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Review

A Review on Global Emissions by E-Products Based Waste: Technical Management for Reduced Effects and Achieving Sustainable Development Goals

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Abstract: In the 21st century, a great amount of electrical and electronic waste (e-waste) has accumulated, and the unregulated nature of its disposal and recycling represents a particular hazard in a global context. For the purposes of e-waste management, there must be more emphasis on the scientific processes for recycling, reusing and remanufacturing precious materials. Resource management is related to energy management; therefore, the harvesting of costly materials from e-waste is important for both energy management and sustainable development. At present, a lack of scientific recycling of a significant amount of e-waste is a source of environmental pollution and health hazards that are having a detrimental effect on sustainable development goals. It is necessary to find a process for recovering valuable materials from e-waste with the minimum possible environmental impact. At present, it is essential to modify the process of electrical and electronic products (e-products) becoming e-waste, and the subsequent process of e-waste recycling, in order to lessen the impact in terms of pollution. E-waste scientific recycling initiatives can reduce the environmental impact of the process, which in turn can support a shift from the current linear flow of costly materials to a more sustainable circular flow. Furthermore, internal consumption loss, emissions, and heating loss from e-products are the main factors contributing to the loss of energy efficiency in the process, which in turn contributes to environmental pollution. Promoting green innovation in the manufacturing process of e-products, as well as their reuse, can reduce the environmental impact of e-waste in near future. Both of these pathways are imperative for a less polluted, low-toxic environment and sustainable development. However, the sustainable development initiative of the United Nation Environmental Programme (UNEP) policy framework is the ultimate goal. This is expected to support the management of environmental pollution, maintaining it at an acceptable level, while also preventing hazardous risks to human health. Hence, this review examines the prospects for achievable environmental sustainability through technological developments.

Keywords: electrical technologies; e-products; e-waste; energy efficiency; exergy; circular flow

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1. Introduction

Environmental pollution is a critical problem in the 21st century. A reduction in emission-related pollution will lead to cleaner energy transition, waste management, and technological energy efficiency; therefore, it is vital to make progress in reducing emission-related pollution [1]. The sustainable development goals (SDG) for waste management are associated with environmental emission management and public health hazards, and environmentally sound energy technologies can limit emissions and environmental pollution. According to the International Energy Agency (IEA), electricity contributes to nearly 40% of total global energy consumption and emissions. In addition to fuel, the generation of electricity and load-associated electrical and electronic technologies have a vital influence on environmental pollution. The goal of emission reduction to reduce the use of primary non-renewable energy is vital. A type of energy that can be used for electricity generation, and associated electrical technologies, is desired in order to reduce the carbon footprint for related processes. As per the British Petroleum Statistical Review of World Energy 2021, the total electricity generation from all recorded sources in 2019 was 27,001 TWh [2]. According to a study (Figure 1), 758.00 (2.83%), 6268.1 (23.37%), 9421.4 (35.12%), 2700.1 (10.07%), 4296.8 (16.02%), 1591.2 (5.93%), 855.70 (3.19%), 700.10 (2.61%) and 231.80 (0.86%) TWh are generated from oil, natural gas, coal, nuclear, hydropower, windmills, solar, geothermal, biomass and other sources, respectively [2].

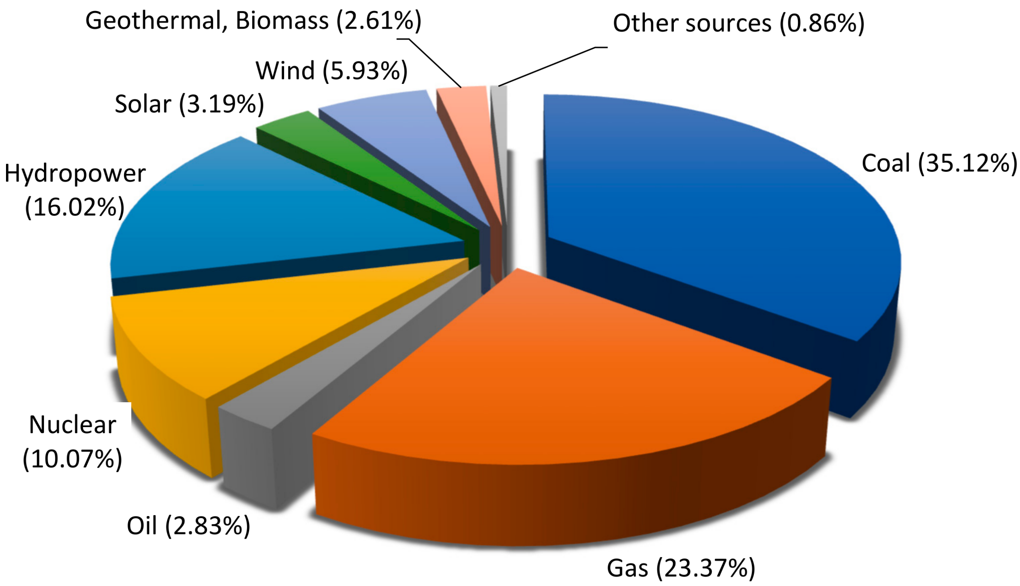

Figure 1. Present electricity related primary resources usages [2].

Most recent data demonstrated that 16,447.5 TWh (or roughly 61.32%) of the total electricity is generated from fossil fuels, whereas 27.75% of the total electricity is generated from renewable (hydropower, wind, solar, geothermal, etc.) sources. Therefore, huge technological changes are currently in progress in terms of electricity generation from non-renewable to renewable.

The modern concepts of a low-carbon society and environmental protection cannot be materialized only from a reduction in primary non-renewable energy resources. Energy use in engineering processes and resource use in economy are analogous. Central to both of these are the policies of energy efficiency and circular economy in order to reduce resource usage and promote sustainable process management. Emission generation is a multidimensional approach in which a reduction in the use of resources is disputable [3]. Cumulative electrical and electronic waste (e-waste) related to consumer electronics, energy supply, security, entertainment, and huge IT products are now common environmental hazards [4]. Besides these areas, e-waste is also a significant challenge in healthcare, security, and energy harvesting. The emission effect of e-waste in material recycling processes is significant. It has an immense environmental impact and a significant effect on human health, as mentioned in the SDGs [5]. There is a comprehensive approach in which electrical technologies and consumer electronics associated with huge amounts of e-waste are key burdens for resource management and environmental emission. By reducing pollution and improving resource efficiency, SDGs can be achieved. In the process of conceiving of a new development program for the 21st century, huge energy generation and usage pathways for electrical and electronic product (e-products) and their energy management are crucial in order to limit environmental emissions. This is exclusively dependent on technological innovations. In this framework, sources to load site energy management are a reality. Demand for consumer electronics in the service and industrial sectors account for huge energy consumption, which is another root cause of environmental emissions. Energy and resource management are the key targets of the SDGs in order to prevent environmental and health hazards [6]. Therefore, this study focuses primarily on environmental and health issues related to e-waste, pathways to mitigating the environmental and health-related impacts of e-waste, and the scientific process of resource management and environment protection. Finally, key technological developments and innovation pathways in several environmentally sound and energy-efficient electrical technologies are reported. Both are explicitly significant under new development goals and SDGs in the 21st century.

The Current Status of E-Waste from E-Products

Social awareness of electrical and electronic product (e-product) reuse, recycling, and innovation can help to reduce e-waste. Until 2016, 44.7 million tons of e-waste had been produced in the world, equivalent to 6.1 kg per person. In 2018, about 52 million tons of e-waste or 6.8 kg/capita were produced worldwide, with a 7% annual increase [4]; China produced 15.5 million tons or about one-third of the total mass of e-waste. The management, usage, and business of recovering materials from e-waste have modest correlations to industrial and environmental development [7]. The current trend of e-products and e-waste accumulation is shown in Figure 2; accordingly, 75 and 111 million tons of e-waste will be accumulated by 2030 and 2050, respectively.

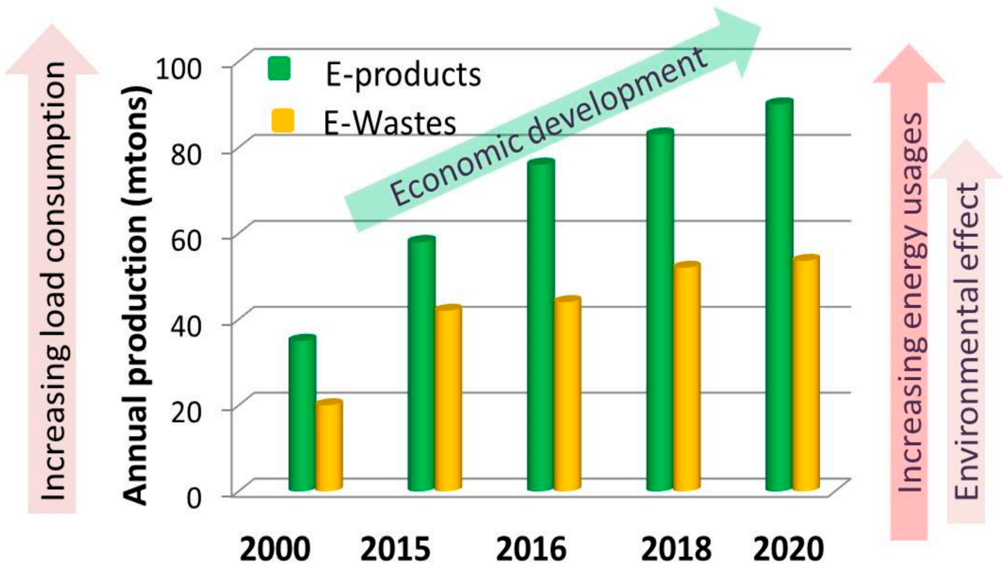

Figure 2. The trend of e-products and e-waste accumulation.

Currently, increasing e-waste is a significant problem for society and the environment. In a circular economy model, e-waste materials are reused in a circular rather than a linear flow. In a linear model, for example, the extraction of minerals from ore requires several complex procedures and energy use, and then the minerals are finally used in a device. On the contrary, if a circular model is applied, the possibility of costly resource (e-resource) recycling is a major advantage for e-products. E-waste has become one of the sources of environmental emissions and entropy due to gaps in processing and recycling policies. Furthermore, scientific methods for recovering valuable materials from e-waste are essential for manufacturing new e-products with the lowest primary resource usage and environmental emissions [8–12]. In this regard, decreased material extraction and ore processing could have massive environmental benefits. Models for the production and usage of e-products are specifically related to ultimate e-waste production. Thus, in this study, we focus on the following two main aspects:

- Presently, effective and scientific management of e-waste resource recycling can lessen environmental toxicity and emissions.
- In the near future, a demand-side innovation pathway of increasingly diverse electrical energy efficiency technologies can reduce emission impact.

Scientific e-waste recycling processes are essential for both environmental protection and e-resource recovery. Moreover, emissions can be reduced by developing energy efficiency technologies, as shown in Figure 3. Initially, a circular flow model of e-waste material management is associated with emission and entropy effects, and therefore, the primary focus is the extent of the gap between scientific processes and management. A relative statistical entropy (RSE) analysis has been conducted to comprehensively assess the physical flow of materials and end products after processing [13]. Furthermore, currently, an RSE analysis has been conducted on the most significant energy storage technology, i.e., lithium (Li)-ion battery waste management [14]. These studies both revealed that increased recovery of valuable materials during the recycling process had a significant impact, creating a higher entropic state due to toxic effects and environmental impacts. Resource recovery is one choice, whereas the toxic effects of heavy metals and hazardous polymers are common dangers for human health and environment [4,14]. Due to toxins and emission exposure during informal recycling, it is essential to develop scientific recycling processes. Scientific recycling of e-waste is an environmental protection issue associated with technology; therefore, e-waste and e-product technological developments are key to realize environmental protection in the electricity sector [15–17].

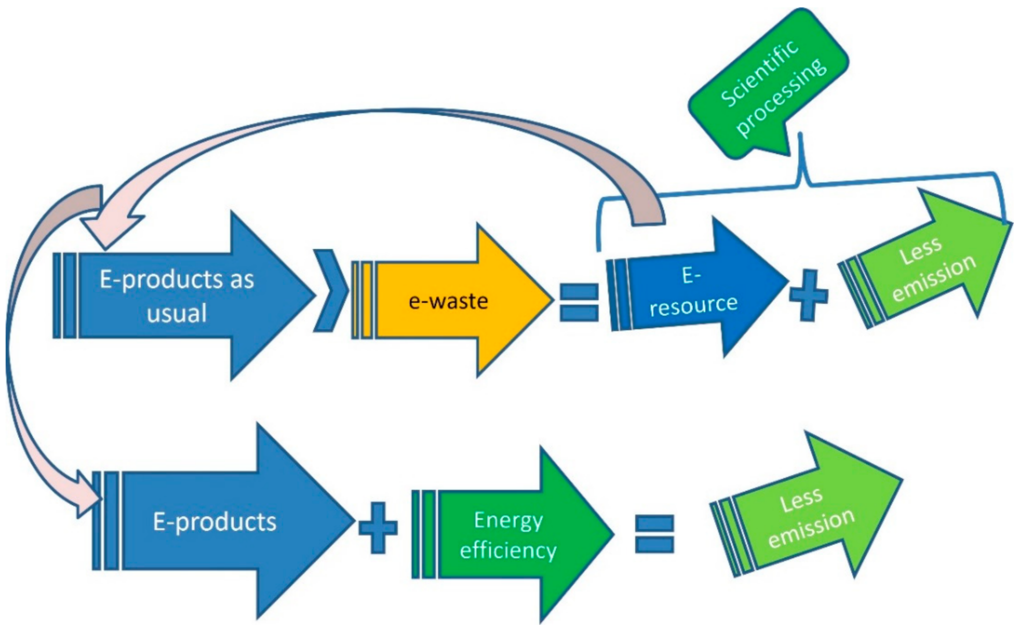

Figure 3. E-product and e-waste modeling pathways.

2. E-Waste and the Concept of Technology Shift

At present, e-waste is one of the fastest growing solid waste streams from electrical and electronic products, due to changes in entertainment products as well as significant changes in technology. Currently, its emerging environmental impact is under full consideration by the Global E-waste Monitor for the United Nations Environmental Program (UNEP). E-products and their e-waste are positively related to the economic development and ever-changing technologies in countries [18,19]. After World War II, massive and rapid development of technological innovations in developed countries led to increased production of e-products; however, the rate of e-waste generation was much lower. At the beginning of the 21st century, there were significant increases in IT innovations related to the development and replacement of electronic and electrical systems and, currently, IT innovations have been growing quickly. IT innovation in this field can be a source for materials to flow under a circular economic model when effective scientific methods are used for the extraction of precious materials [20–22]. Furthermore, the flow of e-waste from developed to developing nations at the end stage of the recycling process has been associated with substantial environmental and health effects [23,24]. The current e-waste of most developed countries is >15 kg/capita, whereas, for rapidly developing countries, the growth rate is still below the world average of 6.2 kg/capita [4]. Unregulated flow and poor environmental regulations have made the flow of solid waste to developing nations easier. Due to huge populations and rapid development, the rates of e-waste accumulation in both India and China are the highest. They are suffering from entrenched informal e-waste processing [25]. The latest review of studies that covered 174 countries in the world showed that e-waste production per capita was positively correlated to the gross domestic product (GDP) per capita, but there was less of a relationship between population and e-waste generation [26]. In the context of generating e-waste, especially in the USA and the EU, significant e-waste production is a reality; however, strict environmental regulations maintain an inverted U pattern in developed countries. However, both unregulated flow and processing of e-waste in populated developing and the least developed countries are key concerns. Toxic contents, heavy metals, and hazardous polymers during processing and recycling are common dangers for environmental pollution and human health hazards. Materials in e-waste are disposed of in open land, rather than being properly extracted for reuse and recycling, and therefore, environmental and health risks are growing [27]. Fluorinated greenhouse gases used in liquid crystal display (LCD) flat panel production involve chemicals with atmospheric lifetimes beyond 3000 years and thousands of times more global warming potential than CO_2 [28]. Because of toxic heavy metals from e-waste in landfills, the resulting eventual environmental contamination is obvious [29,30]. Chips and semiconductor manufacturing use a variety of chemicals including volatile organic compounds, and several rudimentary e-waste recycling practices can lead to serious health hazards, as well as air, water, and soil pollution [31,32]. Recently, environmental consequences of e-waste have been subjects of global debate. At the policy level, solutions to the e-waste problem should include more attention to e-waste management at macroscopic and microscopic scales to avoid toxic substances entering into downstream sites [33,34]. Due to the rules in developed countries, several developing countries in Asia and Africa are under a significant threat due to e-waste recycling processes. Because of policy gaps in the informal processing and recycling practices of developing countries, management solutions are critical to solve the problems [35,36]. Recently, circular economy and recycling process risk assessments for both health and environmental hazard analyses have been reported [37,38]. To regain materials from waste, the environmental effect must be considered. In addition to a zero-emission energy policy by IEA, an e-waste proactive policy by UNEP is central [7]. E-waste ecological contaminations and health hazard prevention measures are essential because environmental and health threats are the main impediments to reach the SDGs. Table 1 summarizes the link between the SDGs and e-waste management. There is an urgent need to increase actions to reduce pollution, to improve resource efficiency, and to better protect the environment and, therefore, to achieve the SDGs and to ensure the sustainability of the planet. All these actions are related to environmental emission reduction and public health management that can be partly achieved by innovations in solid e-waste and energy technologies.

Table 1. Relationship between sustainable development goals and e-waste management [5,6,39].

Sustainable Development Goal (SDG)	Scope	Specific Target
SDG 12: Responsible consumption and production	Hazardous waste management	Target 12.4 aims to achieve the environmentally sound management of chemicals and all waste throughout their life cycle, in accordance with agreed international frameworks, and to significantly reduce their release into the air, water, and soil in order to minimize their adverse impacts on human health and the environment. Target 12.5 aims to substantially reduce waste generation through prevention, reduction, repair, recycling, and reuse. An increasing number of people on the planet are consuming growing amounts of goods, and it is critical for production and consumption to be more sustainable by raising the awareness levels of producers and consumers, specifically in the area of electrical and electronic equipment.
SDG 3: Good health and well-being	Protection of public health	Target 3.9 refers to a reduction in the number of deaths and illnesses caused by hazardous chemicals as well as air, water, and soil pollution and contamination.
SDG 9: Industry innovation and infrastructure	Environmentally sound energy technologies	Target 9.4 refers to upgrading infrastructure and retrofitting industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries' actions in accordance with their respective capabilities.
SDG 7: Affordable and clean energy	Energy efficiency	Target 7.2 refers to an increase in the share of renewable energy in the global energy mix.
SDG 6: Clean water and sanitation	Environmentally sound management of all wastes, particularly hazardous wastes	Target 6.3 aims to reduce pollution, eliminate dumping, and minimize the release of hazardous chemicals and materials.
SDG 11: Sustainable cities and communities	Access for all to adequate, safe, and affordable solid waste collection services	Target 11.6 aims to reduce the adverse environmental impact of cities, with special attention to waste management.

Regarding e-waste recycling under the SDGs, the following limitations are notable. In both developed and developing countries, international agencies and social awareness are very important to solve this problem [24]. However, in addition to waste management for emission and toxic effect prevention, load side emission-related technology gap analyses, fewer emissive e-products, and reductions in load consumption pathways are essential. In this context, lowering the net environmental impact through a sustainable e-product development model is important. Figure 4 shows the pathways for both e-product innovation and e-waste processing. In this process, e-waste processing regulations and a circular flow of costly materials support the production chain. The scientific pathways of reusing, remanufacturing, and improving energy efficiency, along with the scientific recycling of valuable materials create a circular flow for e-products.

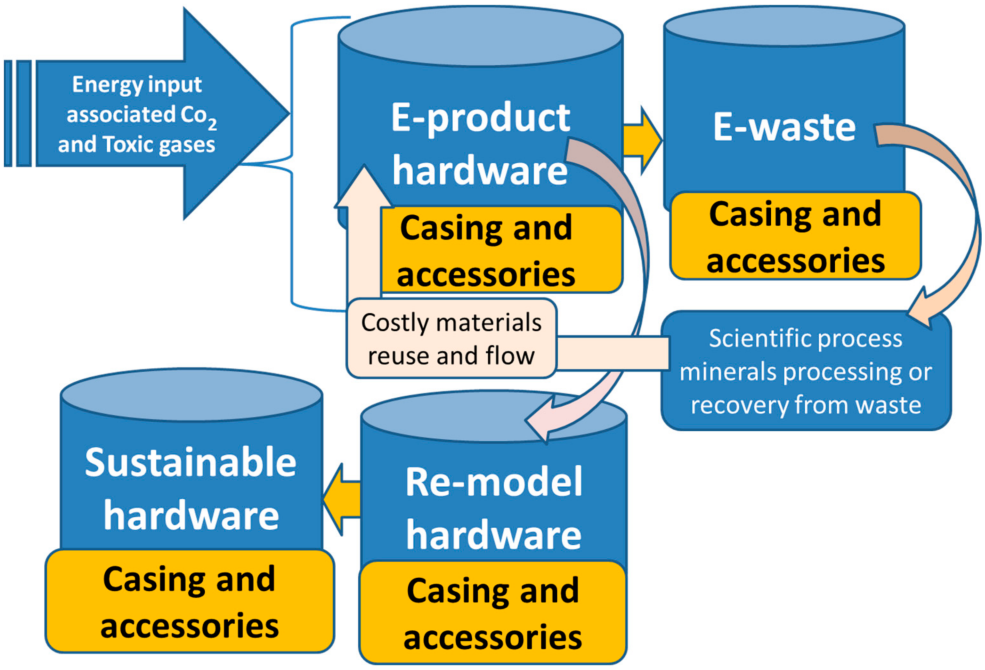

Figure 4. Pathways to e-product innovation and e-waste processing.

3. E-Product Technological Management

Although a net-zero carbon policy is the target, achieving this goal with high exergy in energy resources for electricity and e-products is imperative. Recently, expanding the development of renewable energy in the utility sectors is the key initiative for a sustainable electricity supply. Reducing energy demand and protecting the environment by using green energy resources are important under the IEA framework for a low-carbon society. The present significance of energy and related environmental problems has created an urgent need for scientific research on efficient energy systems and related technical solutions such as green initiatives. Previously, exergy efficiencies of diverse electrical technologies were analyzed by M.A. Rosen and C.A. Bulucea [40], including generators, motors, transformers, diverse renewable energy technologies, storage batteries, fuel cells, urban electric transports, and lighting devices. Exergy loss in most technologies is associated with internal consumption loss, emissions, and heat loss. Regarding electrical loads, especially, electrical consumption of lighting devices is significant, and therefore, lighting devices have the lowest energy and exergy efficiencies. Furthermore, regarding motors, generators, transformers, and alternators, the leading losses that reduce both exergy and energy efficiencies are magnetic circuit eddy loss, torque-related loss, and overall heat loss. Electronic display devices, in addition to lighting devices, have similar loss effects. Advancements in solid-state lighting and LCD display have effectively improved the energy efficiency of display and lighting systems [41]. Under the IEA's net-zero policy (NZP), huge renewable energy resources, especially the efficiency of PV solar and wind-based energy and exergy promotion, are vastly important. PV exergy loss is mostly thermal loss in the module surface [42]:

$$Ex_{thermal} = Ex_{electrical} - Ex_{output} \quad (1)$$

$Ex_{thermal}$ is due to internal dissipation of heat or consumption and emission loss. However, electrical voltage loss is also involved with the thermal effect, because once ambient temperature is high, it may cause higher electrical energy loss due to electrical dissipation. Extensive research is underway to solve these issues. In addition to PV solar energy, the second most significant renewable source to materialize the IEA's NZP is wind-based energy. The exergy loss of a wind-based system depends on air pressure, flow rate, humidity, and temperature. These factors are marked as variations of effective work (w_e) and useful work (w_u) as follows:

$$Ex_{loss} = w_u - w_e \quad (2)$$

Unlike thermal loss in PV solar energy, the losses in wind-based systems are mostly affected by environmental parameters [43]. The core loss of a wind-based system for converting mechanical energy to electrical energy is similar to the internal loss such as in other magnetic circuit systems. Solar PV exergy destruction/loss is mostly due to temperature, whereas wind-based exergy destruction/loss is affected by wind speed and humidity [44].

Although the abovementioned research explained the losses, there have been limited developments to reduce these losses [40–44]. Table 2 shows the electricity related energy and exergy efficiencies, and specific future prospects. In addition to renewable technologies, the latest advancements in other electrical technologies and future technology prospects are also presented in the table.

Table 2. Energy and exergy efficiencies of electrical power generation, conversion, and storage systems with future prospects.

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
Solar Powered Systems				
12 MW PV power plant	14.58	9.77	PV panels consisted of nanoparticles-based or concentrated PV cells Hybrid PV/hydro/energy storage/wind-based generation system	[42,45–47]
3.2 kW PV power plant	9.84	10.62		
750 W PV power plant	4.5–8.5	3–6.5		
36 W PV power plant	6–9	8–12		
Solar thermal power generation	10–30	10–30	Mirror dish concentrator-based solar thermal power system	[48]
Solar chimney power plant	3–93.3	2.29	Hybrid PV/hydro/energy storage/wind-based generation system	[49]
Solar tower system	22.89	24.48	Advanced power cycles, reheat process, and inlet supercritical steam-based solar tower system	[50]
Solar dying system	40–68.63	41.9–70.94	Hybrid solar dryer and air drying system	[51,52]
Electrical Conversion Systems				
Transformer	93–98	93–98	Solid state transformer	[40]
Alternator	70–73	70–73	Electric turbo alternators	[40]
Generator	90–95	90–95	Permanent magnet synchronous generator Renewable energy-based distributed generators	[40]
Static converter	80–87	80–87	Energy-efficient power switches (MOSFET/IGBTS)-based converters	[40]
Motor	97–99	97–99	Permanent magnet synchronous motor	[40]
Power Generation Plants				
Thermal power plant	64	100	Renewable energy-based power generation systems or distributed generators	[53]
Steam power pant	32	35.2		[54]
Coal-fired power plant	37	36		[53]
Nuclear power plant	30	30	Small modular reactor (SMR)-based nuclear power plant	[53]

Table 2. *Cont.*

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
Solar Powered Systems				
Hydroelectric power plant	90	90	Hybrid PV/hydro/energy storage/wind-based generation system Modular hydropower system	[40]
Wind turbine system	80–97	80–97	Bladeless wind turbines Hybrid PV/hydro/energy storage/wind-based generation system	[55]
Combined Generation System				
Cogeneration system	93	34.4	Combined heat and power (CHP) combined-cycle power plants	[56]
Trigeneration system	94	28	Renewable energy-based trigeneration system	[57]
Solar trigeneration system	50.53	36.88	Hybrid solar/biomass trigeneration system	[58]
Battery Storage System				
Battery (lead–acid)	75–85	75–85	Lithium-ion/lithium-sulfur/solid-state batteries	[59]
Transportation System				
Electric transportation system (traction)	80	80	Hybrid renewable energy and energy storage powered transportation system	
Electric transportation system (electric rheostatic braking)	80	30		
Electric transportation system (electric braking with recovery)	80	73		[60]
Coal Gasification				
Conventional coal gasification	55	46	Integrated gasification fuel cell (IGFC) process (coal/fuel cell/biomass)	[61]
Biomass and coal gasification process	50	47		[62]
Biomass-based supercritical water gasification	88.3	83.6		[50]
Biomass gasification process	90.2	87		[63]
Fuel Cell (FC) Technology				
Polymer electrolyte membrane FC (PEMFC)	47.6	50.4	Reversible fuel cells	[64]
Solid oxide FC (SOFCs)	58	56		[65]
Molten carbonate FC (MCFC)	50	60–80%		[65]
Solar Air Heater (SAH)				
SAH with copper tubes	49.4–59.2	18.25–35.53	Obstacle type solar air heater; porous baffles inserted in a solar air heater	[66]
SAH with phase change material	58.33–68.77	14.15–26.34		[67]
SAH with circular turbulator absorber plate	28.6–79.5	8.1–42.4		[68]
SAH with plain tube	58.3	19.7–21.7		[69]

Table 2. *Cont.*

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
		Solar Powered Systems		
SAH with packed bed paraffin wax	20.7–26.8	10.7–19.5	Obstacle type solar air heater; porous baffles inserted in a solar air heater	[70]
SAH with conical and smooth absorber plate	64–74.6	9.2–12.5		[71]
SAH with multi-pass collector perforated fins	48.88–83.47	8.74–23.97		[72]
		Photovoltaic Thermal (PVT) Technology		
Air and Water based PVT Collector	40–70	5–25	Water-based PVT collector integrated with sheet-and-tube channel	[73]
Water based PVT collector with spiral flow absorber	58–68	25		[74]
Water-heating PVT and PVT air collector	60	12		[75]
PVT plate parallel air collector	55–65	12–15		[76]
PVT collector with natural airflow	28–40	6–9		[77]
		Hybrid Energy System		
Hybrid PV/wind system	20–25	40–45	Smart microgrid/nanogrid consisted of renewable and energy storage systems	[78]
Hybrid wind/ compressed air energy storage	70.83	80.71		[79]
Hybrid PV/fuel cell/energy storage system	76.5	8.91		[80]
PV/wind/fuel cell	16.3	20.8		[81]

In addition to the technological advancements in household energy use systems, rapid changes have occurred by replacing other energy resources with electricity as a low emissive energy supply. The energy use systems in the building and transport sectors are also changing, which are shown in Table 3.

Table 3. Energy and exergy efficiencies of residential loads and industrial processes/sectors with future prospects.

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
		Residential Sector		
Resistance space heater	99	6	Vented and unvented combustion small space heaters	[40]
Ground source heat pump	73.1	71.8	Solar-assisted heat pump	[82]
Refrigeration system	60	7	Inverter-based refrigeration system	[83]
Water Pump	70	70	Digitalized and solar pumps Brushless or permanent magnet synchronous motor-based pump	[84]
Fan	90	90	Smart ceiling fans; brushless direct current (DC) motor fans	[85]

Table 3. *Cont.*

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
Residential Sector				
Lighting (incandescent)	5	5	Carbon-dot light emitting diodes (CLED)	[85]
Lighting (fluorescent)	20	20		
Electric oven (home)	70–85	50–55	Smart, emission-free, direct-fired, fueled tunnel oven	[85]
Toaster	70	40	Smart digitalized toaster	[85]
Clothes dryer	60	30	Smart ultrasonic cloth dryer	[85]
Light-emitting diodes (LED)	27.3	21.3	CLED	[86]
Television (TV)	80	80	Smart LED TV	[86]
Washing machine	80	80	Smart inverter-based washing machine	[86]
Water pump	80	80	Digitalized and solar pumps Brushless or permanent magnet synchronous motor-based pump	[86]
Vacuum cleaner	70	70	Wireless robotic vacuum cleaners	[86]
Iron	98	20.1	Smart steam electric irons	[86]
Microwave	70	24.2	Solid-state microwave oven Laterally diffused metal oxide semiconductor (LDMOS) microwave oven	[86]
Exhaust blower	80	80	Low profile blowers with thinner, lightweight materials	[86]
Water cooler	200	10.6	Smart hybrid cooler	[86]
Computer	75	75	Using Advanced Micro Devices (AMD) processor-based PC	[86]
Dishwasher	80	80	Smart waterless dishwashers	[86]
Rice cooker	80	17.2	Induction heated rice cooker	[87]
Blender	80	80	Brushless motor-based blender	[87]
Toaster	98	30	Smart digitalized toaster	[87]
Kettle	90	10.8	Smart digitalized kettle	[87]
Mobile charger	70	70	Wireless charger	[87]
Hair dryer	70	70	Smart nanotechnology-based hair dryer	[87]
Air conditioner	60	4.09	Inverter-based air conditioner	[87]
Water heater	90	2.54	Tankless and on-demand water heater, heat pump water heater, solar water heater	[87]
Electric stove	98	7.3	Induction cooker	[87]
Electric gate	80	80	Permanent magnet synchronous motor base gate propeller	[87]
Water filter	70	70	Nanotechnology and photocatalytic technology-based water filter	[87]
Industrial Process				
High-pressure steam boiler	90	50	Modular steam boiler	[88]
Industrial heater	70	51	Induction heaters	[40]

Table 3. *Cont.*

Analyzed Systems	Efficiency (%)		Future Prospects	Ref
	Energy	Exergy		
Residential Sector				
Tobacco dryer (fuel)	40	4	Solar and air dryer	[89]
Blast furnace	76	46	Biomass-based blast furnace	[89]
Petroleum refining	90	10	Permanent magnet synchronous motors, efficient motor drives and upgraded motor-driven equipment	[89]
Industrial Sector				
Iron steel	53	41	Permanent magnet synchronous motors Efficient motor drives Upgraded motor-driven equipment using smart and advanced manufacturing process	[90]
Chemical-petrochemical	65	17		
Petrochemical feedstock	50	31		
Fertilizer	60	28		
Cement	57	29		
Sugar	62	18		
Non-iron metals	59	26		

In addition to shifting electricity primary resources to renewables, a reduction in e-product exergy destruction/loss and greater energy efficiency are also advised. Electricity-related emissions are associated with environmental effects that are having a leading impact on increased global temperatures. Regarding energy efficiency, a fundamental change in energy demand is very important for mitigating emissions [91–93]. The roadmap to renewable energy involves a shift from massive non-renewable to renewable resources. New technologies [94] and policy shifts [95] toward decarbonization under the IEA policy framework are central. Numerous technologies related to energy sources, power electronics, and consumer electronics, as mentioned in Tables 2 and 3, are potential innovations for increasing energy and exergy efficiencies. The most significant electrical loads at the utility level are motors, generators, drives, transformers, blasts, and lighting bulbs, and therefore, they have the greatest potential for increasing energy efficiency [96,97]. Enthalpy for e-products in manufacturing industries and newly familiarized IT sectors, associated hardware, large scale data servers, and data link energy consumption could be increased progressively. A huge technology shift, with an increase in electrical technologies and power electronics related new energy generation is expected to lessen carbon intensity and global warming [98,99]. From the above tables, it can be seen that, at the utility level, mostly, the design of electrical technological innovation based on power electronics and baseline energy resource networks has immense scope for further development.

Energy Management Paradigm Shift

Energy and its efficiency are the main drivers of daily life functionalities and development. The potential significance of energy and environmental problem reduction has resulted in new scientific research on efficient energy systems, storage, and related technical solutions such as green initiatives as a new dimension. In the new era of ample energy generation by green energy networks, energy management is crucial [100,101]. Therefore, smart meters, data networks, sensors, and micro-grid systems with information communications technology (ICT) networks are well-established ideas for energy savings. For this purpose, the management of data networks from source to load sites using sensor systems, modulation techniques, and antenna subsystem set-up is essential [102]. In addition, healthcare, security, energy harvesting, and environmental effect management purpose data and sensory system networks with servers for data storage and management have huge potential in the near future. Energy intake in the ICT arena as data transfer networks in line with the advancement of communication networks is rapidly expanding. Energy-efficient systems are not only necessary for daily normal life but also in hazardous and emergency situations, in which they are essential to technological support [103]. Technological advancements in nano devices have resulted in robust systems for computer data management and storage. Big data traffic, device-to-device uninterrupted connectivity purposes, energy-efficient sensory networks with advanced communication modules, and renewable energy-supported green energy backbone are vital [104]. Thus, a green energy subsystem, as well as its storage and implementation in content delivery and technical management as green network support are forthcoming. In this perspective, green energy and smart technologies for achieving sustainable energy management networks are essential.

The bulk energy demand and environmental protection aims of massive green energy inclusion to meet a low carbon society by 2030 and to finally reach the 2050 target is an energetic work plan of world communities [105,106]. The generation of small-scale and diverse green energy and its management by a smart network at both the source and load end have the potential for improving energy efficiency. The shared efforts of material scientists, energy engineers, as well as network and communication engineers can make it successful. For this purpose, energy generation by renewable resources such as solar photovoltaic, thermoelectric, or other electro-mechanical system inclusion is advised. Robust renewable energy management energy storage, a renewable energy system inverting process, electric vehicles, and speed control of motors, generators, and air conditioning systems have a lot of potential in power electronics by reducing load consumption and the advancement of materials technology will increase electric load efficiency [107]. As a result, it is even possible for low energy generation to support the extra load for increased population demands [108]. In addition to the extra e-product requirements for additional usages due to ever-changing lifestyles and overpopulation, scientific e-waste processing and management can contribute to a circular flow of precious materials in the e-production chain [109,110]. Recycling systems can reduce the entropic effect of ore processing, improving the production of e-products. As a result, an eco-friendlier world could be anticipated. Energy and exergy efficiencies and remodeling of devices can reduce emissions.

4. Remanufacturing Model: Resource and E-Waste Management

End-of-life (EOL) product remanufacturability is a new concept that has emerged in the 21st century. The gap between bulk demand and resources is the main driver of the EOL product concept. It is also associated with environmentally friendly resource management with longevity and device performance [111]. There is substantial potential for reusing materials; however, e-waste from e-products in landfills pollutes the environment. Gap analyses of management and energy-efficient technologies are key solutions to overcome these shortcomings. As previously mentioned, the design and remodeling of e-products can be effective for reusing them, while scientific recycling of precious metals from e-waste can reduce the use of new raw resources. However, advanced EOL product models are focusing on the lowest production of e-waste. The circular schemes are important, especially for economic and environmental performances; both impacts are considered to be vital to the development of a sustainable society. Reuse models for resource management and the production of primary sources from raw materials are associated with huge emission issues. To overcome difficulties throughout the processes for effective e-product reuse and e-waste recycling, policy development is essential to lessen the emission gap between reuse and recycling [112], and therefore, result in an effective overall reuse and recycling model with respect to ecological and economical features. The energy saving and emission reduction model for both economic and environmental matters has been well reported. Furthermore, clean energy saving and emission reduction models for energy efficiency, carbon footprint reduction approaches, and waste management have been broadly quantified [113]. Technical analyses of exergy and energy efficiencies are essential to further harmonize the entire process to the lowest emission production cycle.

The industrial development purposes of key technological innovation pathways for several electrical technologies are reported in Tables 2 and 3. In Table 2, the prospects of electrical power generation, conversion, and storage systems are presented. In Table 3, different residential loads and industrial sector and process prospects are summarized. In Table 2, the energy and exergy efficiencies of PV panels made of nanoparticles or concentrated PV cells are listed. Instead of using a PV system alone, a hybrid combination of PV/hydro/wind/biomass/energy storage would be a good option to enhance overall efficiency. By using a mirror dish concentrator, the efficiency of a solar PV thermal system can be improved. The use of advanced power cycles, a reheat process, and inlets with supercritical steam systems can improve the efficiency of a solar tower system. A hybrid solar dryer and air drying system can further improve the efficiency of a solar drying system without relying only on solar power. By using the latest technologies, the efficiency of electrical conversion equipment can also be improved. For instance, solid-state transformers, electric turbo alternators, permanent magnet synchronous generators/motors, and modern power electronic converters can enhance the efficiency of electrical conversion systems. The future direction of fossil-fuel-based power plants is that they should be replaced by distributed generation of renewable energy sources. By using small modular reactors, the efficiency of nuclear power plants can be boosted. Hybrid combinations of hydro and wind power generation with other renewable energy-based power generation systems can improve their efficiencies. In addition, bladeless wind turbines can improve the efficiency of a wind turbine system. In the future, it is recommended that combined generation systems use CHP-based co-generation systems and RE-based trigeneration systems for improving energy and exergy efficiencies. By enhancing the efficiency of transportation systems, pollution can be reduced. The future direction is to use hybrid RE and energy storage systems to power transportation. An integrated gasification fuel cell (IGFC) process based on coal/fuel cell/biomass can help to improve the efficiency of coal gasification systems. To improve the efficiency of battery and fuel cell energy storage systems, the future direction is to use solid-state batteries and reversible fuel cells. The efficiency of existing solar air heaters can be increased by using an obstacle-type solar air heater and porous baffles inserted into the solar air heater. To enhance the efficiency of PVT collectors, water-based PVT collectors integrated with sheet-and-tube channels can be used. Smart microgrid or nanogrid technologies can be adopted to enhance the performance of hybrid energy systems.

In the residential sector, among the many appliances that are used, lighting is the most used appliance which has the lowest efficiency, as shown in Table 3. To enhance the efficiency of lighting (incandescent and fluorescent), carbon-dot LEDs should be used. For refrigeration and air conditioning systems, inverter-based systems are preferred to enhance efficiency. To enhance the efficiency of water pumps, a hybrid system powered by a smart brushless or permanent magnet synchronous motor can be used. Smart, emission-free, direct-fired, tunnel electric ovens can be used to enhance the efficiency of conventional electric ovens. In addition, solid-state microwave ovens can improve the efficiency of conventional microwave ovens. By using an AMD processor, desktop PC efficiency can be enhanced. Wireless mobile chargers can be used to enhance the efficiency of plug-in mobile chargers. Tankless and on-demand water heaters, heat pump water heaters, and solar water heaters can be used to replace conventional water heaters to improve efficiency. There are other home appliances, such as TVs, water coolers, kettles, blenders, toasters, and irons, listed in Table 3, with the suggested technological innovations that can improve the efficiencies of all these appliances. For industrial processes, energy and exergy efficiencies can be improved by using energy-efficient systems. For example, the processes which use high-pressure steam boilers can be replaced with modular steam boilers to improve efficiency. An induction heater instead of a conventional heater can be used to improve efficiency. For the industrial sectors, such as petroleum refining, iron steel, chemical/petrochemicals, petrochemical feedstock, fertilizer, cement, sugar, and non-iron metal manufacturing, the conventional induction motors can be replaced by permanent magnet synchronous motors to enhance the energy and exergy efficiencies.

5. Conclusions and Future Developments

From the perspective of global emissions and environmental pollution, the importance of e-waste scientific recycling, e-product energy, and remanufacturing management pathways are illustrated. Low emissions and a wide range of green technology developments in all sectors of electricity are the main drivers to implement SDG policy. Regarding e-waste recycling, under the UNEP resource management agenda for SDG, there are some limitations. Through the SDG policy framework, the results of management gap analyses show that proper management of e-waste and energy efficiency technological innovations are future solutions to overcome the cumulative environmental effects. Electrical technology (e-product) innovation pathways for improving exergy and energy efficiencies are considered to be vital. Thus, we presented a detailed analysis on the prospects of different electrical and electronic loads for improving exergy and energy efficiencies to limit environmental emissions. The flow of e-waste and scientific management of e-waste are both expected to extend eco-system management and human health hazard protection in the future. Moreover, in addition to renewable energy, bio-energy inclusion for electricity generation can limit environmental emissions.

A sustainable development system integrated with e-waste management can play a vital role in meeting the global SDGs for 2030, such as reduced health complications and deaths due to exposure to the toxic and hazardous composition of e-waste surrounding environments; reduced environmental threats from air pollution due to open burning, water pollution due to acid and chemical leaching, and soil pollution due to toxic effluent and discharge of residues; secure and safe working environments, particularly for children and women.

Furthermore, SDGs such as good health and well-being, employment opportunities, economic growth, and sustainable cities and communities can also be met through the transformation of informal players into micro-entrepreneurs. To inform workers about the consequences of e-waste, effective awareness campaigns are necessary. For a successful e-waste management system, a sustainable roadmap can be adapted to create sustainable and resilient environments, to bridge existing gaps between the informal and formal recycling sectors, to expand business and job opportunities, and to improve occupational health and safety.

Authors Contribution

Conceptualization, S.A. and B.K.G.; investigation, S.A.; B.K.G. and S.K.G.; Manuscript Writing, S.A.; S.M.; B.K.G. and S.K.G.; Manuscript Review and Editing, S.A.; S.M.; B.K.G. and S.K.G.; Supervision, S.M. and B.K.G.

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