional tin-lead alloy. This transition significantly lowers the toxic emissions associated with conventional lead-based soldering processes. Moreover, materials such as silicon carbide and gallium nitride are used in place of traditional silicon, minimising heat and power dissipation, which enhances energy efficiency. Printed electronics employ an eco-design approach that maximises material

efficiency through recycling (Martins et al., 2023). Consequently, printed electronics are preferred because they limit the use of hazardous materials, thus promoting environmental sustainability.

- **Waste heat recovery and circular resource flows:** Implement systems to capture and reuse waste heat from processes such as ovens, etching, and testing equipment, redirecting it to other production lines or for facility heating, thereby improving overall energy efficiency. In addition, adopt closed-loop systems to reclaim and recycle process chemicals, reducing resource consumption and environmental impact.

Transportation and logistics

- **Supply chain optimisation**: Reducing transport emissions by locating input suppliers closer to production sites and utilising lower-carbon mass transit options, such as rail.

End-use phase

- **Energy-efficient design:** Designing chips, displays, and circuits to reduce power consumption (e.g., more efficient OLED/AMOLED (organic light emitting diode/active-matrix organic light emitting diode) technologies and advanced power management in CPUs (central processing units). Establishing default power-saving modes (such as sleep, hibernate, or low-brightness).
- **Longer product life:** Providing ongoing software support and updates beyond the standard two to three-year cycles. Designing hardware for easy repair and facilitating battery or component replacements. Implementing trade-in or refurbishment programmes to extend the lifespan of devices and reduce the overall environmental impact per unit of functionality.

Consumer awareness

- Use of labels to indicate energy consumption and encourage responsible usage habits.

End-of-life management/circularity

- **Take-back programmes and reverse logistics**: Using collection points for old devices, alongside safe transportation to recycling facilities. High-quality recycling occurs in specialised facilities that recover precious metals such as gold, copper, palladium, and rare earth elements with minimal environmental impact.
- **Refurbishment and remanufacturing**: The process of reselling or donating used electronics, as well as upgrading devices to extend their lifespans.

2. THE SOUTH AFRICAN POLICY LANDSCAPE AND SUSTAINABILITY RISKS

This section discusses existing waste management laws in South Africa, such as the Extended Producer Responsibility Regulations, which are global policy efforts that have been enacted by nations in the European Union, for example. The section also discusses domestic policy risks in the electronics industry, as well as key actions in other nations that encourage sustainability by reducing emissions.

2.1. Extended Producer Responsibility Regulations

In South Africa, the Department of Forestry, Fisheries and the Environment (DFFE) published the EPR Regulations in 2020, which came into effect a year later, in 2021, and are mandatory for producers. The regulations are designed to hold producers accountable for the entire lifecycle of their products post-consumer stage, including managing collection, pre-treatment (sorting and dismantling), reuse, recovery (recycling and energy recovery), or final disposal of the producer’s product and packaging.

According to the DFFE, the objective of the regulations is to ensure the efficient and effective management of identified end-of-life products, as well as to enable the implementation of circular economy projects. Furthermore, these laws apply to a variety of industries, including electrical and electronic equipment, paper and packaging, and lighting; they also have implications for producers, importers, brand owners, distributors, and retailers in these industries (eWASA, 2024). The EPR Regulations are essential because disposing of electronic waste (e-waste) in landfills poses significant health risks, such as exposure to contaminated soil and water, as well as environmental dangers like air pollution and toxic leaching from harmful materials found in electronic devices. In South Africa, landfilling is the most common method of waste disposal; in 2017, the country generated 55 million tonnes of general waste, with only 11% diverted from landfills (DEFF, 2020). Therefore, recovering and recycling e-waste is crucial to mitigate these risks. This policy plays a vital role in shifting towards a circular economy, focusing on waste minimisation and resource optimisation.

2.2. South African carbon taxes

The South African government introduced carbon taxes as a market-based mechanism to encourage emissions reductions. A carbon tax is levied on carbon emissions above a specific threshold and payable to the state by manufacturers as a form of excise tax. The more carbon gases a company emits, the more tax it must pay. In South Africa, carbon taxes were introduced in 2019 as a phased approach. The first phase has a headline rate of R120 per tonne of carbon dioxide equivalent (tCO_2e) (SARS, 2024). In addition, industry-specific tax-free allowances ranging between 60% and 95% of emissions were also included in the first phase. The second phase proposes an increased carbon tax rate, projected to reach R190 per tonne of tCO_2e in 2024, with annual increases planned. The second phase also includes more sectors and reduces allowances (National Treasury, 2024).

Although the carbon tax addresses approximately 80% of South Africa’s emissions, its effective rate is low compared to global standards. This is largely due to tax-free allowances and exemptions granted to Eskom, as well as a focus on direct emissions (Montmasson-Clair and Patel, 2024). In 2022, the global average effective carbon tax rate was around US$6, whereas South Africa’s effective rate ranged from R6 to R48 per tCO_2e, which is approximately US$0.30 to US$2.60. The National Treasury plans to increase the carbon tax, aiming for US$30 per tCO2e by 2030. However, this target still falls short of the emerging markets’ goal of US$50 per tCO2e set by the International Monetary Fund (Parry, 2022; Loewald, 2024; Montmasson-Clair and Patel, 2024).

In addition, the government provides a trade exposure tax-free credit for enterprises exposed to international trade competitiveness. The allowance was implemented to decrease the danger of carbon leakage and address negative implications on industry competitiveness (National Treasury, 2024). According to the National Treasury, the maximum trade exposure tax-free allowance is 10% for sectors with a trade intensity of 30% or more; however, the trade intensity criterion will climb to 50% in January 2026. Furthermore, the electronics sub-industries are eligible for the tax exposure allowance. The National Treasury proposed a 10% trade exposure allowance for sub-industries such as computing machinery, electronic valves, radio and communication apparatus, television and radio receivers, and professional equipment.

2.3. Initiatives in other countries to reduce emissions

The need to recycle and reuse electronic devices to extend lifespans has prompted governments to implement rules that encourage longevity. For example, some nations, notably in Africa, have implemented the extended producer Regulations. Nigeria, for example, has extended producer regulations for electronics, and Ghana’s has implemented the Hazardous and Electronic Waste Control and Management Act, 2016, and Regulations. Furthermore, the European Union announced new legislation in July 2024 that allows consumers to have their products repaired rather than replaced, increasing the lifespan of commodities and contributing to a circular economy. The European Union’s Right to Repair policy generally applies to consumer electronics, such as refrigerators, washing machines, smartphones, and computers, as well as other durable goods. It requires manufacturers to provide repair services for these goods both during and beyond their warranty period. Additional initiatives are noted in Table 2.

Table 2: Significant initiatives in other countries aimed at reducing emissions

COUNTRY	INITIATIVES TO REDUCE EMISSIONS	ELECTRONICS SUBINDUSTRY
European Union	Right to Repair policy	Consumer Electronics
	Circular Economy Action Plan	
	France: The Anti-waste Law for Circular Economy	
Africa	Nigeria: Extended Producer Regulations for Electronics	
	Ghana: Hazardous and Electronic Waste Control and Management Act and Regulations	
America	Chile's Circular Economy Roadmap	
	25 American states have e-waste recycling legislation	
Asia	China: The Circular Economy has set targets for the Electronics Industry	
	South Korea: The Extended Producer Responsibility scheme for e-waste covers 27 or more products nationally	
European Union	Energy Efficiency and Renewable Energy directives promote energy recovery for data centres.	ICT

Source: PWC, 2023.

3. CONCLUSION

Carbon emissions from electronics production are primarily classified as Scope 3 emissions, i.e., most companies use these inputs but do not manufacture these products themselves. This category includes all indirect emissions throughout a company's value chain, such as those associated with raw material manufacturing, transportation, and the disposal of electronic products. To address these challenges, it is important to recognise that downstream activities – including the disposal and recycling of electronic devices, as well as product transportation and distribution – also contribute to the overall carbon footprint. Data centres, which operate in the downstream phase of the value chain, are particularly energy-intensive, leading to notable carbon emissions. Moreover, the disposal of electronic products at the end of their lifecycle results in significant waste, which poses environmental challenges.

The electronics industry can significantly reduce its carbon footprint by adopting innovative technologies and sustainable manufacturing practices. By implementing circular economy principles, such as recycling materials and extending product lifecycles, it is possible to minimise electronic waste and conserve resources. Therefore, transitioning to sustainable practices is essential for mitigating the impacts of climate change, enhancing operational efficiency, and improving cost-effectiveness. Ultimately, this shift will lead to the decarbonisation of the electronics industry.

The policy landscape in South Africa is evolving with initiatives such as the Extended Producer Responsibility Regulations, which represent a proactive approach to environmental sustainability. These regulations empower producers to take charge of their products and packaging throughout the entire lifecycle, including collection, pre-treatment (sorting and dismantling), reuse, recovery (recycling and energy recovery), and final disposal. In addition, the implementation of a carbon tax serves as a vital tool to encourage emissions reductions across various sectors. While there is currently a gap in data regarding emissions from South Africa's electronics industry, this presents an opportunity for improvement. DEFF is planning to conduct a survey in the near future, which will provide valuable insights and help inform further actions to address emissions in this sector.

REFERENCES

DFFE (2020). National Waste Management Strategy 2020. Department of Forestry, Fisheries and the Environment. Available at: https://www.dffe.gov.za/sites/default/files/docs/nationalwaste_management_strategy (Accessed January 2025).

DFFE 2022. *National GHG Inventory Report South Africa 2000-2020.* Department of Forestry, Fisheries and the Environment. Available at: https://www.dffe.gov.za/sites/default/files/reports/8 nationalgreenhousegasreport2022.pdf (Accessed October 2024).

DMRE (2023). *The South African Energy Sector Report 2023.* Department of Mineral Resources and Energy. Available at https://www.dmre.gov.za/Portals/0/Resources/Publications/Reports/Energy%20Sector%20Reports/SA%20Energy%20Sector%20Report/2023-South-African-Energy-Sector-Report.pdf?ver=6TOu3ZWrjDaMhxVQWcR3vQ%3D%3D (Accessed January 2025).

eWASA (2024). Working towards Sustainable Waste Management Systems for South Africa Since 2008. EPR Waste Association of South Africa. Available at https://ewasa.org/ (Accessed November 2024)

Ezema Ike-Eze, I.C. O. N. Ucheji, O.N., Ubi, P.A., Oji, E.O., Aigbodion, V.S., Omah1 A.D. and Ogbuefi, U.C. (2023) 'An Overview of Flame Retardants in Printed Circuit Boards for LEDs and other Electronic Devices'. *J. Mater. Environ. Sci*, 2023(4), pp. 410–420. Available at: http://www.jmaterenvironsci.com.

Furgal, J.C. and Lenora, C.U. (2020) 'Green routes to silicon-based materials and their environmental implications'. *Physical Sciences Reviews*, 5(1). doi:10.1515/psr-2019-0024

International Copper Association (2023) Copper: The pathway to net zero. Available at: https://internationalcopper.org/wp-content/uploads/2022/10/ICA-GHG-Measurement-202210-Final-Spreads (Accessed January 2025).

Gupta, U. Lee, H-H.S, Wei, G-Y., Brooks, D. and Carole-Jean Wu, C-J. (2020) 'Chasing Carbon: The Elusive Environmental Footprint of Computing'. Available at: http://arxiv.org/abs/2011.02839

Huang, Y.A., Weber, C.L. and Matthews, H.S. (2009). Carbon foot printing upstream supply chain for electronics manufacturing and computer services. *2009 IEEE International Symposium on Sustainable Systems and Technology* (pp. 1-6). e

Loewald, C. (2024) *Carbon taxation in South Africa and the risks of carbon border adjustment mechanisms*. Available at: http://www.resbank.co.za.

Martins, P., Pereira, N., Lima, A.C., Garcia, A., Mendes-Filipe, C., Policia, R., Correia, V. and Lanceros-Mendez, S. (2023). Advances in printing and electronics: From engagement to commitment. *Advanced Functional Materials*, *33*(16), p.2213744.

Montmasson-Clair, G. and Patel, M. (2024) *A policy primer for green industrialisation in South Africa*. Available at: www.tips.org.za (Accessed January 2025).

National Treasury. 2024. *Carbon Tax Discussion Paper: Phase Two of Carbon Tax*. Available at: www.treasury.gov.za (Accessed November 2024).

Parry, I. (2022) *Carbon Taxes or Emissions Trading Systems? Instrument Choice and Design*. International Monetary Fund.

Pelcat, M. (2023) *GHG emissions of semiconductor manufacturing in 2021*. Available at: www.statista.com.

Plastics SA (2024). Annual Review 2023/2024. Available at: https://www.plasticsinfo.co.za/wp-content/uploads/2024/11/20241021_PSA-Annual-Review_20232024_low-res.pdf (Accessed January 2025.

PWC (2023) *Future Proofing the Electronics Industry: The case for circular business models*. Available at: www.pwc.com (Accessed November 2024).

SARS (2024). *Carbon Tax*. South African Revenue Service. Available at: https://www.sars.gov.za /customs-and-excise/excise/environmental-levy-products/carbon-tax/ (Accessed January 2025).

Singh, N. and Ogunseitan, O.A. (2022) 'Disentangling the worldwide web of e-waste and climate change co-benefits'. *Circular Economy*, 1(2). Available at: doi:10.1016/j.cec.2022.100011.

Silva, C.A., Vilaça, R., Pereira, A. and Bessa, R.J., (2024). A review on the decarbonization of high-performance computing centers. *Renewable and Sustainable Energy Reviews*, *189*, p.114019.

TechCentral (2024). *Data centres are straining electricity grids worldwide*. Available at: https://techcentral.co.za/data-centres-straining-electricity-grids/239668/ (Accessed November 2024.

Uddin, M. Memon, J., Zaidi, M., Rozan, A., Alsaqour, R. and Rehman, A. (2015) 'Virtualised load management algorithm to reduce CO2 emissions in the data centre industry'. *International Journal of Global Warming*, 7(1), pp. 3–20. doi:10.1504/IJGW.2015.067413.

US EPA (2016). F-GHG Emissions Reduction Efforts: Flat Panel Display Supplier Profiles. United States Environmental Protection Agency Available at: https://19january2017snapshot.epa.gov/sites/ production/files/2016-09/documents/fpd_full_supplier_profiles_2016_508compliant.pdf (Accessed November 2024).

WasteAid (2024) Circular Opportunities for E-Waste repair and reuse of electrical and electronic equipment in South Africa. Available at: www.wasteaid.org (Accessed November 2024).

World Bank. (2024). Measuring the Emissions and Energy Footprint of the ICT Sector: Implications for Climate Action. Available at: http://documents.worldbank.org/curated/en/099121223165540890/ P17859712a98880541a4b71d57876048abb (Accessed November 2024).

World Bank and International Telecommunication Union. (2024). *Measuring the emissions and energy footprint of the ICT sector: Implications for climate action*. Available at https://documents1. worldbank.org/curated/en/099121223165540890/pdf/P17859712a98880541a4b71d57876048abb.p df (Accessed October 2024).

World Health Organization. (2024). Electronic waste (e-waste). Available at: https://www.who.int/ news-room/fact-sheets/detail/electronic-waste-%28e-waste%29? (Accessed November 2024).