

# Towards Sustainable Digital Transformation: 5G/6G Adoption and E-Waste Management in the Kingdom of Saudi Arabia

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**Abstract—** The rapid evolution of the network generation of mobile technologies alters the economic system of the world, redefines the industries, and accelerates the digital transformation. The adoption of technologies in the Kingdom of Saudi Arabia (KSA) is at the center of the objectives of Vision 2030, which is to diversify the economy, reduce the effect of oil revenues, and turn the country into a digital hub. However, the similar issue of electronic waste (e-waste), which threatens environmental sustainability and human health, is also an aspect of technological progress. The two-fold agenda of the paper regarding the improved uptake of 5G and concurrently e-waste management in Saudi Arabia is a solution to sustainable economic development. The paper determines the opportunities and threats of the next generation (6G) of telecommunication and e-waste dynamics by integrating the services of secondary data analysis, international benchmarking, and policy review. The results reveal that Saudi Arabia has significantly advanced in 5G deployment and digital infrastructure, and the amount of e-waste is growing annually; the policy ought to address the issue. The paper suggests a combined framework that connects the use of technology to the concept of the circular economy and makes suggestions, including incentive recycling schemes, government-corporate collaboration, and investment in green telecommunication infrastructure. The study is an appendix to the subject of sustainable digital transformation and presents policy implications, which might be applied to new economies that want to modernize their economy, and yet are concerned about the environment.

**Keywords-** Electronic waste, Saudi Arabia, sustainable development, 5G, 6G, Vision 2030, digital transformation, circular economy

## I. INTRODUCTION

The digital revolution is transforming the global economy, and the fifth generation (5G) and the new sixth-generation (6G) telecommunications networks are at the center of this revolution. These technologies have the potential to provide

new speeds, extremely low latency, connectivity of devices on a massive scale, and support high-level applications, such as smart cities, autonomous vehicles, industrial automation, and immersive digital experiences [1]. For the Kingdom of Saudi Arabia (KSA), the deployment of 5G and preparation for 6G adoption align directly with the strategic objectives of Vision 2030, a comprehensive national plan that seeks to diversify the economy beyond oil dependence, enhance technological innovation, and foster sustainable development [2]. By investing in digital infrastructure, the Kingdom aspires to become a regional leader in information and communications technology (ICT), attract foreign investment, and create new avenues for economic growth.

However, technological advancement carries an ecological cost. Electronic waste (e-waste) is being produced at an alarming rate across the globe as networks develop and devices become obsolete at an extremely high rate. The Global E-waste Monitor [3] estimates that the world generated 53.6 million metric tons [4] of e-waste in 2019 [5], and the figure is expected to rise to 74 million metric tons by 2030. The amount of e-waste in the Middle East is increasing at a rate of about 7-8 percent per year [3]. In the case of Saudi Arabia, this trend presents its own challenges, as the rate of digital adoption is increasing, and the systems of e-waste management remain in a developmental stage, which endangers the health of the environment and the sustainability of economic benefits. The misuse of electronic equipment causes toxic chemical spillage [6], air and soil pollution, and adverse health effects on the population [5].

The convergence of 5G implementation and e-waste management poses fundamental questions regarding how the Kingdom can continue to achieve technological advancement without compromising its environmental pledges. The Vision 2030 demands explicitly the balancing of growth and sustainability, which is reflected in its objectives to enhance waste management, advance the principles of a circular

economy, and protect natural resources [2]. In addition, international conventions like the Basel Convention highlight the role of states in reducing the production of hazardous waste and encouraging recycling that is environmentally friendly.

The paper will deal with the two-fold problem of promoting the use of 5G/6G and responsible e-waste management in Saudi Arabia. The research problem is as follows: How can Saudi Arabia combine the adoption of next-generation telecommunications with the effective management of e-waste to attain sustainable economic growth in accordance with the Vision 2030?

To address this problem, the study pursues three objectives:

1. To examine the current state of 5G adoption and its economic implications in Saudi Arabia.
2. To analyze trends and challenges in e-waste generation and management within the Kingdom.
3. To propose integrated strategies that link digital transformation with environmental sustainability in network generations.

By situating the Saudi experience within global benchmarks and theoretical frameworks of sustainable development, the paper seeks to contribute both practically and academically. On the practical side, it offers policy recommendations for government and industry stakeholders to build a resilient, green digital economy. On the academic side, it expands the discourse on the intersection between ICT growth and environmental stewardship in emerging economies.

In doing so, the paper argues that sustainable digital transformation is not merely a technological or economic challenge but a holistic societal endeavor. Balancing rapid 5G deployment with effective e-waste management represents not only a test of Saudi Arabia's policy agility but also a critical step in fulfilling the sustainable development pillars of Vision 2030.

## II. LITERATURE REVIEW

### A. *Global Perspectives on 5G and 6G Adoption*

Fifth generation (5G) networks represent a change in basic assumptions in mobile communications, offering speeds up to 100 times faster than 4G, ultra-low latency, and the capacity to connect billions of devices simultaneously [7]. Globally, 5G is enabling smart cities, autonomous vehicles, telemedicine, and industrial automation [1]. As of 2022, more than 200 mobile operators across 80 countries had launched 5G services, with subscriber numbers projected to surpass 1.7 billion by 2025 [8].

The emergence of sixth-generation (6G) technology, expected by 2030, builds on this foundation. It promises terahertz frequencies, AI-driven networks, holographic communications, and quantum-level security [9]. Early research suggests 6G will expand the socio-economic impact of ICT by enabling hyperconnected societies and bridging physical and digital realities [10]. However, adoption challenges remain, including high infrastructure costs, spectrum allocation, and the risk of exacerbating digital divides [12].

### B. *Digital Transformation and Economic Growth*

Digital transformation is widely recognized as a catalyst for economic diversification and productivity growth. The World Bank emphasizes that broadband infrastructure, particularly advanced mobile networks, correlates strongly with GDP growth in both developed and developing countries [13]. For example, a 10% increase in mobile broadband penetration can raise GDP by 1–2% [14].

In the Gulf Cooperation Council (GCC) region, 5G deployment is positioned as a key driver of smart cities, e-government services, and fintech ecosystems [15]. Saudi Arabia, in particular, has invested heavily in all cities, which rely on seamless 5G connectivity to enable AI-driven urban living. Nevertheless, studies caution that digital growth must be balanced with sustainable resource use, as energy consumption from ICT infrastructure can significantly contribute to carbon emissions [16].

### C. *The Challenge of E-Waste in Network Generations*

One of the rapidly increasing waste streams in the world is electronic waste. According to the Global E-waste Monitor 2020, the world produced 53.6 million metric tons [17] of e-waste in 2019 [5], of which just 17.4 percent was officially recorded, collected, and recycled [3]. E-waste not only includes precious metals like gold, copper, and rare earth metals, but also includes some dangerous substances like lead, mercury, and brominated flame retardants.

The ecological and health hazards of inaccurate e-waste disposal are correctly recorded. Research associates informal recycling and landfilling with respiratory diseases, soil pollution, and water pollution in areas where the regulations are poorly implemented [6]. The developed economies replied by implementing circular economy principles that highlight extended producer responsibility (EPR), product take-back initiatives, and eco-design [18].

In the Middle East, e-waste management remains underdeveloped. The region recycles less than 5% of its e-waste, relying heavily on landfilling and informal disposal methods [19]. Electronic waste (e-waste) represents one of the world's fastest-growing waste streams. Within the Arab

region, Saudi Arabia ranks among the largest generators, producing an estimated 617–620 million kilograms of e-waste annually. Alarming, around 85% of this waste is disposed of in landfills, resulting in significant resource losses and posing serious environmental risks [20].

Most of the existing body of research on electronic waste has primarily focused on general categories of electronic products, such as household appliances, computers, and mobile devices, with limited attention given to the emerging e-waste challenges associated with 5G and future 6G technologies.

While the Global E-Waste Monitor [4] and related literature provide valuable insights into global waste generation, collection, and recycling rates, they tend to address e-waste as a broad category [17]). The specific implications of next-generation network infrastructure, including 5G base stations, antennas, routers, and Internet-of-Things (IoT) devices, remain underexplored. These systems involve highly specialized materials, such as rare earth elements, advanced semiconductors, and high-frequency components, which present unique recycling and recovery challenges not adequately covered by current research or policy frameworks.

Moreover, the transition from 4G to 5G and soon to 6G has triggered massive hardware replacement cycles and accelerated device obsolescence. Network densification (i.e., the deployment of a larger number of smaller, high-frequency base stations) amplifies the potential e-waste burden. However, empirical studies and policy analyses specific to 5G/6G infrastructure e-waste remain scarce, particularly in developing and emerging economies.

#### *D. Linking ICT Growth and Sustainability*

The intersection of ICT adoption and sustainability has gained attention in academic and policy circles. Green ICT frameworks highlight the need to reduce the carbon footprint of digital infrastructure while ensuring proper end-of-life management of electronic devices [21]. Researchers argue that technological innovation can simultaneously enable environmental sustainability, for example, smart grids and IoT-enabled waste management, while also generating new risks through increased energy use and waste [2].

Saudi Arabia's Vision 2030 emphasizes the integration of digital transformation with environmental stewardship. The Kingdom has pledged to increase renewable energy use, implement waste management reforms, and strengthen the circular economy [22]. However, scholarly research evaluating the synergies between telecom expansion and sustainable waste practices in KSA remains limited, representing a significant gap that this paper seeks to address.

#### *E. Identified Research Gaps*

While the literature underscores the economic potential of 5G/6G and the environmental risks of e-waste, few studies address both dimensions together, particularly in the Saudi context. Specific gaps include:

- Limited empirical analysis of how Saudi Arabia's 5G/6G rollout aligns with e-waste policy.
- Insufficient exploration of circular economy models tailored to Gulf states.
- A lack of integrated frameworks linking ICT adoption, sustainability, and economic diversification.

This paper addresses these gaps by developing a holistic analysis that situates Saudi Arabia's digital transformation within its sustainability agenda, offering insights for policymakers and scholars alike.

### III. CONCEPTUAL FRAMEWORK

The adoption of advanced telecommunications in Saudi Arabia can be understood through three complementary perspectives. The Technology Acceptance Model (TAM) [23] and the Diffusion of Innovation Theory [24] explain how modern technologies are embraced. In this context, the expansion of network generations depends not only on technical capacity but also on citizens' and industries' perceptions of usefulness, ease of use, and the broader influence of innovators and early adopters. Government initiatives, subsidies, and awareness campaigns play a decisive role in accelerating diffusion across key sectors such as healthcare, finance, and education.

At the same time, the Circular Economy (CE) framework [25] provides a foundation for addressing e-waste challenges. Instead of the linear take-make-dispose model, CE focuses on the reduction of consumption, the reuse of products to increase their life, and the recycling of valuable materials. Implementing all these principles into the digital ecosystem, Saudi Arabia will have an opportunity to ensure that the beneficial results of the fast development of connectivity will not be neutralized by the adverse impact on the environment.

Finally, the Green ICT approach sheds light on the enabling and problematic nature of information technologies [21]. ICT can cause sustainability through smart grids, computerized monitoring, and energy-saving applications, but it also causes energy usage and wastefulness. The risks are manageable with the aid of the lifecycle approach that consists of production, use, and end-of-life phases.

The paper is going to integrate such perceptions to formulate an integrated conceptual model of Saudi Arabia (see Figure 1).

Technology adoption models explain the diffusion process, the ideals of the circular economy explain the sustainability of using resources, and Green ICT is the plan that helps to align the progress of telecom with the national sustainability goals. They are all oriented to sustainable economic development based on innovation and environmental and social protection.

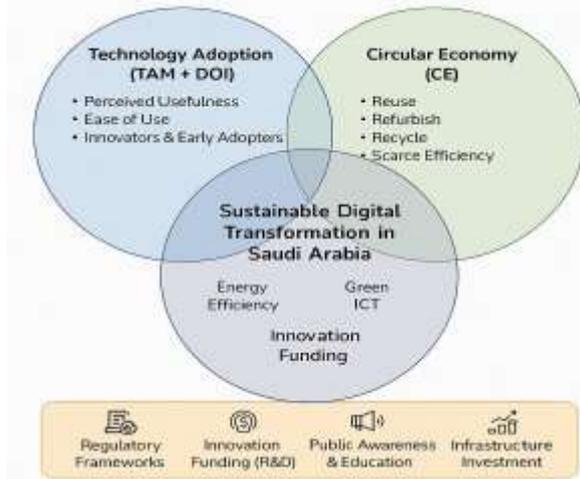


Figure 1. Integrated Framework for Sustainable Digital Transformation in Saudi Arabia's Telecommunications Sector

#### IV. METHODOLOGY

The research design incorporates a secondary quantitative analysis and a qualitative review of the policy. Such an approach will allow both exploring the dual agenda of network adoption and e-waste management in Saudi Arabia in detail, both in the context of measurable variables, such as network rollout, ICT penetration, and e-waste volumes, and more broadly, in the context of more general policy frameworks related to the Vision 2030 and the Saudi Green Initiative.

The study engages plausible national and global sources of information. Reportedly, on the domestic level, the information on the digital transformation, the work of the infrastructure development, and the environmental governance are to be found in the reports of the Ministry of Communications and Information technology (MCIT), the Communications, Space and Technology Commission (CST), the General Authority of Statistics (GaStat), and the National Center of Waste Management. At the international level, the acts of comparison and global perspective on the development of ICT and its sustainability are presented by organizations such as the International Telecommunication Union (ITU), GSMA Intelligence, the World Bank, OECD, and the Global E-waste Monitor.

They were collected based on the official databases, industry reports, and policy documents spanning the period between

2016 and 2024. It was normalized and standardized to allow comparison, and given an analysis based on trend to project adoption and waste ingrowth and benchmarking, which was in comparison to the steps made by Saudi Arabia compared with the leaders of the world, like South Korea, Japan, and the EU. Correlations between broadband penetration, GDP growth, and e-waste generation were found using SWOT analysis was used to highlight opportunities and risks in the Saudi context.

The study acknowledges certain limitations. Due to the lack of disaggregated e-waste data in Saudi Arabia, some projections rely on regional averages. Moreover, forecasts regarding 6G development are speculative, as the technology is still in the research stage. The study relies on secondary data from reputable sources, including the United Nations Agency for Information and Communication Technologies, the Organisation for Economic Co-operation and Development, the United Nations Institute for Training and Research, and the European Commission, the Ministry of Communications and Information Technology in Saudi Arabia. Data selection and acknowledgment of limitations were made transparent to reduce potential bias. The recommendations are framed within the context of Saudi Arabia's Vision 2030 and aligned with global sustainability standards.

#### V. RESULTS AND FINDINGS

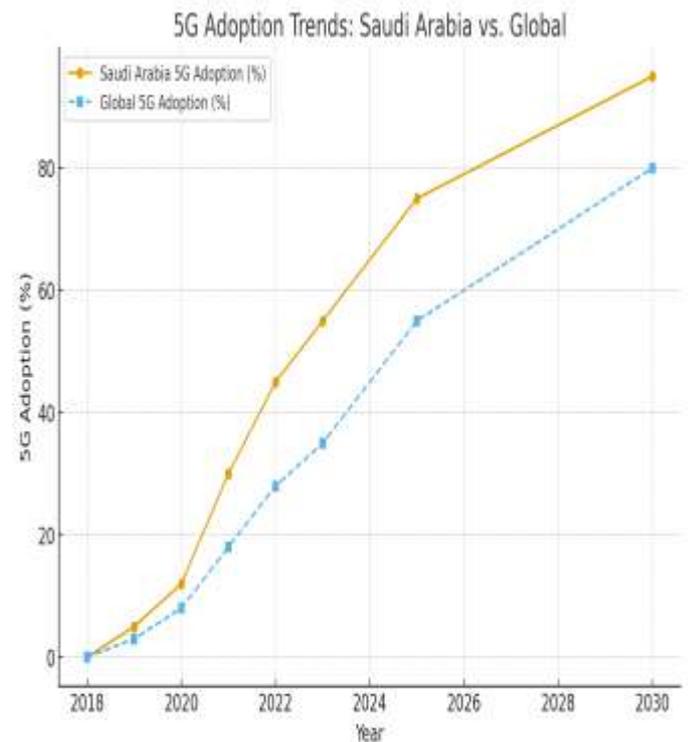


Figure 1. 5G Adoption Trends: Saudi Arabia vs. Global (2018–2030)

The country has also made a strong step concerning 5G adoption, with over 70 percent of the urban population

covered by 2022, which is a top ten country in terms of coverage [26]. Trend analysis indicates that the adoption may be as high as 95 percent in 2030, by far surpassing the global average of 80 percent (see Figure 1). This development indicates government investment, massive investment by telecom companies including STC, Zain, and Mobily, and inclusion of future connectivity in national mega-projects. In comparison, though, numerous areas such as portions of Europe and Africa remain underdeveloped because

of infrastructure and regulatory obstacles.

TABLE 1. COMPARATIVE INDICATORS: SAUDI ARABIA VS. SOUTH KOREA, JAPAN, AND THE EU

Indicator (2016–2024)	Saudi Arabia	South Korea	Japan	European Union (avg.)	Source
5G Readiness / Deployment Year	2020 (commercial launch by STC, Zain)	2019 (global early adopter)	2020	2019–2021 (progressive rollout)	ITU (2024), GSMA (2024)
Broadband Penetration (% of population)	99%	98%	99.3%	94%	MCIT, ITU, Eurostat 2024
Mobile Subscriptions (per 100 people)	181	112	249	118	ITU, DATA HUB, 2024
ICT Contribution to GDP (%)	15%	13%	9.7%	5.5%	MCIT, OECD, Eurostat 2022–2023
E-Waste Generated (kg per capita)	17	18	21	18	Global E-Waste Monitor (2024)
E-Waste Recycled (%)	NA	17.4%	23.25%	42.8%	UNITAR / ITU (2024)
National Circular Policy	A guidance document (CST–ITU Toolkit, 2025)	Established (2017)	Mature (since 2001)	Comprehensive EU WEEE Directive (2003)	ITU, OECD
Green ICT Framework	Emerging (CST 2025, Vision 2030)	Advanced (K-Green ICT Policy)	Advanced	Institutionalized at the EU level	ITU, EC Reports

In the future, the development of 6G is projected to gain pace around the entire world, as other countries, such as the United States, China, South Korea, Germany, and Japan, are already experimenting with testbeds [27]. This has already been indicated by Saudi Arabia, where the CST has already put in place a strategy to evaluate its 6G applications by 2025. The

comparison with South Korea, a proven 5G innovator, indicates the value of investing in R&D at an early stage and participating in international partnerships to keep up with the competition [28].

Concurrently, there is a growing menace of e-waste management in the Kingdom. The volumes are raised to 2.1 million tons in 2018 to 3.4 million tons in 2023 [29] and are expected to exceed 5.3 million tons in 2030 [30]. The per-capita production is one of the largest in the Middle East, which is indicative of a fast replacement rate and increased consumer need. However, more than 85% of this waste is not recycled, and it mostly goes into landfills or is exported [20].

In comparison, the recycling rate of e-waste in the European Union is at least 40 percent [31], [32], [33], and Japan achieves over 23 percent of its rate through innovative recycling processes and stringent laws. This comparison brings out the disparity in the existing structure in Saudi Arabia. The economic contribution of ICT development is also evident: the broadband stimulation is associated with the GDP growth, which also introduces an increase in the ICT sector to the GDP share, starting with 2.5% in 2017 to 15% in 2023 [26]. Nevertheless, the ecological price of inefficient recovery of the e-waste remains significant, and the pound of precious materials (estimated at USD 3 billion annually) will not be recovered [3].

The international standards indicate that although Saudi Arabia is doing well in connectivity and GDP growth. However, statistical data on hazardous waste were scarce, and no specific figures were reported for electronic waste (see Table 1). The comprehensive coverage of 5G in Korea, the role of telecom growth and recycling innovation in Japan, and the introduction of Extended Producer Responsibility (EPR) in the EU are indications that Saudi Arabia needs to balance its blistering digital transformation with organized environmental strategies.

## VI. DISCUSSION

The findings show that a digital transformation of Saudi Arabia has two sides. On the one hand, the Kingdom has already turned into a pioneer in terms of the deployment of 5G, and it is expected that it will cover the entire country by 2030. It facilitates national mega-projects, competitiveness of industries, and turns Saudi Arabia into a digital hub in the region. Conversely, electronic waste is on the increase, and it is resulting in compromising the objectives of sustainability, which are causing issues with the efficiency of resources, human beings' health, and environmental safety. To ensure that the two courses are balanced, it is necessary to incorporate technology implementation and sustainability models.

Saudi Arabia's adoption of advanced telecommunications from 2016 to 2024 can be understood through the Technology Acceptance Model and the Diffusion of Innovation Theory

(DOI). Based on TAM [23], people and organizations are more willing to use digital tools when they see them as useful and easy to use. Growth in digital government, online banking, and e-health services suggests that both usefulness and ease of use have improved. At the same time, DOI [24] helps explain how these technologies spread through society. Strong government support, funding, and public awareness campaigns have sped up adoption, helping the country move from early adopters to the early majority. Compared with South Korea and Japan, where digital growth has leveled off, Saudi Arabia's progress shows how national policy can drive faster and broader diffusion of technology.

The 5G introduction and the predicted shift to 6G also possess potential for economic diversification. Industry 4.0 is used to build smart cities, improve production, and information-coordinated relationships with the help of the digital connection. One such innovation that would help reshape accessibility to healthcare, specifically in underserved areas, is remote surgery using telemedicine and telemedicine robots, and Fintech and digital education will focus on increasing the number of individuals working in the healthcare sector and increasing the human capital levels. The elements of diversity and employment outside of the hydrocarbon economy can be seen in the fact that the ICT industry has contributed more than USD 32 billion to the Saudi GDP in 2022 [26], [34].

However, there is a cost to the environment of this development. E-waste is one symptom of the excessive turnover of devices and consumer demand of more than 5.3 million tons that are estimated to have been achieved in the year 2030 [30]. Not recycling does not merely subject the ecosystems to toxic chemicals that contain mercury and lead, but also to billions of dollars of potentially recoverable resources, such as rare earth elements. The traditional yardsticks all around testify that the circular economy is a true win. Recycling is being promoted in such areas as the EU and Japan to a remarkably high percentage by initiatives such as Extended Producer Responsibility (EPR) and high-quality recycling installations. When Saudi Arabia emulates the same gimmicks, it would open the doors to full-scale industries, which involve recycling of material, and the telecom professionals would be in a position to roll in more trade-ins and moving back programs. The cooperation with the private sector, issuing eco-design bonuses, and organizing campaigns so that people can actually become even more aware of them all will help to strain this whole setup, which implies that ICT keeps growing, without shattering the planet.

Even the National Center of Waste Management, created in 2021 [35], is a step towards working, but the system of collecting and recycling waste and putting the producers in the spotlight is at an initial stage. The system for collecting and recycling electronic waste is still developing. Most programs target general solid waste. E-waste, such as old phones and computers, is only now getting policy attention. Growth in

digital infrastructure and 5G devices has increased e-waste far beyond what current facilities can handle.

Although there are many opportunities in the future, there are many hurdles. The 6G implementation, the recycling ethos of the people, and an uneven distribution of legislation- all exist. All this contributes to the conclusion that the future of the Kingdom of Saudi Arabia is conditional on the finely turned balance between digital transformation and sustainability. This kind of equilibrium is one that does not just sustain Vision 2030 alone, but it enables the Kingdom to be the digital and sustainable pioneer in the world.

## VII. POLICY RECOMMENDATIONS

Recently, the Saudi Commission for Communications, Space & Technology (CST) has partnered with the International Telecommunication Union (ITU) to introduce a Global Toolkit for Policy and Regulation Practices for E-waste Management to be used as a global framework. This step would close the current gap between international advocacy and local implementation, ensuring the Kingdom not only supports global sustainability efforts but sets the standard for the Middle East and Global South in responsible ICT lifecycle management [36].

As stated, the level of recycling in Saudi Arabia is planned to reach 90 percent by 2035 through the policies of Extended Producer Responsibility [37]. However, having the benefits and minimizing the environmental risks associated with the increased use of e-waste, Saudi Arabia should approach 5G/6G implementation in a multi-layered way that equates to government-led, private-sector-driven, societal-level integration, and research-driven.

The design of circular practices on e-waste will ensure that manufacturers and importers are liable for the entire lifecycle of ICT products. Incorporating these mechanisms into the legal and regulatory framework of Saudi Arabia would ensure that manufacturers are involved in the collection and recycling processes. At the same time, a roadmap of a circular economy unique to the field of ICT should be clearly defined in all environmental initiatives. This roadmap would provide clear goals of waste reduction and resource recovery in addition to enhancing the partnership between such sectors as energy, technology, and waste management.

For instance, to have operational resilience and sustainability within the telecommunications sector, it is recommended that national regulators and telecom operators adopt a circular economy-driven policy framework that integrates lifecycle management, resource recovery, and resilient supply practices into network operations. Such a policy should encourage operators to establish decentralized circular spares pools, enabling the reuse of refurbished and certified components to reduce dependency on original equipment manufacturers and minimize downtime from repair delays. This approach can

significantly improve service continuity while lowering maintenance costs. In addition to that, setting gradual integration of circular practices during network modernization will reflect policy measures, particularly as operators expand full-fibre and 5G/6G infrastructure and decommission legacy copper and 3G systems. Reintroducing recovered equipment and components will ensure smoother transitions and lessen the environmental impact of large-scale upgrades. A national standard for circular asset management should be established to formalize proactive asset recovery, enhance reverse logistics, and ensure transparent tracking of equipment lifecycles. This would improve resource visibility, optimize inventory use, and reduce unnecessary capital expenditures across the sector. The policy framework must ensure the sustainability of supply chain resilience by adopting circular economy strategies that focus on reuse. Therefore, decentralized procurement and repurposing existing infrastructure can mitigate the risks associated with supply shortages for telecom companies and integrate sustainability and digital transformation. This strategic move is a unique opportunity for the telecom sector to set an example in infrastructure sustainability by integrating circular economy principles into Saudi telecom sector policies. Telecom operators who invest in energy-efficient 5G/6G base stations and environmentally friendly devices should also be given incentives in the form of carbon credits to encourage sustainability further.

The private sector also plays a key role. There should be e-waste collection and processing plants established throughout the country, and cooperation between the telecom operators and recycling companies. These would diversify financial risk and create general economic value in the recovery of resources and in job creation. Companies may also enhance the device take-back and refurbishment programs, offer buyback and trade-in programs that extend product life, reduce waste, and develop the second-hand markets in refurbished electronics. The innovations that can lead to a shift towards a sustainable product lifecycle include the eco-design of electronic devices that are designed to be modular, repairable, and recyclable. This would prolong the life of the products, minimize waste, and invite manufacturers to focus on environmental responsibility in the design process and beyond.

At the social level, a change in the attitude of consumers is equally crucial. The process of electronics recycling should become a concern as both an economic and environmental necessity, and the vision of sustainability should be introduced into the educational system, the digital media, and the mass media propaganda. Incentive-based programs (i.e., discounts and loyalty points on returning used devices to official collection centers) can be implemented to provide more incentives that will increase responsible disposal.

Additionally, long-term investment in research and development (R&D) is the key to green technology development and contribution to the long-term objectives of

sustainable transformation. The pioneers of green ICT and recycling technologies can be organization-based specialized research centers, such as KAUST and KACST. The areas of focus should be AI-enabled sorting systems, e-waste traceability based on blockchain, and low-carbon telecom infrastructure. Additionally, quality data and surveillance systems are crucial for evidence-based policymaking. Based on successful implementation, National dashboards would be established that can track e-waste flows, collection rates, and recycling performance to ensure accountability, as well as provide direction in adaptive policy measures.

Finally, these suggestions should be in line with the three pillars of Vision 2030. The growth of digital access will help to create a vibrant society, green innovation will help to create a prosperous economy, and global leadership in sustainable ICT will help to make Saudi Arabia a country with ambitious goals. Through a well-planned combination of telecom development and e-waste management, the Kingdom can become a role model in the world in terms of balancing digital innovation and environmental stewardship.

## VIII. CONCLUSION

The rapid rollout of 5G and preparation for 6G adoption in Saudi Arabia highlight the Kingdom's ambition to become a global leader in digital transformation. This study demonstrates that the expansion of advanced telecommunications networks offers substantial opportunities for economic diversification, job creation, and technological innovation in alignment with Vision 2030. As Saudi Arabia continues to host major international events and advance its ambitious giga-projects, the Kingdom stands at the forefront of global economic transformation in high-speed, low-latency networks, which can enable smart cities, Industry 4.0 applications, and advanced healthcare solutions, positioning Saudi Arabia at the forefront of the global digital economy.

At the same time, the analysis underscores the growing challenge of e-waste, with Saudi Arabia projected to generate over 5.3 million tons annually by 2030 [19]. Without effective management, this trend risks undermining environmental sustainability, wasting valuable resources, and conflicting with the Saudi Green Initiative's commitments to a circular economy and carbon neutrality. The comparison with leading nations such as South Korea, Japan, and the EU highlights a critical gap: while Saudi Arabia leads in telecom adoption, it lags in systematic e-waste collection and recycling.

To address this imbalance, the study recommends an integrated approach combining technology adoption models, circular economy principles, and Green ICT frameworks. The policy recommendations presented span government action, private sector initiatives, consumer engagement, and research investments—demonstrating a clear pathway for balancing rapid ICT growth with environmental responsibility. If successfully implemented, Saudi Arabia can achieve a "triple

win" of economic resilience, social inclusion, and ecological sustainability.

#### IX. LIMITATIONS AND FUTURE RESEARCH

This study is based on secondary data from government reports, international organizations, and industry publications. While, the absence of disaggregated e-waste statistics specific to Saudi Arabia introduces some uncertainty, as estimates are often inferred from regional averages. Similarly, projections for 6G adoption remain speculative, as commercial deployment is unlikely before 2030.

Future research should therefore:

- Conduct primary data collection (e.g., surveys, interviews, field studies) on consumer behavior and industry practices regarding e-waste in Saudi Arabia.
- Model the economic value of recovered resources from e-waste under different policy scenarios.
- Explore the social dimensions of 5G/6G adoption, including digital inclusion, skills development, and equity of access.
- Examine the carbon footprint of ICT infrastructure in Saudi Arabia and evaluate renewable energy integration in telecom networks.

Such research will enrich the evidence base and help policymakers refine strategies for integrating digital transformation with sustainability. Saudi Arabia stands at a crossroads where the promise of advanced digital infrastructure intersects with the imperative of environmental stewardship. By aligning 5G/6G adoption with robust e-waste management policies, the Kingdom has an unprecedented opportunity to transform its economy while safeguarding ecological systems for future generations. In doing so, it can not only achieve the aspirations of Vision 2030 but also emerge as a global role model for sustainable digital transformation.

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