TRADE & INDUSTRIAL POLICY STRATEGIES

INDUSTRY STUDY

TECHNOLOGICAL CHANGES IN THE 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 report aims to provide an overview of emerging processes and product technologies that are expected to have an impact on the electronics industry.

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ABBREVIATIONS

3D-IC	Three-dimensional integrated circuit
AI	Artificial Intelligence
CNC	Computer Numerical Control
CT	Computed Tomography
DSI	Department of Science and Innovation
ICT	Information and Communication Technology
IoT	Internet of Things
LEDS	Land Electronic Defence Systems
PCB	Printed Circuit Board
PDTS	Product Development Technology Station
R&D	Research and Development
RoHS	Restriction of Hazardous Substances
SMT	Surface Mounting technology
SPII	Support Programme for Industrial Innovation
THRIP	Technology and Human Resources for Industry Programme
THT	Through-hole technology
TIA	Technology Innovation Agency
TiTruss	Titanium Truss Cages
TSP	Technology Station Programme
TSV	Through Silicon Via
WFP	Wafer-Level Packaging
WLCSP	Wafer-level Chip Scale Packaging

INTRODUCTION

The electronics manufacturing industry is evolving rapidly, fuelled by technological advancements, shifting consumer demands, and an amplified emphasis on sustainability. Electrical devices have undergone several cycles of change in the same way the miniaturisation of devices (i.e., size of components and printed circuit boards (PCBs) is driven by technological advancements. Furthermore, it is essential to incorporate cutting-edge technologies into the production process as it leads to increased productivity, improved product quality, streamlined supporting processes, and greater adaptability within manufacturing systems (Bagnoli, et al., 2022; Javaid et al., 2022).

At each stage of the electronics value chain, advancements in technology enhance efficiency. These include innovations such as additive manufacturing, advanced packaging, the Internet of Things (IoT), artificial intelligence (AI), and machine learning. In addition to technological progress, concern is growing about the environmental impact of electronic products and their fabrication. As a result, manufacturers are adopting eco-friendly practices, such as using sustainable materials in their production processes. Furthermore, producers are shifting away from silicon-based electronics, which can harm the environment due to waste generated during processing and the toxicity of the materials used in manufacturing. Instead, they are now embracing printed electronics.

The electronics industry encompasses a wide range of manufacturing processes and products. A critical component of the industry's value chain is microchips, which are essential for modern devices including smartphones, computers, medical scanners, and cars. This report focuses on the manufacturing side of the industry, covering the production of electronic components (such as valves and tubes), office machinery (i.e., computers), telecommunications equipment, medical instruments, and precision instruments (including information and communication technology (ICT)). In addition, this report discusses the application of electronics across various industrial sectors.

This report aims to provide an overview of emerging processes and product technologies that are expected to have an impact on the electronics industry. The section on international technology trends discusses technological advancements in the use of electronics across various sectors. The second section describes these technologies based on their functions and discusses their connection to environmental sustainability. The third section focuses on technological changes in South Africa's electronics industry, highlighting the manufacturing landscape and the institutional support for innovations from both private and public entities, including government incentives. The report concludes in the final section.

1. INTERNATIONAL TECHNOLOGY TRENDS IN THE ELECTRONICS INDUSTRY

The electronics manufacturing industry continues to be influenced by emerging technologies, such as IoT and additive manufacturing. These technologies are significant in improving the production processes for electronic products and enhancing efficiency. Furthermore, advanced packaging technologies like 2.5D and 3D stacking, as well as three-dimensional integrated circuits (3D ICs), have enabled the integration of multiple semiconductor chips into a single package, thereby enhancing performance. Moreover, noticeable technology trends are seen in the electronics assembly (such as PCBs), leading to transformative changes in the industry.

1.1. The Internet of Things (IoT)

IoT is transforming production processes across industries. IoT is described as physical objects like devices, vehicles, buildings, and equipment that are interconnected through micro-electronic sensors, software, and processors, enabling them to communicate via the internet (TIPS, 2022). This connectivity allows objects to gather and share data, as well as facilitating cloud-based data processing, analysis, and communication between different devices. By integrating IoT into the electronics industry, companies can significantly enhance their operational and management practices by reimagining and optimising their core processes.

According to Sayyad Liyakat and Sayyad Liyakat (2023), IoT has transformed electronic manufacturing businesses by empowering machines to autonomously store, process, and digitally connect data. Other advantages of adopting IoT and using IoT devices include reducing costs and risks, increasing output, expediting time to market, harmonising processes, and improving connections through predictive optimisation (Sayyad Liyakat and Sayyad Liyakat, 2023). Consequently, integrating smart IoT-based equipment potentially advances firms in the industry. In various manufacturing industries, IoT is changing traditional factories into smart factories, with IoT equipment such as sensors, networked devices, and software monitoring production processes (Soori, Arezoo, and Dastres, 2023). Other benefits of adopting IoT include quality control, predictive maintenance, inventory control, and asset tracking (Sayyad Liyakat and Sayyad Liyakat, 2023; Soori et al., 2023).Furthermore, the study by Wijaya et al. (2024) concluded that edge cloud-IoT architecture (IoT technology) delivers insights and influences decisions in a way that detects problems early. Therefore, IoT technologies are used by manufacturing companies to influence decision-making capabilities.

1.2. Additive manufacturing: Printed electronics

The integration of 3D printing in additive manufacturing is transforming the production of electronic components, bringing about constructive changes in the global industry. Several 3D printing technologies such as conductive inks, displays, and sensors are used in the production of electronics and the fabrication of electronic components. Moreover, printing technologies used in the fabrication of electronics include contact printing technologies (i.e., screen printing, gravure printing) and non-contact techniques including inkjet printing and spray printing (Martins et al., 2023). Furthermore, using additive manufacturing to print electronic materials benefits firms in the industry through cost-effectiveness, and low material waste, and firms can print a functional structure (Martins et al., 2023).

1.3. Advanced packaging

The demand for electronic products over the years and advancements in technology caused firms to rethink the packaging of electronic products such as circuit packing by reducing size, being cost-effective, and increasing its performance. Thus, some advantages of advanced packing include a reduction in costs, improved processes, and design efficiency (Chen et al., 2023). Technology such as wafer-level packaging technology are the main technology platforms for advanced packing including Flip Chip, Fan-out, 3D IC, wafer-level chip scale packaging (WLCSP) (Chen et al., 2023). Since 2000, advanced packaging technologies such as wafer-level packaging, 2.5D stacking, and 3D stacking have become commercially available (McKinsey & Company, 2023). After 2010, developments in stacked wafer-level chip-scale packaging (WLCSP) in chip manufacturing gained prominence. WLCSP involves making electrical connections and moulding at the wafer level, followed by dicing the chips using a laser. This process includes two key techniques in the chip industry: 2.5D stacking and 3D stacking (McKinsey & Company, 2023). 2.5D stacking is an advanced packaging technology used in integrated circuits that allows multiple semiconductor dies to be placed side by side on a silicon interposer. In contrast, advanced 3D stacking packaging techniques involve arranging multiple chips face down on top of one another, with or without the use of an interposer.

1.4. Technologies in electronics assembly

Printed circuit boards play a vital role in enabling the functionality of most electronic devices. A PCB functions as a crucial intermediary for linking electronic components within an electrical circuit. PCB production and assembly processes can be automated, with configurations that vary from single-sided to double-sided and multi-layer designs. Moreover, component mounting on PCBs involves technologies prevailing in the PCB industry, such as Surface Mounting Technology (SMT), Through-hole Technology (THT), and Hybrid Assembly.

SMT reformed electronic assembly as it changed the method of integrating electronic components into the printed circuit board. By attaching electronic components directly to the surface of a printed circuit board, this technique eliminates the need for holes and wire leads. Reflow soldering or wave soldering procedures are then used to ensure reliable electrical and mechanical connections for soldering surface-mount technology components onto the board (Gowda and Veena, 2024; Ravindra, 2024). Furthermore, the processes involved in SMT include component replacement, solder paste application, reflow soldering, and inspection and testing (Gowda and Veena, 2024). In addition, Ravindra (2024) finds that using SMT is essential in the successful completion of PCB designs and assembly of electronic devices. Thus, SMT replaced the through-hole components with lightweight, more compact, and effective alternatives transformed the electronic assembly process (Gowda and Veena, 2024).

Further, by using this technique, SMT benefits manufacturers as it makes higher component densities on PCBs possible, thus reducing production costs and enhancing manufacturing efficiency (Gowda and Veena, 2024). While Ravindra (2024), argues that surface mounting is favourable for smaller components such as Integrated Circuit chips , resistors, transistors, and capacitors. In addition, SMT technology is widely used in various industries due to its versatility, efficiency, and ability to accommodate miniaturised electronic components. This has stimulated innovation in diverse sectors such as automotive, consumer electronics, and telecommunications.

2. EMERGING TECHNOLOGIES AND ENVIRONMENTAL SUSTAINABILITY

This section highlights the latest technologies implemented in the global electronics industry and demonstrates their environmental sustainability capabilities with practical examples of how the technology is helping to mitigate environmental challenges. For instance, printed electronics are being favoured over traditional silicon-based components in the assembly of electronic parts to reduce the environmental impact caused during production. The adoption of IoT technologies can also help companies minimise the environmental repercussions of electronic waste, thus promoting sustainable practices. Moreover, energy efficiency is a key aspect of sustainability, and the small footprint and high efficiency of surface-mount technology components are instrumental in advancing reliable and cost-effective renewable energy solutions.

2.1. IoT technology and environmental sustainability

IoT technologies play a crucial role in elevating manufacturing processes by enabling efficient data management, strengthening connectivity, and offering real-time production control and monitoring. This results in a reduction of errors. For example, IoT sensors can collect and communicate valuable information about machinery, equipment, energy usage, temperature, and vibration during the chip formation process, leading to enhanced operational efficiency (Soori et al., 2023). Furthermore, manufacturers can leverage IoT sensors to meet and exceed customer expectations by continuously monitoring and maintaining product quality(Sayyad Liyakat and Sayyad Liyakat, 2023).

The escalating demand for eco-friendly products and responsible manufacturing practices has generated a heightened global consumer consciousness about environmental issues. Consequently, manufacturers, including those in the electronics industry, are being prompted to embrace sustainable measures such as reducing waste, incorporating sustainable materials, and optimising energy efficiency in their production operations. According Soori et al. (2023), implementing IoT sensors allows manufacturers to monitor and optimise energy use during part of manufacturing, resulting in significant energy savings and promoting sustainability in production. Other ways to provide sustainable production processes are IoT technologies that can help smart factories integrate renewable energy sources (i.e., solar or wind power), smart lighting, and energy storage (Soori, et al., 2023).

In addition, manufacturers are also implementing lean manufacturing techniques in their production to reduce waste. Farjana et al. (2023) proposes an integration of IoT devices and sensors to manage and monitor the collection and disposal of e-waste, a process called a smart e-waste management system. In addition, IoT devices such as sensors can be integrated into production processes to monitor energy usage and material waste, for example. Therefore, using IoT technologies enables firms to reduce the environmental impact of electronic waste, reduce waste in the production process, and promote sustainable manufacturing.

2.2. Printed electronics and environmental sustainability

Non-contact printing techniques in the electronics industry, particularly through methods like inkjet printing and other additive processes, are increasingly recognised for their environmental benefits compared to traditional manufacturing methods. Printing technology is classified according to its physical contact with a substrate or not. There are two types of printing techniques: contact printing and non-contact techniques (Martins et al., 2023; Wu, 2022). Non-contact techniques expel the materials by a nozzle without physically contacting the substrate (Martins et al., 2023; Wu, 2022).

Global awareness of environmental sustainability in the electronics industry has compelled manufacturers to explore alternatives to traditional silicon-based electronics, leading to the development of printed electronics. According to Martins et al. (2023), silicon-based devices contribute to environmental problems, including waste generated during processing and the toxicity of the materials used in manufacturing. In contrast, printed electronics technology is environmentally friendly, as it reduces energy consumption, thanks to processes that can be performed at room temperature, and minimises waste (Wu, 2022). Additionally, the materials used in printed electronics play a significant role in sustainability; therefore, using organic printable materials with good degradability and suitable substrates is the best option for addressing environmental concerns.

2.3. Advanced packaging and environmental sustainability

Advanced 3D stacking packaging techniques involve the arrangement of multiple chips stacked face down on top of one another, with or without the use of an interposer. One key technology within this realm is Through Silicon Via (TSV), which plays a crucial role in semiconductor manufacturing and the 3D integration of chips. By enabling the vertical stacking of chips, TSVs reduce the overall volume and weight of semiconductor packages. This reduction can lead to lower material consumption during manufacturing and less waste throughout the product lifecycle. Moreover, TSVs contribute to energy efficiency. For example, using TSVs as interconnect technology for 3D ICs results in lower power consumption, higher density, and improved electrical performance (Chen et al., 2023). Thus, TSV interconnect technology is more energy efficient.

In addition to TSVs, other advanced packaging techniques, such as wafer-level packaging (WLP), also help minimise waste. WLP reduces the amount of material needed for packaging by utilising smaller chip sizes. This approach decreases waste during production and leads to lower power consumption during both manufacturing and operation. Furthermore, System-in-Package technologies offer significant advantages to firms in the industry due to their small size, rapid development time, lower power consumption, and high adaptability (Wang et al., 2023).

2.4. Advancements in electronic assembly and environmental sustainability

Surface Mount Technology employs environmentally friendly practices through advanced innovations that promote sustainability within the electronics manufacturing industry, thereby reducing its ecological footprint. SMT generates minimal waste during the manufacturing process. By precisely placing components on PCBs, SMT techniques create less excess material compared to traditional manufacturing methods, which facilitates easier recycling and efficient waste disposal. Additionally, SMT uses eco-friendly materials, such as lead-free solder, unlike traditional soldering processes that utilise lead-based solders, which can harm the environment. In addition, nitrogen soldering techniques are also critical to sustainability, nitrogen is preferred due to its inertness, as well as its low oxide properties (vs air and the oxygen it contains).

3. TECHNOLOGICAL TRENDS AND INNOVATIONS IN SOUTH AFRICA

In the domestic electronics manufacturing sector, companies are investing in advanced equipment and technology to meet client needs. For instance, in the electronic valves and tubes manufacturing subsector, SAAB Grintek Defence produces electronic equipment for the aviation and marine defence industries. The company supports the South African National Defence Force by providing sophisticated electronic warfare systems, including the Land Electronic Defence Systems Mk 4. SAAB Grintek is developing the Land Electronic Defence System Mk 4, a laser warning system, with trials having started last year in 2023. Additionally, the company has launched its new third-generation U/SME-400 naval radar warning and electronic support measures system, which stands out for its transition to a fully digital design featuring a wideband receiver (Defenceweb, 2024).

Technological advancements, particularly in advanced manufacturing, have significantly transformed the assembly of electronic components, especially PCBs[1]. For instance, Master Circuits, a PCB manufacturer, has adopted advanced manufacturing techniques by introducing immersion silver as a Restriction of Hazardous Substances (RoHS)-compliant final finish for PCBs (Master Circuits, n.d.). As noted in section 1.4 of this report, advanced assembly methods, such as SMT and THT, are commonly used to mount components on PCBs. As a result, local electronic manufacturers, including PCB assemblers, have embraced these modern technologies, which facilitate both lead and lead-free soldering processes. Microtronix Manufacturing is a prominent player in the SMT industry, specialising in electronic PCB assembly, and has a component placement capacity exceeding eight million units per day (Microtronix, no date). Similarly, ExpandoWorks, another SMT manufacturer, has invested in advanced pick-and-place machines capable of placing over 1.5 million components per hour (ExpandoWorks, 2023). Lastly, Procircuit, a PCB assembly company, utilises automated production methods for soldering THT components, employing high-tech solder paste jet printers, pick-and-place machines, and reflow ovens to enhance the efficiency of PCB assembly.

Moreover, in the ICT market, which encompasses software development, large firms have increasingly adopted AI for their operations. For example, 4Sight Holdings, a local IT company, has implemented

[1] Note: PCBs are used as production components in various industries, including healthcare, consumer electronics (e.g., smartphones), automotive electronics, and industrial applications such as automation equipment, sensors, and control systems.

AI technologies to improve its products and services. This includes the use of predictive analytics, enhanced computing power, and personalised customer experiences enabled by AI (Who Owns Whom, 2024). Most recently, in 2024, 4Sight Holdings released its Annual Integrated Report using advanced artificial intelligence technology (ITWeb, 2024).

The integration of electronics into innovative healthcare solutions has spurred advancements in the medical devices sector, as manufacturers adopt automated cutting-edge practices. For example, the Product Development Technology Station (PDTS) at the Central University of Technology utilises advanced Computer Numerical Control (CNC)[2] machines, including 5-axis milling machines, for post-processing additive-manufactured components. This technology is essential for achieving high-precision finishes on medical devices, such as dental implants and surgical guides. In addition, PDTS employs other CNC machines, including Doosan 3-axis CNC milling machines, which are used to manufacture tools and dies during the development and production of medical devices.

CNC technologies also play a significant role in the electronics industry, particularly in the manufacturing of printed circuit boards, the assembly of electronic devices, and the production of semiconductor components. Medical manufacturers are further innovating by embracing emerging technologies, such as additive manufacturing, and by introducing new products. Examples are provided below.

- LRS implants provide custom implant solutions (CiS) in collaboration with surgeons, where they manufacture custom implant cases where it would be otherwise impossible to with off-the-shelf implants (LRS Implants, n.d.). According to the company website, implants are manufactured using conventional milling and turning, or 3D printed from titanium (Ti6AI4V). In addition, the company also designs and manufactures custom titanium truss cages (TiTruss) for large segmental long bone defects treatment. The process followed is that TiTruss cages are designed using Computed Tomography (CT) data from each patient, and then cages are 3D printed in Ti6AI4V. In a recent case, the company used a patient's CT data to design a 3D-printed implant with a central peg and trabecular mesh structure to support osseointegration (LRS Implant, 2024).

- M and L Medical Suppliers CC, a subsidiary of Viva Medical, produced Africa's first local needle-free connector. The company developed Vivasite needleless IV injection sites, which integrated appropriate designs that complied with international standards cheaper to manufacture. Furthermore, applying the localisation strategy (i.e., the company aims to localise the production of needleless IV injection sites) therefore reduces import costs. The company exports to other African countries as well as to the Asian market.

- Southern Implants, a manufacturer of dental implants, has produced multiple innovations in the manufacture of its product. Their implants are made from pure grade IV titanium (ASTM F67), as well as introduced new products, including the Inverta Implants, and Provata & Zygex implants (Southern Implants, n.d.)

[2] Note: CNC is a pivotal manufacturing technology that automates the control of machine tools through computer programming. This automation enhances precision, efficiency, and flexibility in various manufacturing processes, particularly in the production of electronic components.

3.1. Institutional support

As a means of encouraging innovation in the manufacturing sector, government institutions offer a variety of support instruments, including financial assistance for innovation.

The Department of Trade, Industry, and Competition (the dtic) primarily provides industry support through programmes such as the Support Programme for Industrial Innovation (SPII) and the Technology and Human Resources for Industry Programme (THRIP).

Financial aid is available from the Technology Innovation Agency (TIA). A tax refund through the Department of Science and Innovation (DSI) is also available to enterprises performing technological research and development (R&D) in South Africa. See Table 1 for more information on institutional support.

Table 1: Institutional support provided for innovations in the electronics industry

INSTITUTION	SUPPORT PROVIDED
The Centre for Rapid Prototyping and Manufacturing (CRPM) at Central University of Technology	The centre specialises in additive manufacturing or 3D printing. Established in 1997, it functions as a centre that includes commercial work and research using rapid prototyping, medical product development technologies, rapid manufacturing, and rapid tooling.
The Product Development Technology Station (PDTS) at Central University of Technology	The PDTS was launched in 2000 at the Central University of Technology, Free State. PDTS was funded by the TIA through the Technology Station Programme (TSP). TSP's primary objective is to increase innovative activities among targeted sectors, specifically SMEs, through Higher Education Institutions and, at the same time, strengthen and upgrade institutional capacity and infrastructure to service the needs of these sectors. * PDTS also specialises in printed circuit board and firmware development.
Technology Innovation Agency (TIA)	TIA provides funding instruments for technology innovations across sectors of the economy. This includes funding in advanced manufacturing, ICT, agriculture, health, and energy.
	a) Advanced manufacturing: TIA funds focus areas include advanced electronics, advanced materials, and converging technologies.
	b) ICT sector: TIA supports the development and exploitation of ICT-driven innovations. Further, the entity supports the development of technologies and grassroots innovators. Its focus areas include artificial intelligence and advanced communication systems.
Department of Science and Innovation (DSI): R&D tax incentive	The R&D tax incentive provided by the DSI is an incentive whereby companies conducting scientific and or technological R&D in South Africa can deduct 150% of their R&D expenditure from their taxable income.
Department of Trade, Industry and Competition (dtic)	
Support Programme for Industrial Innovation (SPII)	SPII provides financial assistance for the development of innovative products and or processes in a way that promotes technology development in South Africa's industries.

Technology and Human Resources for Industry Programme (THRIP)	The grant aims to promote collaborative partnerships between government, industry, academia, and scientific researchers. This collaboration will focus on applied research and development projects in science, engineering, and technology. The projects will operate on a cost-sharing basis to produce highly skilled human resources and technology solutions, as well as improve industry and enterprise competitiveness.
SEDA Technology Programme Incubation Programme	The programme offers support incentives for technology and market validation, process/product development, small-scale manufacturing, as well as market entry and development.
Khoebo Innovation Promotion Programme	The initiative supports innovations developed locally across industries, such as novel products, processes, and technology.

Source: Departments, entities, and higher education institutions websites.

4. CONCLUSION

The electronics industry plays an essential role in the economy, producing vital electronic components that serve various sectors, including automotive, healthcare, telecommunications, defence, and aerospace. The continuous advancements in technology significantly shape this industry, driven by the growing demand for innovative electronic products in consumer electronics and automotive applications, alongside the ongoing trend of miniaturising electronic devices.

Embracing modern technologies such as the Internet of Things, additive manufacturing (3D printing), and advanced packaging presents an opportunity for companies to enhance their production processes. These integrations can lead to improved productivity, optimised quality control, and reduced production costs. Furthermore, incorporating emerging technologies in electronics assembly can greatly boost efficiency on assembly lines. Adopting sustainable manufacturing practices, such as printed electronics and environmentally friendly materials, has the potential to transform the electronics industry by minimising waste and power consumption. This shift not only lowers carbon emissions but also advances environmental sustainability. These trends are being observed globally and are elaborated on in Section 1 of this report, which explores the impact of electronics in various industries. Domestically, companies should prioritise the adoption of these modern technologies, considering the significant advantages observed from their implementation in production and processes, as evidenced by global trends.

Local electronic manufacturers have begun adopting emerging technologies, such as Surface Mount Technology in electronic component assembly, while tech companies have embraced the Internet of Things. Innovations from medical device manufacturers and electronic component producers indicate that local companies are indeed innovating, although this appears to be on a small scale. Growing consumer concern for environmental sustainability has prompted businesses to change their production processes, beginning from the initial design phase and continuing through the assembly of value chains. In the electronics industry, the environmental impact of traditional silicon-based components has led to a global shift towards printed electronics, which are recognised for their environmentally friendly manufacturing processes, waste reduction, and energy conservation. This transition presents local manufacturers with the opportunity to adopt eco-friendly production methods that utilise organic and reusable materials, facilitating progress toward environmental sustainability.

In terms of policy, there are valuable government resources available, including financial support, industry assistance, and innovation incentives. However, to fully capitalise on these resources, it is essential to prioritise and enhance skills development within the sector. The growing demand for AI presents a significant opportunity for workforce development. In addition, implementing a sector master plan for the electronics Industry can effectively guide and stimulate its growth and development, thereby creating a robust and innovative sector.

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